EFFECTS OF RAINFALL VARIABILITY ON FARMING ACTIVITIES IN MACHAKOS SUB COUNTY, KENYA

BY

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DECLARATION

I, **INDIATSY CHRISTOPHER MASINDE** hereby declare that this thesis is my original work and that it has never been presented for award of any degree or academic work in any other University.

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DEDICATION

To my Family members, in particular my late parents Baba Joshua Masinde Indiatsy and Mama Janet Truphena Njeka, laying the foundation of my academic ladder. With all my Love, I honor their contribution in my life.

ABSTRACT

Varying climatic conditions with increased uncertainty mainly in rainfall and temperature are salient features in marginal areas globally, adversely affecting farming activities particularly in Africa. Kenya experiences variations of annual rainfall with considerable uncertainty. These variations ranging from below 500mm to above 2000mm annually, cause droughts and floods respectively, affecting farming activities and yields. This study focused on Machakos sub County, a semi arid area, East of Central Kenya highlands. Information on the effects of rainfall variability on farming activities in Machakos, have concentrated on small holder maize cultivation and covered broad areas of the Eastern region and Machakos County, leaving out other crops and livestock. They mainly cover the period between 1930 - 1990. After this period, very scanty information exists. The main objective of the study was to investigate the influence of rainfall variability on farming activities in Machakos sub County, focusing on Maize, Coffee and Cattle farming. The specific objectives were to; establish the historical rainfall variability at monthly, seasonal and annual basis in Machakos sub County between 1990 - 2014; determine the human factors that influence rainfall variability in Machakos sub County and to assess the relationship between rainfall variability and Coffee, Maize and Cattle Yields in Machakos sub County. A cross sectional research design was used. A sample of 384 from 35,605 households was drawn using the Webster (1995) formulae and stratified into units based on the twelve locations. Primary data was collected through; household questionnaires, interviews, observation and photographs. Publications from Meteorological Department Nairobi and sub county Agricultural offices provided secondary data. Using SPSS, quantitative data was analyzed using descriptive statistics such as Means, Standard deviation and percentages. Inferential statistics using Pearson's Correlation coefficient was used to determine relationships between variables. Coefficient of variability, Relative variability and Precipitation Concentration index measured Rainfall Variability. Qualitative data was analyzed through themes and patterns, conclusion and generalization. The study established that monthly, seasonal and annual rainfall distribution in Machakos sub County was highly variable, erratic and unpredictable over the 25 years with a CV of 24% and a PCI of 10. Human activities influencing rainfall variability such as overgrazing and deforestation were evidenced by high land carrying capacity, use of firewood and charcoal as the main source of fuel and timber extraction. Correlation between annual rainfall totals and maize yields ($r = 0.632$) and coffee yields ($r = 0.695$) were statistically significant at 0.05 significance level. Maize and coffee yields increased with high rainfall. Cattle production showed a positive relationship with the rainfall trends. There is high temporal rainfall variability (CV of 24% and PCI of 10) in the sub County. Deforestation, overgrazing and over cropping are evident. Rainfall variability has a strong relationship with Maize, Coffee and cattle farming and yields. Disseminating information on rainfall forecasts, rainwater harvesting for irrigation, proper cattle stocking, a forestation and reforestation programs were highly recommended.

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LIST OF ACRONYMS AND ABBREVIATIONS.

ASALs	Arid and semi arid Lands
SSTs	Sea Surface temperatures
ENSO	El Nino Southern Oscillation
ITCZ	Inter Tropical Convergence Zone
CFCs	Chloro-floro Carbons
UNHCR	United Nation High Commission for Refugees
IBID	Same Author/Source as above
GOK	Government of Kenya
PCI	Precipitation Concentration Index
KAR1	Kenya Agricultural Research institute
SPSS	Statistical Package for Social Sciences
MAMJ	March April May June (Short rainfall season in Machakos)
ONDJ	October November December January (Long rainfall season in Machakos)

DEFINITION OF OPERATIONAL TERMS

- **Rainfall characteristics**: Refers to intensity (total), frequency, duration and variability of rainfall. Intensity is the total amount in a given period of time. Frequency is how often the rain occurs from one season to another, duration is the time taken by rainfall in a season.
- **Rainfall variability**: Refers to the degree to which rainfall amounts vary across an area or over a given period of time. When these variations are taken at various locations across a region for a specific time, it is referred to as areal variability. Where the variations are taken at one location over a specified period of time it is becomes temporal variability.
- **EL NINO-** An abnormal state of ocean atmospheric System in the tropical pacific which triggers exceptionally warm and long lived ocean currents that disrupt global rainfall and wind patterns causing drought or floods in far flung regions
- **Topography**. The general terrain of the landscape. The landscape has a varied terrain including valleys, plains, plateau, highlands escarpment e.t.c.
- **Drought** – Absence of precipitation for a period long enough to cause moisture deficiency, biotic loss, crop failure, loss of both human and animal life.
- **Famine** – A sudden rise in food shortages leading to mass starvation and death of people
- **Desiccation** A progressive increase in aridity of an area resulting from natural causes or human causes.
- **Desertification** – spread of desert like conditions or encroachment of desert conditions into areas that are productive.
- **Marginal lands** transitional zones from one climate type to another. Climate characteristics of one type merge into those of another type.
- **Sahel** climate conditions in Africa South of the Sahara desert and North of the Savanna grasslands.
- **Evapo transpiration** The release of water vapour from the earth surface (land & water) by evaporation and vegetative plants by transpiration.
- **Doldrums** – An equatorial belt of low atmospheric pressure where trade winds (Westerlies and Easterlies) converge.
- **Precipitation** – Rain, snow or hail that falls from above the surface on to the surface of the earth

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CHAPTER ONE
INTRODUCTION

Rain is the most important element determining climate and the world's climate is categorized based on rainfall and temperature. Variability of rainfall is a global problem disrupting farming activities in most parts of the world. The factors influencing rainfall variability were looked at in terms of natural and human factors. The Main objective of the study was to investigate the effect of rainfall variability on farming activities. The study area was limited to Machakos sub County which is a semi arid area in Eastern Kenya. The farming activities studied included crop farming and livestock farming. The particular crops studied were coffee and Maize focusing on yields. The livestock studied were Cattle. The study findings are expected to help in formulating development strategies to counter the problems of rainfall variability.

1.1 Background to the Study

Rainfall variability is the degree to which rainfall amounts vary across an area or over a given period of time. When this variation of rainfall amounts is taken at various locations across a region for a specific time, it is referred to as areal variability. Where the variation of rainfall amounts is taken at one location over a specified period of time is known as temporal variability. For the purposes of this study, the variability considered is temporal variability as the study area, is one area, Machakos sub County. Temporal dispersion in rainfall can be either from month to month, season to season or from year to year from the long term average. This variability can cause drought or floods (Ribot et al.; 1996). Rain fed agriculture in the affected areas suffers in terms of reduced yields, crop failure and to extremes livestock deaths. Subsistence crop production becomes uncertain (Medug, 2009)

Rainfall in many parts of the world is subject to variability and uncertainty as a result of fluctuations. According to Jose (2007), climate change has made rainfall in the tropical regions of the world more irregular. It used to start raining in October and continue in July every year in the Brazilian Semi-Desert region that currently suffers from drought. Today rainfall in this Brazilian region is unpredictable, streams are disappearing and water available for agriculture has drastically reduced.

An elaborate analysis of annual, seasonal and monthly rainfall of 16 rainfall stations over a period of 30 years between 1960 – 1990, was conducted in India. The results revealed high variability patterns across the country. The impact of the variability was seen in terms of environmental issues like desertification in northwestern India, river channel changes over the Gangetic plains and rising trend in surface temperature variation over the whole country (Nityanand, 2009). A study conducted by Phillips et al (1999) stated that the effects of rainfall variability have continued to affect global food production throughout history. Rainfall variability in Australia has adversely affected the eastern part of the country with the effects of expanding the desert condition (Nicholls et al., 1977).

Rainfall variability has led to expansion of the Sahara desert and encroachment of the savannah and steppes land during modern times (Ngaira, 1999). African countries are the most vulnerable to rainfall variability as they mostly depend on rain fed agriculture for their livelihood (Alberto, 2013). A close study of documented rainfall datasets reveal that rainfall variability in Southern Africa experienced significant modifications affecting agricultural activities (Richard, 2000). Assessing rainfall variability is a frequent practice in climatology. An important application is the estimation of total rainfall over an area, e.g. a catchment area as an input of climate model (Barrow, 2003). Rainfall variability has been common in the Sahel South of Sahara, East and Central Africa. Many countries of the Sahelian region of Africa are today affected by prolonged droughts adversely affecting crop yields (Ominde and Juma, 1991). In West Africa, a study by (Gribin, 1975), indicated that the area experienced prolonged droughts, which were responsible for decline in agricultural harvests.

Inter annual rainfall variations in equatorial East Africa are tightly linked to the Elnino Southern Oscillations (ENSO) with more rain and flooding during elnino and droughts during lamina years both having severe impact on human habitation and food security (Gerald,2011). According to Young and Lowry (1977), variability in the rainfall total is one of East Africa's handicaps from year to year; the total might fluctuate from half the average causing drought, to double the average causing floods. Many areas of East African countries suffer from excessive and deficient rainfall with frequent occurrences of drought and floods. It is characterized by extreme variability of rainfall amounts with partterns of rainfall changing over different periods and causing fluctuating subsistent crop production (Shongwe, et al., 2009).

Kenya's rainfall is characterized by variability in the annual total and considerable uncertainty in the time of the year the rains are expected (Ngaira,1999). This is mainly witnessed in marginal areas like Garisa, Mandera, Magadi and Kajiado, Samburu and Machakos which are semi arid

(Ojany and Ogendo,1973). A study conducted by Ovuka (2016) analysed rainfall trends of the Central highlands of Kenya, between 1972 – 2012. Results indicated that rainfall decreased over the 40 year period and that extreme fluctuations were recorded between 2000 – 2012. The drought periods elongated over the same period adversely impacting on agricultural production. A study by Sisanya et al.(2016) on semi arid lands in Kenya, indicated that variability is persistent in the arid and semi arid lands of Kenya and continues to affect vegetation condition and consequently crop production.

Machakos Sub county receives erratic and unpredictable rain, less than 500mm per annum. The higher areas towards the North and North East receive more rainfall (slightly above 1000mm) than the lowland areas in the Southern parts (less than 500mm) and particularly those in the rain shadow of the hills in the East. The rainfall is associated with erratic patterns and fluctuations in distribution over different years. Droughts are a common feature in the district with records revealing an occurrence of 4 out of 10 years (GOK, 2013). Studies conducted on rainfall variability in Machakos District such as Michael and Tiffen (1992) mainly cover the period 1930 –1990. The current study covers the period 1990 – 2014 and focuses on Machakos sub county which was the Central Division of the former larger Machakos District, currently Machakos County. The study therefore brings out a clearer picture on the current levels and effect of rainfall variability on farming activities in Machakos Sub county, focusing on maize, coffee and cattle.

In addition, these existing studies on rainfall variability in Machakos reveal some inadequacies. Analysis of rainfall variability have not assessed the historical rainfall variability at monthly seasonal and annual scales on a time series basis which this study sought to address. The study analyzed variability patterns using such terms and measures such as precipitation concentration index, drought intensity and coefficient of variability at historical, monthly seasonal and annual scales to measure the extent of rainfall variability in the study area. The current study focuses on Machakos sub County, a smaller area as compared to the larger former larger Machakos District (Now Machakos County). Focus on a smaller area will bring out the variability patterns more clearly than the generalized results for the larger area.

These studies on rainfall variability at global, continental and regional level have mainly focused on areal rainfall variability that covers various locations across an area such as a country or countries. Such studies provide generalized results over the wide areas they cover. This may not bring out clearly rainfall characteristics of particular or specific areas covering smaller unit areas such as a sub county or a division in a country. It is this gap that the current study seeks to address by covering a smaller geographical area, Machakos sub county.

Factors that have been emphasized in studies such as Thornthwaite (1999), as causes of rainfall variability include; Elnino phenomenon, Sea Surface Temperatures (SSTs), Inter-Tropical Convergence Zone (ITCZ), Topographical Contrasts and Human activities (Wenner, 2012). Each of these can alter the prevailing dynamics and circulation (Nicholson, 1989). Elnino is an abnormal state of ocean atmosphere system in the tropical pacific which triggers exceptionally warm and long lived ocean currents that disrupt global rainfall and wind patterns causing drought or floods in the far flung regions (Ngaira,1999). Although Elnino is centered in the pacific, it influences global wide Sea-Surface temperatures which in turn affect Africa (Wenner, 2012). The SSTs present a clear contrast between abnormally low SSTs during the wet 1950's and abnormally high SSTs during the dry 1980s. SST Patterns produce expected anomalies of fluctuating rainfall patterns. This is particularly true for the Sahel where the overall characteristic of variability changes abruptly and drastically from decade to decade (Ngaira,1999). These changes in variability affects Africa including the Machakos sub County. Predicting the timely occurrence and the effects of Elnino in tropical countries such as Kenya has been one of the major challenges of meteorologists in the region. This results will help farmers in coming up with efficient programs of activities and preparedness of the possible effects of rainfall variability to overcome their adverse effect on farming activities.

ITCZ is the point of convergence of air masses characterized by low surface pressure and rising air movement. The convergence creates a strong instability, reinforcing upward movement of moist air forming deep cumulo-nimbus clouds resulting in heavy down pour in Kenya (Karugah and Kibuuka,2003). One of the reasons for large rainfall variations in Kenya is the tremendous topographical contrasts including the altitudinal range and partly the presence of and distribution of large water bodies such as the Indian Ocean and Lake Victoria (Ojany and Ogendo, 1973). Human activities like deforestation, particularly in the water catchment areas, bush burning, over grazing and poor farming methods interfere with the hydrological circle, hence reduced and fluctuating patterns of rainfall (Karugah, 2003). Agricultural expansion leading to depletion of forests and grasslands was greater over the 30 years between 1950-1980, (Ojany and Ogendo, 1973). Information on human factors that influence rainfall variability has been sourced from studies such as Chisanya (2011) which have covered broad areas of the Eastern and South Eastern regions bringing out generalized results. This study focuses on a small area, Machakos sub County to bring out specific elaborate results. The information available has predominantly covered natural factors leaving very little on human factors. Hence the Human factors that influence rainfall variability in the study area have not been adequately covered in the past studies. The current study aimed at determining the human factors that influence rainfall variability by identifying and determining their evidence. Knowledge of these factors will lead to designing measures to reduce rainfall variability and its effect on farming activities.

The effects of rainfall variability include disruption of farming calendars and activities, reduced productivity, and uncertainty in planning farming activities and diversification of economic activities. Either high or low extremes of rainfall from the average (700mm-1200mm) can be disastrous to agricultural activities (Young and Lowry, 1977). Agricultural activities include, crop farming, livestock farming, ranching, and irrigation farming (Warah, 2009). The effects of rainfall variability on these activities include reduced crop yields, crop failure, livestock deaths, and diversification of agricultural activities.

Studies conducted on the effect of rainfall variability in marginal areas such as Ngaira, (1999) and Briggs and Smithson, (1985) have concentrated on the environment in general. Their findings revealed the effects of rainfall variability on both agriculture and environmental features such as lakes, rivers and vegetation. Other studies on the effect of rainfall variability in Machakos sub County, such as Baron (2004) and Wanjala (1978) have concentrated on maize cultivation by small scale farmers. Other crops were not covered. The current study goes beyond general studies on the environment and the focus on small scale maize cultivation to investigate the effect of rainfall variability on coffee, maize and cattle farming by the people living in Machakos sub County. Studies on the influence of rainfall variability on farming activities in Machakos sub county covered in the literature review have concentrated mainly on small scale maize production and generally the effect on the environment such as that of Mua and Ndunda (2013), focused on the whole county giving generalized results. This study looked at coffee, maize and cattle farming on both small scale and large scale making the study more detailed by focusing on a smaller area as compared to the previous studies in the area**.**

The heterogeneity of the environment where farmers in marginal areas farm, necesitates a research that produces diverse products such as crop varieties adopted to low rainfall and erratic climatic conditions which also produce well under limited inputs (Otieno, 2003). Rural development projects in marginal areas seek to improve the well being and incomes of small holder farmers through sustainable increase in productivity and food security (Jude, 2007). In Machakos sub County, rainfall is erratic, unpredictable and low, about 500mm annually. This makes the residents to seek support in their farming activities through development projects such as irrigation. Seed varieties adapted to such conditions like Katumani maize are widely used (GOK, 2013). The study aimed at establishing the extent to which rainfall variability affects farming activities in the district to come up with diverse mechanisms of adaptability of the harsh climatic conditions and mitigating the effect of rainfall variability.

It is against this background that the study intended to assess the effect of rainfall variability on farming activities among the people living in Machakos sub county. The crops studied were coffee and maize. The livestock studied were cattle.

1.2 Statement of the Problem

Rainfall variability is a global predicament that impedes the success of farming activities, particularly in marginal areas. High intensities of rainfall such as that above 2,000mm per annum cause floods as those experienced in the Gangetic plains of Asia, Congo basin and parts of Kenya including Tana delta, Kano plains, Budalangi and Athi-kapiti plains where Machakos County falls (Mburu, 2011). Low intensities particularly below 500mm per annum cause drought and desertification in the affected areas (Ngaira,1999).

Kenya’s rainfall is characterized by variability in the annual total and considerable uncertainty in the time of the year when the rains eventually are expected. Machakos Sub County receives erratic and unpredictable rainfall, less than 500mm per annum. The rainfall is associated with erratic patterns and fluctuations in distribution over different years. Droughts are a common feature in the district with records revealing an occurrence of 4 out of 10 years. Droughts disrupt farming calendars and activities; hence reduce crop and livestock yields, sometimes crop failure resulting into low harvests and food shortages especially in arid areas such as Machakos Sub County. Knowledge on the effect of rainfall variability on farming activities, will enable economic planners, the government and farmers to formulate alternative ways of adapting and mitigating the effect of rainfall variability in the study area.

As per specific objective one, studies conducted on rainfall variability in Machakos sub County such as Michael and Tiffen (1992) and Chisanya (2011) have not adequately analyzed the variability patterns in terms of historical rainfall variability at monthly seasonal and annual basis. The current study focused on historical rainfall variability in terms of distribution patterns, drought intensity, relative variability, coefficient of variability and precipitation concentration index on monthly seasonal and annual basis in Machakos Sub county between 1990 - 2014. As per specific objective 2, information on factors that influence rainfall variability in the study area has been very scanty as they have covered broad large areas, hence providing generalized results. This has necessitated the need to cover a smaller area like Machakos sub county, to come up with specific elaborate results on human factors that have influenced rainfall variability. Studies such as Otieno (2008) have indicated that human activities like deforestation leads to disruption of the hydrological cycle and hence reduced rainfall over time. Kibuka (2003) indicated that overgrazing will reduce transpiration and hence precipitation.

In addition, studies conducted on rainfall variability in Machakos District such as Michael and Tiffen (1992) mainly cover the period 1930 –1990. The studies have concentrated on small scale maize farming and the environment in general. The third specific objective of the current study intended to assess the effects of rainfall variability on farming activities, a focus on Coffee, Maize and Cattle farming in a smaller area Machakos Sub County between 1990 - 2014. This period 24 years is adequate to determine rainfall variability and climate of the area.

1.3 Objectives

The general objective of the study was to investigate the influence of rainfall variability farming activities in Machakos sub County. The specific objectives of the study were: -

i. To establish the historical rainfall variability at monthly seasonal and annual basis in Machakos Sub County between 1990 - 2014.
ii. To determine the human factors influencing rainfall variability in Machakos sub County.
iii. To assess the relationship between rainfall variability and Coffee, Maize and Cattle yields in Machakos sub County.

1.4 Research Questions

The study was based or guided by the following Research Questions.

i. What have been the historical rainfall variability patterns on monthly seasonal and annual basis in Machakos sub County between 1990 – 2014?

ii. What are the human factors influencing rainfall variability in Machakos sub County?

iii. What is the relationship between rainfall variability and Coffee, Maize and Cattle farming in Machakos Cub county?

1.5 Justification of the Study

The findings of this study will provide a deeper understanding of fluctuating patterns and trends of rainfall and how they affect agricultural activities in marginal areas. Detailed analysis and trends of variability patterns and measures in terms of, distribution patterns, drought intensity, relative variability, coefficient of variability and precipitation concentration index (PCI) on monthly and annual basis will help farmers to plan effective farming calendars so as to improve on their productivity. Knowledge and understanding of how human activities influence rainfall variability will help in coming up with ways to curb or minimize their effect on farming activities. Understanding the effect of rainfall variability on farming activities, will help economic planners, the government and farmers to formulate alternative ways of adapting and mitigating the effect of rainfall variability in the study area. The study will also help Meteorologists in predicting unexpected rainfall patterns and coming up with suitable information on any disasters that may result from rainfall variability. The study can also be a basis for further research on coping with disasters that may result from rainfall variability. The choice of Machakos sub County as study area was guided by the fact that the area is a semi arid area with acute rainfall variability. Coffee was chosen as it was the major cash crop in the area, maize was chosen as the major food crop and cattle was chosen because it the animal kept by the majority of the householders in the study area.

1.6 Scope and Limits of the Study

The study was conducted in Machakos Sub county of Machakos County. The sample population was drawn from Machakos sub County. The region is a stretch of Marginal low lying plains cutting across the southern part of Machakos County. The region lies in Athi kapiti plains. The area is a transitional zone from wet and cool Kenya highlands to the dry semi desert region of the Nyika plateau. The study was limited to evaluating historical rainfall variability at monthly and annual basis in terms of, distribution patterns, drought intensity, relative variability, coefficient of variability and precipitation concentration index in Machakos sub County. It also assessed the relationship between rainfall variability and farming activities focusing on crop and livestock in Machakos sub County. The crops studied were Coffee and Maize. The livestock type studied was Cattle. The scope of farming aspects studied were Coffee, Maize and cattle (milk) yields.

1.7 Assumptions of the study.

The following assumptions formed the basis of the study.

i) Rainfall trends and patterns clearly come out for analysis of rainfall variability.
Looking at the rainfall charts of the two meteorological stations that is Kari Katumani (Central Division) and Mutisya mango farm (Kalama Division) we have the impression that rainfall trends and patterns will clearly come out help understand the analysis of rainfall variability

ii) There are several human activities that are practiced which factors that enhance influence rainfall variability patterns in Machakos sub County.

iii) Rainfall variability has a strong relationship with farming activities in Machakos sub County.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Rainfall is an important element of both weather and climate (Ngaira, 1999). Rainfall is the most important element determining climate. Broad divisions of climatic types of the world have been based on rainfall and temperature (Karugah and Kibuuka, 2003). Reliability is the ability of a system to perform and maintain its functions, in routine as well as hostile or unexpected circumstances (Wenner, 2012). Reliability may also be defined as the ability of a system or component to perform its functions under stated conditions for a specified period of time (Karugah, 2003).

Variability is the degree or extent to which data points in a statistical distribution or data sets diverge from the average or mean. Variability describes how spread out or closely clustered, a set of data is. It may be applied to many different aspects e.g. climate variability, and Rainfall variability (Wenner, 2012). Variability also refers to the extent to which data points differ from each other (Bevan, 2002). Rainfall variability refers to the degree to which rainfall amounts vary across an area or over a given period of time. The variation of the amounts at various locations across a region for a specific time interval is known as areal variability and when the variation of the amount is at a particular location, within a given period of time is called temporal variability (Nicholls et al., 1997). Assessing rainfall variability is a frequent practice in climatology. An important application is the estimation of total rainfall over an area e.g. catchment area as an input of climatic models (Wenner, 2012).

2.2 Rainfall Distribution, Patterns and Variability

2.2.1 Distribution, patterns and Variability at global, regional, and local levels

Precipitation, particularly rainfall is in many cases the most important input factor in a climatological modeling (Wenner, 2012). However this input is subject to uncertainty as a result of fluctuations (variability), measurement errors and systematic errors in the interpolation method, due to random nature of rainfall (Barrow, 2003). Rainfall in many parts of the world is subject to variability and uncertainty as a result of the fluctuations. According to Jose (2007), climate change has made rainfall in the tropical regions of the world more irregular. It used to start raining in October and continue in January every year in the Brazilian semi-desert region that currently suffers from drought. Today rainfall in this area is unpredictable, streams are disappearing and water available for agriculture has drastically reduced.

Rainfall variability has led to expansion of the Sahara desert and encroachment of the savannah and steppes land during modern times. Remarkable fluctuations of rainfall have occurred over nearly the entire continent (Ojany and Ogendo, 1973). Rainfall variability has been common in the Sahel south of Sahara, East and Central Africa. Young and Lowry (1977) posits that variability in the rainfall total is one of East Africa's handicaps from year to year; the total might fluctuate from half the average causing drought, to double the average causing floods. Kenya's rainfall is characterized by variability in the annual total and considerable uncertainty in the time of the year when the rains are expected (Ngaira, 1999). This is mainly witnessed in marginal areas like Garissa, Mandera, Suguta plains, Magadi, Machakos, among others.

The above studies have generalized rainfall variability for the broad and large regions of the world prompting the need to focus on a smaller area within a country. Environmental and rainfall patterns differ from one area to another within or outside a country (Ovuka, 2016). Generalizing rainfall patterns for the whole country or region does not provide adequate understanding of rainfall variability in a given particular area (Richard, 2003). This study focused on a small area in Kenya's marginal lands, Machakos sub County.

Studies on the mean annual rainfall of Kenya reveal the general inadequacies of the amounts of rainfall received by large parts of the country. This is clearly revealed in Table 2.1. Drought is one of the most basic problems of development in Kenya. Two other characteristics of this rainfall are also important but not apparent from the maps. There are wide variability in the annual total and considerable uncertainty in the time of the year when the rains can be expected. Planned agriculture is therefore made difficult to carry out (Ojany and Ogendo, 1973).

Table 2.1 Rainfall Distributions in Kenya 1973.

Rainfall in mm	**Area in Km^2**	**% of Total Area**	**Cum percentage**
0 – 253	157470	27.0	27.0
254 – 507	209 011	35.9	62.9
508 – 761	105692	18.1	81.0
762 – 1015	48692	8.4	89.4
1016 – 1269	28490	4.9	94.6
1270 – 1523	19425	3.3	97.6
1524 – 1777	9583	1.6	99.9
1778 – 2031	3885	0.7	99.9
2032 +	518	0.1	100.1

Source Ojany and Ogendo, 1973.

The reasons for this large rainfall variations is partly, the tremendous topographical contrasts, including great altitudinal range and partly the distribution and presence of large water bodies such as lake Victoria (Karugah and Kibuuka, 2003). The alternate cooling and heating of the lake and surrounding land initiates on shore and off shore breezes. The prevalent easterly winds meet the land breezes and the two bring about subsidence of air and hence small amounts of rainfall. This is the reverse of the western shores. Prominent topographical features stand out as highlands or pockets of high topographic points initiating rainfall (Ojany and Ogendo, 1973). A more serious drought however characterizes the Northern and North Eastern Kenya which is in fact, part of the dry region that covers North Eastern Africa and Arabia (Minns, 1984). Table 2.1 shows rainfall distribution in Kenya. It shows that 27% of Kenya is arid and 40% of the total land area is semi arid and that a smaller area (10%) receives over 1000mm. This clearly shows the high variabilities of rainfall across the country.

The study area, Machakos sub County receives erratic and unpredictable rain, less than 500mm per annum. Rainfall varies with altitude. The rainfall has abnormal patterns with a significant difference in distribution over different years. The short rains occur in March to May while the long rains fall in October to December, although it is not very reliable. Historical data indicates that in 4 out of 10 years, there is a major drought in the district (GOK, 2013). The above studies have focused on annual and monthly rainfall distribution patterns and left out other characteristic aspects measurement of rainfall variability such as distribution patterns, drought intensity, relative variability, coefficient of variability and precipitation concentration index that makes deeper understanding of rainfall variability.

2.2.2 Distribution and Variability of rainfall in Marginal areas

Marginal areas refer to transitional zones from one climate type to another climate type. They are broad zones of transition where climatic characteristics of one type progressively merges into those of the next zone (Karugah and Kabuuka, 2003). Most of the Eastern Kenya falls in this transitional zone called marginal areas. Temperatures are high throughout the year ranging between 21^0C - 26^0C. The mean annual temperature is low 5^0C. Rainfall is low and variable and generally rarely exceeds 500mm annually. The rainfall patterns and amounts are extremely variable (Ojany and Ogendo, 1973). The term marginal area is generally applied to farming the marginal lands (not as good as the prime land) that farmers use when demand is exceeding supply and prime land is at maximum capacity. Marginal land will produce less per acre than prime land, but it will realize a profit if demand is high (Jose, 2007).

According to Jude (2007), marginal environments can be defined as areas where agriculture is dominated by variations in agro ecological and socio-economic conditions. Such heterogeneous and erratic climatic conditions, variable topography results in complex stress and high production risks. The heterogeneity of the environment where these farming activities take place, a research develops that produces diverse products such as crop varieties adapted to low fertility and erratic climatic conditions which also produce well under limited inputs (Mitchelle, 2007). Rural development in marginal areas initiate projects that improve the well being and incomes of small holders (Jude, 200). Extreme variations of patterns and totals of rainfall are responsible for extreme weather conditions like droughts and floods. Droughts and floods are common features of the Kenyan climate. Both these extremes are due to rainfall anomalies and cause great difficulty for an essentially agricultural people in Kenya who have to farm large marginal areas (Mburu, 2005). The above studies have covered large expansive areas and regions giving generalized focus on broad marginal areas. A study made in a small area will provide detailed, exact, clear and precise results. The current study sought address this problem by focusing on a smaller marginal area, Machakos sub County in Eastern Kenya.

2.3. Causes of Rainfall Variability

Factors that have been emphasized as causes of rainfall variability include the following; El-nino phenomenon, Sea Surface Temperatures (SSTs), Land atmospheric feedback, Topographical contrasts, Transitions of the Inter Tropical Convergence Zone (ITCZ) and human activities (Wenner, 2012). Each of these can alter the prevailing atmospheric dynamics and circulation such as the Hadley and Walker circulations or upper level jet streams resulting in high fluctuations of rainfall. (Nicholson, 1989).

2.3.1 Natural Causes

El-nino is an abnormal state of ocean atmospheric system in the tropical pacific which triggers exceptionally warm and long lived ocean currents that disrupt global rainfall and wind patterns causing drought and floods in the far flung regions (Mburu, 2003). The warm and long lived ocean currents develop low pressure, increases evaporation of sea and ocean waters which upon condensation bring about heavy rainfall in both immediate and far flung areas. The Southern Oscillation is a 'seesaw of atmospheric pressure between the eastern equatorial Pacific and Indo–Australian areas' closely linked with El Nino," according to research from the National Drought Mitigation Center, based in Lincoln, Neb (Tulsa, 2015). During low temperatures, the cool and long lived ocean currents develop a high pressure belt, reduced evaporation and hence droughts. Although El-nino (ENSO) is centered in the Pacific, it influences global atmospheric circulation and worldwide Sea Surface Temperatures which in turn affect Africa (Ngaira, 1999). The three timescales dominant in rainfall variability over East and Southern Africa are evident in both the ENSO cycle and SSTs throughout the tropical Atlantic and Indian Ocean (Nicholson, 1989).

According to Wenner (2012),trends in Sea Surface Temperatures portray a clear contrast between extremes in low SSTs during the wet 1950's and abnormally high SSTs during the dry 1980's. This association is even larger in scale with the continental rainfall patterns of 1950's and 1980's being coincident with cold and warm SSTs respectively and anomalies occurring throughout most of the Atlantic and Indian Ocean between 40^0N and 40^0S (Bevan, 2002). Warm surface temperatures initiate low pressure belt, increased evaporation and high rainfall in the surrounding areas and vice versa. Warming trends in SSTs occurred in 1960's when rainfall began to decline over much of Africa. This is particularly true for Sahel where the overall character of variability is from decade to decade (Ngaira, 1999). The time range between 1950's and 1980's is adequate time to determine a climate change.

Topographical contrasts stand out as Islands or pockets of high orographic features which disrupt the wind patterns causing orographic rainfall in some parts (windward's sides) and little or no rainfall on the leeward side. The effect of topographical contrasts is fluctuations in rainfall patterns and amounts (Ojany and Ogendo, 1973). The reasons for the large rainfall variations in

Kenya is partly, the tremendous topographical contrasts, including great altitudinal range and partly the distribution and presence of large water bodies such as lake Victoria (Karugah and Kibuuka, 2003). The alternate cooling and heating of the Lake and surrounding land initiates on shore and off shore breezes. The prevalent easterly winds meet the land breezes and the two bring about subsidence of air and hence small amounts of rainfall.

Inter-Tropical Convergence Zone (ITCZ) is a wide belt at the Centre of Tropical Circulation characterized by low surface pressure, rising air movements and convergence of air masses (Mburu, 2005). The convergence in the area creates a strong instability which reinforces the upward movement of air until it reaches the height of the dew point where condensation commences and ascending air enters the cloud stage. Deep cumulonimbus clouds form, which results in a very heavy down pour in the region (Mburu, 2005). The belt shifts its position North and South of the equator according to the position of the overhead sun. Places in the Northern Hemisphere that are further away from the equator experience one rainy season when the sun is overhead the equator in the region and along dry season when the sun's position shifts to the southern hemisphere (Karuggah and Kibuuka, 2003). The ITCZ is a low pressure belt which shifts its position North and South of the equator in response to the migratory patterns of the over head sun. These migratory patterns initiate differences in rainfall patterns (rainfall variability) over the affected areas (Mburu,2005). It appears therefore that any rains in the dry parts of Eastern Kenya are brought about by seasonal movement of the convergence between trade winds at the ITCZ (Minns, 1984).

2.3.2 Human Activities that Influence Rainfall Variability

Human activities like deforestation, bush burning, overgrazing and over cultivation interfere with the hydrological cycle hence reduced amounts and varying patterns of rainfall (Karuggah and Kibuuka, 2003). Grazing or overgrazing will result in two changes in the environmental conditions which will influence microclimate. First the removal of vegetation by the grazing animals will reduce transpiration and hence precipitation. Second, the compaction of soil by the hooves of the animals will reduce the capacity of the soil to absorb water hence making it less able to store water (Otieno, 2008). The additional water made available by reduced transpiration will run off and result in erosion damage (Waikwa, 1998). If the forest is cut down leaving the soil with few plants in it, the rain that falls on the soil doesn't stay in the area but drains immediately as run offs into the nearest river. The rainfall may decrease. Forests also encourage rainfall by improving or enhancing hydrological cycle via evapo-transpiration (Turner, 1994). The rate at which rainfall decreases, is further enhanced by deforestation.

Generally the influence of man upon climate is displayed over normally small areas where some obvious changes have been made on the surface (Jakeman, 1993). The rate of change has not been uniform across the world regions. Instead, agricultural expansion, forest clearing, wetland drainage, irrigation of grasslands and expansion of human settlements and similar processes have traced a spiraling area that is determined for the most part by political and economic control (Clarke, 1989). As productivity has increased so has determination of the land, humans now plan and assign tasks to all categories of the land. Intensification of land use is intensification of control (Kates, 1989).The key global land use cover classes are cultivation, forests, grasslands, wetlands and settlements. Land use change cover in two ways. The first is conversion, a change of cover from one class to another (Markids, 1997). The second is modification and alteration of the existing cover that converts it to a different cover type (Turner and Mayor, 1994).

Deforestation and overgrazing which lead to loss of vegetation particularly in the tropical areas increase the albedo reflectivity of a surface and decreases radiation balance making it more negative. Albedo reflectivity is the measure for reflectivity or heat reflected from the earth surface. This interferes with the hydrological cycle, hence reduced rainfall. (Ronald, 1977). The removal of trees benefits cropping and grazing in the short run, but soon the water table may start to fall. The unprotected soil will be eroded and the area may become more arid and dusty due to high evaporation (Makaya, 2009). This may limit the soil and reduce rainfall in the affected regions. The moisture theory states that the removal of vegetation and reduced soil moisture contributes to a decrease in rainfall (Ngaira, 1999). Albedo theory states that the clearing of vegetation leaving exposed surfaces raises surface albedo and increases heat loss from the surface creating a cold spot in the atmosphere and increasing the rate of subsidence, thus reducing rainfall in the area (Karuga, 2003). The areas of Woodland destruction in the arid and semi-arid areas of Africa include; Burkina Faso, Mali and Mauritania. In a deforested area which has been reduced to a Savannah cropland, precipitation and evaporation decreases by about 10% (Lima, 2004). Intensive agricultural exploitation of desert margins such as the Sahelian region of Africa create a dust pool in the atmosphere by exposing larger areas of surface materials to depression in dust storms. This atmospheric dust increases atmospheric temperatures and reduces rainfall. Observations on dust levels over Atlantic, during drought years of the late 1960s and early 1970s in the Sahel, suggest that degraded surfaces of that time made to a great increase in the atmospheric dust hence temperatures (Ngaira, 1999).

Recently many meteorologists have become convinced that the climate is going to change dramatically within the next few decades, not due to the hands of nature but the influence of people on the global weather machine (Bryan, 1994). The change is rather easy to identify because it has produced wide ranges of temperatures just a time when natural cycles of rainfall, would indicate a decline to be due. Arid and semi arid areas (ASALs) in Kenya are at the brink of total destruction due to numerous human activities including deforestation and overgrazing (Mua and Ndunda, 2013). The studies above focus on the human activities that influence rainfall variability at global, regional and Kenyan level which is general. The current study focuses on a specific smaller area, Machakos sub County.

According to Machakossub county Development Plan (GOK,2013), there are two gazetted forests namely Mutituni and Mumbuni forests covering an area of 5.0327 Km^2. There are also two Non-gazetted forests namely Kola and Kilima Kimwe covering an area of 7.5490 Km^2. Other than crop farming, rainfall variability affects forest production. This demonstrates the trans boundary nature of rainfall. Improved rainfall in the highland areas of the sub County contribute to increased forest products. The main forest products include woody forest products; Timber, poles, posts, wood fuel and honey. According to FAO (2009) information for production and trade in 2008 and updated in 2017, the Forest Department of FAO, considered fruits, honey, fodder and medicinal herbs as forest products. There are 80,000 people engaged in forestry and two million seedlings are produced per year. The quantity of timber produced per year is 212.2 tones.

2.4. Effects of Rainfall Variability on Crop and Livestock Farming

Rainfall variability has an effect on both farming activities and yields of both crops and livestock. The effect includes crop failure and death of livestock, when the rains fail. Droughts destroy crops and farmlands leading to reduced harvest and hunger.

2.4.1 Effects of Rainfall Variability on Crop and Livestock Farming in the World

According to Ngaira (1999), close to 630 million people or 14 percent of the world's inhabitants live in the arid or semi arid environments. Out of these, some 50 million people are constantly faced with malnutrition and possible deaths when the rains fail. Farm crops fail leading to reduced or no harvests at all and livestock die leading to food shortages. The affected areas include regions like Middle East countries, Southern Brazil, California in the U.S.A, Australia among others. Variability of rainfall has affected the Eastern region of Australia with an effect of expanding the Australian Desert (Nicholls et al., 1997). The Brazillian semi desert currently suffering from drought, was once an area receiving high equatorial rainfall beginning in October to January every year. This change has been triggered by acute rainfall variability that has affected many parts of the world (Jose, 2007).

2.4.2 The Effects of Rainfall Variability on Crop and Livestock Farming in Africa

Climates of Africa during the Pleistocene and Holocene represent two extreme scenarios with the expansion of the Sahara desert at the peak of the last glacial period and encroachment of the savannah and the steppes lands during modern times (wenner, 2012). However remarkable fluctuations of rainfall have occurred over nearly the entire continent. During the 1950's drought affected more extensive areas of Africa especially the southern part. In the Sahel and other lands bordering the Southern Sahara, the drought which commenced in 1968 nearly extended to the 1974 and 1975 (Ngaira, 1999). Documented data sets observed fluctuating changes in rainfall amounts at monthly, seasonal and annual basis in southern Africa. Significant modifications were experienced in the variability of rainfall in the region adversely affecting farming programmes (Richard, 2002).

Studies carried out by Gribbin, (1975) in West Africa revealed that persistent drought in the Sahara region of Africa in the early 1970's were responsible for decline in agricultural harvests associated with a south ward shift climatic zones. In the North Western states of Nigeria for example, the groundnut harvest fell from 765,000 tons in 1968 – 1969 to 400,000 tons in 1970 – 1971. In 1971 – 1972 it was down to 250, 000 tons and in 1973 it was 25, 000 tons. The drought shrunk Lake Chad from 22,000 Km^2 in 1962 – 6,000Km^2 in 1973. In Ethiopia, the famine was one of the causes of the civil war which led to overthrow of Emperor Haile Selassie (Ngaira, 1999). As people notice the increased effect of human activities on the environment such as accelerated cycles of rainfall, deforestation and pollution, the effects are affecting climate (KNAP, 1994). Rainfall variability has begun to affect the nomadic people of the Sahel region in Niger. Rainfall in this semi-arid area is becoming increasingly unpredictable, with changes in timing frequency and amount of rainfall. Temperatures are rising gradually.

There have been severe droughts in Eastern African regions since 1973 causing massive loss of livestock (Mburu, 2011). Rainfall variability is having a major impact on the natural grasslands resulting in the spread of the desert and the loss of soil fertility (Ronald, 1997). Rainfall variation can affect livelihoods through impacts such as in the case of livestock trade; bans imposed by government due to rainfall related disease outbreak such as the rift valley fever, mosquito borne virus epidemic malaria triggered diseases. Livestock trade could also be affected by deaths resulting from prolonged droughts. Some pastoralists are forced to dispose their animals at a throw away prices (Mwamba, 2007). Elnino Southern Oscilation (ENSO) has been associated with inter annual variations of rainfall in Equitorial East Africa. More rain and floods are experienced during elnino and droughts during lamina. The two scenarios have severe impacts on food security and human habitation (Gerald. 2011).

2.4.3 The Effects of Rainfall Variability on Crop and Livestock Farming in Kenya

In Kenya both climatological records and oral knowledge show that major droughts with serious results to both man and animals have occurred in the following years: - 1928, 1933 – 1934, 1939, 1942 – 1944, 1952 – 1955, 1960 – 1961, 1965 and 1968. Major floods in certain low lying parts of the Nyanza, Western and lower Tana have occurred in 1937, 1947, 1951, 1957 – 1958, 1997 and 2007 (Ojany and Ogendo, 1973). The anomalies in rainfall have caused widespread famine as drought brings about crop failure while excessive rain causes flooding in the fields during crucial growing periods (Ngaira, 1999). The serious drought of 1991 – 1992 had a lot of negative socio-economic effects in many areas of Kenya. For example in 1992 alone at least 82,316 herds of cattle and 228,826 goats died in Turkana District, there was widespread occurrence of malnutrition diseases, lose of human life and animals in Mandera, Wajir, Turkana Samburu and Machakos Districts (Ngaira, 1999). According to Ovuka (2016), farmers perception of rainfall are related to rainfall variability in the Central Highlands of Kenya. The source indicates that rainfall has decreased in the last 40 years and that extreme variations were recorded between 1972 – 2014. Drought periods were elongated in the same period impacting adversely on agricultural production. About 57% of Kenyan population lives in poverty, largely reliant on climate sensitive economic activities including rain fed subsistence or small holder agriculture (Karanja, 2009). Small holder agriculture is used to describe the rural producers who farm mainly using family labor and whom the farm provides the principal source of income (Ojwang, 2012).

These farmers are faced with a number of challenges including, abnormal onset of the rainy season which results in severe consequences, where abrupt droughts destroy infrastructure and hamper physical mobility, damage crop fields, increased diseases and epidemics, death to livestock and severe impact on livelihoods. Droughts have led to rampant environmental degradation, resource use conflicts and desertification (Ojo, 2009). Increased frequency and severity of droughts has led to aridity of dry lands and affecting ecosystem balance (biodiversity and habitats) livelihood of communities that depend on livestock and small holder rain fed agriculture and overall food security (Gribbin, 1975). Prolonged droughts lead to famine which adversely affects particularly elderly women and children and often results in severe malnutrition, disease and deaths.

According to Ojwang (2010), the impacts of rainfall variability on agricultural activities are compounded in the following; Population displacement as families become squatters or rely on food aid/hand outs and sometime forced to live in abject poverty, migrations to nearby towns in search of relief or better opportunities for employment, social evils such as crime and prostitution often associated with HIV aids risks, influx of slums with poor or deplorable hygienic conditions, damage of crop fields and loss of livestock resulting in hunger and food insecurity, persistent water stress and disease epidemics affecting both human and animals. This effects lead to untold losses.

A study by Rao et al., (2011) examines farmers' perceptions of short- and long-term variability in rainfall, their ability to discern trends in climate and how the perceived trends converge with actual weather observations in five districts of Eastern Province in Kenya where the climate is semi-arid with high intra- and inter-annual variability in rainfall. Field surveys to elicit farmers' perceptions about climate variability and change were conducted in Machakos, Makueni, Kitui, Mwingi and Mutomo Districts. Long-term rainfall records from five meteorological stations within a 10 km radius from the survey locations were obtained from the Kenya Meteorological Department and were analyzed to compare with farmers' observations.

Farmers' responses indicated that they are well aware of the general climate in their location, its variability, the probabilistic nature of the variability and the impacts of this variability on crop production. However, their ability to synthesize the knowledge they have gained from their observations and discern long-term trends in the probabilistic distribution of seasonal conditions is more subjective, mainly due to the compounding interactions between climate and other factors such as soil fertility, soil water and land use change that determine the climate's overall influence on crop productivity. The study results of farmers perception could have weaknesses such as the human subjective nature and lack of adequate knowledge in farming activities. This could provide misleading results. The current study utilizes both questionnaire and secondary published data to outsource adequate data. The studies can help formulate development strategies that will counter the problems brought about by the effect of rainfall variability and also assist in economic planning. This study is similar to the current study as it was carried out in the semi arid Eastern province but covered five district which presently are Counties. This is a large and broad region as opposed to the current study which covers a smaller area Machakos sub County.

Ngugi et al,. (2014) carried out a study to investigate the effect of soil and water conservation practices on grain yield of improved maize varieties (Katumani and Makueni) generated with and without Nitrogen fertilizers under both normal (< 250mm), normal (≥ 250mm – 350mm) and above normal season (≥ 350mm) in Katumani and Makindu in Machakos and Makueni counties in Eastern Kenya. Results indicated that yields were significant (< 0.01) under the different seasons and treatment with magnitude of the yields response varying. Highest yields were in Katumani (3370kg) were obtained during below normal seasons. The current study also indicated that Katumani was the most preferred variety as farmers showed that it was hardy and most productive.

Shisanya et al.,(2011) conducted a study on the effect of rainfall variability in semi arid lands of Kenya. Results indicated that variability was persistent in the arid and semi arid lands of Kenya affecting vegetation and consequently crop production. Climate change and rainfall variability are projected to contribute to increased drought episodes, food insecurity, irreversible decline in herd sizes and deepening poverty. The ASALs are inflicted by a major drought once in every five years resulting in widespread food insecurity, poverty, and irreversible decline in yields and herd sizes (Gichuki,1991). The constraints posed by climate change on agriculture range from pronounced seasonality of rainfall to severe and recurrent droughts. Evaluating the response of maize to a changing climate can provide viable options for enhancing adaptive capacity of small holder farmers in the ASALs (Omuoyo et. al, 2015). The above study cut across the South Eastern part of the country including Machakos County and Makueni County and Kitui County which is an expansive large area giving generalized results. It also looked at the effect of soil and water conservation practices on grain yield of improved maize yield. Soil and water practices depend on amount of rainfall. The study also involved fertilizer which the current study did not apply. The current study covers a smaller area, Machakos sub County.

Studies identified in the literature review on rainfall variability in the study area have concentrated on small scale maize production. Others like Chisanya, (2011) above covered the environment in general, other major crops like Coffee have been left out. The studies cover the broad large areas of Eastern Kenya. This study covered a smaller area Machakos sub County. It covered both small scale and large scale Maize and Coffee farming and Cattle keeping. The period 1990 – 2014 has been chosen on the basis that existing studies on rainfall variability in Machakos like Michael and Tiffen (1992) and Gichuki (1991), cover the period up to 1990. This leaves another knowledge gap that the current study sought to address to cover the new Machakos sub County. The period 1990 – 2014 was adequate enough to determine the effects of rainfall variability on farming activities in the study area. The period is also adequate to determine climate change of an area.

2.5 Time Series Analysis Technique of long term rainfall trends

Monthly or annual variability statistics do not reveal the trends or time sequence of rainfall occurrence. Hence the need to use a more appropriate method that can analyze long term trends of rainfall in particular years. This method is called Time series analysis technique (Nicholson, 1989). Domonkos (1993) analyzed time series of monthly rainfall totals in Hungary between 1901 – 1998 to detect the long term changes in rainfall characteristics and found significant decline of annual totals by 15 – 22%.

Analysis of annual rainfall time series by Tanzania Meteorological Agency (2000) indicated a significant decrease of rainfall trend for more of the stations but with greater variability in cycle

(Alberto, 2013). In the current study, Time series data analysis technique was used to study rainfall variability patterns and trends in Machakos sub County between 1990 – 2014. The results showed long-term fluctuations in rainfall or drought periods. Drought is the most significant sign of rainfall variability.

2.6 Gaps identified in the literature review

The literature review above reveals some of environmental impacts of rainfall variability. It also reveals the impact of rainfall variability on farming practices in broad areas. Hence existing studies have concentrated on the impact of rainfall variability on the environment in general. These studies have also concentrated on the study of the impacts on broad or wider areas and therefore generalized studies. The impact of rainfall variability differs from one place to another and from one community to another. Hence generalized results may turn out to be untrue for certain particular areas. It is against this background that this study focused on a smaller area within the marginal areas of Kenya, Machakos sub County. The study goes beyond the past studies that have concentrated on the environment and generalized wider areas to study the effect of rainfall variability on farming activities in a smaller semi arid area of Machakos sub County.

In addition, studies made on the effects of rainfall variability on farming activities in Machakos, like Baron (2004) and Wanjala (2010) have also concentrated on small holder maize cultivation. This study focused on the effects of rainfall variability on both small scale and large scale maize, coffee and farming in Machakos sub County.

Objective one Sought to establishes historical rainfall variability at monthly seasonal and annual scales. Variability has been analyzed and measured in terms of distribution patterns, drought intensity, relative variability, coefficient of variability and precipitation concentration index on monthly seasonal and annual basis in Machakos Sub county between 1990 – 2014. In this literature review, studies on rainfall variability in former larger Machakos District like Jesse (1996) provide Machakos District rainfall patterns that cover the period up to 1990. The current study covered the period between 1990 – 2014 and covered the current Machakos sub County to fill the identified gap.

Objective two Sought to determine the human factors influencing rainfall variability in Machakos sub County. The literature review has elaborately covered the natural factors that influence rainfall variability. Human factors that influence rainfall variability in the study area have broadly covered the Eastern and South Eastern regions of Kenya, generalizing the study. Which may be inadequate and not true for some areas covered in the study. The current study fills this gap by identifying and analyzing the human activities influencing rainfall variability in Machakos sub County.

Objective three Sought to assess the influence of rainfall variability on Maize, Coffee and Cattle Yields in Machakos sub county. Studies identified in the literature review on rainfall variability in the former larger Machakos District have concentrated on small scale maize production. Other major crops like Coffee have been left out. Cattle has also not been covered. This study covered both small scale and large scale Maize, Coffee and Cattle production. The period 1990 – 2014 has been chosen on the basis that existing studies on rainfall variability in Machakos District like Michael and Tiffen (1992) and Gichuki (1991), cover the period up to 1990. This leaves a knowledge gap that this study sought to address. The period 1990 – 2014 is adequate enough to determine the effects of rainfall variability on farming activities in the study area.

In summary, it is observed that the studies in the literature review focused on the effect of rainfall variability on farming in general, covering large broad areas and leaving out other major crops. The periods of the studies mainly covered up to 1990. Farmers in Machakos sub County practice rain fed subsistence farming and therefore are at risk of crop failure due to rainfall variability posing a danger to food security in the area. This study aimed at analyzing the effects of rainfall variability at annual, and monthly basis and their effect on maize, coffee and cattle.

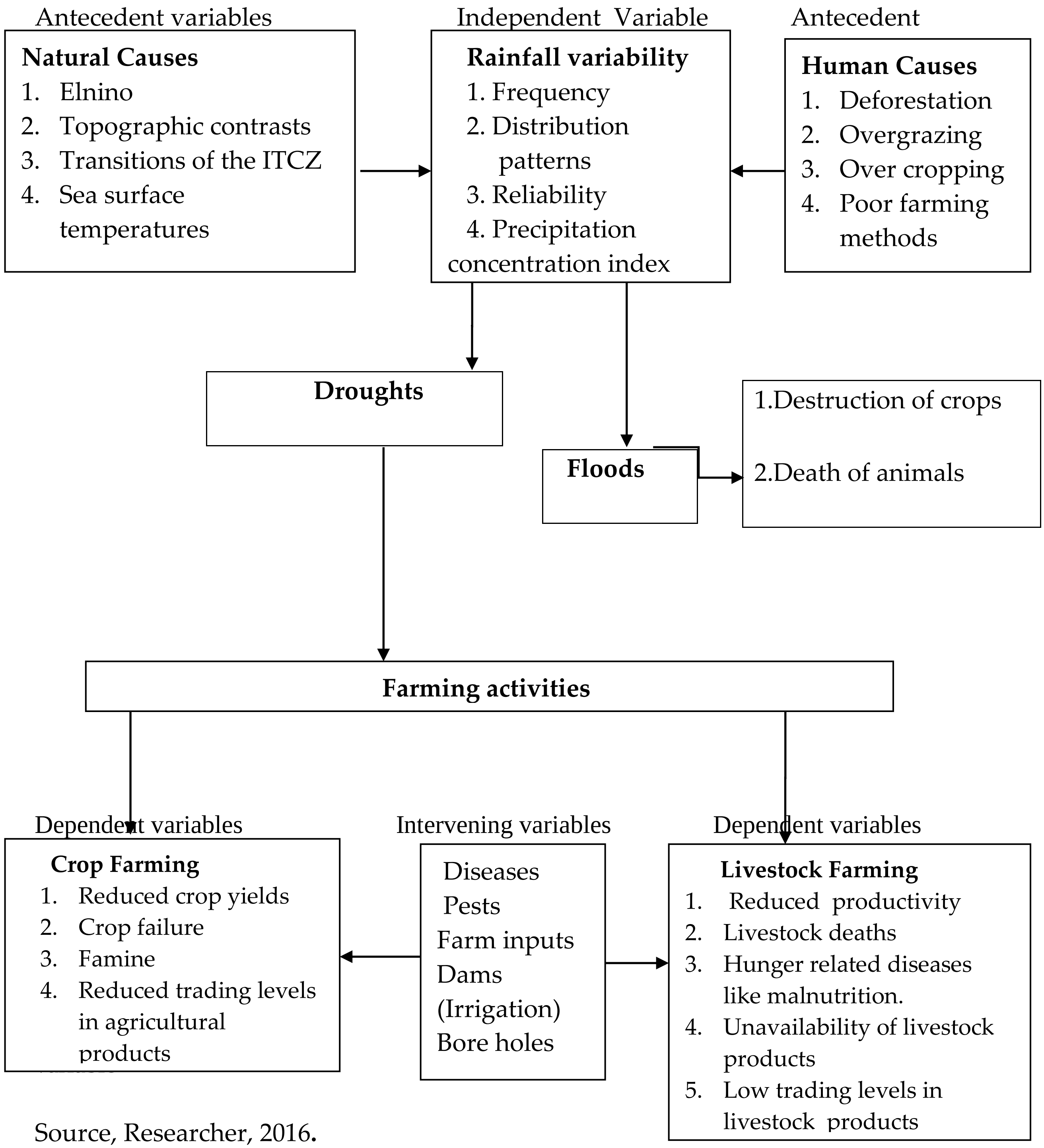
2.7 Conceptual Framework

Rainfall variability in the study area is caused by both natural and human related factors. Natural factors include; transitions of the ITCZ which is the main determinant of varying patterns of rainfall. ITCZ which is part of the global wind patterns is responsible for long rains, short rains and dry spells in East Africa. Another natural factor is Elnino. An abnormal state of ocean atmosphere system in the tropical Pacific which triggers exceptionally warm and long lived ocean currents causing drought or floods in far flung areas (Mburu, 2005). Houghton (1977) observes that the sea surface anomalies in temperatures dominate the patterns of floods and droughts in the tropics. Topographical contrasts influence the rising and falling of wind patterns hence initiating different patterns of low and high rainfall (rainfall variability).

On the other hand human causes of rainfall variability include: Deforestation which triggers prolonged droughts when it interferes with the hydrological cycle. Overgrazing and bush burning contributes to removal of vegetative cover on the land surface leading to loss of soil moisture and erosion hence encroaching of desert conditions. Poor farming methods contribute to increased dust in the atmosphere leading to increased temperatures, high evaporation rates and dwindling of rainfall in the tropics (Ngaira, 1999).

Rainfall variability has different characteristics including, frequency, distribution patterns, precipitation concentration index and reliability. These characteristics are indicators of rainfall variability and drought. Rainfall variability causes droughts or floods. Drought has an effect on agricultural activities like crop farming in form of reduced crop yields, crop failure, famine, soil desiccation. On livestock farming in form of reduced livestock productivity, increased livestock deaths, unavailability of livestock products, and reduced trading levels in livestock products as portrayed in the conceptual, framework. This leads to acute food shortages and hunger. Floods causes crop destruction and drowning and death of animals.

Intervening variables to crop yields and livestock farming include; Diseases and pests which reduce both crop and livestock productivity. Fertilizer influences crop productivity. Dams and boreholes provide solutions of water during droughts such as irrigation. Both natural and human factors causing rainfall variability will form the Antecedent variables



Source, Researcher, 2016.

Fig 2.1 Conceptual framework. The effect of rainfall Variability on Crop and Livestock Farming

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter focuses on the study area including Location and size, Topography and Geology, Drainage, Climate, Administrative and Political Units, Land and Soils and Economic activities. It also covers the study design including, Research Design, Types, Sources and Methods of Data collection and the Research Instruments. Household Questionnaires, Interview schedules, Observation Checklists and photographs. The choice of Machakos sub County as the study area was guided by the fact that it is a semi arid area with interesting and rainfall variability patterns ranging from floods in the lower Kapiti plains to persistent elongated droughts.

3.2 Study Area

3.2.1 Position and size

Machakos sub County lies within the foreland plateau between the Eastern Rift Valley and Nyika Plateau. It lies between latitude $0^0\ 50'$ and $1^0\ 05'$ South of the Equator and Longitude $37^0\ 15'$ and $37^0\ 45'$ East of Greenwich Meridian (GOK, 2013). It borders Kathiani sub County to the North, Konza North sub county to the South. Towards the East it borders Emali, Makueni County while Mavoko (Athi river) District to the West. The sub County has a total surface area of 808 Km^2 which is subdivided into two Administrative Divisions. It is a transitional zone from the cool wet Eastern highlands to the dry Nyika plateau (Ojany and Ogendo, 1973).

3.2.2 Relief and drainage

The topography of the sub County is varied consisting of a large plateau which is elevated to about 1200m in the west and slopes to about 700m above sea level to the south. The plateau is characterized by a series of hill masses of metamorphic rocks across the north (Waikwa, 1998). These hills act as catchment areas for many springs and streams in the area. The crystalline rocks of the basement system occupy much of the county. The basement system comprises various types of Precambrian sediments which were transformed into gneiss, schist's, quartzite and marble (Ojany and Ogendo, 1973).

Drainage is guided by the topography of the sub County which has had some impact on the development of the study area (Gichuki, 1991). The hill massifs of Iveti, Mua and Kangundo not only act as catchment areas for numerous springs and streams which are sources of several small scale water projects, but are also relatively high potential areas for agricultural production because they receive relatively high rainfall in comparison with the low lying areas (Gichuki, 1991). The overall drainage is from West to East. Most of the streams are seasonal with sandy deposits along their beds (Michael and Tiffen, 1992)

MACHAKOS DISTRICT

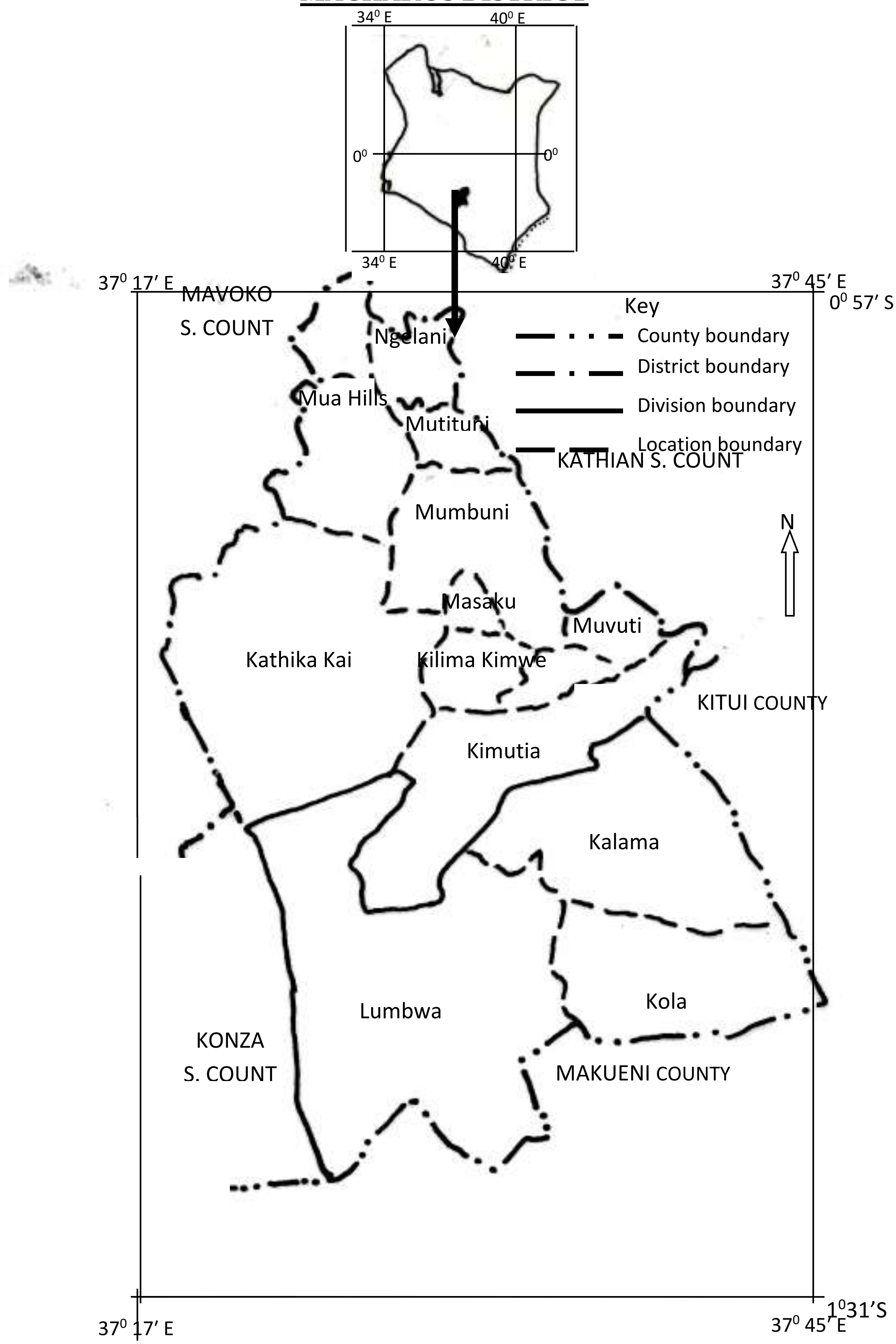


Figure 2.2: Map of Machakos **SCALE: 1:50,000 CM**

Source: Machakos County development plan 2015.

3.2.3 Climate of the area

Machakos sub County is found in the Savannah climate. It receives erratic and unpredictable rain - less than 500mm per annum in the lower southern parts. The higher and hilly areas, like Mua, and Iveti hills have higher rainfall (750mm – 900mm) compared to the low lying areas. Especially those in the rain shadow of the hills, are dry most of the year (Mbula and Tiffen,1992). Total annual rainfall ranges from slightly over 1000 mm in some of the highlands to slightly less than 500mm in the low lying areas. The rainfall has fluctuating patterns with varied distribution over different years. Temperatures vary from 16^0C - 20^0C in the highland areas to 21^0C -23^0C in the lowland areas (Gichuki, 1991).

The short rains occur in March to May and are associated with floods in the low lying Kapiti plains while the long rains fall in October to December although not reliable. They negatively affect agricultural activities. Historical data indicates that in 4 out of 10 years, there is a major drought in the sub County (GOK, 2013). The lowland areas especially the Athi-Kapiti with low rainfall are best suited for livestock and drought resistant crops.

3.2.4 Soils

Soils include, Vertissols found in lowlands. They are poorly drained, deep, greyish, brown or black cracking clays. They are prone to flooding, in some places they are bouldery and stony and in others they are sandy (Mbula,1992). They have moderate to high fertility hence good for farming activities. Acrisols/ferrasols are deep, friable and excessively dry soils. They range from brown to dark red in color and have moderate to low fertility (Ojany and Ogendo, 1973).

Plano - soles are imperfectly drained, hence prone to flooding. They are moderately deep, dark grayish brown black and very firm. They are of moderate to low fertility. Cambisols (a mixture of Andesols and Lava) are excessively drained to well drained, deep, dark red to dark yellowish, very friable sand clay loams to sandy clays. They are easily erodible forming deep gullies. In some places they have thick acid humic top soils. They are of various fertility (Mbula,1992).

3.2.5 Socio - economic factors

The major Economic activities are agriculture and livestock**.** Agriculture sector is characterized by diversity as individual farmers are diverse in their activities and decisions. For instance the delineation of small scale and large farms is not definite but will depend on the farm size, intensity of production, the enterprise mix and other related factors on the other hand (Michael and Tiffen,1992). Whether a crop is a cash crop or food crop may just depend on whether it is sold or utilized for food at home. Crops grown include: coffee, horticulture mainly fruit and vegetables, cotton, maize, beans. Livestock rearing is the major economic activity in the district with cattle and goats being the major livestoc animals (GOK, 2013).

Small scale farms are the most contributors of most livestock products: Average farm sizes are 7 - 20 acres. Families keep an average of five cows and 8 goats. It is characterized by overgrazing, poor fencing, poor patterns and communal silted dams. Large scale farms include co-operatives, companies and individual holdings. Poor management of cooperatives has led to increasing number of individual holdings. Animals kept include dairy cattle, beef cattle, goats, and sheep. Other livestock, include pigs, poultry and bee keeping (Michael and Tiffen, 1992). Sand mining employment on large farms and organizations are other sources of income.

3.3 Research Design

A cross sectional descriptive study design was used. A descriptive research design was used as data was collected from a cross section of response units at one point in time. The design guides the selection of sources and types of information. It is a framework for specifying the study variables (Ntale, 2010). The choice for descriptive research design was guided by; first, it is the most efficient design for collecting data from a large number of respondents at one point in time. Secondly it allows for comparative analysis between or among variables or a group of variables. Thirdly, the approach enhances the credence of results by providing conclusions on data as at a given point in time (Baro, 2000). The research design offered an opportunity to establish the effect of rainfall variability on maize, coffee and cattle yields. To determine the human activities that influence rainfall variability. Time series technique was also used to analyze rainfall characteristics between 1990 – 2014 and relating it with production of coffee and maize over the same period.

3.4 Population of the Study

The population of the study involved the households of Machakos sub County in Machakos County. The target population was the rural households who engage themselves in a wide range of agricultural activities like crop farming and livestock farming, for their livelihood. Machakos sub county has a total population of 224,175 and the total number of households is 35,605.

3.5 Sampling Procedure

Data was collected in Machakos sub County. The area lies in the semi arid areas of Machakos County.The main sampling method was stratified random sampling. Stratified random sampling was used in selecting respondents from Machakos sub County to provide information on crop farming and livestock keeping. The study area was stratified into twelve locations of the sub County. This was followed by randomly picking the households to be involved in the study in every location. The method was used to ensure that all locations in the county participated in the study. Webster (1995) formula was used to estimate the sample size. Targeted respondents were mainly adult female or male who have lived in the area for at least twenty years. The rural population is not exactly known. In such a situation Webster (1995) suggests the following formulae to be used to estimate the sample population size.

$$\mathbf{n = \frac{Z^2 \pi (1 - \pi)}{(Error)}}$$

Where **π** is taken to be 50% proportion diversified rural population to the total County population. At 95% desired Level of confidence and margin error of 5% the Sample size (**n**) is calculated as indicated below:

$$\mathbf{n = \frac{(1.96)^2 (0.5)^2}{(0.05)^2} = 384.6 = 384 \text{ households.}}$$

The questionnaire was to be administered on 384 respondents each representing a household in Machakos sub County out of a population of 35,605 households. The unit of analysis was households.

The study area was stratified into twelve locations namely Kalama, Katheka kai, Kilima kimwe, Kimutia, Kola, Lumbwa, Masaku, Muwa hills, Mumbuni, Muvuti, Mutituni, and Ngelani. The sample size for each location was computed as outlined in the table below.

Table 3.1 Population sample size

DIVISION		LOCATION	POPULATION	PERCENTAGE	FORMULAE	SAMPLE SIZE
CENTRAL						**H/HOLDS**
	1.	**MASAKU**	**19,980**	**8.91%**	**8.91 / 100 X 384**	**34**
	2.	MUVUTI	12,156	5.42%	5.42 / 100 X 384	21
	3.	KILIMA KIMWE	22,741	10.1%	10.1/100 X 384	39
	4.	KIMUTIA	17,265	7.7%	7.7 / 100 X 384	30
	5.	KATHKA KAI	17,485	7.8|%	7.8 /100 X 384	30
	6.	MUTITUNI	14,300	6.4%	6.4 / 100 X 384	25
	7.	MUA HILLS	8,579	3.8%	3.8 /100 x 384	15
	8.	NGELANI	11,989	5.3%	5.3 / 100 x 384	20
	9.	MUMBUNI	49,802	22%	22 / 100 X 384	84
KALAMA						
	1.	KALAMA	21,702	9.6%	9.6 /100 X 384	37
	2.	KOLA	14,567	6.49%	6.4 /100 X 384	25
	3.	LUMBWA	13,609	6.1%	6.1 /100 x 384	24
		TOTAL	**224,175**	**100%**		**384**

3.6 Methods of Data Collection

3.6.1 Primary Data The unit of analysis was the household. Research instruments for primary data included household questionnaires, interview schedules for key informants, photographs and observation check lists. The instruments used in the study were pretested before actual data collection took place and correction on errors identified was done. Original and first hand data was obtained from Machakos sub County.

Household questionnaires The questionnaires elicited information on coffee, maize and cattle farming and yields in the area between 1990 and 2014, their changing trends and causes. The questionnaires focused on Coffee and Maize farming; the varieties grown, acreage under each crop, and production trends. Livestock farming; Cattle types, numbers, production and problems faced.

Observation. Observation checklists were used to record observation areas, such as health of animals, Coffee and Maize farms, features and important scenes. This supplemented the other collecting instruments.

Photography. Photographing sites of Coffee and Maize farms, and Cattle was done. This supplemented the information collected by household questionnaires and interview schedules on crop farming and livestock .

key Informants Interview

Interview schedules were administered to institutional representatives and key informants in Meteorological Department to give data on rainfall totals, distribution patterns and duration. Interview schedules were also administered to top officials in government offices such as Ministry of agriculture and livestock development to give information on Coffee, Maize and Cattle farming and their production trends. District forest officer gave information on forestry, deforestation, forest products, a forestation and Cereals board to give information on Maize production trends.

3.6.2 Secondary Data

This involved evaluation of the available literature on the research problem. Secondary data was obtained from documented sources including journals, textbooks, newspapers, magazines and publications. These sources were found in public university libraries and UNEP library in Nairobi. Documented Sources of data on rainfall totals, distribution patterns, and duration were gotten from four meteorological stations within the District and publications from meteorological department. They covered the period between 1990 – 2014. This is the period seen to be having notable rainfall anomalies in most parts of the world. The rainfall data was used to determine, mean annual rainfall, monthly and annual frequencies, annual variability, drought patterns. Monthly totals were used to determine seasonal distribution throughout the year. Crop farming/ Production and livestock keeping information was elicited from reports and documents from government offices like Ministry of Agriculture, Coffee board of Kenya and Cereals board. The publications provided data on agricultural production, statistics and trends of economic development, and economic activities.

Published reports from the district weather stations, meteorological department in Nairobi provided data on rainfall totals between 1990 - 2014. Other published reports were found at the sub County and County offices. Other sources of documented data on rainfall patterns in Machakos sub County included, Michael and Tiffen, et al., (1992), Jese, (1996). Quantitative data was collected using Questionnaires and documentary analysis of the data. Qualitative data was collected using question guides, interview schedules, observation checklists, photographing and tape recording.

3.7.1 Reliability of the instruments. Reliability is a measure of the degree to which a research instrument yields consistent results or data after repeated trials (Mugenda and Mugenda, 2003). Reliability of this study was determined by carrying out a pilot study in Mua location as it had the least number of households. It was not to be part of the actual sample.

3.7.2 Validity of the instruments. Validity is the degree to which obtained results from the analysis of data actually represent the phenomena under study (Mugenda and Mugenda, 2003). For validity to be ascertained, research items were presented to experts in the School of environment and Earth Sciences of Maseno University whose views were incorporated in the final instruments to make them suitable for data collection.

3.7.3 Summary for Methodology for each Objective

Objective one; Rainfall data included annual totals, monthly totals, duration, seasonal distribution from 1990 – 2014. Time series technique was also used to analyze rainfall characteristics between 1990 - 2014. Descriptive statistics were used, such as a) Mean, to determine Mean annual and Monthly rainfall ammount. b) Standard deviation to compute the extent to which annual rainfall deviate from the Mean. Inferential statistic used were a) Coefficient of variability to determine the degree of variability and b) precipitation Concentration index to determine distribution of precipitation.

Objective two; Information on natural factors was sourced from published reports, text books and journals. Information on human factors was based on the household questionnaires to determine human activities that derived aspects of overgrazing, deforestation and poor farming methods. These are the factors that influence rainfall variability. Interview schedule for the district forest officer elicited information on forestry, a forestation and deforestation activities. Table ranking was used to rank the human activities based on responses from the questionnaires to determine the most and the least practiced activities.

Objective three; Household questionnaires elicited information on Coffee, Maize and Cattle production in the study area, their changing trends and causes. The questionnaires focused on Coffee and Maize farming; the varieties grown, acreage under each crop and cropping patterns.

Livestock farming; Cattle population, production and problems faced. The relationship between annual rainfall totals and yields of Coffee, Maize and Cattle population, was investigated by use of, Pearson's Product Moment coefficient (r). This determined the nature and strength of the relationship among the variables rainfall and yields of Coffee, Maize and Cattle farming with r ranging from -1 to +1. The data on yields of maize and coffee was obtained from the sub County agricultural office.

$$r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{X_i - \bar{X}}{s_X}\right)\left(\frac{Y_i - \bar{Y}}{s_Y}\right)$$

Where n = sample size. x_i and y_i = single samples indexed I. $\sum$ = summation of.

$\bar{Y}$ = the mean of Y. X the mean of X

Intervening variables include; Diseases, pests and fertilizer for crops. Diseases and pests for animals. Dams and boreholes for irrigation and livestock. Related studies on the effects of rainfall variability on farming activities in Machakos sub County such as Gichuki (1991), Jesse (1992) and Michael and Tiffen (1992) have not captured intervening variables like pests, diseases and fertilizers. This study acknowledged these intervening variables, but since they occurred occasionally throughout the period of study, the researcher held them constant. The study mainly focused on the effect of rainfall variability on Cattle, Maize and Coffee farming. The difference between studies of Jesse (1992), Gichuki (1999) and Michael and Tiffen (1992) is that their studies covered large expansive and broad areas of the Eastern Kenya and the larger Machakos Ditrict. The current study focused on a smaller area Machakos sub County.

Measuring Production. Maize was measured by number of bags per year. Data was obtained from the sub county ministry agricultural offices. Coffee was measured in terms of tones per year, Data was obtained the sub county ministry of agriculture. Cattle production was measured by number of liters of milk produced per day. Data was obtained from individual farmers. The effect of rainfall variability on cattle was also measured by production over the study period. Data was obtained from individual farmers and the Ministry of Agriculture and livestock development.

3.8 Data Analysis and Interpretation

Quantitative data was analyzed using descriptive statistics such as frequency charts, percentages, means standard deviation and inferential statistics such as coefficient of variability and Precipitation Concentration Index (PCI) were used to analyze and measure rainfall variability. Pearson's correlation coefficient method was used to determine the relationship between rainfall variability and farming activities. On crops, the focus was on coffee and maize farming. On livestock the focus was on cattle keeping.

Rainfall Variability is the temporal variation in rainfall from season to season and year to year. A coefficient of variability of over 20% shows that rainfall in the area is highly variable and unreliable. It possesses uncertainty problems especially drought (Ngaira, 1999).

The highest PCI values are found in areas where the seasonal precipitation occurs in one month. PCI of between 8.3 and 10 shows equal monthly rainfall distribution. A value of above 20 shows marked seasonal rainfall concentration. An index of 100 shows extreme monthly concentration (Wenner, 2012).

To establish the nature and magnitude of the relationship between the variables, the researcher considered the use of parametric tests in particular, Pearson's Product Moment Correlation. The relationship between rainfall variability and farming of Coffee, Maize and Cattle, was investigated by calculating, Pearson's Product Moment Coefficient (r). This determined the nature and strength of the relationship among the variables, rainfall variability and farming of Coffee, Maize and Cattle with r ranging from -1 to +1. Data from interview schedules was put into various categories and processed in an ongoing process as themes and patterns, conclusion and generalization made accordingly. Texts, statistical charts, graphs and maps were used to present the research results.

3.9. Techniques of Determining and Measuring Rainfall variability

The following were the techniques are used to determine and Measure rainfall variability. They include Mean ($\bar{X}$), Standard deviation (SI), Drought intensity (DI), Relative variability (RV),

Coefficient of variability (CV), Precipitation concentration index (PCI)

1. **The Mean**

This refers to the average spread over a given period of time monthly (mean monthly) or annually (Mean annual). It is calculated using the following formula;

Mean = $\bar{X}$ = Σx / n

Where Σx = the summation of X, n = the number of observations and $\bar{X}$ = the mean (average)

2. **Standard Deviation**

This is a technique used to compute the extent to which annual rainfall totals deviate from the mean. It is calculated by the following formula.

$$SD = \frac{\sqrt{\sum (X - \bar{X})}}{N}$$

Deviation below the Mean indicates drought years and above the Mean indicates wet years.

3. **Drought intensity**

Drought intensity refers to the ratio of rainfall deficit to the long term mean (Pence et.al 2000). It is measured by the departure of rainfall from the long term mean and is expressed as a percentage. Drought intensity is calculated by the following formulae.

$$\textbf{Drought Intensity (D I)} = \frac{X - \bar{X}}{X} \times 100$$

Where D1 = Drought intensity.

X = Annual rainfall for a given year.

$\bar{X}$ = Mean rainfall for 1990 – 2014 (Long term mean).

$\bar{X}$

4. **Relative Variability**

This refers to the sum of all deviations from the mean without respect to sign. It is derived by the number of observations expressed as a percentage of the mean (Ngaira, 1999). It is derived by the following formula.

R.V = $\underline{\sum (X - \bar{X})}$ x 100

N / $\overline{X}$

Where $\sum \underline{(X - \overline{X})}$ = Sum of all deviations from the mean.

__N__ = Number of observations.

$\overline{X}$ = The mean

5. Coefficient of variability

Coefficient of variation (CV) is calculated by the following formula;

Coefficient of variation (CV) = σ/ʋ x 100

Where = σ standard deviation and ʋ = mean

6. Precipitation Concentration Index

Precipitation concentration index (PCI) is an important concept in climatology which gives clues as to whether monthly rainfall is equally distributed, seasonally or highly concentrated in one month. PCI is calculated using the following formula;

PCI $= \frac{\sum X}{\sum X2}$ x 100 Where X = the mean monthly rainfall for each month of the year.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents results, data analysis and discussion, interpretation, findings and discussions based on objectives of the study. The chapter has been divided into three parts; the first part presents the analysis of historical rainfall variability at monthly seasonal and annual scales. The second part presents analysis of the human activities that influence rainfall variability patterns in Machakos sub County. The third part presents the assessment of the effects of rainfall variability on coffee, maize and cattle farming in Machakos sub County between 1990 and 2014.

4.2.1 Response Rate of the Questionnaires administered to Respondents

A total of 384 questionnaires were administered in the two divisions of Machakos sub County namely Central and Kalama Divisions. Out of these 301 questionnaires were duly completed and returned. This represents a response rate of 78.4 %. According to Fowler (1984) a response rate of 60% is representative. This was therefore considered a representative sample for further analysis. This was a higher response rate compared to that of similar studies conducted, such as Ngaira, (1999) 72%, Alberto, (2013) 64% and Mburu, (2011) 76%

Table 4.1 shows the overall response rate of the respondents in the two divisions by location. All the 12 locations were adequately represented in the survey as shown in the table.

Table 4.1 The response rate per location and overall response rate.

DIVISION		LOCATION	SAMPLE	NO. OF RESPONSES	% RESPONSE
CENTRAL	1	Kilima kimwe	39	34	87.2 %
	2	Kalama	37	33	89.2 %
	3	Katheka kai	30	17	56.7 %
	4	Kimutia	30	25	83.3 %
	5	Kola	25	20	80 %
	6	Masaku	34	24	70.6 %
	7	Mua hills	15	11	73.3 %
	8	Mumbuni	84	77	91.7%
	9	Muvuti	21	11	11.3 %
KALAMA	1	Mutituni	25	20	80 %
	2	Ngelani	20	13	65 %
	3	Lumbwa	24	16	75 %
	4	**TOTAL**	**384**	**301**	**78.4%**

Source: Field data 2016

4.2.2 Demographic Characteristics of Respondents

This section sought to identify the demographic characteristics of respondents including Gender, Age and Education level of the respondents in Machakos sub County. These characteristics are important because they are known to influence variables of the study such as crop farming and livestock farming. Markides (1997) argues that economic activity diversification is an entrepreneurial behavior whereby people are engaged in different economic activities for their livelihoods. The activities are influenced by gender, age and educational level (Bryan,1994).

4.2.2.1 Gender Composition of the Respondents

Table 4.2 shows the percentage gender composition of the respondents in the two divisions of Machakos sub County.

Table 4.2 Gender composition of respondents

	Gender	**Number**	**Percentage**
1	Male	147	49 %
2	Female	154	51%
	Total	**301**	**100%**

Source: Field data 2016

While this research did not precisely focus on gender equity, as shown in Figure 4.6 below, the findings show that majority of the respondents were female 154 (51%) followed by male 147 (49%). The findings are in line with the National and population census report which showed the population structure comprising of majority women in as compared to men. The gender composition of the respondents conforms to the gender composition of the entire population of Machakos sub County Female 51% and Male 49% (G.O.K, 2013). This section sought to identify gender composition of the respondents in order to assess the economic activities by gender. Kring and Gordon, (1998) observed that there is a relationship between gender differences in personality, characteristics and nature of activities they do. Gender influences the characteristics and nature of activities practiced by individuals and consequently productivity.

4.2.2.2 Age of Respondents

Age influences the type and nature activities done by various individuals and hence productivity. Efforts to establish the respondent’s age, has been associated with productivity in faming activities. Table 4.3 shows the breakdown of respondents by age in terms of frequency and percentage. Age has been associated with productivity in economic activities such as farming.

Table 4.3 Breakdown of respondents by age

	Age	**Frequency**	**Percentage**
1	25 – 35	120	39.9%
2	36 – 50	112	37.2%
3	Above 50	69	22.9%
	Total	**301**	**100%**

Source: Field data 2016

The breakdown of respondents by age was as follows; 39.9% were in the age bracket 25 - 35 years old. 37.2% percent were in the age bracket 36 to 50 years. 22.9 % of the resondents were over the age of 50 years. This suggests that most of the respondents were in active ages (Not too old or too young) and were actively engaged in economic activities particularly farming.

Majority of the respondents were in the age backet of 36 to 50 years. These are the groups that are actively involved in activities such as farming and other meaningfull economic activities. The age bracket of above 50 years formed the minority group.

A study by FAO (2014) sought to find out how the age of farmers influenced the knowledge and understanding of the effect of rainfall variability on farming activities in India. Findings showed that Age between 40 and 69 years old live in households with at least 10 years engagement in farming and better knowledge and understanding of the effect of rainfall variability on farming activities. A broad age range of respondents and a requirement to have at least 10 years in farming were used to ensure that those who are more aged and substantial experience would contribute their experiences to the study. The current study targeted respondents who have at least ten years engagement in farming activities in the study area.

4.2.2.3 Education Level of the Respondents

Table 4.4 below shows the educational level of the respondents who participated in the survey to provide information required.

Table 4.4: Education Level of the Respondents

	Level	**Frequency**	**Percentage**
1	No formal education	21	7 %
2	Primary	77	25.6%
3	Secondary	123	40.9%
4	College	61	20.2%
5	University	19	6.3%
	Total	**301**	**100%**

Source: Field data 2016

The results indicated that those who never went to school were 7%, primary level 25.6 %, secondary level 40.9 %, college 20.3 % and university 6.3% (Table 4.12). Education level influences the type and nature of occupation or economic activities carried out by the respondents. Educated respondents understand better the rainfall variability patterns and how they affect farming activities. This survey indicated that most respondents had at least primary and secondary school level education and hence were able to accurately respond to questions regarding farming activities in relationship to rainfall variability (Rosegrant and cline, 2003).

4.2.2.4 The main Occupation of the Respondents

Figure 4.1 shows the main occupations of the respondents across the District. The main occupation of the respondents given understanding on the type of economic activities practiced in the study area was farming.

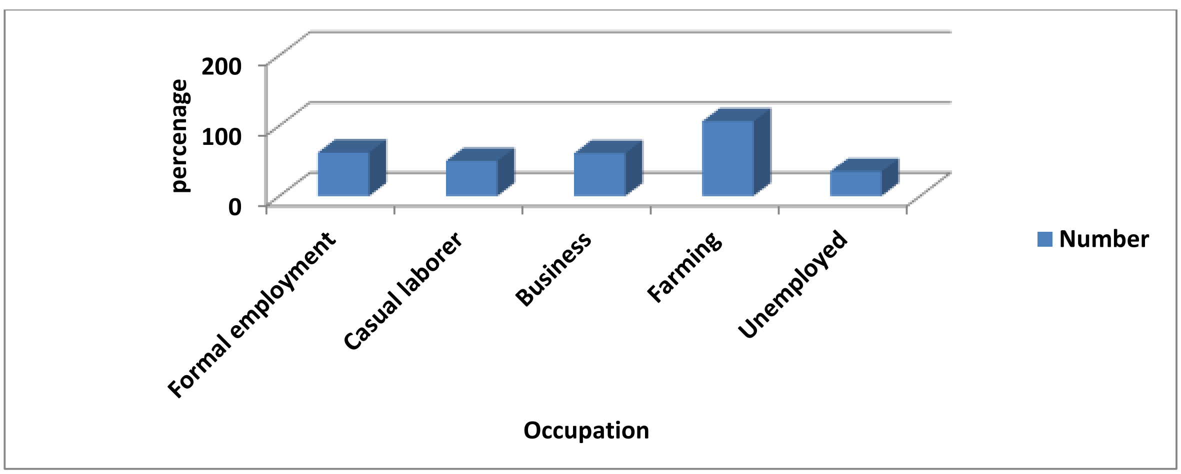


Figure 4.1 Occupation of the respondents

The results indicated that those engaged in formal employment were 19.7 %, casual laborers 15.1 %, businessmen 19.4 %, farmers 33.8% and unemployed 11.9 %. This implied that the main economic activity in the district is farming comprising of cash crop, subsistence and livestock farming. Business activities follow. Crop farming is mainly practiced on small scale due to the small sizes of land but owing to low harvests resulting from rainfall variability, they supplement their source of livelihood with other activities such as livestock keeping and sand mining (GOK, 2013). Formal employment, casual employment and the unemployed formed the minority. Occupation of respondents is an indicator on the type of human or economic activities practiced in the study area as a source of livelihood (Rosegrant and cline, 2003).

4.2.2.5. The main Land use by Respondents.

Information on the main land use in the district can equally provide information on the type of economic activities practiced in the area and how they are influenced by climate change. Respondents were asked to give the main land use on their farms. Table 4.5 shows the main land use by respondents.

Table 4.5 The main land use

	Land use	**Frequency**	**Percentage**
1	Cash crop farming	41	34.5%
2	Subsistence farming	56	47.1%
3	Livestock keeping	15	12.6%
4	Tree planting	07	5.58%
	Total	**119**	**100%**

Source: Field data 2016

From the table the results indicated that cash crop farming recorded 34.5%, subsistence farming recorded 47.1%, livestock keeping 12.6% and tree planting 5.58%. Tree planting is the least land use (5.58%).This implies that the main economic activity is farming which involves both cash crop, subsistence farming and livestock keeping. Land use indicates how the residents of Machakos sub County respond effectively to long term droughts and environmental challenges initiated by rainfall variability, climate change and encouraging economic growth (GOK, 2013)

4.2.2.6 The size of land owned

This section sought to find out the size of land owned by households. Table 4.6 shows the size of land owned by respondents.

Table 4.6 Size of land owned by householders

	Land size	**Frequency**	**Percentage**
1	Below 1 - 3 acres	158	73.2 %
2	4 - 6 acres	35	I6.2 %
3	7 - 9 acres	13	6 %
4	10 and above	10	4.6%
	Total	**216**	**100%**

Source: Field data 2016

Table 4.1 indicates that, majority of the farmers owned below 1 - 3 acres (73.2 %). Followed by 4 - 6 acres (16.2 %), 7 – 9 acres (6%) and 10 acres and above (4.6%) respectively. This indicates that majority of the people in the study area are small holder farmers owning below 1 – 3 acres. They practice subsistence crop farming but owing to low harvests resulting from extreme effects of rainfall variability, they supplement their source of livelihood with other activities such as livestock keeping and sand mining (GOK, 2013).

4.3 Analysis of Monthly and annual Rainfall variability in Machakos sub County 1990 - 2014

Rainfall received in Machakos sub County was low, less than 500mm is received in the lowland areas in the south and highly variable. The Northern parts are high and hilly and receive higher rainfall, 750mm – 900mm. Rainfall data obtained from meteorological department headquarters in Nairobi for the sub County, focused on two weather stations namely, Kari, Katumani in Central Division and Mutisya mango farm location in Kalama Division. Central and Kalama are the two divisions that make up Machakos sub County. The Annual and monthly rainfall totals in the two stations of Machakos sub County were analyzed to determine their variability between 1990 and 2014.

4.3.1 Analysis of historical Monthly and Annual Rainfall totals and Means between 1990 – 2014 in Central Division

Table 4.7 Shows the annual and Monthly rainfall totals and means of Kari centre Katumani in Central Division for the last 25 years (1990 – 2014).

Table 4.7 Monthly and Annual rainfall Mean and total for Kari Center Katumani, Central Division, Machakos sub County.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	42.8	23..2	217	250.7	65.9	5.1	0.0	3.4	0.0	0.0	208.5	110.2	**975.9**
1991	29.2	13.3	43.5	80.5	57.5	3.1	1.4	8.9	3.4	46.5	119.5	156.7	**563.9**
1992	12.0	6.1	5.0	193.7	35.0	1.1	6.8	0.0	0.7	31.0	114.2	186.2	**621.8**
1993	265.5	84.9	60.9	20.8	13.7	6.3	0.5	3.1	0.6	26.0	150.8	152.5	**776.6**
1994	0.0	103.5	70.3	83.6	29.8	8.2	3.3	9.9	4.3	116.9	308.2	143.7	**881.7**
1995	28.5	83.5	150.1	49.6	33.0	0.9	4.1	3.2	5.1	103.7	46.6	87.4	**595.5**
1996	22.4	56.5	73.7	96.4	42.8	19.3	2.2	2.2	0.7	0.0	187.7	1.5	**505.4**
1997	3.8	0.0	46.0	208.5	21.5	0.5	1.2	4.3	0.0	83.2	270.3	117.3	**816.3**
1998	295.4	219.5	118.0	123.0	162.6	38.7	15	2.9	1.8	0.0	113.9	15.8	**1106.9**
1999	16.0	2.2	121.0	113.8	9.8	2.4	4.9	0.0	5.0	20.6	257	108.6	**661.3**
2000	7.0	0.0	53.3	68.5	15.6	6.2	0.3	1.8	2.3	41.0	181.9	99.7	**485.6**
2001	244.5	0.0	113	88.9	15.3	4.3	4.3	2.5	0.0	7.3	169	43.6	**693**
2002	79.5	7.5	89.0	120.4	126.1	1.4	0.0	0.2	8.8	21.2	144.3	182.4	**780.8**
2003	31.6	17.2	115.2	153.2	133.8	0.0	0.0	26.3	21.5	30.8	121.1	24.1	**674.8**
2004	48.0	47.9	83.1	121.5	59.8	0.7	0.0	0.0	1.0	47.6	161.3	89.5	**660.4**
2005	12.2	19.2	101.7	165.1	100.5	0.0	0.0	1.5	0.0	8.4	93.4	112.8	**614.8**
2006	30.9	53.1	105	175.9	106.7	2.4	0.6	17.5	2.1	10.7	328.4	321.3	**1154.6**
2007	61.4	44.8	205	143.9	41.7	2.7	27	5.2	4.3	18.3	128.2	82.4	**764.7**
2008	117.4	7.3	73	129.3	4.5	0.3	1.3	0.2	9.1	23.9	112.8	39.9	**529.0**
2009	74.2	26.3	3.2	145.4	29.7	5.2	0.0	0.0	1.2	41.3	34.4	129.1	**488.0**
2010	57.1	64.1	232	107.9	120.9	1.4	2.7	1.3	0.6	29.3	116	125.4	**858.7**
2011	9.1	71.8	209.8	1.0	37.8	27.3	3.4	0.7	5.9	50.2	232.5	28.2	**677.7**
2012	14.7	4.6	1.6	286.7	205	36.9	3.3	0.4	4.5	22.3	119.7	173.2	**872.9**
2013	22.4	43.3	96.3	184.4	234.4	4.1	3.2	11.4	0.2	33.1	123.5	54.2	**810.5**
2014	32.6	12.1	124.6	235.3	185.3	22.4	1.4	4.0	1.9	50.0	124.0	34.5	**828.1**
TOTAL	**1549.5**	**1012**	**2512**	**3348**	**1888**	**204**	***85***	**116**	**80.0**	**912.1**	**4015.6**	**2678.2**	**18399**
MEAN	**62.0**	**40.5**	**100.5**	**133.9**	**75.5**	**8.1**	***3.4***	**4.6**	**3.2**	**36.5**	**160.6**	**107.1**	**736.0**

Source. Kari Center Katumani, Weather Station (2015).

Table 4.7 reveals the erratic (Unpredictable/Not entirely certain) rainfall patterns in semi arid Central Division. Rains failing when they are expected and coming when they are least expected. It shows monthly and annual rainfall totals in Central Division. In semi arid Central Division, the known dry months were June, July, August and September when the long term mean monthly rainfall was below 10mm. A monthly mean of below 10mm indicates a dry month. If continuous it culminates into drought. In some years, these dry months received totals above the monthly long term mean such as June 1996, 1998, 2011, 2012 and 2014. July 2007, 1999 and 1992. August 2003, 2006, and 2013. September 2003 and 2008.

The designated wet months were March (100.5) to April (133.9) and November with a mean of 160.6 mm and December with a mean of 107.1mm. as shown on Table 4.1. Some months in the designated wet months received very low or no rainfall below 50mm. such as March 1992, 2009 and 2012, April 2011, 1994 and 1993. November 1995 and 2009. December 1996, 1998, 2003 and 2011. On many occasions the rains failed in the time they were expected, only to come the time they were least expected such as in 1992, 2009 and 2012 they were expected in March. In 1993, 1998, 2001, 2008 January received very heavy rains that were not expected. This rainfall pattern was erratic/unpredictable to create anxiety and uncertainty among the inhabitants. The Variability of rainfall in amounts was shown in mean monthly rainfall in Kari Katumani station of Central Division. Monthly mean rainfall of 10mm is too low. If continuous it becomes a true arid condition.

Central Division lies near the high areas in the northern parts which receives higher rainfall. This kind of rainfall was erratic or unpredictable. Monthly rainfall below 50mm indicates a dry month. If continuous becomes drought. A similar study carried out in Kahangara Division in Northern Tanzania by Alberto (2013), showed that rainfall was highly variable and unpredictable in terms of onset and totals. The results are similar with the current study with differences coming in the months the wet and dry spells occured in the two areas. In Kahangara the wet season was from October to May and the dry season was between June and August. A study Nicholson (2000) sought to assess rainfall variability in Eastern Africa between 1950 and 1980. Results indicated an annual declining trend with increasing variability. The results are similar to those of the current study. The difference is that the current study focuses on a small area which gives actual results compared to a large area which gives more general results.

The erratic nature of rainfall in Machakos sub Coumty is almost similar to that of semi arid Baringo in Ngaira's (1999) study. Baringo recorded seven years, when the rains were low or failed during the expected rainy season, compared to Machakos which recorded four years. Moreover, the annual rainfall trend was analyzed to find out the general fluctuations and trends of the rainfall totals over the 25 year period as shown in Figure 4.1.

Figure 4.2 Shows the characteristics and trends of annual total rainfall in Central Division for the period 1990 – 2014.

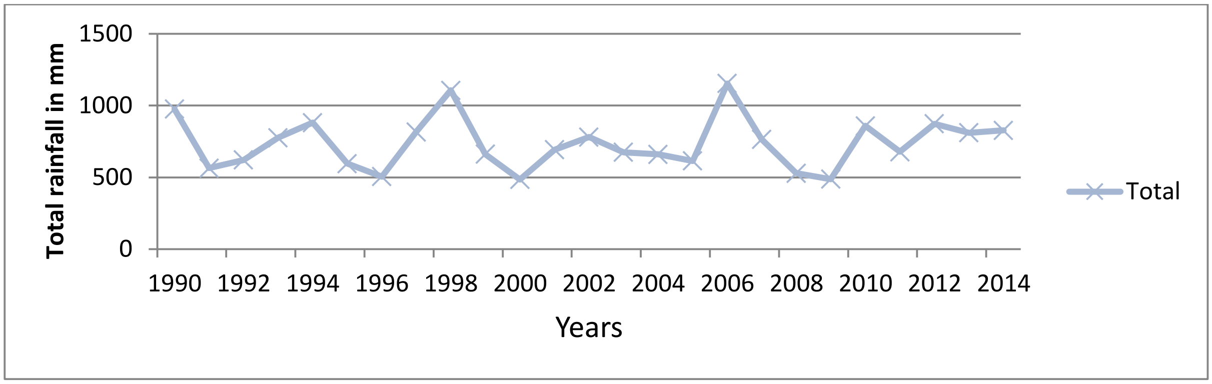


Figure 4.2: Annual Total and trends for the period1990 – 2014. Kari Katumani (Central Division)

From the figure, the highest annual total was 1154 mm, recorded in 2006 followed by 975.9mm which was recorded in 1998 and 1990. The lowest rainfall totals (562.9 mm). were recorded in 1991, 505.4 mm. in 1996, 2000 (485.56 mm) and 2009 (488.0 mm). A comparison made from Table 4.1, The highest disparities were recorded between 2005 – 2016 (539 mm), 1998 – 1999 (445 mm) and 1990 – 1991 (412 mm). The lowest disparities were recorded in 2003 – 2004 (106mm), 2012 – 2013 (95.2mm) and 2013 – 2014 (62.4mm). High disparities imply high variability in Machakos, the study area. According to Alberto (2013) Kahangara Division, has high variability of annual total rainfall with some years having more rainfall than others. Normal rainfall is less likely in this area, though there are still chances that it can occur once within four years. Chances of normal rainfall occurring are higher (2/3) in Central Division of Machakos sub County as compared to Kahangara Division as shown in the distribution patterns on Figure 4.1.

The fluctuating patterns over the twenty five year period 1990 - 2014 (Figure 4.1) was an indication of a high rainfall variability year to year in the sub County. Central Division is wetter towards the hilly northern parts. This gives the reason why coffee and maize are mainly grown in Central Division particularly in the hilly northern and north eastern parts. The long term mean rainfall was 736mm over the twenty five year period. Eleven out of twenty five years recorded totals below the long term mean. It is only during the Elnino rains, such as those of 1997 (October – November) and 2015 (March to June) that high continuous rainfall was experienced favoring fast maturing crops like beans, vegetables and katumani maize. Similar results have been reported by Nicholson (2000) who assessed climate variability in Eastern Africa 1950s to 1980s and findings revealed that rainfall trends had high fluctuations and continuous reduction in their totals. Time series study of rainfall (1960 – 2002) by Ngongondo (2005) in Malawi, had similar results as those of this study. It revealed significant departures from the mean hence variability.

4.3.2 Analysis of Monthly and Annual Rainfall totals and Means between 1990 – 2014 in Kalama Division.

The Table 4.8 shows the historical monthly and annual rainfall totals and means of Mutisya Mango farm in Kalama Division of Machakos sub County. This is the second station that falls under the analysis of the current study area which was used to establish the rainfall variability patterns. Machakos sub County

Table 4.8: The Historical Monthly and Annual Rainfall totals and Means of each year over the last 25 years Kalama Division.

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Totals Rainfall
1990	51.4	29.7	154	202	23.0	0.0	6.6	1.8	0.0	34	203	151.	**856.9**
1991	123	2.3	70.0	89.4	53.6	7.7	3.8	15.6	7.0	14	141	128	**654.8**
1992	25.8	42.5	14.0	231	22.9	0.0	3.0	1.5	5.7	19	121	191	**677.1**
1993	260	91.5	31.9	45.1	41.0	6.5	0.0	4.6	0.0	38	117	105	**739.2**
1994	0.0	61.5	100	86.5	36.5	1.2	12.3	6.6	18.2	75	220	133.	**749.9**
1995	6.8	75.4	150.	60.0	28.5	20.5	3.8	14.4	0.6	115	127	100.	**702.1**
1996	25.1	34.0	140	43.5	93.5	12.1	4.4	5.6	0.0	0.0	385	46.2	**789.8**
1997	7.3	0.0	16.0	281	102	4.6	8.0	0.0	0.0	86	438	310	**125.9**
1998	492	172	33.7	129	159	15.4	30.8	3.2	0.0	0.0	114.	30.6	**1180.4**
1999	52.2	0.0	23.2	181	5.0	0.0	0.0	10.0	0.0	27.5	308	114	**720.1**
2000	30.9	0.0	30.1	123	21.3	9.5	8.0	8.0	7.8	0.0	166	86.4	**491.1**
2001	145	21.0	106	42.7	25.0	11.0	13.0	2.8	5.2	13	220	9.0	**613**
2002	82.2	12.0	99.3	141	57.2	0.0	0.0	6.0	0.0	40.7	161	217	**816.8**
2003	0.0	13.2	72.0	151	121	0.0	0.0	0.0	2.5	48.4	157	23.2	**558.1**
2004	29.0	30.5	59.3	86.4	23.1	2.0	0.0	0.0	0.0	79.4	75.0	101.	**486.1**
2005	0.5	36.5	51.3	93.9	35.1	0.0	0.2	0.0	0.0	11.5	56.7	5.8	**291.5**
2006	25.4	41.9	28.7	175	44.8	0.0	2.4	0.0	0.0	26	218	160	**721.8**
2007	39.7	8.7	29.0	64.8	27.1	4.1	14.2	2.3	2.3	36	129	31.9	**388.8**
2008	60.5	0.0	70.5	23.4	0.0	0.0	1.2	0.0	0.0	17	131	5.2	**308.7**
2009	28.4	0.0	25.6	75.5	29.6	0.0	0.0	0.0	0.0	37	34.1	101	**331.1**
2010	51.5	69.2	55.4	60.2	71.8	0.0	0.0	0.0	0.0	20	144	12.5	**484.5**
2011	6.2	21.2	80.4	~~55.6~~	24.0	2.1	0.0	2.1	0.0	23	12.4	96.0	**353.1**
2012	64.2	40.5	75.2	30.0	12.4	12.3	23.2	0.0	0.0	42	45.0	200	**544.9**
2013	25.6	15.8	54.7	44.0	54.5	5.7	0.0	1.4	1.2	49	21.2	65.2	**338.3**
2014	94.4	56.0	42.3	85.9	66.0	7.3	13.2	0.0	2.5	56.7	76.4	65.0	**565.7**
Totals	**1757**	**876**	**1612**	**2600**	**1178**	**122**	**148**	**85.9**	**53.0**	**908**	**3818**	**2487**	**1564.67**
Mean	**70.3**	**35.0**	**64.5**	**104**	**47.1**	**4.9**	**5.9**	**3.4**	**2.1**	**36.4**	**153**	**99.5**	**625.9**

Source. Mutisya mango farm location. Weather Station (2015).

Kalama Division which is a lowland area lying towards the east, has more months with no rainfall (52) than Central Division (18), hence it is drier. The eastern side of Kalama lies in the rain shadow of Makueni hills. June to September received below a long term mean of 10mm but there were cases when these designated dry months received totals above a long term mean of 10mm that is in June 1995, 1996, 1998, 2001 and 2012; July 1994, 1998, 2001, 2007 and 2012; August 1991, 1995 and 1999; September 1994. The wet months in Kalama Division are April (Long term mean of 104mm) and November (Long term mean of 153mm). Cases where a total of less than 50mm was experienced in these wet months were in April 1993, 1996, 2001, 2008, 2012 and 2013; November 2009, 2011, 2012 and 2013 as seen in Table 4.2. In Kalama Division (Mutisya mango farm location) the driest months are August with a mean of 3.4mm June (4.9), July (5.9) and September with a mean of 2.1mm. The wettest months are April with a mean of

104 mm and November with a mean of 153 mm which is similar to Central but differing in amounts and occasionally receiving less than 50mm of rainfall. This differs from those of Kahangara Division in Tanzania where the wettest months were October and may (Alberto, 2013). The differences could be attributed to topographical differences and the geographical position of the two areas. Kahangara is close to lake Victoria, where the influence of land and lake breezes could modify the micro- climate of the area. Machakos sub County is close to the hill massifs of Iveti, Mua and Kangundo that attacts more rainfall in the Northern parts of the Sub County Making them wetter than the lower southern parts. The eastern part lies in the rain shadow of Kitui hills.

The high rainfall periods in the study area are short lived and the short rainfall periods are long, meaning more drought periods. Analysis of annual rainfall provides significant insights of the growing seasonal rainfall variability. The analysis provide a general understanding of the patterns which may provide guidelines on planning farming activities. Comparing results with related studies also helps us to evaluate our own work and guides us more to appreciate our findings.

Variability in Kalama Division is very high since the total number of years receiving less than 50mm in April are 7/12. A wet month was recorded in nine years. Central recorded wet months in five years. The wettest month in Central recorded a mean of 160mm where as in Kalama the wettest month recorded a mean of 99.5mm. The long term mean of Kalama is 625.9 and central Katumani is 736. The driest months in Kalama were August (3.4mm) and September (2.1mm) and in Central Division. (July 3.4mm) and September (3.2mm) This implies that Kalama Division was drier with a higher variability. Nicholson’s (1989) study of climate variability in East Africa 1950s to 1980s reported similar results with results revealing that rainfall trends had high fluctuations implying high variability.

A study carried out on effects of drought in semi arid Laikipia District by Mburu (2011) also revealed high variability and fluctuations in rainfall totals and trends. Laikipa lies to the west of the central highlands while Machakos lies to the east of the central highlands. These high variations and unreliability disrupt farming activities and their calendar. Prolonged droughts and generally dry spells in the division led to crop failure and lower yields. Dry years recorded low maize yields such as 1997, 2000 and 2005 recorded below 150,000 bags

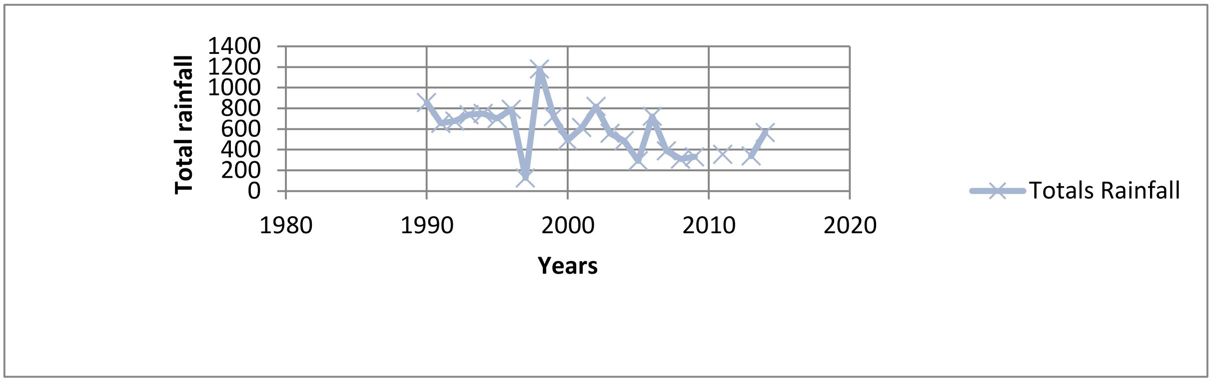


Figure 4.3: Rainfall totals for the period 1990 – 2014. Mutisya farm station (Kalama Division)

Moreover, the annual rainfall trend was analyzed as shown in Figure 4.2 below to find out the general fluctuations and trends of the annual rainfall totals in the Kalama Division for the 25 year period. From the results in Figure 4.2, the highest annual total was recorded in 1998 (1180.4 mm) followed by 1990 (856.9 mm) and 2002 (816.8mm). The lowest rainfall totals were recorded in 2009 (331.1mm), 2008 (308.7 mm), 2005 (291.5 mm) and 1997 (125.9 mm. The highest disparities were recorded between 1997 – 1998 (1054.5 mm), 2006 – 2005 (430.3 mm) and 2002 – 2003 (258 mm). These conditions can be attributed to the Elnino and lanina effects of 1997/98 and the prolonged droughts experienced after four years. The lowest disparities were recorded in 1995 – 1996 (87.7mm), 1992 – 1993 (62.1mm) and 1993 – 1994 (10.7 mm). This can be attributed to a long dry spell in average rainfall 1992 -1995.

The fluctuating patterns over the twenty five year period 1990-2014 is a clear indication of a high rainfall variability in the Division. Table 4.1 and table 4.2 shows monthly, annual, rainfall totals and means to determine variability in the two rainfall stations that provide rainfall data for Machackos District. Generally Kalama Division is drier (overall long term mean of 625 mm). Equally it has more erratic rainfall as evidenced in the higher variability. A mean annual rainfall of 500mm -750mm indicates semi arid and below 500mm to indicates drought condition. Kalama Division recorded more severe semi arid conditions with many years recording below

500mm. In Central Division most years recorded above 750mm. These conditions make Kalama Division to have more severe and harsh drought conditions, leading to adverse crop failure and lower harvests. A similar study was conducted in Baringo District by Ngaira (1999). The study made a comparison of variability between two divisions, Marigat and Nginyang both of them revealing high erratic rainfall and anomalies in monthly distribution leading to intense drought conditions adversely affecting farming activities.

4.3.3. Analysis of annual Rainfall Totals, Means, Standard deviations, Anomalies and Coefficient of Variation in Machakos sub County.

Table 4.9 and 4.10 Shows annual totals, means, coefficient of variation and anomalies of each year recorded over the last 25 years (1990 – 2012) in Katumani (Central Division) and Mutisya (Kalama Division) respectively. Formulas used to calculate each of the above variables have been clearly shown in methodology section.

Table 4.9 A summary of Annual Rainfall totals, Means, Standard deviations, Anomalies and Coefficient of variation of each year over the last 24 years. (1990 – 2014). Katumani KARI. Central Division, Machakos District.

Year	Total rain fall (mm)	Mean Monthly	Std Deviation	Anom Alies	Year	Total rainfall (mm)	Mean	Std Dev	Anoma lies
1990	**975.9**	**81.3**	**93.15**	**20**	**2004**	**660.4**	**55.0**	**52.043**	**-10**
1991	**563.9**	**47.0**	**49.914**	**-30**	**2005**	**614.8**	**51.2**	**58.961**	**-20**
1992	**621.8**	**51.8**	**75.801**	**-20**	**2006**	**1154.6**	**96.2**	**119.68**	**40**
1993	**776.6**	**64.7**	**81.905**	**10**	**2007**	**764.7**	**63.7**	**64.560**	**0**
1994	**881.7**	**73.5**	**89.567**	**20**	**2008**	**529.0**	**44.1**	**52.146**	**-40**
1995	**595.5**	**49.6**	**47.574**	**-20**	**2009**	**488.0**	**40.7**	**49961**	**-50**
1996	**505.4**	**42.1**	**56.066**	**-50**	**2010**	**858.7**	**71.6**	**71.386**	**10**
1997	**816.3**	**68**	**96.278**	**10**	**2011**	**677.7**	**56.5**	**80.099**	**-10**
1998	**1106.9**	**92.2**	**97.121**	**30**	**2012**	**872.9**	**72.7**	**98.711**	**20**
1999	**661.3**	**55.1**	**79.674**	**-10**	**2013**	**810.5**	**67.5**	**77.046**	**10**
2000	**485.6**	**40.5**	**57.132**	**-50**	**2014**	**828.1**	**69.0**	**79.132**	**10**
2001	**693**	**57.8**	**80.550**	**-10**	**TOTALS**	**18399**			
2002	**780.8**	**65.1**	**66.409**	**10**	**MEAN**	**736.0**			
2003	**674.8**	**56.2**	**56.681**	**-10**	**STD DEV**	**178.88**			
2014	**660.4**	**55.0**	**52.043**	**-10**	**C.V**	**0.24**			

Source. Katumani KARI Cente Weather Station (2015)

Table 4.10 A summary of Annual Rainfall totals, Means, Standard deviations, Anomalies and Coefficient of variation of each year over the last 24 years. (1990 – 2014). Mutisya mango farm location. Kalama Division, Machakos District.

Year	Total rain fall (mm)	Mean	Std Deviation	Anom Alies	Year	Total Rainfall (mm)	Mean	Std Dev	Ano malis
1990	**856.9**	**71.4**	**81.3**	**0**	**2005**	**291.5**	**4.3**	**30.6**	**-110**
1991	**654.8**	**54.6**	**53.9**	**0**	**2006**	**721.8**	**60.2**	**77.5**	**10**
1992	**677.1**	**56.4**	**9.6**	**10**	**2007**	**388.8**	**32.4**	**35.5**	**-60**
1993	**739.2**	**61.6**	**74.5**	**20**	**2008**	**308.7**	**25.7**	**41.2**	**-100**
1994	**749.9**	**62.5**	**65.9**	**20**	**2009**	**331.1**	**27.6**	**32.5**	**-90**
1995	**702.1**	**58.5**	**53.6**	**10**	**2010**	**484.5**	**40.4**	**43.5**	**-30**
1996	**789.8**	**65.8**	**109**	**20**	**2011**	**353.1**	**29.4**	**32.2**	**-80**
1997	**125.9**	**104.4**	**152**	**50**	**2012**	**544.9**	**45.4**	**54.1**	**-10**
1998	**1180.4**	**98.4**	**140**	**50**	**2013**	**338.3**	**28.2**	**24**	**-90**
1999	**720.1**	**60**	**95.9**	**10**	**2014**	**565.7**	**47.1**	**33.593**	**-10**
2000	**491.1**	**40.9**	**54.5**	**-30**	**Totals**	**15646.7**			
2001	**613**	**51.1**	**69**	**0**	**Mean**	**625.9**			
2002	**816.8**	**68.1**	**73.3**	**20**	**Std dev**	**246.213**			
2003	**558.1**	**49**	**61.4**	**-10**	**C.V**	**0.39**			
2004	**486.1**	**40.5**	**37.9**	**-30**					

Source. Mutisya mango farm location. Weather Station (2015).

1.Mean = $\overline{X}$ = Σx / n

Where Σx = the summation of X n = the number of observations and $\overline{X}$ = the mean (average).

Mean for the year 1990 rainfall in Katumani = 975.9/12 = 81.3 and Kalama 856/12 = 71.

The technique was used to compute Mean annual rainfall e.g 500mm -750mm to indicate semi arid and below 500mm to indicate drought. Kalama recorded a long term mean of 625.9 while Central Division recorded a long term mean of 736.0 over the 25 year period. The significance between rainfall variability in the two stations can be established using the **students T-test** to ascertain whether there was a significant difference in rainfall variability between Katumani and Mutisya. The student T-test was employed using calculations from table 4.3 and 4.4.

$$t = \frac{736 - 625.9}{178.85 + 246.22} = \frac{110}{18.25+23.01} = \frac{110}{41.2} = 2.66$$

At 0.05 significant level, the result t = 2.66 indicated a significant difference in rainfall variability between Central Division and Kalama Division. In addition, Kalama Division of Machakos sub County had more severe semi arid conditions with nine out of 25 years recording below 500mm while in Central Division, most years recorded above 750mm with one year (2009) recording less than 500mm (Table 4.3.) and Table 4.4 on page 48 and 49 respectively shows the figures used in the calculations). A related study was carried out by Ngaira's (1999). A comparison of rainfall long term total means between two Divisions in Baringo District, Marigat (588mm) and Nginyang (536mm) indicated severe droughts. Mburu's (2011) study compared monthly and annual totals and means of rainfall between Central Division and Mukogodo Division of the semi arid Laikipia District between 1975 – 2005. Findings showed that Central Division had a long term mean of 636 mm and Mukogodo had a long term mean of 507mm implying that Mukogodo Division was drier than Central Division. This reflects similar results like those of Machakos sub County.

2. Standard Deviation. It is calculated by the formulae $SD = \frac{\sqrt{\sum (X - \bar{X})}}{N}$

From the analysis it was observed that there were significant departures of annual rainfall totals from the mean for the 25 year period. Standard deviation technique was used to compute the extent to which annual rainfall totals deviate from the annual mean. Deviation below the Mean indicated drought years and above the Mean indicated wet years. Hence standard deviation helped to determine the drought and wet years to understand the rainfall variability patterns. The figures used in calculation of standard deviation are found on the two tables 4.3 and 4.4 Drought years in Central Division were 1995, 2004 and 2010. In Kalama Division the drought years were, 1991, 1995, 2004 and 2014. Mburu's (2011)' study results showed drought years in Central Division of Laikipia District as; 1980,1982,1983,1984,1985,1987,1988,1991, 1992,1993,1994,1996, 1999 and 2000. In Mukogodo Division of the same district the drought year were;1976,1980,1982,1983, 1985, 1987, 1991, 1992,1993,1994,1995, 1996, 1999, 2000,2002 and 2005. This clearly shows that Laikipia District with more and continuous drought periods is drier than Machakos sub County. The study of Baringo District between Marigat (588mm) and Nginyang (536mm) showed a more drier climate compared to Machakos sub county. The analysis of wet years and drought years assists in understanding of the variability patterns and their effect on farming activities in the study areas. Kalama with more severe drought periods recorded more crop failure. Central Division had less severe drought periods. Coffee and maize yields had a strong relationship with rainfall variability (drought years recording very low yields).

A similar study by Alberto (2011) in kahangara Division of Northern Tanzania, also found that cassava and potato yields had a strong relationship with rainfall variability, drought years recording very low yields. In Laikipia District, Central Division, out of 14 drought years the total number of dry months was 11 (78.6%) for December, 12 (85.7%) for January, 14 (100%) for February and 11 (78.6%) for March. In Mukogodo Division , out of 17 drought years, the total number of dry months was 12 (70.6% for December, 16 (94.1%) for January, 15 (88.2%) for February and 12 (70.6%) for march (Mburu,2011). This clearly indicates that Laikipia District is drier than Machakos sub County. The three areas are drawn from semi arid areas of Kenya, but in different parts of the country. Differences in variability is as a result of different geographical location and the physical features found in these areas. Analysis show that, Machakos sub county, Laikipia District and Marigat are semi arid areas characterized with high rainfall variability which endanger farming activities. The unpredictable nature of the onset disrupts farming calendars and programs.

3.Drought Intensity

Drought intensity refers to the ratio of rainfall deficit to the long term mean (Pence et.al 2000). It is measured by the departure of rainfall from the long term mean and is expressed as a percentage. Drought intensity is calculated by subtracting the long term mean of rainfall from the annual rainfall total for a given year. For this study the long term mean (736), is the mean for the 25 years (1990 – 2014) for Central Division and a long term mean of (625) for Kalama Division. A similar study conducted in Kahangara Division in Northern Tanzania by Alberto (2013), the calculated long term Mean for 24 years 1989 – 2010 was (643.10). The results look almost similar though found in different climatic zones. Drought intensity is calculated as a percentage as shown below. Kalama Division was drier than Central Division. Kahangara was drier than Central Division of Machakos sub County. The differences in results could be attributed to rainfall patterns and geographical positions of the areas.

Drought Intensity (D I) = $\frac{X - \bar{X}}{X}$ x 100

Where D1 = Drought intensity.

X = Annual rainfall for a given year.

$\bar{X}$ = Mean rainfall for 1990 – 2014 (Long term mean).

Dl for Katumani (Central Division) in 1990 = $\frac{975.9 - 736 \times 100}{975.9}$ = 24.58

D1 for Mutisya (Kalama Division) in 1990 = $\frac{856.9 - 625 \times 100}{856.9}$ = 27.06

(Table 4.3 and Table 4.4 shows the figures used in the calculations for each year)

Doorembos (1976) suggested that a rainfall data with a DI of 0.2(20%) and a above is highly variable. This follows that Machakos sub county is highly variable.

4.Anomaly.

Table 4.3 shows the results of the analysis of annual rain fall anomalies in Central and Kalama Division over the 25 year historical period. Anomalies show the percentage departure of annual total rainfall from the long term mean. It is expressed as a percentage. It is calculated with the formula.

$\frac{TAM - LTM \times 100}{TAM}$

where **TAM =** Total annual rainfall

TLM = Long term mean

The rainfall anomaly has been calculated for the two weather stations, Katumani Kari in Central Division (Table 4.3) and Mutisya mango farm in Kalama Division (table 4.4). In Katumani, the highest anomalies were recorded in 2006 (+40%), 1998 (+30%), 1996 (-50%) and 2009 (-50%). 2006 and 1998 registered a positive deviation from the long term mean of 40% and 30% respectively. This indicates wet years, while 1996 and 2009 a negative of 50% from the long term mean was registered, indicating drought years. The Variations were minimal in some years such as 1993, 2001, 2013 and 2014 but very wide in 2000, 2005, 2006 and 2009. In Kalama Division, acute negative deviations from the mean were recorded such as 2008 (-100%), 2005(-110%) and 2013 (-90%). These were severe drought periods. The highest positive deviations were recorded in 1997 (+50%), 1998 (50%) and 1990 (30%). These analysis indicate that historically there was high variability in Machakos sub County.

A similar study was conducted in Kahangara Division in Tanzania over a 21 year historical period. 8/21 years recorded a percentage above the long term mean 679.4 mm, indicating wet years. 6/21 years recorded below the mean, indicating drought years (Alberto, 2013) The study in Kahangara Division, Tanzania, revealed high anomalies both negative and positive. Exceptional dry years were 2009 and 2010 and the wetter years were1998, 2002 and 2006). The largest departures were recorded in 2009 (99.5mm) and in 2002 (1427.2mm). Normal rains may occur but the tendency has been towards below the long term mean over the 21 year period. This indicates the aspects of rainfall variability in the area.

5.Relative variability

Relative variability refers to the sum of all deviations from the mean without respect to sign.(- or +) It is derived by the following formula.

$$R.V = \frac{\sum (X - \bar{X})}{N / \bar{X}} \times 100$$

Where $\sum (X - \bar{X})$ **= Sum of all deviations from the mean.**

N = Number of observations.

$\bar{X}$ **= The mean**

For example the RV for 1995 Katumani in Central Division $= \frac{\sum (595.5 - 49.6) \times 100}{12/49.6} = 24\%$

The RV for 1995 Mutisya in Kalama Division $= \frac{\sum (701.1 - 58.5) \times 100}{12/58.5} = 32\%$

A relative variability in the annual amounts of rainfall of less than 15% is typical in the high rainfall areas such as Atlantic and Pacific depressions. A relative variability of between 20 – 25 % is typical of semi arid areas of the world (Doorenbos,1976). This means the reliability of rainfall is reduced very much giving way to prolonged spells of drought. Relative variability in excess of 40% is typical of deserts of Arabia, Africa, Asia and along the west coast of South

America (O'Hare, 1992). The relative variability for the two stations has been calculated on annual basis as seen in table 4.3 (katumani 1990 – 20% and 1991 – 30%).

The overall long term mean for the 24 years in Central Division was 625.9 between 1990 – 2014; This analysis shows that historically, there was still some variability of rainfall either below or above the long term mean. That normal rainfall rarely occurs but the tendency has been towards below the long term mean. This confirms the aspect of rainfall variability in the sub County. This implies that farming activities are mostly affected by this variability leading to low yields. Coffee and maize yields have been heavily determined by variability patterns. High yields have been associated with low variability and low yields associated with high variability. This was also found in Laikipia District were high variability and droughts adversely affected farming activities (Mburu, 2011).

In Central Division, 11 out of 25 years recorded above normal (736mm) and 13 out of 25 years recorded below normal (736mm). Normal rain was recorded in one year only (2007) The wetter years were 1990, 1998, 2005 and 2012. Exceptionally dry years were 1996, 1999, 2007 and 2008. The long term mean over the 25 years was 736mm;

Kalama Division experienced more adverse crop failure and low yields (Table 4.2). In Lakipia District both Central and Mukogodo drought intensity varied from year to year with Central recording -52.8% with a long term mean of 636.6mm while Mukogodo recorded a drought intensity of – 40.5% with a long term mean of 507.8mm (Mburu, 2011). This implies that Laikipia District has a high drought intensity than Machakos Mahakos Sub county. In Ethiopia, the 1984 drought recorded rainfall that was 22% below the long term mean, some areas more than 50% below the long term mean (Web et al. 1991). Similar results have been reported by Nicholson (2000) who reviewed climate variability in East Africa between 1950s to 1980s.

The study reported high variations of rainfall totals on a declining trend. For anomalies in Kahangara Division, 7 out of 21 years had below normal rainfall(679.4mm), 8 out of 21 years rainfall was above normal (679.4mm) and 6 out of 21 years had normal rainfall (Alberto,2013). Kahangara had the highest anomaly in 1990 (+110) and in 1997 (-110) compared to Machakos in 1994 (-50) and in 2000 (-50). Kahangara had more normal rain years (6 out of 21years) compared to Machakos where normal rainfall rarely occurs (2 out of 25 years)

6. Coefficient of variability

Variability is the temporal variation in rainfall from season to season and year to year. A coefficient of variability of over 20% shows that rainfall is highly variable and very unreliable. It posses uncertainty problems especially drought (O' Hare, 1992). Coefficient of variation (CV) is calculated by the following formula;

Coefficient of variation (CV) = σ/υ x 100

Where = σ standard deviation and υ = mean

For example the CV for the 25 year period for Katumani (Central Division) is calculated as follows;

Coefficient of variation (CV) = σ / υ x 100 = 178.88/736 = 0.24 x 100 = 24 %

CV for the 25 year period for Mutisya (Kalama Division) is calculated as follows;

Coefficient of variation (CV) = σ / υ x 100 = 246.22/625.9 = 0.393 x 100 = 39.3 %

This means that Kahangara Division in Tanzania with a CV of 40% has a higher variability and unreliable rainfall as compared to Machakos which is, 24% + 39.3% =59.3/2 = 29.65%.

A CV of 24% reported in Central Division shows high variability and uncertainty in rainfall. This is an expected result as Machakos sub County is a transition zone to the dry Nyika plateau towards the Kenyan Coast (Mbula,1992). Four of the years, 1996, 2000, 2009, and 2005 had annual totals far below the mean of 736mm. On the other hand a few years had rainfall totals significantly above the mean, these are 1990, 1998, 2006 and 2012. According to O'Hare (1992) a coefficient of variability of over 20% indicates a highly variable and unreliable rainfall which posses problems of uncertainty such as drought. It follows that the value of coefficient variability 0.24 (24%) in the annual rainfall of Katumani station, shows that rainfall is highly variable and very unreliable in Central Division. Moreover the annual rainfall trend was also analyzed as seen in Figure 4.3 below.

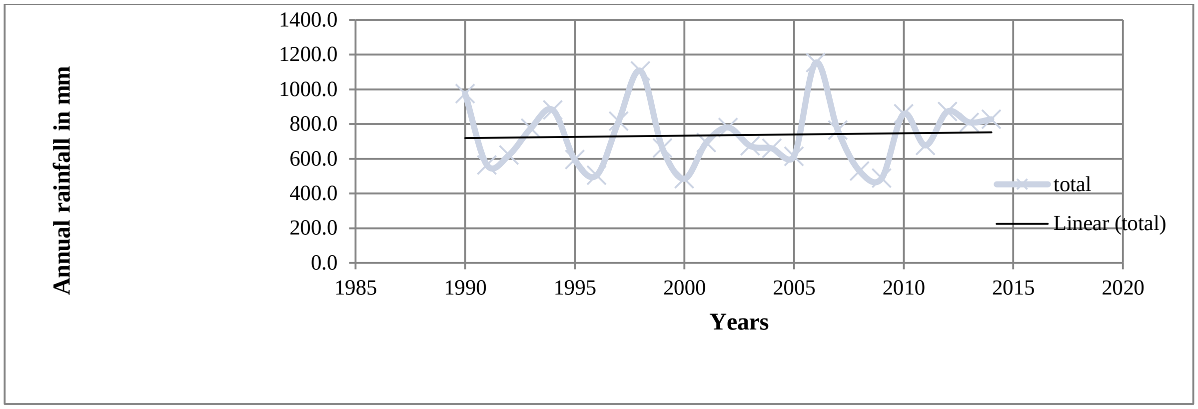


Figure 4.4 Total rainfall distribution and trends 1990 – 2014. Katumani station.

Analysis show that rainfall has been slightly increasing over the twenty five years though it is insignificant (r^2 = 0.003). The statistical record in figure 4.3 shows fluctuations over 25 historical year period interspersed by exceptionally high values in 1998 and 2006. The rather low values were experienced in 1996, 2000 and 2009. High variability is indicated by the high disparities in the study area. Alberto (2013) posits that Kahangara Division, has high variability of annual total rainfall indicate by high disparities with some years having more rainfall than others. Chances of normal rainfall are low as seen from Figure 4.1. The fluctuating patterns over the twenty five year period 1990 - 2014 (Figure 4.1) was an indication of a high rainfall variability year to year in the sub County.

Kalama Division shows a high variability and uncertainty in rainfall (CV of 39.3%). Doorenbus (1976) suggested that rainfall data with **Coefficient variability** of 0.2 (20%) or above is highly variable. As may be seen in 1990, 1998, 2006 and 2012 total rainfall of the years were very high compared to 1996, 2009 and 2005. The highest rainfall total recorded 1154.6mm was in 2006 and the lowest recorded was 485.6mm in 2000. The overall long term mean was 736mm over the last 24 years (1990 – 2014) for Central Division and overall long term mean of 625mm over the last 24 years (1990 – 2014) for Kalama Division. The CV for both Central and Kalama Division reveal that the two regions are classified as semi arid with varying degrees of aridity. This posses a big problem to Coffee, maize and cattle farming activities, delayed rainfall causing uncertainty on when to plant or prepare land, crop failure and low yields. In the current study the high coefficient in the two stations namely Katumani 0.24 (24%) and Mutisya 0.39 (39%) is an indication that the area is prone to drought which may cause desertification especially if there is mismanagement of the environment through practices such as deforestation and overgrazing. Ngongondo (2000) examined the long term rainfall variability and trends in Malawi between 1960-2000. The study found significant departures of rainfall from the annual mean of rainfall and the annual rainfall coefficient of variability (CV) for the forty years was 0.3. A frequently used measure of rainfall variability is the coefficient of variability. According to O'Hare (1992), a coefficient of less than 15% is found in equatorial regions of Zaire, Amazon and parts of Indonesia. A coefficient of over 25% is restricted in arid and semi arid regions. Areas of the world where rainfall is highly unreliable are parts of the world on dry hot desert margins where the coefficient is over 40% (Jackson, 1997 and Parry et al., 1988).

Figure 4.5 Shows total rainfall distribution and trends between 1990 – 2014. In Mutisya mango farm.

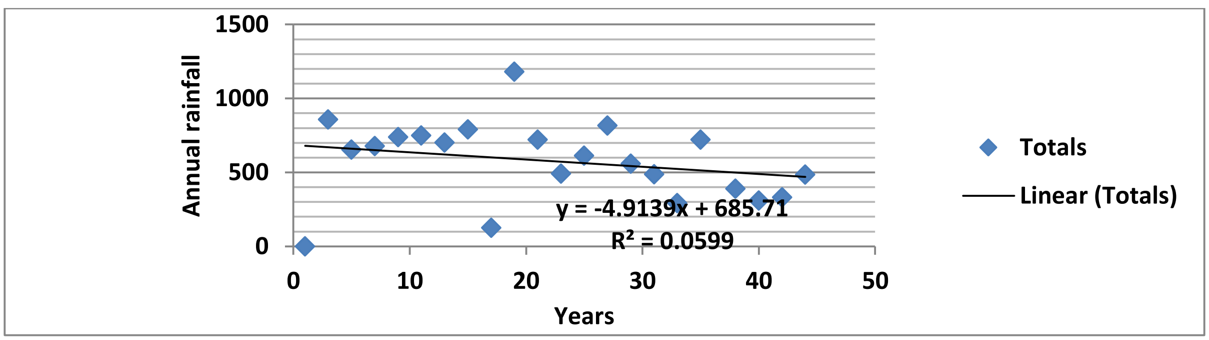


Figure 4.5 Total rainfall distribution and trends 1990 – 2014. Mutisya mango farm

The annual rainfall trend analyzed in figure 4.5 shows that rainfall has been decreasing over the twenty five years. The statistical record in figure 4.5 shows fluctuations over 25 historical year period interspersed by exceptionally high values in 1998, 1990 and 2002.The rather low values were experienced in 1997, 2005, 2008 and 2009. The declining rainfall is significant as (r^2 = 0.059). This poses a big problem to farming activities and yields in Kalama division. Similar results have been reported by Nicholson (2000) who made a study on climate dynamics and variability in Eastern Africa between 1950 and 1980. The study found that, generally annual rainfall trend is a reduction in rainfall throughout the period.

However in anomalies, analysis showed that there were less frequent occurrences of above average rainfall throughout the continent. World meteorology organization (2000) reported that in Pampas province (Argentina) there were significant decline in rainfall between 1921 and 2000 with occurrences of extreme droughts cycle whose peak was in 1940 until 1960 (Esther 2013).

7. Precipitation concentration index (PCI) This is an important concept in climatology which gives clues as to whether monthly rainfall is equally distributed, seasonally or highly concentrated in one month. PCI is calculated using the following formula; Precipitation Concentration index of two rainfall stations in Machakos sub County in Table 4.11 and 4.12, that is Central Division and Kalama Division has been calculated. Both Kalama Division and Central Division have highly, variable and erratic/unpredictable rainfall with (PCI of 11and 10) respectively

Table 4.11 Mean monthly rainfall in mm for the 25 year period Katumani Kari (Central Division

	X	**X^2**
January	62.0	3,844
February	40.5	3844
March	100.5	1,640.25
April	133.9	10,100.25
May	75.5	17,689.21
June	8.1	65.61
July	3.4	11.56
August	4.6	21.16
September	3.2	10.24
October	36.5	1,332.25
November	160.6	25,792.36
December	107.1	11,470.41
	$\sum X$ =735.9	**$\sum X^2$ =77677.55**

Table 4.12 Mean monthly rainfall in mm for the 25 year period. Mutisya mango farm (Central Kalama Division).

	X	**X^2**
January	70.1	4,914.01
February	35.0	1,225
March	64.5	4,160.25
April	104.0	1,0816
May	47.1	2,218
June	4.9	24.01
July	5.9	34.81
August	3.4	11.56
September	2.1	4.41
October	36.4	1,324.96
November	152.7	23,317.29
December	99.5	9,900.25
	$\sum X$ = 625.	**$\sum X^2$=57,950.96**

1. PCI for Katumani Kari (Central division)

$$PCI = \frac{\sum X}{\sum X2} = \frac{735.9}{77677.55} \text{ x } 100 = 9.8 \text{ (10)}$$

2. PCI for Mutisya mango farm Center (Kalama Division)

$$PCI = \frac{\sum X}{\sum X2} = \frac{625.6}{57950.95} \text{ x } 100 = 10.779 \text{ (11)}$$

PCI = $\frac{\sum X}{\sum X2}$ x 100 Where X = the mean monthly rainfall for each month of the year.

A PCI value above 20 shows marked seasonal rainfall concentration. An index between 10 – 19 shows erratic seasonal rainfall distribution where rainfall occurs in a few months and a value of 8 - 9 shows equal monthly distribution (Oliver, 1960). Table 4.5 and 4.6 shows the PCI of the two stations. These conditions create anxiety and uncertainty among the inhabitants of the region disrupting farming activities and calendars affecting coffee and maize yields.

A similar study carried out by Ngaira (1999), found that Baringo District a semi arid region equally had erratic, unpredictable and unreliable rainfall with an average PCI of 11 each for the two rainfall stations. A condition that created uncertainty among the inhabitants of the region. Inhabitants become undecided whether or not to plant on the onset of sudden rainfall coming in expected dry months (season) or wait for the next wet season. They equally are not sure what to do when the rains fail suddenly during a known wet season. Analysis of annual rainfall provides significant reflection of the growing seasonal rainfall variability.

The highest PCI values are found in those areas where seasonal precipitation occurs in one month. Precipitation concentration index of between 8.3 and 9.0 shows equal monthly rainfall distribution. A value above 20 shows marked seasonal rainfall concentration. An index between 10 – 19 shows erratic seasonal rainfall distribution (Oliver1960). The PCI s of the two stations clearly indicates erratic seasonal rainfall distribution posing a risk to maize coffee and cattle farming.

Although the coefficient of variability in the two areas are different as per the shown calculations, the significance between rainfall variability in the two areas has to be established. This can be done using the **students T-test** as follows; In order to establish whether there was a significant difference in rainfall variability between Katumani and Mutisya the student T-test was employed using calculations from table 4.5 and 4.6.

$$\boldsymbol{t = \frac{736 - 625.9}{178.85 + 246.22} = \frac{110}{18.25+23.01} = \frac{110}{41.2} = 2.66}$$

Significant level was taken at 0.05 and the result t = 2.66 showed there was a significant difference in rainfall variability between Central Division and Kalama Division. According to Downing et.al (1989), a total annual rainfall variability of over 40% indicates that an area is prone to uncertain occurrences of drought. It is therefore difficult to predict the coming of a drought and the length of the drought in Machakos sub County. This situation brings about uncertainty in planning farming calendars and predicting the onset of rains. This interferes with crop and animal farming activities.

In the understanding of the researcher, analysis of annual rainfall provides insight and knowledge in understanding the trends in rainfall patterns and may be used to predict future patterns and trends. It may also assist in forecasting seasonal patterns and trends which is a very useful tool in planning farming activities and farming calendars. Studies such as those of Nicholson (2000), World meteorology organization (2000) and Domonkos (2003) entails regional studies of large geographical areas such as Africa, Pampas of Argentina, Malawi and Hungary. This study focused on a small geographical area; The sub County of Machakos in Kenya and how the variability affects farming activities

4.4.1 Analysis of Seasonal Rainfall in Central Division (Katumani Kari station)

Maize growing seasons in Machakos sub County lies between March – June/July (MAMJJ) and between October – December/ January (ONDJ). The two seasons extent from the planting to harvesting period. The analysis aimed at determining seasonal totals, trends and anomalies in the study area. Coffee is a perennial crop and cuts across the seasons. Table 4.13 shows the monthly rainfall distribution, seasonal rainfall totals, means and anomalies in Central Division of Machakos District between 1990 – 2014.

Table 4.13 Monthly rainfall distribution, seasonal rainfall and anomalies 1990 -2014.

	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Total (mm)**	**Mean**	**Anomalies %**
1989/1990	217	250.7	65.9	5.1	0.0	3.4	542.1	90.3	40
1990/1991	43.5	80.5	57.5	3.1	1.4	8.9	194.9	32.48	- 80
1991/1992	5.0	193.7	35.0	1.1	6.8	0.0	241.6	40.2	-40
1992/1993	60.9	20.8	13.7	6.3	0.5	3.1	105.3	17.5	-200
1993/1994	70.3	83.6	29.8	8.2	3.3	9.9	208.1	34.68	-60
1994/1995	150.1	49.6	33.0	0.9	4.1	3.2	240.9	40.15	-40
1995/1996	73.7	96.4	42.8	19.3	2.2	2.2	236.6	39.43	-40
1996/1997	46.0	208.5	21.5	0.5	1.2	4.3	282	47	-20
1997/1998	118.0	123.0	162.6	38.7	15	2.9	460.2	76.7	30
1998/1999	121.0	113.8	9.8	2.4	4.9	0.0	251.9	41.9	-30
1999/2000	53.3	68.5	15.6	6.2	0.3	1.8	145.7	24.2	-130
2000/2001	113	88.9	15.3	4.3	4.3	2.5	228.3	38.05	-50
2001/2002	89.0	120.4	126.1	1.4	0.0	0.2	337.1	56.18	10
2002/2003	115.2	153.2	133.8	0.0	0.0	26.3	428.5	71.41	20
2003/2004	83.1	121.5	59.8	0.7	0.0	0.0	264	44	-30
2004/2005	101.7	165.1	100.5	0.0	0.0	1.5	378.9	63.15	10
2005/2006	105	175.9	106.7	2.4	0.6	17.5	408.1	68.01	20
2006/2007	205	143.9	41.7	2.7	27	5.2	425.5	70.9	20
2007/2008	73	129.3	4.5	0.3	1.3	0.2	208.6	34.7	- 60
2008/2009	3.2	145.4	29.7	5.2	0.0	0.0	183.5	30.5	-90
2009/2010	232	107.9	120.9	1.4	2.7	1.3	466.2	77.7	30
2010/2011	209.8	1.0	37.8	27.3	3.4	0.7	280	46.6	-20
2011/2012	1.6	286.7	205	36.9	3.3	0.4	533.9	88.9	40
2012/2013	96.3	184.4	234.4	4.1	3.2	11.4	533.8	88.9	40
2003/2014	124.6	235.3	185.3	22.4	1.4	4.0	573	95.5	40
TOTALS	**2512**	**3348**	**1888**	**204**	**85**	**116**	**8,158.7**		
MEAN	**100.5**	**133.9**	**75.5**	**8.1**	**3.4**	**4.6**	**32.635**		
STD DEV	**64.29**	**69.075**	**66.63**	**11.4**	**5.8**	**6.17**	**13.75**		
C.V	**0.64**	**0.52**	**0.9**	**1.4**	**1.7**	**1.34**	**0.421**		

Source. Katumani Kari Centre Weather Station (2015).

Statistical analysis of seasonal rainfall for Central Division indicates that total rainfall for the entire period of 25 years (first growing Season) was 8,158.7mm. The long term mean was 32.635 mm and the Standard deviation was 13.7466 mm. The coefficient of variation (CV) in total seasonal rainfall amounts was 0.42 (42%) which was significantly high. The highest rainfall was recorded in 2013/2014 season (573 mm). The seasons that recorded the highest rainfall above the long term mean (32.635mm) that is above 500mm were 1989/1990, 2011/2012, 2012/2013 and 2013/2014; The lowest rainfall was 105.3mm recorded in 1992/1993 season, while those seasons that recorded the lowest rainfall amount far much below the long term mean (below 200mm) were 1990/1991, 1992/1993, 1999/2000 and 2008/2009. The months that received no rainfall were June, 2003 and 2005. July 1989, 2001, 2002, 2003, 2004, and 2008. August 1991, 1998, 2003 and 2008. July (mean of 3.4mm) and August (mean of 4.6mm are the driest across the seasons of the historical period and April (mean of 69.075mm) and May (mean of 66.63 mm) were the wettest in the historical period; 1990 – 2014. The variability is profoundly marked in the 25 year period.

In Benin, an analysis of monthly rainfall variability between 1948 – 2002 by Yusri et.al, (2012) found that November and April were the wettest 10.9% and 11.2% of the total annual average while January and August were the driest months with 5.1% and 4.9% of the total annual average. These results are somehow similar with those of the current study as the two studies indicate April as the wettest month and August the driest. These variations in rainfall totals indicate high variability of rainfall in Machakos sub County which affects the production and yields of maize and coffee through low yields and to extremes ,crop failure.

The first growing season starts in March with a long term mean of 100.5mm and ends in July with a long term mean of 3.4 mm. The second maize growing season starts in October – December/January. This is the main growing season because it is wetter, with transitions of low rainfall in July long term mean (3.4 mm) and September long term mean (3.2 mm). Variability in total rainfall amounts cuts across different months over the 25 year period during the growing seasons. For example in March 2011/2012 on the onset of the growing season the lowest rainfall was recorded. Same happened in April 2010, 2011. This delayed the planting. Coefficient of variation and standard deviation in rainfall assesses variability within the months which ranges from lowest 0.6 in March to 0.5 in April. This affects the growing crops, sometimes leading to crop failure and lowered yields. Ming-ko (1998) reported that most of the rainfall variability exhibit such characteristics as false onset of the rains, late onset and pronounced breaks leading to drastic alterations of expected yields.

4.4.2 Analysis of Monthly Rainfall Distribution in Machakos Sub County within the Rainy season Katumani Kari station.

The historical trend of monthly rainfall totals, means, standard deviations, coefficient of variation and anomalies during the rainy seasons from 1989/1990 - 2013/2014 seasons is shown in Table 4.14

Table 4.14 Seasonal variations in Monthly rainfall for Machakos District. 1990 – 2014.

Season	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Total	Mean	
1989/1990	217	250.7	65.9	5.1	0.0	3.4	0.0	0.0	208.5	110.2	42.8	23..2	975.9	81.3	93.15
1990/1991	43.5	80.5	57.5	3.1	1.4	8.9	3.4	46.5	119.5	156.7	29.2	13.3	563.9	47.0	49.914
1991/1992	5.0	193.7	35.0	1.1	6.8	0.0	0.7	31.0	114.2	186.2	12.0	6.1	621.8	51.8	75.801
1992/1993	60.9	20.8	13.7	6.3	0.5	3.1	0.6	26.0	150.8	152.5	265.5	84.9	776.6	64.7	81.905
1993/1994	70.3	83.6	29.8	8.2	3.3	9.9	4.3	116.9	308.2	143.7	0.0	103.5	881.7	73.5	89.567
1994/1995	150.1	49.6	33.0	0.9	4.1	3.2	5.1	103.7	46.6	87.4	28.5	83.5	595.5	49.6	47.574
11995/1996	73.7	96.4	42.8	19.3	2.2	2.2	0.7	0.0	187.7	1.5	22.4	56.5	505.4	42.1	56.066
1996/1997	46.0	208.5	21.5	0.5	1.2	4.3	0.0	83.2	270.3	117.3	3.8	0.0	816.3	68	96.278
1997//1998	118.0	123.0	162.6	38.7	15	2.9	1.8	0.0	113.9	15.8	295.4	219.5	1106.9	92.2	97.121
1998/1999	121.0	113.8	9.8	2.4	4.9	0.0	5.0	20.6	257	108.6	16.0	2.2	661.3	55.1	79.674
1999/2000	53.3	68.5	15.6	6.2	0.3	1.8	2.3	41.0	181.9	99.7	7.0	0.0	485.6	40.5	57.132
2000/2001	113	88.9	15.3	4.3	4.3	2.5	0.0	7.3	169	43.6	244.5	0.0	693	57.8	80.550
2001/2002	89.0	120.4	126.1	1.4	0.0	0.2	8.8	21.2	144.3	182.4	79.5	7.5	780.8	65.1	66.409
2002/2003	115.2	153.2	133.8	0.0	0.0	26.3	21.5	30.8	121.1	24.1	31.6	17.2	674.8	56.2	56.681
2003/2004	83.1	121.5	59.8	0.7	0.0	0.0	1.0	47.6	161.3	89.5	48.0	47.9	660.4	55.0	52.043
2004/2005	101.7	165.1	100.5	0.0	0.0	1.5	0.0	8.4	93.4	112.8	12.2	19.2	614.8	51.2	58.961
2005/2006	105	175.9	106.7	2.4	0.6	17.5	2.1	10.7	328.4	321.3	30.9	53.1	1154.6	96.2	119.68
2006/2007	205	143.9	41.7	2.7	27	5.2	4.3	18.3	128.2	82.4	61.4	44.8	764.7	63.7	64.560
2007/2008	73	129.3	4.5	0.3	1.3	0.2	9.1	23.9	112.8	39.9	117.4	7.3	529.0	44.1	52.146
2008/2009	3.2	145.4	29.7	5.2	0.0	0.0	1.2	41.3	34.4	129.1	74.2	26.3	488.0	40.7	49961
2009/2010	232	107.9	120.9	1.4	2.7	1.3	0.6	29.3	116	125.4	57.1	64.1	858.7	71.6	71.386
2010/2011	209.8	1.0	37.8	27.3	3.4	0.7	5.9	50.2	232.5	28.2	9.1	71.8	677.7	56.5	80.099
2011/2012	1.6	286.7	205	36.9	3.3	0.4	4.5	22.3	119.7	173.2	14.7	4.6	872.9	72.7	98.711
2012/2013	96.3	184.4	234.4	4.1	3.2	11.4	0.2	33.1	123.5	54.2	22.4	43.3	810.5	67.5	77.046
2013/2014	124.6	235.3	185.3	22.4	1.4	4.0	1.9	50.0	124.0	34.5	32.6	12.1	828.1	69.0	79.132
Total	2512	3348	1888	204	85	116	80.0	912.1	4015.6	2678.2	1549.5	1012	18399		
Mean	100.5	133.9	75.5	8.1	3.4	4.6	3.2	36.5	160.6	107.1	62.0	40.5	736.0		
SD	64.29	69.075	66.63	11.4	5.8	6.17	4.64	29.11	73.235	71.974	81.729	48.26	178.8		
CV	0.64	0.52	0.9	1.4	1.7	1.34	1.5	0.8	0.5	0.7	1.3	1.2	0,24		

***Source. Katumani Kari Centre Weather Station (2015)*.**

From the Table it is clearly seen that rainfall begun in march with a long term mean of 100.5mm reaching the peak in April with a long term mean of 133.9mm and ended in June with a long term mean of 8.1 mm, which is designated as a dry month. Sometimes the rains failed in March to start in April such as in the following seasons 1991/1992, 2008/2009 and 2011/2012. This is the growing season for maize and other crops. Sometimes the rains come as early as January or February such as in the seasons of 1992/1993, 1993/1994, 1997/1998, 2000/2001, 2007/2008. This is brought about by a wide variability during the said periods. This delays the planting and affects the growing of crops, sometimes leading to crop failure and lowered yields. The main planting season begins in October with a long term mean of 36.65, reaches the peak in November With a long term mean of 160.6 and ends in January with a long term mean of 40.5

March to July rainfall season

March

In March rainfall totals above the long term mean of (100.5 mm) were recorded in the seasons of 1989/1990, 1994/95, 1997/98, 2000/2001 and rainfall total below the long term mean were recorded in the seasons 1990/91, 1991/92, 1993/94, 1995/96, 1996/97, 1999/2000, 2001/2002 and 2003/2004. The coefficient of variability was 0.64 (64%) and the standard deviation was 64.29. Doorenbos (1976) posited that rainfall data with coefficient variability of 0.2 (20%) or above is highly variable. There was high variability of annual total rainfall with some years having more rainfall than other years. The coefficient of variability for March is very high 0.64 (64%). The wettest seasons were 2010/2011, 2006/2007and 1994/95. The driest seasons were 1991/92, 2008/2009 and 2011/2012. The results imply that in the month of March most seasons received unreliable rainfall which was below the long term mean, implying high variability. This can adversely affect plant development leading to low yields. Similar results by Meertens et,al (1999) saw the distribution of rainfall in semi arid areas of Northwest Tanzania during the rainy season was highly variable. Distribution and length of the period of rain during the growing season is a factor that affects success of crop farming.

April

In April rainfall totals above the long term mean of (133.9mm) were recorded in the seasons 1989/90, 1991/1992 and rainfall totals below the long term mean were recorded in the seasons 1990/91, 1992/93, 1993/94, 1995/96, 1997/98, 1998/1999, 1999/2000, 2001/02, and 2003/2004. The coefficient of variability was 0.52 and the standard deviation was 69.075. Since according to Doorenbos (1976) a CV of 0.2 (20%) or above is highly variable, it follows that the 0.52(52%) is highly variable. The standard deviation of 69.075 indicates a very high variability for the months of April. Nicholson (2000) made similar observations in East Africa between 1950s and 1980s with a variability of (50%) with a less frequent occurrence of above average annual rainfall. Another study carried out in India by Goswani et.al (2006) observed the decreasing trend and increasing variability of rainfall. The results of this study imply that in the month of April most seasons received unreliable rainfall below the long term mean; a situation affecting plant growth development leading to reduced yields and crop failure.

May

In May rainfall totals above the long term mean of (75.5mm) were recorded in the seasons 1997/98, 2001/02, and 2002/2003. and rainfall totals below the long term mean were recorded in the seasons 1989/90,1990/91, 1991/92, 1992/93, 1993/1994,1994/95, 1995/1996, 1996/97, 1998/99, 1999/2000, 2000/2001 and 2003/04. The coefficient of variability was 0.9 and the standard deviation was 66.63. Since a CV of 0.2 (20%) or above is highly variable, it follows that the 0.9 (90%) is highly variable. The standard deviation of 66.63 indicates a very high variability for the month of May. This was the highest recorded variability within the month. A similar study was carried out by Mos, et.al (2010), who noted the significant frequency increase of rainfall totals above the long term mean in may in East Africa. Hulme's (1996) study observed that most parts of East Africa were likely to experience 5-20% increase in rainfall from December to February by 2050 which is contrary to this study recording a sharp decline in rainfall totals which is attributed to differences in physical characteristics and human activities highly affecting farming activities.

June

In June rainfall totals above the long term mean of (8.1mm) were recorded in the seasons 1997/98, 1995/96, 1997/98, 2010/11, 2011/12, 2013/14 and rainfall totals below the long term mean were recorded in the seasons 1989/90,1990/91, 1991/92, 1992/93,1994/95, 1995/1996, 1998/99, 1999/2000, 2000/2001, 2001/02 and 2003/04. The coefficient of variability was 1.4 and the standard deviation was 11.4. Since a CV of 0.2 (20%) or above is highly variable, it follows that the 1.4 (140%) is highly variable. The standard deviation of 11.4 indicates a high variability for the month of June. The results imply that in the month of June most seasons received unreliable rainfall below the long term mean; Similar results were observed in Uttaranchal (USSR) by Sen Roy and Balling (2004) which found high variability in monthly rainfall. The situation adversely affects plant growth development leading to reduced yields and to extremes may lead to crop failure.

July - September

July (3.4mm) and August (4.6mm) and September (3.2 mm) recoded the lowest mean rainfall across the seasons in 24 years. The second rainfall season began in October (36.5mm). November (160.6mm) to December (107.1mm). The coefficient of variation (CV) value in the annual rainfall total obtained (Table 4.8) Shows that rainfall is highly variable and is very unreliable in the District. Since rainfall data with coefficient variability of 0.2 (20%) or above is highly variable. There was high variability of annual total rainfall with some years having more rainfall than other years. The onset of the rainy season, Started in (March 100.5 mm) rising to the peak in April (1333.9 mm) and starting to reduce in May (75.5 mm) to July (3.2mm), August(4.6mm and September (3.2 mm) Which was the driest month.

In July, several years did not receive any rainfall at all. These were 1989, 2001,2002, 2003, 2004, 2008 and September 1989, 1996, 2000 and 2004. The rainfall started rising in November (106.6mm), December (107 mm). The Highest rainfall mean was April (133mm and CV 0.52mm) long term mean and the lowest was September (3.2mm and CV 1.5mm). The months of March, April, May, November and December had high monthly rainfall means over the last 24 seasons. These variations indicate high variability in Machakos sub County. The results imply that most seasons received unreliable rainfall below the long term mean; a situation affecting plant growth development leading to reduced yields and to extremes may lead to crop failure.

October to December

In October rainfall totals above the long term mean of (36.5 mm) were recorded in the seasons of 1990/91, 1993/94, 1994/95,1996/97, 1999/2000, 2003/04, 2008/09, 2013/2014 and 2010/2011 and rainfall total below the long term mean were recorded in the seasons 1989/90, 1991/92, 1992/93, 1995/96, 1997/98, 1998/99, 2000/01, 2001/2002 and 2003/2004. The coefficient of variability was 0.8 and the standard deviation was 29.11. Doorenbos (1976) posited that rainfall data with coefficient variability of 0.2 (20%) or above is highly variable. There was high variability of annual total rainfall with some years having more rainfall than other years. The coefficient of variability for March is very high 0.64 (64%). The wettest seasons were 1993/1994, 1994/1995. The driest seasons were 1989/90, 1995/19962, 1997/8. The results imply that in the month of October most seasons received unreliable rainfall which was above the long term mean, implying high variability. This can adversely affect plant development leading to low yields. Similar results by Meertens et al. (1995) saw the distribution of rainfall in semi arid areas of Northwest Tanzania during the rainy season was highly variable. Distribution and length of the period of rain during the growing season is a factor that affects success of crop farming.

November

In November rainfall totals above the long term mean (160.6 mm) were recorded in the seasons 1989/1990, 1993/1994, 1995/1996, 1996/1997, 1998/1999, 1999/2000, 2003/2004, 2005/2006 and 2009/2010, Rainfall totals below the long term mean were recorded in the seasons 1990/91, 1991/1992, 1992/2093, 1994/1995, 1997/2098, , 2001/2002, 2002/2003 2006/2007, 2007/2008, 2009/2010, 2011/2013. The coefficient of variability was 0.52 and the standard deviation was. Since according to Doorenbos (1976) a CV of 0.2 (20%) or above is highly variable, it follows that the 0.52(52%) is highly variable. The standard deviation of 69.075 indicates a very high variability for the months of April. Nicholson (2000) made similar observations in East Africa between 1950s and 1980s with a variability of (50%) with a less frequent occurrence of above average annual rainfall. Another study carried out in India by Goswani et.al (2006) observed the decreasing trend and increasing variability of rainfall. The results of this study imply that in the month of April most seasons received unreliable rainfall below the long term mean; a situation affecting plant growth development leading to reduced yields and crop failure.

December. Rainfall totals above the long term mean of (107.1mm) were recorded in the seasons 1989/90, 1990/91, 1991/92, 1992/93, 1993/1994, 1996/1997,1998/1999, 2001/02, 2004/2005, 2005/2006, 20092010 and 2011/2012. and rainfall totals below the long term mean were recorded in the seasons,1994/95, 1995/1996, 1997/98, 1999/2000, 2000/2001, 2002/2003 and 2006/07, 2007/2008, 2010/2011,2012/2013,2013/2014. The coefficient of variability was 0.7 and the standard deviation was 71. 974. Since a CV of 0.2 (20%) or above is highly variable, it follows that the 0.7 (70%) is highly variable. The standard deviation of 71.974 indicates a very high variability for the month of December. This was one of the highest recorded variability within the months. A similar study was carried out by Mos, et.al (2010), who noted the significant frequency increase of rainfall totals above the long term mean in May in East Africa. Hulme's (1996) study observed that most parts of East Africa were likely to experience 5-20% increase in rainfall from December to February by 2015

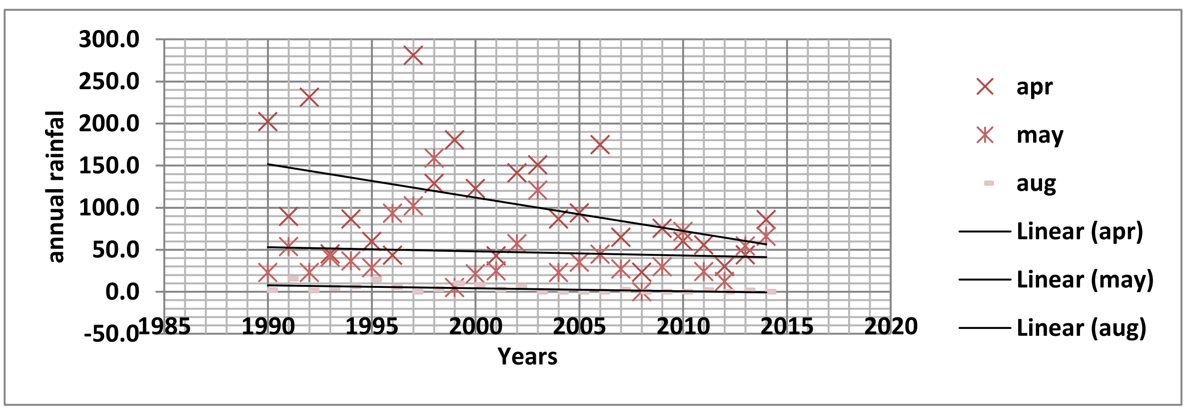


Fig 4.6 Seasonal variations in Monthly rainfall for Katumani Machakos District 1990 - 2014

Studies of rainfall variability in the former Machakos District by Tiffen in the 1970's – 80's indicated July to August as the driest months in the growing season while April as the wettest month (Kimani, 2004). Similar studies conducted by Smith (2006) indicated extreme rainfall variability in the growing seasons in Sub – Saharan Africa and the savannah lands. The study area lies in the savannah lands of Africa. Studies on rainfall variability in Machakos sub County like Michael, (1992) cover the period up to 1990.

4.5 Factors that Influence Rainfall variability in Machakos sub County

This section focused on factors that influence rainfall variability patterns in Machakos sub County. Natural factors such as Elnino, Sea Surface Temperatures (SSTs), Topographical contrasts and Inter Tropical Convergence Zone have been elaborately covered in the literature review. This section mainly focused on human factors that influence rainfall variability in Machakos sub County. Primary data was collected from 301 respondents using questionnaires administered to household heads or their representatives in Machakos sub County.

The first section of the questionnaire sought information Human activities that influence rainfall variability basing on the second specific objective. A variety of human activities have been known to influence changes in elements of weather and climate in particular rainfall amounts and patterns. Information relating to this section was sourced using the household questionnaire, administered to the members of the household.

4.5.2 Human factors influencing Rainfall variability

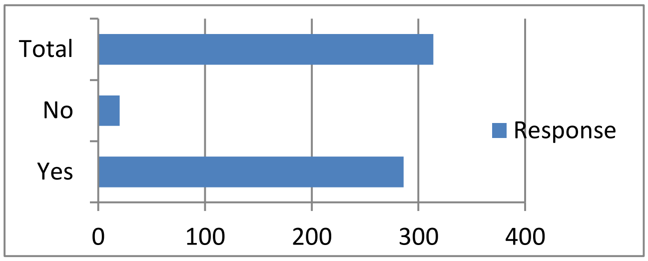
This section sought to analyze human activities to identify and determine the human factors that influence rainfall variability in the study area. The section focused on eliciting the evidence of human activities influencing rainfall variability in the sub County. A variety of human activities have been known to influence changes in elements of weather and climate in particular rainfall amounts and their variability patterns. Understanding of this was aimed at coming up with proper measures of environmental management on these practices. These activities include overgrazing, deforestation, and over cropping.

4.5.2.1 Overgrazing

A number of activities can lead to overgrazing. Focus was based on activities done on farm or off farm that indicated overgrazing. The following activities can be used to determine the extent to which the land has been overgrazed.

a) Number of households keeping livestock

Respondents were asked to state if they kept livestock or not. Figure 4.7 shows the number of households keeping livestock in the study area.



Key

Yes – 91.1 %

No -- 8.9%

Figure 4.7 Number of households keeping livestock

The results in figure 4.7, indicated that the majority of the respondents kept livestock (91.1%). Only 8.9% did not keep livestock. Considering the fact that 73.2 % of the householders own between less than 1 - 3 acres of land (Table 4.6), the number of livestock kept was high. This was an indicator/evidence of activities leading to overgrazing in the area. The small sizes of land, less than 1 – 3 acres had to be shared between crop farming and animal keeping. This evidently indicated overgrazing in the area. Overgrazing occurs when vegetation is exposed to intensive grazing for an extended period of time, without sufficient recovery periods. This results into soil erosion and land degradation, reduced rainfall culminating in the spread of desert conditions.

A study carried out in Mongolia by Yusri et al. (2012) examined the influence of changing climate and overgrazing on land degradation, reduced rainfall culminating in the spread of desert conditions. Non Parametric trend tests were applied on time series of annual precipitation over the period 1988 – 2008. Results indicated that most parts of the country experienced decreasing precipitation as a result of human activities and in particular overgrazing. The result is different to the current study in which declining and unpredictable rainfall affects farming activities. However in both studies, overgrazing is identified as a human activity influencing rainfall variability.

b) Number and type of livestock kept per household

Respondents were asked to give the number and type of livestock they kept. Table 4.15 shows the type and number of livestock kept by households in the study area.

Table 4.15 Number of livestock kept by household

	Type	Household	Percentage %
1	Cattle	124	13.6%
2	Sheep	221	24.2%
3	Goats	325	35.6%
4	Donkey	140	15.3%
5	Pigs	103	11.3%
	Total	**913**	**100**

Source: Field data 2016

The results in the table reveal that**,** Goats were the majority in numbers kept (35.6%) followed by sheep (24.2%), cattle (13.6%), donkeys (15.3%) and pigs (11.3%) in that order. The large number of livestock kept were browsers such as goats and grazers, such as sheep and cattle which enhanced overgrazing. Considering the small size of farms, and the fact that for most farmers put more than ¾ of their farms under crops, it was an indicator of overgrazing. The households practice tethering and free range grazing methods after harvesting period. Overgrazing can be caused by either livestock in poorly managed agricultural applications or by overpopulation of livestock on farm land (Michael and Tiffen, 2009) Overgrazing increases soil erosion, reduction in soil depth, soil organic matter and soil fertility destroying the land's future natural beauty and agricultural productivity. Extreme cases of rainfall variability leads to decreased yields and crop failure resulting in food shortages and famine.

c) Livestock land carrying capacity

Overgrazing was also determined by livestock land carrying capacity. The concept of a carrying capacity which must not be exceeded if environmental damage is to be avoided has caused a long conflict between expert views and Kamba practice. It is now generally recognized that overstocking results either from large human populations with each family resolving to keep enough stock for its survival, or, when famers keep livestock far in excess of what is needed for survival. The main problem in Machakos has been perceived as the former, combined with mal distribution so that some farmers had large herds while other farmers had none (Owako, 1999). He further states that; the relatively small numbers of cattle kept by individual households were often in excess of the available grazing areas. A similar conclusion was reached by the Carter Commission in 1993 (Kenya Land Commission, 1994).

Table 4.16 shows the total livestock population in Central Division of Machakos sub County .

Table 4.16. Total livestock population in Central Division of Machakos subCounty.

	Type of livestock	Category	Population
1	Cattle	Dairy	7,800
		Beef	95,400
2	Goats	Indigenous	8,800
		Dairy (exotic)	700
3	Sheep	Indigenous	5,320
4	Donkeys	Indigenous	50
	TOTAL		**109, 020**

Source. Sub county livestock production office (2015)

Table 4.16 reveals the livestock population in Central Division. Dairy Cattle totaled to 7800 and beef 95,400, Goats; indigenous 88,000 and Dairy (exotic 700) Sheep 5320. Total population of animals; 109,020 and the division total land surface area is 88 kilometers squared (GOK, 2013). 109,020/88 = 124 animals per square kilometer. This is an indicator of overstocking and that the area is highly overgrazed resulting in soil erosion and land degradation culminating in reduced precipitation, prolonged droughts and extremes in rainfall variability affecting farming activities.

4.5.3.2 Determining Deforestation.

The following human activities determined the extent to which the land has been deforested in the sub County.

a) Land preparation practices

This survey sought to find out the land preparation activities practiced in the study area. Table 4.17 below shows land preparation activities practiced in the sub County.

Table 4.17. Land preparation activities.

N0.	Land preperation activities	Percentage
1	Cutting trees	27.16%
2	Bush burning	15.64%
3	Slashing	21.3%
4	Slash and burn	35.9%
		100%

Source: Field data 2016

Respondents were asked to state the land preperation activities they carried on their farms. From the results depicted on Table 4.17, the main land preparation activities were Slash and burn (35.9%) and cutting trees (27.16%) which indicated deforestation. Bush burning and slashing alone were the minor land preparation activities. Cutting down of trees in every planting season cannot match with the rate at which newly planted trees can mature to replace the ones cut down. This is an indicator of deforestation**.**

Plate 1 below, shows the forest on Mutituni hill. This section of the forest is made up of Cyprus. The trees are mainly cut for timber, poles for construction. Charcoal burning is also practiced. The respondents gave fire wood and charcoal as their main sources fuel. Areas covered by forest in the sub County are found in the hilly areas in the north receiving higher rainfall compared to the lowland areas in the south.

Plate 1. Mutituni Forest

Plate 2 below, shows a section of eucalyptus species in Mutituni forest regenerating after being cut down. The trees are mainly harvested for timer building poles for sale. Unlike cyprus, eucalyptus are capable of regenerating to grow afresh after being cut. Forests are known to influence rainfall. Over exploiting leads to deforestation. This eventually interferes with hydrological cycle leading to reduced rainfall.

Plate 2. A section of Mutituni Forest regenerating after being cut

Bush burning and slash and burn which are other forms of land preparation activities, contribute heavily to removal of the lands' vegetative cover. Respondents indicated that slash and burn activities are mainly undertaken on clearing after harvest crop remains and bush land left to fallow for sometimes. Oyoo (2011) posits that uncontrolled burning of vegetation destroys not only the aerial parts of the plants but also much of the surface organic materials and hence leads to more run off and less soil storage of the increased water supply. This interferes with hydrological cycle and eventually contributes to reduced rainfall and spread of the desert conditions known as desertification**.** Bush burning and slash and burn, contribute to increased carbon dioxide in the atmosphere which leads to global warming as a result of greenhouse effect. This contributes to climate change characterized by rising temperatures and declining rainfall (Waikwa, 1998).

The moisture theory (Ngaira, 1999) states that the removal of vegetation and reduced soil moisture contributes to a decrease in rainfall. In Machakos sub County, these activities were practiced during preparation of land for planting. Since most of the land was under crops (Table 4.13) then bush burning and slash and burn was a predominant practice in the sub county. Bush burning and slash and burn also destroy young seedlings and plants that could grow into big trees to enhance increased rainfall resulting in further reduced rainfall in the area.

Plate 3 below shows a small holder farm prepared and ready for the planting season. Bananas and Napier grass can be seen in the foreground while eucalyptus planted forest can be seen in the background. In some sections particularly around the hilly north, eucalyptus forests form part of the land use. Eucalyptus enhances evapo-transpiration. However deforestation is reducing the area under forest at an alarming rate, paving way to reduced rainfall and spread of desert conditions.

Plate 3. Small holder farms. Prepared for planting.

b) Species of trees planted and their use

This section found out the main species of trees planted and their use in the district. Table 4.18 shows the species of trees planted and their use in the district.

Table 4.18 The species of trees planted and their use in the district.

	Species	**Frequency**	**Use**
1	Eucalyptus	125	Timber
2	Cyprus	15	Timber
3	Pine	18	Timber
4	Grevila	57	Timber
5	Jacaranda	130	Firewood
6	Others	88	Firewood

Source: Field data 2016

The Table shows the species of trees planted and their use in the district. The main species planted are eucalyptus and jacaranda which are used for timber and firewood. Eucalypts contribute positively to the environment in afforesting denudated sites; and providing a land use for saline and alkaline soils. Ojwand (2014) posits that, in some areas eucalyptus help save biodiversity by meeting fuel and small wood needs otherwise coming from natural forest. Great potential exists for increased yield through tree breeding and planting. Plantations are developed for fuel, poles, timber and industrial wood; In developing countries production for multipurpose improves the economic returns.

Plate 4 below shows sawn timber from Mutituni forest awaiting transport to the markets. Continuous timber and pole harvesting aggravated by the rising population leads to forest destruction affecting the hydrological cycle and reduction in rainfall amounts.

Plate 4. Harvested timber ready for transport.

Timber used in the Machakos sub County mainly comes from within the sub County. In addition the main types of fuel used in the area are firewood and charcoal, which comes from the sub County (Table 4.18). As timber, charcoal and firewood are tree products, it is an indicator of acute cutting down of trees in the sub county which is deforestation**.** A study done in the semi arid Makueni by Mua and Ndunda (2013) evaluated the impact of direct anthropogenic activities on land degradation in arid and semiarid regions.

According to the study results of Mua and Ndunda (2013), a unit increase in deforestation raises the probability of land degradation by 28%. Deforestation in the study area occurs as people cut trees for timber, wood fuel and farming. The significance of deforestation to land degradation may be because this exposes land to direct sunlight, rainfall, wind and consequently soil erosion and spread of desert conditions. These results are similar to the current study as deforestation in the study area occurs as people cut trees for timber, fuel wood and farming.

c) Types of fuel used in the sub county

Respondents were asked to give the types of fuel used for domestic purposes. Table 4.19 shows the type of fuel used in the sub County.

Table 4.19 Type of fuel used in the sub County.

	Fuel	Frequency	%
1	Firewood	143	65
2	Charcoal	72	32
3	Gas	01	0.4
4	Electricity	03	1.3
5	Sawdust	01	0.4
	Total	**220**	**100**

Source: Field data 2016

From Table 4.19 the results indicated that the main source of fuel were firewood (65%) and charcoal (32%). Others like gas (0.4%), electricity (1.3%) and saw dust (0.4%) are not much used. These sources of fuel; firewood and charcoal are contributors to deforestation when the locals cut them for firewood and charcoal**.** Currently, some 465,000 hectares of land has been taken up by settlements as population increases, expansion of this type of land use is increasing fast and this goes hand in hand with increased use of wood fuel.

Heavy use of wood fuel, charcoal and bush burning, contributes to increased Co_2 in the atmosphere leading to global warming through greenhouse effect. Deforestation interferes with the hydrological cycle leading to decreased rainfall, prolonged droughts, extreme rainfall variability and spread of desert conditions. The moisture theory states that the removal of vegetation and reduced soil moisture contributes to a decrease in rainfall. Global warming and reduced rainfall amounts and changing rainfall patterns culminate into climate change. These are the main contributors of deforestation particularly in dry areas (Mua and Ndunda, 2013). This is the same as that in Machakos District. Deforestation influences climate change. With no trees, landscapes that were once forests can potentially become barren deserts. The removal of trees also causes extreme fluctuations in temperature.

4.5.2.3 Determining over cropping

The portion of land under crops

The proportion of land under crops as compared to livestock, helps to assess the amount of cropping in terms of under cropping or over cropping. Table 4.20 shows the portion of land under crops in the sub County. If the area of land under crops exceeds the area set aside for grazing by a big margin say over 80%, the remaining 20% is to be shared between grazing and the home stead area. This indicates over cropping.

Table 4.20 The proportion of land under crops

	Proportion of land under crops on the total land owned	Frequency	Percentage
1	Less than 1/4	89	33.2%
2	1/4 -1/2	45	16.8%
3	1/2 – 3/4	20	7.5%
4	over ¾	114	42.5%
	Total	**268**	**100%**

Source: Field data 2016

The results indicated that (42.5%) of the farmers allocated over 3/4 s of their land for crops followed by less than 1/4 (33.20%), between 1/4 - 1/2 (16.78%) and more than 1/2 - 3/4 (7.5 %) This is an indicator of over cropping. Most of the land was under crops, leaving very little for grazing. It also led to destruction of other forms of vegetation like trees and grass which covered the soil and hence the land was exposed to agents of soil erosion. Loss of soil vegetative cover leads increased surface albedo, increased heat loss and reducing rainfall through reduced evapo-transpiration and extreme variability of rainfall and subsequently the spread of desert conditions.

A study conducted in Mwingi sub County reported that the area experienced low rainfall from early 2004, and low harvests for maize in the 2005/2006 short rains season. Most rivers were dry through most parts of the year, water levels in the shallow wells dug near streams either gets significantly low or dry up during the dry periods. The population also had to walk long distances in search for water for both domestic use and livestock watering. During the short rains over cropping was evident to maximize the short periods of rainfall with maize, sorghum, millet, beans and peas (County program Annual report.2014). Since Makueni lies close to Machakos District, their cropping patterns were similar.

4.6 The influence of Rainfall variability on Maize, Coffee, and Cattle production in Machakos sub County.

Published data collected from the sub County Ministry of Agriculture on maize and coffee production was supported by primary data collected from 301 respondents in households of Machakos sub County. The information collected was on historical rainfall events over the past 25 years and on how rainfall variability affected the production (yields) of Maize, Coffee and Cattle in Machakos sub County.

4.6.1 The influence of rainfall variability on Maize farming and yields

a) Proportion of land under maize in the sub County.

This section sought to find out the proportion of land under maize among households in the sub County. The results as seen in the Table 4.21 shows the proportion of land allocated to maize.

Table 4.21 Proportion of land under maize

	Proportion of land under maize on households' total land area	Frequency	Percentage
1	more than 3/4	188	63.1
2	between 3/4 – 1/4	91	30.5
3	between 1/2 – 1/4	12	4.1
4	less than 1/4	07	2.3
	Total	**298**	**100**

Source: Field data 2016

The table shows that farmers who allocated more than 3/4s of their land for maize production accounted for (63.1%), 3/4 -1/2 acres (30.5%), 1/2 –1/4 acres (4.1%) and less than 1/4 (2.3%). Meaning that most farmers set aside over 1/2 of their land for maize farming. Other crops and livestock take the other fraction. Since the majority of the farmers owned small scale farms then it follows that maize was gown basically for subsistence. The few with large farms grew maize for commercial purposes. This implies that maize was mainly grown for subsistence in Machakos sub County

Omuoyo (2015) posits that maize is the most important and widely consumed food crop in Kenya. It is the staple food crop for 96 % of the population with 125 kg per capita consumption and provides 40 % of the calorific requirements in Kenya. Determining the proportion of land under maize provides the basis on which we compare maize production with rainfall variability over the study period. Size of land under maize could also be affected by variability patterns.

b) The variety of maize seed grown in the sub County

Deferent varieties of maize seed were grown in the District. Table 4.22 shows the type of maize seed variety grown. The results as seen in the table, indicated that majority of the farmers plant the hybrid variety (58.16%), local variety was planted by (25%) and those who planted both were (17%). The main Hybrid maize seed variety is Katumani as shown in figure 4.22. It is a drought tolerant variety and fast growing. The number of responses differ as some respondents failed to respond to some questions by leaving them blank.

Table4.22 Maize seed variety grown

	Variety	**Frequency**	**%**
1	Hybrid (Katumani)	114	58.16 %
2	Local	49	25 %
3	Both local and hybrid	33	17 %
	Total	**196**	**100**

Source: Field data 2016

Local variety was less important due to low and unreliable rainfall as it took longer to mature. As the area was dry the best suited variety was a fast growing drought resistant variety which was Katumani. The local variety takes longer to mature and prone to crop failure in the event of drought. Katumani was well suited for dry lands. It took three months to mature. The local variety took 6 months to mature hence it was not widely grown. Other hybrid varieties were rarely planted. Local seed represented by number 2 was the second most important because of its hardy characteristics as compared to the hybrid seed. Hybrid seed was also popular due to its high productivity. Mugo (1998) posits that compared with other drought tolerant maize breeds, Katumani, the early maturing cultivar was the most drought tolerant with large biomass accumulation in both stress and non-stress environments.

A similar study was carried out by Miruka et al.,(2015) which determined drought tolerant maize for Africa (DTMA project) in the former larger Machakos and Makueni Districts. Farmers in the sample named some 22 varieties which they were growing during 2005–14. Five out of these 22 were local types (*Kangundo*, *Kikamba*, *Kinyanya*, *Mulava* and *Mukunga*). Out of the 17 improved varieties, two were well-known open-pollinated varieties, namely, Katumani (Katumani Composite B or KCB) and Makueni (Dry land Composite 1 or DLC1). Both Miruka et al.'s (2015) and the current study are in agreement that katumani was the most best variety suited for dry lands as it was a fast growing drought resistant variety.

Plate 5 below shows a maize crop ready for harvesting. The maize seed variety shown was the local breed *Kikamba* grown by most small holder farmers in the district. This is a hardy breed. Farmers who cant afford the commercial hybrid seed, mainly plant the local variety.

Plate 5. Maize crop ready for harvesting in Mutituni. Central Division.

Source. Field 2015.

Katumani was the most suited variety for dry lands as it was a fast growing and drought resistant and that most farmers 58.16 grew it (Table 4.22). It could mature within a spell of short rains. The local *Kikamba* variety was hardy and was able to sustain itself longer during droughts and in extreme cases of rainfall variability

c) The number of planting seasons for maize in a year

The survey established the number of maize planting seasons in a year**.** The results as shown in Table 4.2 indicated that 13 out of 258 (51.93%) farmers who responded to this question plant once and 125 out of 258 (48.07%) plant twice in a year. Planting ones is ideal considering the high variability and uncertainty of the rainfall in the area.

Table 4.23 Number of planting seasons in a year

	Planting Seasons	**Frequency**	**Percentage**
1	Planting once	133	51.93%
2	Planting twice	125	48.07%
	TOTAL	**258**	**100%**

The main planting season was between October to January. The second planting season is based on the short rains season that run from March to June. However this rainy season is highly unreliable as evidenced in the trends shown in Table 4.7 and 4.8 on page 46 and 59 respectively. Sometimes rains failed to come when they were expected and came when they were not expected. According to Omuoyo et al.,(2015) the mean onset date for main growing season in

Machakos is 10 October, while the latest onset date is 10 December. The earliest onset of second growing season rainfall is 5 March, while the latest is 30 May. The mean onset date for the second growing season rainfall is on 7 April (Omuoyo et al, 2015). Planting twice is mainly practiced along river valleys where soil water retention is high and possibilities of irrigation can be applied. It is also practiced in the event of occurrences of abnormal rains like Elnino rains. Planting twice increases productivity or supplements a poor harvest.

A study by Omuoyo et.al, (2015) on the effect of climate variability on maize farming in the arid and semi arid lands of south eastern Kenya, seasonal and annual patterns were computed from daily rainfall data, and the variations were illustrated by means of graphs and trend lines. Rainfall data was categorized into two growing seasons March-June (MAMJ) and October-January (ODNJ). The main growing season was ODNJ while the second growing season was MAMJ. To determine the seasons, the seasonal rainfall variations were normalized. The study also established rainfall onset and cessation which is another important parameter that influences crop yields. The results of Omuoyo's study were similar to those of the current study.

c) The most serious problem facing maize farming in the district

The survey also established the most serious problem facing maize farming in the study area. Multiple response questions were asked on the problems facing maize farming. Figure 4.8 shows the most serious problems experienced in maize farming. The results in Figure 4.8 indicates that the most serious problem was prolonged droughts, followed by diseases and pests, unpredictable rainfall and changing patterns of rainfall. The respondents particularly reported experiencing prolonged droughts, delays in rainfall onset and sometimes receiving rainfall earlier than expected. This affected their farming calendars, planting time leading to poor germination and sometimes undertaking multiple sowing which is an extra expense, low yields and sometimes crop failure.

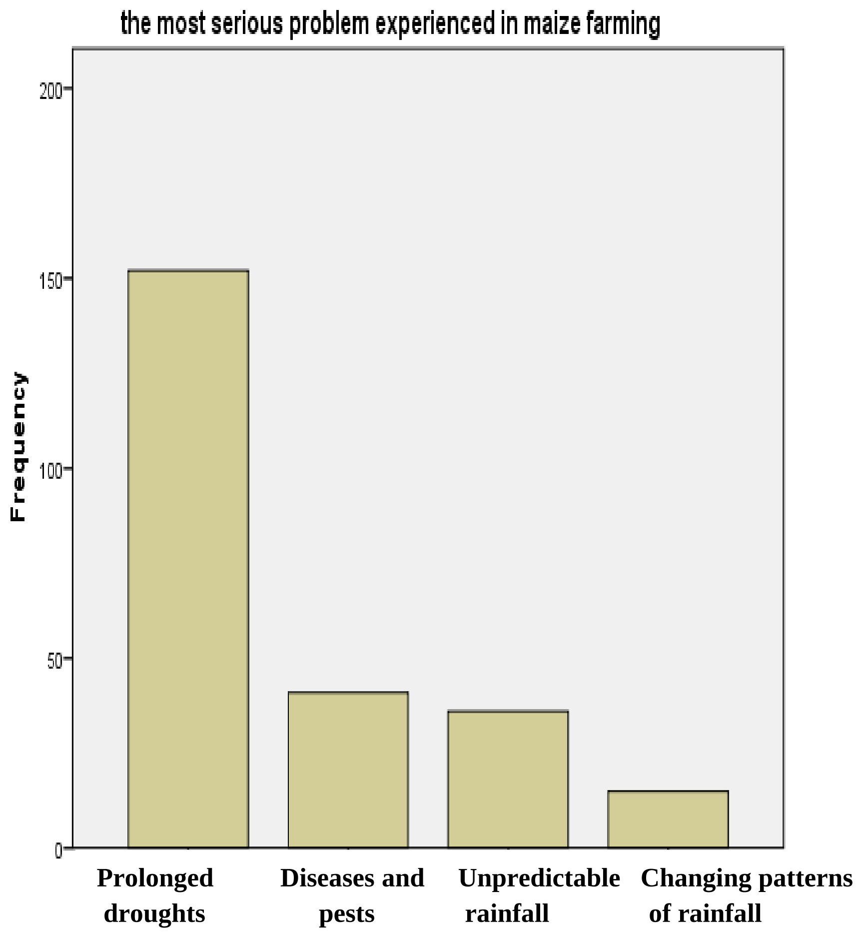


Figure 4.8 The most serious problems experienced in maize faming.

Similar observations were made by Majule, (1969) who reported that subsistence farmers in East African marginal lands believed that rainfall has declined and time of onset has become unpredictable, negatively affecting crop production. Mary, (2009) reported a shift in the onset of rainfall from October/November to December/January with shortening rainfall periods and increased frequency of droughts in North Eastern Tanzania.

Plate 6 below shows a drought affected maize crop showing a complete crop failure. Such scenes are common in the sub County during the droughts period. Prolonged drought which is the most serious problem is responsible for such a situation shown in on the plate.

Plate 6. A maize farm showing crop failure as a result of drought in Kalama location.

Source. Field.

e) The correlation analysis between annual rainfall totals and maize production in Machakos sub County

Table 4.23 shows maize production in sub County between 1990 – 2014. Yields are recorded in terms of number of bags per year. The yields per year were correlated with annual rainfall totals of the 25 year period from 1990 – 2014, using Pearson correlation moment to establish the influence of rainfall variability on maize yields.

Table 4.23a Production of Maize yield and total annual rainfall Machakos sub County between 1990 - 2014

YEAR	NUMBER OF BAGS	ANNUAL RAINFALL (MM) KATUMANI	ANNUAL RAINFALL (MM) MUTISYA	ANNUAL RAINFALL (MM) AVERAGE
1990	223,466	975.9	856.9	916.4
1991	210,266	563.9	654.8	609.35
1992	189,143	621.8	677.1	649.45
1993	197,000	776.6	739.2	757.9
1994	202,733	881.7	749.9	815.8
1995	193.600	595.5	702.1	648.8
1996	188,133	505.4	789.8	647.2
1997	80,100	816.3	125.9	471.1
1998	263,400	1106.9	1180.4	1143.65
1999	284,000	661.3	720.1	690.7
2000	80,000	485.6	491.1	488.35
2001	60,000	693	613	653
2002	188,000	780.8	816.8	798.8
2003	171,466	674.8	558.1	616.45
2004	140,226	660.4	486.1	573.25
2005	66,933	614.8	291.5	453.15
2006	154,666	1154.6	721.8	938.2
2007	83,433	764.7	388.8	576.75
2008	147,658	529.0	308.7	418.85
2009	179,793	488.0	331.1	409.5
2010	172,933	858.7	484.5	671.6
2011	147,000	677.7	353.1	515.4
2012	150,333	872.9	544.9	708.9
2013	106,000	810.5	338.3	574.4
2014	176,666	828.1	565.7	696.9
TOTAL	6,533,250	18,399	1564.67	16,443.85

Source, District Agricultural Office Machakos March,2015.

Table 4.23a   Production of Maize yield and annual Rainfall totals in Machakos sub County between 1990 - 2014

YEAR	NUMBER OF BAGS	ANNUAL RAINFALL (MM) AVERAGE
1990	223,466	916.4
1991	210,266	609.35
1992	189,143	649.45
1993	197,000	757.9
1994	202,733	815.8
1995	193.600	648.8
1996	188,133	647.2
1997	80,100	471.1
1998	263,400	1143.65
1999	284,000	690.7
2000	80,000	488.35
2001	60,000	653
2002	188,000	798.8
2003	171,466	616.45
2004	140,226	573.25
2005	66,933	453.15
2006	154,666	938.2
2007	83,433	576.75
2008	147,658	418.85
2009	179,793	409.5
2010	172,933	671.6
2011	147,000	515.4
2012	150,333	708.9
2013	106,000	574.4
2014	176,666	696.9
TOTAL	6,533,250	16,443.85

Source, District Agricultural Office Machakos March,2015.

Table 4.24 Correlation between Maize production(yield) and annual rainfall from 1990- 2014

		Percentage Mean	Percentage Maize Production in Bags
Percentage Mean	Pearson Correlation	1	0.632*****
	Sig (2 – tailed)		0.05
	N	25	25
Percentage Maize production in Bags	Pearson Correlation	0.632	1
	Sig (2 – tailed)	0.05	
	N	25	25

*** Correlation is significant at 0.05 significant level .**
Source: Field data 2016

The results of the correlation analysis (Table 4.24) shows that the correlation between annual rainfall totals and maize yields between 1990 and 2014, is statistically significant since the calculated correlation r = 0.632. The level of significance being at 0.05, the relationship between annual rainfall totals and maize yields at r = 0.632 is statistically significant. This implies that as rainfall increases maize yields increase and as rainfall decreases maize yields equally decrease. The results of anomalies analysis shown in table mean. Therefore, there were significant relationships between rainfall anomalies with maize yield in each growing season. This analysis derives the premise that, as rainfall increases maize yields equally increase and as rainfall decreases, maize yields decrease too. These results imply that rainfall is very important in determining maize yields in Machakos sub County. Farmers are highly vulnerable to rainfall variability due to high correlation between maize and rainfall.

Similar results were reported by Alberto, (2013) who observed a significant relationship of r = 0.586 between seasonal rainfall with cassava, sweet potatoes and sorghum yields in Kahangara Division in northern Tanzania. A study by Miruka (2015) on the effects of climate variability on maize farming in the ASAL areas of south Eastern Kenya, showed that maize yields were highly declining in Machakos, Kitui, Mwingi, and Makueni Counties. The maize yields fluctuated in response to rainfall amounts. The effect of climate was predominately negative in the period 1994–2008 in all the counties. Rainfall trend analysis revealed that four of the six weather stations were declining up to 3 mm per annum.

The results of Miruka (2012) in the entire South Eastern ASAL areas conforms with the results of the current study. The study by Miruka (2012) further confirmed that the arid and semi arid

Counties suffered from significant climate variability which had huge implications on maize yields and food security of lower Eastern Kenya. These findings were crucial in increasing the awareness of climate change and its impacts on agriculture, and develop appropriate mitigation measures and planning appropriate adaptation mechanisms in support of enhancing resilience of maize production and food security.

4.6.2 The influence of Rainfall variability on Coffee farming and yields

a) Proportion of land under coffee in the sub County

The study found out the proportion of land under coffee in relation to the total acreage of the household farms. Table 4.25 shows the Proportion of land under coffee in the sub County.

Table 4.25 Proportion of land under coffee

	Proportion of land under coffee on householders total land area	**Frequency**	**Percentage**
1	Less than 1/4	44	25.58
2	Between 1/4 – 1/2	117	68.02
3	Between >1/2 – 3/4	07	4.069
4	Over 3/4	04	2.33
	Total	**172**	**100**

Source: Field data 2016

The results in Table 4.25 indicate that for most farmers the proportion of land under coffee was between 1/4 - 1/2 (68.02%), followed by less than a quarter (25.6 %), >1/2 - 3/4 (4.07 %) and over 3/4 (2.3 %) respectively. This implied that coffee as a cash crop was grown on small scale and that coffee formed a small proportion of the entire farming activities but comparably bigger than the proportion allocated for maize farmers with large farms who grow both maize and coffee. Coffee being a cash crop was more valued than maize. Other crops and livestock took the other fraction. The majority (68.8%) who allocated 1/4 – 1/2 were small holder farmers who grew coffee basically as a cash crop. Those who allocated more than 3/4 were few (2.33%) and had large farms. This implied that coffee was a cash crop grown in Machakos sub County. Respondents cited coffee as the main cash crop grown on their farms. Even though the benefits from the cash-crop economy boosted by coffee were obvious in the study area, and indeed, the hilly areas of Machakos sub County, the widespread displacement of food-crops by coffee has led to food shortages in the area (Miruka, 2012). This gave rise to frequent famines and increased vulnerability of the local population. The area of land put under coffee was mainly determined by physical factors in the area (Miruka, 2012). Determining the proportion of land under coffee provided the basis on which coffee production was compared with rainfall variability over the study period

b) The coffee varieties planted in the sub County

The type of coffee seed varieties planted in the sub County was also covered in the survey. Table 4.26 shows the varieties of coffee grown in the area.

Table 4.26 Coffee seed varieties planted in the sub County.

	Variety	**Response**	**%**
1	Arabica	50	29.239
2	Robusta	109	63.742
3	Ruiru 11	12	7. 019
	Total	**171**	**100**

Source: Field data 2016

From Table 4.26, the main coffee variety grown in the District was Robusta (63.72 %) followed by Arabica (29.24 %) and Ruiru 11(7.0%) Coffee is mainly grown on higher altitudes. Ruiru 11 was a variety meant to mature fast and was mainly suited for the highlands. It could also be grown in arid areas like Machakos sub County to utilize the short rains. The main reason of the seed varieties planted was resistant to drought, high productivity, fast growing and resistant to diseases (Table 4.26) This implied that drought was the main problem facing coffee farmers and that productivity and disease resistance were minor reasons for adopting the seed variety. Arabica was mainly suited in higher areas like Mutuitini and Kilima Kimwe whereas Robusta was suited for lower areas. Ruiru 11 was best as it grew fast and more resistant to pests and diseases. Rainfall variability has been a major influence on the coffee seed varieties planted in the Machakos sub County.

c) The most serious problem experienced in coffee farming

This sub section sought to find out the most serious problem experienced in coffee farming in the District. Table 4.27 shows the most serious problem experienced in coffee farming.

Table 4.27 Problems experienced in coffee farming.

	Problem	**Response**	**Percentage**
1	Prolonged droughts	55	41.11
2	Diseases and pests	31	36.6
3	Unpredictable rainfall	02	1.78
4	Changing patterns of rainfall	14	21.52
	Total	**112**	**100**

Source: Field data 2016

The results shown in Table 4.27 indicate that; the most serious problem experienced in coffee farming was prolonged droughts (41.107%) followed by pests and diseases (36.607%). Unpredictable rainfall (1.78%) and changing patterns of rainfall (20.506%) were the least important. Specific problems encountered in coffee farming during drought included reduced crop yields, followed by reduced trading levels in coffee as a result of low yields, pests and diseases and crop failure. The remedies applied in the event of problems encountered in coffee farming during droughts included; planting fast growing varieties like Ruiru 11, planting drought resistant varieties, planting other crops, irrigation and engaging in other forms of economic activities other than coffee farming. The respondents particularly reported experiencing prolonged droughts and reduced rainfall. Similar observations were made by Majule (2009) who reported that farmers in East African marginal lands believed that rainfall had declined and time of onset had become unpredictable, negatively affecting crop production. Mary (2009) also reported shortening rainfall periods and increased frequency of droughts in East Africa.

Respondents also reported pests and diseases during the dry season as a problem in coffee farming. The main diseases attacking coffee were coffee berry, armillaria and leaf rust (Figure 4.9) and the main pests attacking coffee were berry borer, worm and leaf minor. Shao (1999) noted that pests and diseases are among the critical factors contributing to unsustainable agriculture production in most semi arid areas as they are aggravated by the adverse climatic conditions. In adequate rainfall enhances their effect on crops.

d) The correlation between annual rainfall totals and coffee yields in Machakos sub County

Table 4.28 shows coffee production in Machakos sub County from 1990 – 2014. Yields are recorded in terms of Tones per year. The yields per year were correlated with annual rainfall totals of the 25 year period from 1990 – 2014, using Pearson correlation moment to establish the relationship of rainfall variability on coffee yields

The relationship between annual rainfall totals and coffee production in Machakos sub County 1990 - 2014.

Table 4.28a Production of coffee in Machakos sub County between 1990 - 2014

YEAR	**NUMBER OF TONS**	**ANNUAL RAINFALL (MM) KATUMANI**	**ANNUAL RAINFALL (MM) MUTISYA**	ANNUAL RAINFALL (MM) AVERAGE
1990.	2,973	975.9	856.9	916.4
1991	2,653	563.9	654.8	609.35
1992	3,053	621.8	677.1	649.45
1993	2,773	776.6	739.2	757.9
1994	2,560	881.7	749.9	815.8
1995	2,840	595.5	702.1	648.8
1996	2,493	505.4	789.8	647.2
1997	2,226	816.3	125.9	471.1
1998	1,333	1106.9	1180.4	1143.65
1999	2,413	661.3	720.1	690.7
2000	2,840	85.6	491.1	488.35
2001	2,640	693	613	653
2002	2,640	780.8	816.8	798.8
2003	2,700	674.8	558.1	616.45
2004	1,916	660.4	486.1	573.25
2005	1,926	614.8	291.5	453.15
2006	2,608	1154.6	721.8	938.2
2007	2,626	764.7	388.8	576.75
2008	1,982	529.0	308.7	418.85
2009	2,010	488.0	331.1	409.5
2010	2,713	858.7	484.5	671.6
2011	1,973	677.7	353.1	515.4
2012	2,633	872.9	544.9	708.9
2013	2,840	810.5	338.3	574.4
2014	2,706	828.1	565.7	696.9
TOTAL	**62,070**	**18,399**	**1564.67**	**16,443.85**

Source, District Agricultural Officer Machakos March 2015 and Metorological Departm

Table 4.28b Production of coffee in yields and total annual rainfall.

Machakos sub County between 1990 - 2014

YEAR	NUMBER OF TONS	AVERAGE ANNUAL RAINFALL (MM
1990.	2,973	916.4
1991	2,653	609.35
1992	3,053	649.45
1993	2,773	757.9
1994	2,560	815.8
1995	2,840	648.8
1996	2,493	647.2
1997	2,226	471.1
1998	1,333	1143.65
1999	2,413	690.7
2000	2,840	488.35
2001	2,640	653
2002	2,640	798.8
2003	2,700	616.45
2004	1,916	573.25
2005	1,926	453.15
2006	2,608	938.2
2007	2,626	576.75
2008	1,982	418.85
2009	2,010	409.5
2010	2,713	671.6
2011	1,973	515.4
2012	2,633	708.9
2013	2,840	574.4
2014	2,706	696.9
TOTAL	**62,070**	**16,443.85**

Table 4.29 Correlations between Coffee yields and annual rainfall totals from 1990- 2014.

		Percentage Mean	Percentage Maize Production in Bags
Percentage Coffee Production in Tons	Pearson Correlation	1	0.695 *
	Sig (2 – tailed)		0.05
	N	25	25
Percentage Mean Rainfall	Pearson Correlation	0.695	1
	Sig (2 – tailed)	0.05	
	N	25	25

*** Correlation is significant at the 0.05 significant level (2-tailed).**
Source author 2016

The results of the correlation (Table 4.29) shows that the correlation between rainfall variability and coffee yields is statistically significant since the calculated correlation r = 0.695 at 0.05 significant level. Therefore, in this study, if r = 0.695, it is considered to be a strong relationship between two variables. In this case rainfall variability and coffee yields. The level of significance being at 0.05, the relationship between rainfall variability and coffee yields at r = 0.695 is statistically significant. This implies that as rainfall increases coffee yields increase and as rainfall decreases coffee yields equally decrease. The results of anomalies analysis shown in Table 4.7 showed season's yields were high in relation to rainfall above the long term mean. Therefore, in most cases, there were significant relationships between rainfall anomalies with coffee yield in each growing season.

These results imply that rainfall was very important in determining coffee yields in Machakos District. Similar results were reported by Alberto, (2013) who observed the significant relationship r = 0.586 between seasonal rainfall with cassava and sorghum yields in Kahangara Division in northern Tanzania.

4.6.3 The effects of Rainfall variability on Cattle farming.

a) Types of cattle breeds kept by households

Information on the type of cattle kept by the households in the sub County provides the basis of analyzing productivity of cattle in relationship to rainfall variability. Table 4.30 shows the type of breeds and number of farmers keeping cattle.

Table 4.30 Type of cattle breeds

	Breed	**No of Farmers**	**Percentage**
1	Indigenous	141	55.73 %
2	Exotic	39	15.41 %
3	Cross breeds	73	28.85 %
	Total	**253**	**100%**

Source: Field data 2016

The results indicated the following; 141(55.73%) households kept indigenous breeds and 39 (15.41%) households kept exotic breeds and 73 (28.85%) households kept cross breeds. The farmers kept mainly the indigenous breeds as compared to exotic breeds. This could be as a result of indigenous breeds being tolerant to harsh climatic conditions such as long spells of drought and also diseases and pests. Indigenous breeds included (Bos indicus) cattle with humps including Boran and Zebu. According to Miruka, et al., (2015) the Boran was generally vigorous and alert. Being accustomed to desert conditions, it covered vast distances in search of grazing and water and in some areas was only watered on alternate days or on the third day. This implied that Boran was well suited to the semi arid conditions of Machakos and that was why it was the main breed kept by the farmers in the sub County. The Boran breed had been developed into an ideal beef animal suitable for the arid range lands to be found in many parts of the world.

Plate 4 below shows the indigenous zebu breeds drinking water from River Athi. During drought the permanent water sources like River Athi become the main watering sources in addition to boreholes.

Plate 7 Indigenous zebu cattle.

The original strains of the breed came from Ethiopia and were adopted early in the 20[th] Century by commercial cattlemen in Laikipia, Machakos and the Rift Valley Districts of Kenya. Boran and its crosses score consistently better than other Zebu breeds for meat tenderness, carcass marbling and rib eye area. Miruka, et al., (2015) posits that, Zebu was well suited for marginal areas as it was adapted to poor pasture and dry conditions. It was very hardy and disease resistant. These qualities make it suitable for semi arid Machakos sub County.

A number of the exotic breeds were vulnerable to these harsh conditions. The farmers who kept exotic breeds particularly kept Guernsey, Jersey, Ayshire and Friesian. Majority of the farmers kept 1 - 5 exotic breeds whereas the minority of the farmers kept 5 – 10 exotic breeds (Table 430). This could be attributed to high maintenance costs as compared to indigenous breeds. For cross breeds, 51% of the farmers kept 1 - 3 breeds whereas the 18% of the farmers kept 4 – 10 breeds. This could also be attributed to high maintenance costs as compared to indigenous breeds but not as high as the exotic breeds.

Majority of the farmers keep 1-2 indigenous cattle. Some agro-ecological zones (AEZ's) are not suitable for pure breed high yielding milk cows, but can benefit from crossbreeding the local breeds of cattle with exotic breeds mainly for improved quality and increased productivity, plenty of fresh water available, and a reliable source of veterinary drugs were available. Without these conditions the survival rate of cross breeds is likely to be low

b) Type of cattle feeds used by farmers

This section found out the type of cattle feeds used by the farmers in the sub County. Table 4.31 shows the type of cattle feeds.

Table 4.31 shows the type of cattle feeds

	Type	**Frequency**	**Percentage**
1	Natural pastures	117	74.1
2	Farm grown fodder	37	23.4
3	Commercial feeds	04	2.5
	Total	**158**	**100**

Source: Field data 2016

The results revealed the following; Natural pastures accounted for the main cattle feed (74.1%) followed by farm grown fodder (23.4%) and commercial feeds (2.5%). This was attributed to the fact that; natural pastures were more readily available and affordable by many as compared to commercial feeds. Many farmers had small farms to accommodate farm grown fodder. The harsh climatic conditions did not favor farm grown fodder which basically depended on higher rainfall as compared to natural pastures. Smallholder dairying based on crossbred cows maintained almost entirely on well managed forages and pasture grasses and supplemented with home grown and conserved foodstuffs were feasible innovation worth extensive on-farm testing (Miruka, et al., 2015).

FAO (2014) posits that, except for the problems of feed resources and diseases that limited the level of production, the economic aspects of dairying in low potential areas was not too different from that of the high potential regions when expressed in terms of returns to labor and capital investment. The feeding of dairy cattle for improved productivity was best achieved by the integration of herbage from natural rangeland, sown pasture, planted fodders and crop residues. Without the combined use of these different feed resources, increased and sustained milk productivity cannot be achieved. This situation was supported by the results of Table 4.31.

c) Production of milk by indigenous breeds

The study sought to find out the amount of liters of milk produced by an indigenous breed of per day. Table 4.32 s.hows the number of liters of milk produced by indigenous breeds. 24% of the respondents produced 1-2 liters of milk per cow, 55% of the respondents produced 3 – 4 liters of milk per cow, 14% of the respondents produced 5-6 liters per cow per day and 7% of the respondents produced more than 6 liters per cow per day.

Table 4.32 Liters of milk Produced by indigenous breeds per day.

	Liters per Breed	1-2	3-4	5-6	≥ 6	TOTAL
1	Response	10	23	06	03	42
2	Percentage	24%	55%	14%	7%	100

Source: Field data 2016

The results revealed the following. 10 households produced between 1-2 liters of milk per day from one indigenous cow. 23 households produced 3-4 liters per cow per day, 6 households produced 5 – 6 litres. This could be attributed to adequate feeds and care of the cattle. 55% of the farmers who responded to this question produced 3 – 4 litres of milk per one indigenous breed in a day and 7% produced more than six litres of milk per one indigenous breed in a day. The few farmers with a bigger size of land could afford adequate planted fodder to supplement natural pastures improving their productivity. Another possible reason for differences in production was care and maintenance. However comparing production over time brought out production trends to be correlated with rainfall. This brought out the effect of rainfall variability on milk production.

d) Period recorded the highest yield for exotic breeds

The study revealed the period the highest yield was recorded for exotic breeds in the sub County. Table 4.33 shows the highest yield for exotic breeds**.** The results revealed the following;

Table 4.33 The highest yield for exotic breeds

	Period	**Frequency**	**Percentage**	**Mean Rainfall for the period in mm**
1	Early to mid 1990s	27	10.62	749.78
2	Mid to late 1990s	106	41.73	820.29
3	Early to mid 2000s	27	10.62	626.67
4	Mid to late 2000s	72	28.35	693.61
5	Early to mid 2010	22	8.68	633.44
	Total	**254**	**100**	**2890.35**

Source: Field data 2016.

From the Table, the highest yield for exotic breed was recorded mid to late 1990s (41.73%) and the mean rainfall for the period was 820.29 mm, followed by mid to late 2000s (28.35%) with a mean rainfall total of 693 mm, early to mid 1990s (10.62 %) with a total mean of 749.78 mm ,early to mid 2000s (10.62%) with a mean total of (626.67 mm) and early to mid 2010s (8.68 %) with a total mean of 633.44 mm. Mid to late 1990s happened to be the period which experienced the highest rainfall with a mean of 820.29 mm for the period as seen on Table 4.33. It was followed by early to mid 1990s (749.78 mm), mid to late 2000 (693.61mm), early to mid 2010 (633.44 mm) and early to mid 2000s (626.67mm). This implies that there was adequate natural pastures and good production of farm grown fodder in mid to late 1990s which recorded the highest yields. Generally the entire period had rainfall above a mean of 600 mm and recorded the highest yields. It should be noted that the milk yields fluctuated according to the rainfall a mounts. The higher the amount of rainfall the higher the yields (Table 4.33). Early to mid 2000 which was associated with low rainfall and persistent droughts recorded the lowest yield. The pattern of total rainfall shows a clear relationship with the results of Table 4.33. Wesonga (2010) posits that Cattle were reared primarily as long-term investments while goats, sheep and poultry were often sold to meet immediate family financial needs. The daily mean milk production for cattle was estimated at 1.98 liters (Wesonga,2010) This is almost similar to the findings of the current study in milk production. The average production in the sub County 2 – 3 liters per cow per day (Table 4.32)

e) Reasons for the high yield of milk in the period.

The study sought to find out reasons for the high yield in the period as shown above.

Table 4.34 Reasons for the high yield production of milk for exotic breeds.

	Reasons	**Frequency**	**Percentage**
1	Adequate pastures/ Natural pastures	100	68.9%
2	Adequate rainfall/ grown fodder	36	24.8%
3	Adequate commercial feeds	09	6.3%
	Total	**145**	**100**

Table 4.34 shows reasons for the high yields. The main reason was adequate rainfall and natural pastures (68.9%) followed by adequate rainfall/grown fodder (24.8%). Adequate commercial feeds (6.3%) was the minor reason for the high yields.

The high rainfall experienced in this period supports the argument that there was adequate natural pastures and good production of farm grown fodder which boosted the production of milk. 6.3% of farmers gave adequate commercial feeds as reasons for high yields. This indicated that not many farmers could afford commercial feeds and that majority of farmers depended on natural pastures. Integration of herbage from natural rangeland, sown pasture, planted fodders and crop residues improves the productivity of dairy cattle for mainly exotic breeds as compared to indigenous breeds which are used to natural pastures**.**

Without the combined use of these different feed resources and veterinary care particularly for exotic breeds, yields could be lower. Cross breeds were raised to achieve more tolerant breeds to the harsh climate conditions in the sub County (Miruka, et al., 2015). Indigenous breeds can sustain themselves for longer periods against the harsh climate conditions in the sub County and are less expensive to maintain. Increased and sustainable milk productivity can be achieved through improving indigenous breeds by cross breeding. Periods when low yields were recorded corresponded with periods of low rainfall. This explains that low yields were experienced in the periods for low rainfall. During this period, pastures became inadequate and fodder failed to grow or those that survived did not attain maturity.

The harsh climatic conditions do not favor farm grown fodder which basically depends on higher rainfall as compared to natural pastures. According to Miruka, et al, (2015), smallholder dairying based on crossbred cows maintained almost entirely on well managed forages and pasture grasses and supplemented with home grown and conserved foodstuffs produce more than indigenous breeds which purely depended on natural pastures. The current study shows clearly that milk production is closely related to rainfall amounts (Table 4.33).

f) The period recorded the highest number of cattle deaths in the district.

Table 4.35 shows the period the highest number of cattle dying in the sub county were recorded.

Table 4.35 Number of cattle deaths.

	Period	Frequency	%	Mean Total rainfall in mm
1	Early to mid 1990s	48	19.75	749.78 mm
2	Mid to late 1990s	50	20.58	820.29 mm
3	Early to mid 2000s	80	32.92	626.67 mm
4	Mid to late 2000s	65	26.75	693.61 mm
	Total	**243**	**100**	

Source: Field data 2016

The highest number of cattle deaths was recorded between early to mid 2000s (32.92%) followed by mid to late 2000s (26.75%), mid to late 1990s (20.58 %) and early to mid 1990s (19.74%). Reasons for cattle death were mainly droughts. Others were floods and diseases. FAO (2014) carried out a study of cattle mortality in Machakos sub County between 1975 – 1980. The results showed that drought was the main cause of mortality in cattle. Other reasons were diseases of the alimentary tract; skin problems; nutritional problems, trypanosomiasis and diseases of the respiratory systems. Data on cow mortality over 6 years, revealed that the overall mortality rate was 3% per year (FAO, 2014). Both the current study and the study by FAO (2014) found that prolonged droughts were the main reason responsible for cattle deaths in Machakos sub County and generally the arid and semi arid regions of southeastern Kenya. In the current study, the period that recorded the highest number of deaths, early to mid 2000s (32.92%) received the lowest mean of rainfall (626.67 mm). The lowest number of deaths (20.58%) were recorded in the period mid to late 1990s and the mean total rainfall received in the period was 820.29 mm. The pattern clearly reveals that the number of cattle deaths increased with increased rainfall and decreased with deceasing rainfall. This implied that there was a close relationship between the number of cattle deaths and rainfall variability.

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary, key conclusions based on the study findings, recommendations and areas of further research.

5.2 Summary of the major findings

This study analyzed historical monthly, seasonal and annual rainfall variability of the semi arid Machakos sub County over 25 year period (1990 – 2014). The analysis identified various patterns of rainfall, in terms of distribution, frequency, trends and measures of rainfall variability using various measurement techniques such drought intensity (DI), relative variability (RV), coefficient of variability(CV) Rainfall anomalies (RA) and precipitation concentration index (PCI) on monthly seasonal and annual scales in Machakos sub County between 1990 - 2014. The statistical analysis and perceptions of farmers indicated that rainfall in Machakos sub County varies in each growing season within the month and annual totals. The study established that monthly rainfall distribution in Machakos sub County is extremely variable, erratic and unreliable making it difficult to plan farming activities. Variability is shown through marked differences in rainfall amounts between Central Division (Katumani station) and Kalama Division (Mutisya staion). A PCI of 10 for Kari and 11 for Mutisya, indicated erratic, unpredictable and highly variable rainfall. A high coefficient of variability Kari 0.24 (24%) and Mutisya 0.39 (39%) indicates erratic, unreliable and a highly variable rainfall. Kalama Division is more moisture deficient than Central Division. From Table 4.7 and 4.8, the onset of the long rains either came earlier than expected eg 1993, 1998, 2001, 2008 or failed completely eg 1991, 1997 and 2011.

Human activities that influence rainfall variability including overstocking of livestock, uncontrolled burning of vegetation, cutting down of trees and over cropping were evident. Land preperation activities such as cutting down of trees (deforestation), bush burning and slash and burn, contributed heavily to removal of land vegetative cover, interfering with hydrological cycle and eventually contributing to reduced rainfall and spread of desert conditions, adversely affecting farming activities. Uncontrolled burning of vegetation and increased use of wood fuel not only destroys young tree seedlings and accelerating soil erosion but also leads to increased carbon dioxide in the atmosphere leading to global warming through green house effect. These increased temperatures contribute to climate change leading to decreased yields and to extremes, crop failure. Overgrazing was evidenced by overstocking of livestock particularly grazers and browsers which contribute heavily to removal of the land's vegetative cover, accelerating soil erosion, reduced precipitation, increased variability and spread of desert conditions affecting farming activities.

Rainfall variability in seasonal, monthly and annual patterns affect maize and coffee farming particularly through delays in land preparation and planting, plant growth causing stunted growth, sometimes leading to crop failure and lowered crop yields. It was clearly observed that maize and coffee yields fluctuated in relation to rainfall variations and distribution. This was clearly shown through the analysis of person's correlation moment (Table 4.23 and 4.28). These results clearly show that rainfall variability has an effect on maize coffee and cattle farming in Machakos sub County. Frequent droughts are responsible for high livestock deaths due to lack of water and pasture, which culminates into low livestock yields in milk and meat, reduced livestock population in the case of prolonged droughts, subsequent and widespread poverty among the inhabitants of the sub County. Frequent and prolonged droughts cause frequent crop failure leading to food shortages, hunger and prevalent malnutrition.

5.3 Conclusion

The study assessed and analyzed the characteristics of rainfall within the study area. Temporal variability of rainfall is high at monthly, seasonal and annual scales. Total rainfall amounts were increasing and deceasing respectively. The high erratic and unreliable characteristics were established by the high PCI and CV recorded. Variable declining trends of rainfall were also observed. The two Divisions, Kalama and Central have high variability of rainfall. These variability affects the production of maize, coffee and cattle in Machakos sub County. The variability was analyzed in terms of distribution, anomalies, trends, coefficient of variability and precipitation concentration index.

Human activities influencing rainfall variability in the sub County include cutting down of trees, over stocking, over cropping, slash and bush burn which enhanced rainfall variability and spread of desert conditions. Overgrazing, deforestation, over cropping are the human factors that influence rainfall variability in the sub County. These factors caused reduced rainfall, prolonged droughts and increased aridity in the study area.

Rainfall variability has had adverse effects on maize, coffee and cattle farming in the sub County, leading to reduction in maize, coffee and cattle yields and to extremes it extends to crop failure and cattle death. This leads to food shortages and cases of hunger and starvation.

The residents of Machakos sub County need to have the right perception of rainfall variability if any meaningful solutions have to be sought. Otherwise if the problem continues it would put subsistence farming into a risk of constant food shortages and food insecurity.

5.4 Recommendations

A number of strategies need be put in place to assist subsistence farmers in coping with rainfall variability. These strategies come in the form of recommendations by this study as follows;

The meteorological department should disseminate information on rainfall forecasts to farmers so as to create awareness of the effects of rainfall variability which will help on farm decision making. Understanding of rainfall variability and patterns can assist farmers in planning and managing agricultural activities. The inhabitants of Machakos sub County should be sensitized to understand that droughts are a common occurrence and therefore pre-drought planning is important to cope up or overcome the problem. Investment in water supply where rain water is harvested and stored in reservoir tanks or dams for small scale irrigation projects to supplement rainfall. Elnino rains have caused flooding in most parts of the known dry district. If this water could be harnessed and stored in reservoirs, it would really benefit irrigation systems to supplement rainfall and enable longer growing seasons for subsistence crop farming.

Control and management of human activities that influence rainfall variability is very key. Creating awareness on the dangers of deforestation, overgrazing, over cropping and bush burning. Measures such as using alternative sources of fuel, maintaining the right number of animals on farms, and applying best practices in crop management. Modification of the hazard itself is a scientific approach which can be achieved by introducing a forestation and re a forestation programs where massive planting of trees, particularly drought resistant trees is mounted. Such programs will improve the overall water balance of the region by increasing atmospheric humidity through enhanced evapo – transpiration.

It is recommended that farmers to be encouraged to plant short term drought resisting maize and coffee varieties at the onset of the rains in order to rehabilitate semi arid Machakos sub Counties which is adversely affected by rainfall variability. Intercropping of maize and coffee at early stages of coffee growth will maximize on returns in the event of the short rains. More so intercropping maize with coffee aims to intensively utilizing the small farms and to maximize on the available little rains

5.5 Areas of further research

Further research should be carried out to examine the moderating effects of intervening factors such as diseases, pests and farm inputs, on the effect of rainfall variability on coffee, maize and cattle production in Machakos sub County

Another area of further research is to analyze and establish the coping strategies of rainfall variability in Machakos sub County.

Thirdly, further research can be conducted on the impact of climate change on socio economic activities in Machakos sub County.

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APPENDIX 1

HOUSEHOLD QUESTIONNAIRE FOR THE STUDY ON THE EFFECTS OF RAINFALL VARIABILITY ON AGRICULTURAL ACTIVITIES IN MACHAKOS SUB COUNTY

The purpose of the study for which this questionnaire is designed, is to examine the effect of rainfall variability on farming activities in Machakos sub County. All your responses and information will be treated with utmost confidentiality and only be used for analytical purposes of the study. Please give your responses by putting a tick (√) or number (1, 2 or 3) in the appropriate space that correspond with your response.

Background information.

1.0 Bio Data.

101. Division name [ ] 1. Central 2. Kalama
102. Location name [ ] 1.Kalama 2.Katheka kai 3.Kilima kimwe 4. Kimutia 5. Kola 6. Lumbwa 7.Masaku 8.Muwa hills 9. Mumbuni 10. Muvuti 11. Mutitini 12. Ngelani
103. Gender of the respondent [ ] 1. Male 2. Female
104. Age of the respondent [ ] 1. Below 18 2. 18 – 35 3. 36-50 4. above 50
105. Relationship to the household head. [ ] 1. Head 2. Spouse 3. Son. 4. Daughter 5. Others; Specify……………………………………………………………………
106. Educational level of the respondent [ ] 1. Never 2. Primary 3. Secondary 4. College [ ] 5. University [ ]
107. Main source of livelihood to the household [ ] 1. Crop farming 2. Livestock Farming [ ] 3. Formal employment [ ] 4. Trade [ ] 5. Remittance [ ] 6. Casual worker [ ] 7.charcoal burning [ ] 8. Brick making [ ] 9. Sand mining [ ] 10. Others. Specify…………………………………
109. What is the main land use? 1. Cash Crop farming [ ] 2. Subsistence farming [ ]

3. Livestock keeping [ ] 4. Forestry [ ]

2. 0 Human activities that influence rainfall variability

Overgrazing

The following questions intended to establish any determinants of overgrazing in the study area.

201. What is the size of your land? 1. Below 1 acre – 3 acres [ ] 2. 4 – 6 acres [ ] 3. 7 - 9 acres [ ] 4. 10 and above acres

Q. 202 Indicate type of livestock kept.	Q 203 Indicate Number of livestock kept.	Q 204 Indicate one main reason for keeping livestock, 1. Meat 2. Sale 3. Milk 4.Prestig 5.Others specify
a. Cattle		
b. Sheep		
c. Goats		
d. Donkeys		
e. Pigs		

205. What portion of land left for grazing? 1. Less than 1/4 [ ] 2. Between 1/4 and 1/2 [ ] 3. Between > ½ and 3/4 [ ] More than 3/4 [ ]

206. Do you practice on farm after harvest grazing? Yes [ ] No [ ]

207. If yes, how long does the on farm after harvest grazing take? [ ] 1) 1 – 2 weeks 2) 3 – 4 weeks 3) 4 – 6 weeks 4) 6 – 8 weeks

Deforestation and bush burning

The following questions indented to establish any determinants of deforestation in the study area.

208. Which of the following land preparation activities do you practice?

a) Cutting of trees [ ] b) Bush burning [ ] c) Slashing d) Slash and burn

e) Others specify……………………………………………………..

209. Do you plant any trees on your farm? 1. Yes [ ] 2. No [ ]

Q.210.Indicate type of trees planted	Q 211. Indicate the main reasons for planting the trees. 1. Firewood 2.Charcoal 3.Timber 4. Sale 5. Shade for crops 6. Construction	Q 212 Indicate the main use of the trees. 1. Firewood 2.Charcoal 3.Timber 4. Sale 5. Shade for crops 6. Construction
a) Eucalyptus		

b) Cyprus		
c) Pine		
d) Grevillea robusta		
e) Jacaranda		
f) Others specify		

213. Which of the following types of fuel do you mainly use? 1. Firewood [ ]

2. Charcoal [ ] 3. Biomass [] 4. Gas [ ] 5. Electricity [ ] 6) Saw dust.[ ]

214. What is the source of the firewood and charcoal? a) On the farm [ ] b) within the district [ ] c) Outside the district [ ]

215**.** What is the source of the timber used in the making **of** furniture in the District?

a) On the farm [ ] b) within the district [ ] c) Outside the district [ ]

3.0 Crop farming

The following questions intented to establish any determinants of over cropping in the area.

301. What proportion of land is under crops 1. Less than 1/4 [ ] 2. Between 1/4 and 1/2 [ ]

3. Between > ½ and 3/4 [ ] More than 3/4 [ ]

302. What type of cash crops do you grow? a) Maize [ ] b) Coffee [ ] c) Fruits [ ]

The influence of rainfall variability on Maize, coffee and cattle farming.

Maize farming

303. What proportion of your land is under Maize? 1. Less than 1/4 [ ] 2. Between 1/4 and 1/2 [ ] 3. Between > ½ and 3/4 [ ] More than 3/4 [ ]

304. Which type of Maize seeds do you plant? a) Hybrid seeds [ ] b). Local seeds [ ] c) Both [ ]

305. Give the species of the hybrid seeds you plant a) Katumani [ ] b) Others.

Specify…………………………………………………………………

306. What advantages have the Hybrid seeds over local seeds? a) More productive [ ]

b) Resistant to drought [ ] c) Fast growing [ ] d) Resistant to diseases [ ]

307. How many seasons do you plant maize in one year?

1. One season [ ] 2. Two seasons [ ]

308.Which type of fertilizers do you mainly apply? a) Farmyard [ ] b) Chemical fertilizer [ ]

309. Which periods did you record the highest yields for maize? a) Early to mid 1990s [ ] b) Mid to late 1990s [ ] c) Early to mid 2000s [ ] d) Mid to late 2000s

Give possible reasons a) adequate rainfall [ ] b) adequate fertilizer c) increased acreage [ ]

310. Which periods did you record the lowest yields of maize? a) Early to mid 1990s [ ]

b) Mid to late 1990s [ ] c) Early to mid 2000s [ ] d) Mid to late 2000s

Give possible reasons a) Inadequate rainfall [ ] b) Inadequate fertilizer c) reduced acreage [ ]

311. Which of the following is the most serious problem you experience in maize farming?

1. Prolonged droughts [ ] 2. Diseases and pests [ ] 3. Un predictable rainfall [ ]
4. Changing patterns of rainfall [ ]

312. What specific problems do you encounter in maize farming in the event of prolonged droughts? a) Reduced crop yields [ ] b) Reduced trading levels [ ]

c) Crop failure [ ] d) Pests and diseases [ ]

Coffee farming.

313. What proportion of your land is under Coffee? 1. Less than 1/4 [ ] 2. Between 1/4 and 1/2 [ ] 3. Between >½ and 3/4 [ ] More than 3/4 [ ]

314. Which Coffee seed variety do you plant? 1. Arabica [ ] 2. Robusta [ ] 3. Ruiru 11

315. Which type of fertilizer do you apply on your coffee farm? a) Farmyard [ ] b) Chemical fertilizer [ ]

316. Which periods did you record the highest yields for coffee? a) Early to mid 1990s [ ]

b) Mid to late 1990s [ ] c) Early to mid 2000s [ ] c) Mid to late 2000s

Give possible reasons a) adequate rainfall [ ] b) adequate fertilizer c) increased acreage [ ]

317. Which periods did you record the lowest yields for coffee? a) Early to mid 1990s [ ]

b) Mid to late 1990s [ ] c) Early to mid 2000s [ ] d) Mid to late 2000s

Give possible reasons a) Inadequate rainfall [ ] b) Inadequate fertilizer c) reduced acreage [ ]

318. Which of the following is the most serious problem you experience in coffee farming?

(a) Prolonged drought [ ] (b) Diseases and pests [ ] (c) Un predictable rainfall [ ]

(d) Price fluctuations [ ] (e) Changing rainfall patterns

4.0. Livestock farming

Cattle keeping

401. What types of Cattle do you keep on your farm? a) Indigenous [ ] b) Exotic [ ]

402. How many of the given types of Cattle do you keep on your farm?

a) Traditional…………………b) Exotic………………c) Cross breeds…………

403. Which particular exotic breeds do you keep? a) Friesian [ ] ……

(State the number in each case) b) Guernsey [ ] c) Ayrshire [ ] d) Jersey [ ]……………………….

404. Which type of Cattle feeds do you mainly use (a) Natural pastures [ ]

(b) Farm grown fodder [ ] (c) Commercial feeds [ ]

405. How many indigenous breeds of cattle do you keep? 1) 1 – 2 [ ] 2) 3 – 4 [ ]

3) 5 – 6 [ ] 4) More than 6.[ ]

406. How many are kept for milk? 1) 1 – 2 [ ] 2) 3 – 4 [ ] 3) 5 – 6 [ ] 4) More than 6 [ ]

407. How many liters of milk per day are produced by each of the indigenous cattle on your farm? 1– 2 [ ] 2) 3 – 4 [ ] 3) 5 – 6 [ ] 4) More than 6[ ]

408. Which periods did you record the highest yields of milk from exotic breeds?

a) Early to mid 1990s [ ] b) Mid to late 1990s [ ] c) Early to mid 2000s [ ] d)

Mid to late 2000s[ ]

Give reasons a) adequate rainfall/natural pasture [ ] b) adequate fodder [ ] c) adequate commercial feeds [ ]

409. Which periods did you record the lowest yields of milk from exotic breeds?

a) Early to mid 1990s [ ] b) Mid to late 1990s [ ] c) Early to mid 2000s [ ]

d) Mid to late 2000s [ ]

Give reasons a) In adequate rainfall/natural pastures [ ] b) Inadequate fodder [ ]

c) Inadequate commercial feeds [ ]

410. Rank the following problems in order of magnitude as realized in Cattle keeping

i) Diseases and pests [ ] ii) Marketing [ ] iii) Transportation [ ] [iv] Lack of adequate water and pasture [ ] v) Death of livestock

417. When did you experience high death rates of your cattle? a) Early to mid 1990s [ ] b) Mid to late 1990s [ ] c) Early to mid 2000s [ ] d) Mid to late 2000s [ ]

Give possible reasons a) Prolonged droughts [ ] b) Diseases [ ] c) Floods [ ]

APPENDIX Il.

INTERVIEW SCHEDULE FOR KEY INFORMANTS.

1. SUB COUNTY AGRICULTURAL OFFICER.

This interview schedule is prepared for the purpose of collecting relevant information for an academic research proposal entitled, THE EFFECT OF RAINFALL VARIABILITY ON FARMING ACTIVTIES IN MACHAKOS DISTRICT, KENYA. Please provide the appropriate answers for the questions. Information given here is strictly confidential and for research purposes only.

1. Name of the officer…………………………………………………………………

2. Title of the officer……………………………………………………………………

3. What type of crops are grown in the sub County?
   Cash crops………………………………………………………………………
   Subsistence Crops………………………………………………………………

Maize farming.

4. What types of maize varieties are grown in the County? ……………………………

5. Please provide production records of maize under the following;
   (a) 1990s…………………………………………………………………………
   (b) 2000s…………………………………………………………………………
   (c) 2010s…………………………………………………………………………

6. What major problems have faced maize farming in the sub County since 1990?
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………

7. What attempts have been made to counter these problems?
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

Coffee farming

8. What varieties of coffee are grown in the sub County?..
……………………………………………………………………………………………..
……………………………………………………………………………………………..

9.What reasons have made the variety to be mainly grown? ……………………
………………………………………………………………………………………………
……………………………………………………………………………………………

10.Please provide production records for coffee under the following;

(a) 1990s……………………………………………………………………………………

(b) 2000s ………………………………………………………………………………
(c) 2010s………………………………………………………………………………

11.What problems face coffee growing in the sub County?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………………………………
12.What attempts have been made to sub counter these problems?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………

Cattle farming.

13. What types of cattle breeds are kept in the sub County?
(a) Indigenous……………………………………………………………………………
(b) Exotic ………………………………………………………………………………

14. What factors influence the distribution of cattle in the sub County? …………………………
……………………………………………………………………………………………

15. Please provide production records for Cattle under the following;
a) 1990s………………………………………………………………………………
b) 2000s ………………………………………………………………………………
c) 2010s………………………………………………………………………………

16. What problems face Cattle farming in the sub County? ………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………

17. What attempts have been made to counter these problems?…………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
18. Can you give your general view/observation on the effect of rainfall variability on agricultural activities in Machakos sub County…………………………………………
……………………………………………………………………………………
………………………………………………………………………………………

19. What would you recommend to help counter the effects of rainfall variability in Machakos sub County?
…………………………………………………………………………………….
……………………………………………………………………………………..

…………………………………………………………………………………
…………………………………………………………………………………

20. Apart from rainfall variability what other problems affect farming activities in the sub county?....................
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………

2. SUB COUNTY METEOROLOGICAL OFFICER.

This interview schedule is prepared for the purpose of collecting relevant information for an academic research proposal entitled, THE EFFECT OF RAINFALL VARIABILITY ON FARMING ACTIVITIES IN MACHAKOS SUB COUNTY, KENYA. Please provide the appropriate answers for the questions. Information given here is strictly confidential and for research purposes only.

1. Name of the officer…………………………………………………………………

2. Title of the officer……………………………………………………………

3. Please provide rainfall data of the sub County between 1990 to 2012…………………

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

4. Briefly highlight the rainfall distribution patterns in the sub County……………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

5. How are the rainfall patterns related to temperature patterns in the sub County

………………………………………………………………………………………………
………………………………………………………………………………………………
……………………………………………………………………………

6. How does the distribution impact on crop farming and livestock farming in the sub County………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………………………………………………

3. SUB COUNTY FOREST OFFICER.

This interview schedule is prepared for the purpose of collecting relevant information for an academic research proposal entitled, THE EFFECT OF RAINFALL VARIABILITY ON FARMING ACTIVITIES IN MACHAKOS SUB COUNTY, KENYA. Please provide the appropriate answers for the questions. Information given here is strictly confidential and for research purposes only.

1. Name of the officer……………………………………………………………………

2. Title of the officer………………………………………………………………………………

3. What type of forests are found in Machakos sub County a) Natural [ ] b) Planted [ ] c) Both [ ]

4. Which of the forests are gazetted?...
…………………………………………………………………………………………………

5.Which of the forests are Non – gazetted?...

6. What are the products of these forests ?...

7. Do we have any reported cases of illegal logging?...

8. If yes, how do you rate it? a) Not much [ ] b) Much [ ] c) Very much [ ]

9. Which years have experienced acute effect of deforestation?...
……………………………………………………………………………………………

10.What consequences has deforestation had on the rainfall amounts in your opinion?
……………………………………………………………………………………………………
………………………………………………………………………………………………

11.What attempts have been made to counter the effects of deforestation in the sub County?
……………………………………………………………………………………………………
………………………………………………………………………………………

12. Has a forestation programs counter balanced the effects of deforestation?....................
Explain……………………………………………………………………………..

APPENDIX 111. TYPES OF CATTLE BREEDS KEPT IN MACHAKOS S. COUNTY

Plate 8. The Arshire breed

Plate 9. The Boran breed

Plate 10. The Jersey breed

Plate 11. The Fresian Breed.

APPENDIX IV HARVESTING OF TIMBER IN MUTITUNI FOREST IN MACHAKOS SUB COUNTY.

Plate 12. Stumps of Trees Cut down Regenerating. **Plate 13. Poles on Sale**

Plate 14. Harvested Timber on Display for Sale

Plate 15. Harvested Timber and building poles ready for transport.