EFFECTS OF RAINFALL VARIABILITY ON SUGARCANE PRODUCTION IN MUMIAS SUB COUNTY, KAKAMEGA COUNTY, KENYA

BY

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DECLARATION

Declaration by student

I, the undersigned, hereby declare that this thesis is my original work and that it has never been presented for award of degree in any University or institution of higher learning.

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DEDICATION

To my lovely wife Joyce, our sons Hillary, Frankline, Sava and daughters Karen and Tacy; and in memory of my late parents Paul and Rhoda .

ABSTRACT

Temporal rainfall variability phenomenon is the degree to which rainfall amounts change at a given area through time either from month to month, season to season or year to year in relation to long-term average. The associated extreme events such as increase in rainfall amounts or drought adversely affect agricultural production resulting in low yields. Rainfall in Mumias Sub County varies from season to season or year to years such that, between 1982 and 2012 Mumias experienced an increase in annual rainfall amounts. This variability of rainfall had an effect on sugar cane production. Thus, there was need to examine the effects of variation in total seasonal and inter annual rainfall amounts on sugar production in Mumias Sub County, Kakamega County Kenya. Therefore, the purpose of this study was to examine the effects of rainfall variability on sugar cane production. The specific objectives were to: determine historical trends in seasonal, inter annual rainfall amounts and sugarcane yields between 1982 and 2012; establish the effects of variations in seasonal and annual rainfall amounts on sugarcane biomass yields; and assess effects of variations in inter annual rainfall amounts on sugar quantity. Descriptive Cross-sectional research design was adopted. Secondary data were obtained using document analysis to extract information from Mumias Sugar company annual reports on sugarcane biomass yields and sugar quantity yields. Data on total seasonal and inter annual rainfall amounts was obtained from records at Mumias synoptic weather station. Quantitative data on seasonal and inter annual rainfall variability, sugarcane biomass yield, sugar quantity were analyzed using trend analysis, simple linear regression and coefficient of variation. A line graph result show the variability trend at seasonal scale was (positive slope=2.51 for “long rains” and slope=3.85 for “short rains” implying increasing trends). The variability at inter annual rainfall scale was a positive slope=7.98 and a mean coefficient of variation of 0.2(20%) was obtained which suggests low inter- annual rainfall variability. The variations in seasonal and inter annual rainfall were found to be 83.17 % and 67.7% respectively within the study period implying a high level of temporal rainfall variability. The linear regression results show that 55% (r^2=0.55) of variation of sugar cane biomass yields can be explained by total seasonal rainfall whereas61% (r^2=0.61) of variation of sugar quantity can be explained for by total annual rainfall amounts. In addition 55 % (r^2=0.55) of variation in sugar quantity (sucrose content) can be explained by inter annual rainfall variability. It can be concluded that total seasonal rainfall and total annual rainfall amounts affect variation of sugar cane biomass yields and sugar quantity. The study recommends that, due to the high level of temporal rainfall variability that affects sugarcane yields, the departments of agriculture and meteorology to provide farmers with information on rainfall trends so that sugarcane farmers can plan their agronomic activities in accordance with variations in rainfall amounts.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASALs	Arid and Semi-arid Lands
COMESA	Common Market for Eastern and Southern Africa
CV	Coefficient of Variation
FAO	Food and Agriculture Organization
GCM	Global Climate Model
IPCC	Intergovernmental Panel on Climate Change
KESREF	Kenya Sugar Research Foundation
MSC	Mumias Sugar Company
NAO	North Atlantic Oscillation
NASA	National Aeronautical Space and Administration
QBO	Quasi-Biennial Oscillations
SOI	Southern Oscillation Index
TCH	Sugarcane tonnes harvested per hectare
UNEP	United Nations Environmental Programme

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WORKING DEFINITIONS OF TERMS

Sugarcane production: It is the process of growing sugarcane to harvest it as raw sugarcane biomass yield. The raw sugarcane biomass yield is processed in order to get various byproducts such as sugar of which (sugar quantity) sucrose is the main component. Other byproducts include ethanol, molasses and bagasse. In this study sugarcane production was measured in terms of the sugarcane biomass yield as tons per hectare (TCH). The sugar quantity was measured as sucrose concentration percentage per ton (POL).

Sugarcane biomass yield: This is the produce of raw sugarcane harvested from mature sugarcane. It is measured in terms of average tons of raw sugarcane harvested per unit of land cultivated. In this study the sugarcane biomass yield was measured in terms of tons per hectare (TCH).

Sugar quantity: This is the amount of sugar content recovered from processed raw sugarcane and it gives rise to the sweetness tested in sugar. It is the sucrose content per ton of harvested sugarcane biomass yield after milling. This is measured by finding the percentage concentration of sucrose in a ton of sugarcane crushed, which is referred to as the POL. It is percentage sucrose concentration per ton.

Rainfall variability: It is the temporal dispersion in rainfall amounts received in a particular area or region over a period of time such as from month to month, season to season, year to year or decade to decade. It is measured by calculating the ratio of average amount of rainfall received to the standard deviation within the specified time to get coefficient of variation (CV). In this study seasonal rainfall variability and inter annual rainfall variability were calculated.

Coefficient of Variation: It is a measure of relative change to the mean. It obtained by dividing the standard deviation by the mean, multiplied by 100.

Inter annual rainfall variability: The change in rainfall amounts occurring over years. In this study it refers to the dispersion of total annual rainfall amounts over years of the study period. It is measured by first, calculating the average of the total annual rainfall amounts received over the years and secondly, finding the standard deviation then, finally calculating the ratio of the long-term average to the standard deviation to get the coefficient of variation as a measure of inter annual variability

Seasonal rainfall variability: The change in total amount of rainfall received within the main rainfall period in the study area. In this study it is the change in total amount of rainfall received during the long rains (MAM) periods and short rains periods (OND). It is measured by getting the total amount of rainfall received within each rainfall season then getting its long-term mean and dividing it by its standard deviation to get a coefficient of variation.

Trend: It is a general direction in which something is developing from one point to the other. In this study trend is the increment or decrease of the dependent variable (rainfall amounts and sugarcane yields) against independent variable time (years). It is shown by the slope of line graphs. It is measured by subtracting the value of the earlier from the value of the later year and then multiplying the difference over the base year by 100. In this study the base year was taken to be1982 while the later year 2012.

Variation: It is a change in amount typically within certain limits. It defines the amount of dispersion in a dataset. It is measured by measures of central tendency (range, mean, variance and standard deviation).

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Rainfall variability phenomenon in terms of temporal aspect is the degree to which rainfall amounts change at a given area through time either from month to month, season to season or year to year in relation to long-term average (Rodrigo *et al.*, 1999). Studies by Ribot *et al.*, (1996) associate rainfall variability with floods, dry spells or drought. Other related studies, Philips *et al.*, (1999) identify rainfall variability as having a major effect on global agricultural crops production. Reports from The World Meteorological Organization (2000) done in Pambas Province, Argentina, showed a variation in annual rainfall amounts between the years 1921 and 2000, with occurrences of extreme drought cycle and the peak of rainfall being in 1940 and 1960 and were linked to a decline in agricultural production. Studies by National Aeronautical Space and Administration (NASA, (2007)), space flight center indicated that there was a variation in total annual rainfall amounts that increased by 5% in the tropics and affected agricultural crop production. The historical change in rainfall amounts at seasonal and annual scales is a very important variable in examining rainfall variability (Cruz *et al.*, 2007) and inter-annual amounts on agricultural crop production in tropical regions where crops such as sugarcane are grown. In a study done in Mexico, Pablo and Antonio (2015) reported that rainfall variations between 2002 and 2007 were harmful to crop production, in that variations of 10% higher rainfall led to a lower output of 0.8% on average in maize crop.

These studies from various parts of the world point out that increase in total annual rainfall amounts affects agricultural production. A few of the aforementioned studies analyzed the trends on rainfall amounts, however there exists a knowledge gap on how variations in rainfall amounts affect sugarcane production in humid and wet zones such as Mumias sub county.

Studies in Fiji by Gawander, (2007), reported a record sugar production of (516,529 tonnes) in 1994 due to favorable rainfall amounts, but sugar productions in 1997, 1998, and 2003 were 47%, 50% and 43% of the average sugarcane biomass yields respectively, lower than that in 1994 due to variations in rainfall amounts. According to a study by Salter and Schroeder (2012) in MacKay (Australia), that lies in a tropical region there was a strong correlation between seasonal rainfall amounts and total biomass sugarcane yields. Salter and Schroeder, (2012) suggested that one of the requirements in realizing good sugarcane biomass yields is the use of accurate forecasting tools on seasonal rainfall variability. In a study by Naveendrakumar *et al.,* (2018), in tropical Sri Lanka, total seasonal rainfall showed an increasing trend during the main rainy season. The studies done analyzed trends in seasonal rainfall variability, however there is little understanding on how variations in seasonal rainfall amounts affect sugarcane biomass yields and that is what this study intends to fill

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In studies by Porter and Semenov (2005) they elucidated that crop quality is a multi-faceted and complex subject involving growth, storage, processing, pre- and post- harvest and environmental aspects such as soil nutrients and temperature. Teodero *et al*., (2007) in a study over Brazil, found that although there was an increase in sugarcane yields,the early low rainfall amounts affected end of crop growth, resulting to low sucrose accumulation (76.2tons of sugar/ha to 10tons of sugar/ha).. Santos and Sentelhas (2012) in a study done in Brazil revealed that inter annual rainfall variability is the main cause of sugarcane quantity yield fluctuation since it affects the soil water balance. Studies done by Samui *et al.,* (2013) elucidated a mixture of positive and negative correlations with sugarcane yields attributed to inter-annual rainfall variability in the range of 200mm to 400 mm in

Uttar Pradesh, India. In related studies over China, Zhao and Yang-Rui, (2015), reported that less rainfall amounts in early stages mainly reduces cane quality yield leading to low sucrose yield. Shruti, *et al.,* (2017) in a study over tropical India reported that inter-annual rainfall variability affected sugarcane growth. These studies reveal an increase in sugar yields in sugarcane growing regions. The aforementioned studies indicate that the quality of sugarcane yields can be affected by rainfall variability. However; there is little understanding on how changes in precipitation at inter annual scale affect sugar quantity (sucrose) yields in Mumias Sub County.

Studies that have been done on rainfall variability in Africa have focused mainly on its effects on subsistence crops (Ominde and Juma, 1991, Mongi *et al*, 2009;Schreck and Semmazzi, 2004). Studies by Binbol *et al.* (2006) suggested that sugarcane yield strongly correlated with inter annual rainfall variability. Boko *et al*, (2007) predicted that yields of crops from Africa's rain fed farm productions could decrease by 50% by the year 2020, though this generalized the crops. In a similar study done in Ethiopia by Bewket, (2009), it was pointed out that, in 1992 and 2004 maize production was (13.9Qt/ha) that being 36% of annual production and 29% below its ten year mean. In related studies over warm and humid Africa, Nicholson, *et al.,* (2018), stated that inter-annual variability is strong and the increasing trends in the summer and short rains. The aforementioned studies done pointed out that, rainfall variability affects areas under crop cultivation such that with changes in rainfall amounts the land cultivated for the crops varies annually often leading to fluctuations in yields. However, the effect of rainfall variability at inter-annual scale on biennial crops' yields such as sugarcane has received little attention.

Studies by Kurukulasuriya *et al.,* (2006) indicate that the African economies are more vulnerable to rainfall variability and their economies are highly dependent on agriculture and adoption of modern technology is low, leading to poor agricultural crop returns. In a similar study, rainfall variability is expected to adversely affect agricultural production as poor yields (Christensen *et al,* 2007). In tropical region of Ethiopia, where agriculture employs over 80% of the labour force and contributes to about 45% to the national GDP is mostly rain fed, temporal rainfall variability has been a major cause of food shortages (Bewket, 2009). Studies indicate that spatial and temporal precipitation is highly variable in Africa (IPCC, 2013). Most researches done in tropical and sub-tropical larger Great Horn region of Africa in respect to rainfall variability have contradicted each other especially on trends in the March–May (MAM; 'long rains') and the October-December (OND "short rains")(Lyon and Dewitt, 2012). In studies by Chandiposha (2013) in Zimbabwe revealed that sugarcane production has fluctuated with low rainfall amounts. In a study over Ghana, Kyei-Mensah *et al*., (2019), while using analysis of variance (ANOVA) in three regions revealed that variation analysis of major and minor rainfall seasons showed variability in both seasons although it was relatively high in the latter season. They stated also that the high variability of rainfall in the minor season correlated with a reduction in major crop production output that contributes to the national economies. These studies revealed temporal rainfall variability in Africa, however, there is little understanding on how change in total seasonal rainfall amounts affects sugarcane total biomass yield. There is need to analyze trends in rainfall amounts at seasonal scale and the effects of variation in total seasonal rainfall on sugarcane biomass yields under rain fed conditions. This is the knowledge gap that this study intends to fulfill.

Studies by Kenya Sugar Research Foundation (KESREF), (2009) suggested that the decreasing sugarcane biomass yield was associated with seasonal rainfall fluctuations. Predictions about future levels of rainfall in Kenya are complicated because of high spatial-temporal variability, (Herrero, *et al.*, 2010). Extreme events such *El Nino* which complicate rainfall amounts received and rainfall variability have been linked to agricultural activities as suggested by Herrero *et al.*,(2010)**.**In a study over South Africa, Kruger and Nxumalo, (2017), revealed that although South Africa had a relatively extensive rainfall station network, still it was often difficult to detect clear signals of long-term change. Just as in many African countries, insufficient data in Kenya on temporal rainfall variability had led to few studies being carried out on historical characteristics of total seasonal rainfall amounts and inter annual rainfall amounts. This has led to a lot of generalizations on the trends. However due to insufficient data gathered in these studies the findings do not elucidate the nature of historical trends at seasonal and inter annual scale in Kenya. Thus there is need to analyze the historical trends of total rainfall amounts at seasonal and annual scales.

Studies by Amissah-Arthur *et al*., (2002) linked the local short rainy season (October to December) to reduced crops yields, this is despite the fact that increased seasonal rainfall amount is always associated with high yields. The 1998–2000 drought, for example, was estimated to have accounted for economic costs of $2.8 billion from the loss of crops and livestock, forest fires, damage to fisheries, reduced hydro-power generation, reduced industrial production and reduced water supply in Kenya (Stockholm Environmental Institute, Project Report, 2009). The aforementioned studies done in Kenya on seasonal rainfall amounts give conflicting information in that some allude high rainfall amounts are not always beneficial to farmers. Yet, farming in Kenya is rain fed. Furthermore, the few studies done do not establish the effects that the changes in seasonal rainfall will have on sugar cane production yields in terms of the total sugarcane biomass yields.

Following a similar pattern as in other African highlands, Mumias area in Kenya receives bimodal rainfall. Its variability is experienced at onset which is unpredictable and also at times in extremes. Apart from that Mumias sub county lies in the Lake Victoria region that is strongly linked to the El Nino Southern Oscillation (ENSO),(Ropelewski and Halpert, 1987), Ogallo,*et al,* (1988)) Mutai, *et al*,(1988)). An example of this effect was the El Nino of 1997/1998 and the La Nina of 2000/2001. The links between El Nino events and rainfall variability have been suggested by Ropelewski and

Halpert (1987)**.** Few of the aforementioned studies point to their effects on crop production. In a study over Mumias by Jamoza, (2005), focused on adaptation of sugar cane varieties to local conditions while in related studies by Kirungu, (2011) looked at water stress at the late canopy development stage and stalk elongation stage. Similarly, according to Samui *et al*, (2013) availability of moisture during the elongation stage of sugarcane growing improves the yields. They stated that sugarcane in rain fed areas increases stem fiber mass due to increase in soil moisture content. The studies correlated rainfall and sugarcane yields in Mumias in general. The few studies do not analyze the effects of rainfall variability at seasonal and inter-annual scales and trends on sugarcane total biomass yields. In addition, the potential effects of this rainfall variability on sugarcane production remain unknown and have not been adequately addressed in the few studies done. Instead studies done in Mumias have focused on subsistence farming and improving sugarcane variety.

1.2 Statement of the Problem

Rainfall is one of the major sources of soil moisture that determines production of sugarcane. Its variability may have positive or negative effects on the economically viable produce of sugarcane biomass yields and sugar quality (sucrose) yields. This affects the economy of a region. Despite of this, there is limited understanding on how variations in rainfall amounts affect sugarcane production in Kenya. To salvage this situation, there is need to examine the effects of rainfall variability on sugar cane production in Kenya. There should be an understanding on how variations in seasonal and annual rainfall amounts affect sugarcane yields. The historical characteristics of rainfall trends in total seasonal amounts, total inter annual rainfall amounts and trends in sugarcane yields in major sugarcane growing zones such as Mumias sub-county ought to be investigated in details. Mumias Sub County as one of the major sugarcane producing zones accounting for almost half of sugarcane grown in Kenya yet there seems to be a decline in sugarcane yields. In addition, complementary research should be carried out on the effects of total seasonal rainfall amounts on sugar biomass yields and inter-annual rainfall trends on sugar quality (sucrose) in such zones. Therefore, the purpose of this study was to examine the effects of rainfall variability on sugarcane production in Mumias sub-county

1.3 Objective of the study

The main objective of this study was to examine the effects of rainfall variability (seasonal and annual) on sugarcane production in Mumias sub-county during 1982-2012.

Specific Objectives

1. To determine historical trends in total seasonal, total annual rainfall amounts and yields of sugarcane in Mumias Sub County.

2. To determine the effects of seasonal rainfall amounts and annual rainfall amounts on sugarcane biomass yields in Mumias Sub County.

3. To establish the effects of variation in inter annual rainfall amounts on sugar quantity in Mumias Sub-County.

1.4 Research Questions

1. What are the historical trends in total seasonal, inter annual rainfall amounts and yields of sugarcane in Mumias?

2. What are the effects of total seasonal rainfall amounts and total annual rainfall amounts variations on sugarcane biomass yields in Mumias Sub County?

3. What is the effect of inter annual rainfall amounts variations on sugar quantity in Mumias sub county?

1.5 Justification and significance of the study

Rainfall is the most important climatic input in Kenya's agricultural sector since it is the major water resource (Kiunga, 2015). A report by Anyah and Semazzi, (2007) shows rainfall variability affects agricultural crops production especially crops grown by small scale farmers who are not conversant with climate change mitigating strategies. Mumias Sub County has been selected for this study because sugarcane is majorly grown by small scale farmers and the sub county is one of the major producers of locally produced sugar in Kenya. Variations in seasonal and annual rainfall amounts have been observed in the sub county. Few studies have been done on how these variations relate to sugarcane production in Mumias Sub County. It is of importance to study sugarcane biomass yields since one of the major products from sugarcane that is commercially viable is the sugarcane biomass yield and it is what farmers are compensated for as they deliver it to factories as their harvest, therefore high returns from the sugarcane biomass yield will translate to an increase sugarcane production. Additionally, Mumias Sub County has been selected because sugarcane is the main commercial and industrial crop grown accounting for 80% of the crops in this sub county (Republic of Kenya, 2009) and sugarcane production has been declining yet few studies have been done on effects of rainfall variability on sugarcane production. The study period has been selected taking into account the time sugar production was vibrant. The selection of the period of study considered other factors which could also be affecting sugar production such as the effects of management at the giant Mumias sugar factory and the importation of sugar into the local market was still under the "COMESA" quota-system regulations.

The study also focused on 31 years of data (rainfall and sugarcane yields) starting from 1982 up to 2012 the year "The Common Market of Eastern and Southern Africa" (COMESA) Treaty recommended as the commencement of free sugar market in the region .This affected the sugarcane "zoning system" and in turn affected the availability of sugar on the Kenyan market resulting in changes in pricing of sugar. Therefore this study is of paramount importance to the farmers as it will enable them practice proper sugarcane production in relation to rainfall variability in terms of timing the rainfall period for planting sugarcane, harvesting and other agronomic activities in the sub county so as to achieve high yields and returns. It will also provide an understanding of seasonal rainfall trends that will help the sugarcane farmers to plan on appropriate coping strategies to improve sugarcane yields. Additionally, sugarcane millers and economic planners will use the findings to seek alternative ways of helping sugarcane farmers adapt and mitigate the impact of inter annual rainfall amounts changes on sugar quantity so as to produce sugarcane of high quality. The findings of this study will also benefit the stakeholders in the sugarcane industry by providing useful information on carrying out of agronomic activities in relation to seasonal rainfall patterns so as to get maximum production levels of sugar produce thereby increasing profitability of sugar cane farming in Mumias Sub County.

1.6 Scope and Limitations of the Study

This study focused on rainfall variability in Mumias Sub County. The study evaluated historical rainfall variability at seasonal and inter annual trends over the period 1982 and 2012 in Mumias sub county establishing its effects on sugarcane biomass yields and sugar quantity. Rainfall data on monthly and annual amounts for the 31 years study period was collected from five rain gauge stations covering the study area. Sugarcane production parameters focused on sugarcane biomass yields and sugar quantity during the study period. To cater various aspects in farm management, the analysis was done on out grower sugarcane biomass yields, whereas the sugarcane biomass yields for ratoons and varieties was analyzed from the nucleus farm produce. Rainfall data from the five different rain gauge stations showed variations during the study period with a purpose of finding out whether it the rainfall pattern is similar. There were a number of ratoon crops grown by farmers that lacked adequate data due to management lapses and therefore data provided covered the years 1982-1999. Similarly, segregated data on sugarcane biomass yields specifying the variety yields was available from 1996-2003. The variations in rainfall data from the five different rain gauge stations were addressed by carrying out a one way Analysis of Variance (ANOVA) test. The challenge of segregated data detailing the quantity of cane produced from various varieties and ratoons delivered by different stakeholders was addressed by using the ten year available computerized segregated data and thus making it possible to work out analysis for sugar cane biomass yield for ratoons and vanities that farmers preferred during the study period. There were a number of ratoon crops grown by farmers that lacked adequate data. This made the study to evaluate the yields from the main plant crop, first ratoon crop up to third ratoon crop that are economically viable. The study was limited to two sugarcane varieties (CO 945 and CB 38-22) that were extensively grown by the farmers during the study period and data for the varieties was available. The produce of ratoons and sugarcane varieties was not available as a variable for the 31 years and this limited the analysis to be done for the years of study that the data at Mumias Sugar Factory could provide segregated data using the computerized systems that are able to trace farm produce.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of previous related research findings on rainfall variability and sugarcane production. The chapter has been divided into three parts: - the first part deals with assessment of historical trends of seasonal rainfall variability, inter-annual rainfall variability and yields of sugarcane globally. The second part examines the effects of rainfall variability on sugarcane yields from different parts of the world. The third part assesses the effects of inter annual rainfall variability on sugar quality worldwide.

2.2 The historical trends of seasonal, inter annual rainfall amounts and sugarcane yields

Seasonal and inter annual variations in rainfall collectively have an overall control on moisture availability for sugarcane growth, Robertson, *et al,* (1999). According to (IPCC, 2001), changes in the amount of rainfall, the intensity of floods and droughts are uncertain. In studies by Brown (2005), it was reported that Europe received low rainfall during spring and summer of 2003 which showed a remarkable deviation in seasonal rainfall trends. In another study done by Greenland (2005), Louisiana, America, it was established that historical trends of sugarcane biomass yields trends between 1963 and 2002 increased in April to May season when the rains were lower than the average. In a study over India, Padhiary, *et al.*, (2018), reported that between 1980 and 2014 that the annual rainfall trend was increasing. Decreasing and increasing trends of seasonal fluctuations have been observed in different parts of the world. However, none of these studies focused on historical trends in total seasonal rainfall amounts in wet and humid regions such as Mumias sub-county.

Studies done over Spain, Italy, Cyprus and Israel, Alpert *et al*., (2002), reported that there was a tendency of intense rainfall increase in Spain and Italy and also noted an absence of trend in Israel and Cyprus. A study done by Santos and Sentelhas, (2005) over Brazil revealed that inter annual rainfall variability affects soil water balance causing fluctuation in sugar quantity yield. A study in India by Nagaratha and Sridhar,(2009) reported that in a period of three consecutive years as from

2001—2004, Karnataka State experienced low annual rainfall amounts that reduced the state's sugarcane biomass yields .In studies by Berland *et al*., (2013) it was reported that The Lesser Antilles, in Southern Caribbean are subjected to highly inter annual precipitation and prolonged periods of rainfall abundance or deficiency which affect crop production. Similarly, Shruti, *et al.*, (2017) in a study in tropical India reported that annual rainfall variations affected sugarcane growth. In a study over Pakistan, Hussain, *et al*., (2018) cites periodical variations in rainfall amounts as one of the factors affecting sugarcane biomass yields. These studies point out that there are regions that experience variations in inter-annual rainfall amounts which affect sugar production .However, the annual rainfall amounts that are either increasing or erratic have not been analyzed to find the effects of the variations on sugarcane production. Few studies have analyzed the trends in inter-annual rainfall amounts, a gap this study attempted to fill.

A study by Morishama and Akasaka, (2010), on seasonal trends of rainfall over southern Africa between 1979 and 2007 reported that rainfall was generally high in September to December and from March to June then it became abruptly shorter after 1987 contributing to decreasing trends in total seasonal rainfall amounts. In a related study over Mediterranean region between 1901 and 2009, Philandras*et al*, (2011), analyzed the time series of monthly rainfall totals to detect long term series. They found that total number of rain days had a pronounced decrease by 20%.The study connected seasonal matches with inter annual variations over southern Africa. The analysis used percentages of rainy days to determine variations in seasonal rainfall and its effectiveness without relating it to agricultural production. Bayrau, *et al.*,(2015) in a report humid regions Ethiopia projected a reduction in the economic growth as a result of poor sugarcane production caused by climate change. These studies analyzed the trends in seasonal rainfall amounts; however, the studies did not address effects of variations in total seasonal rainfall amounts on sugar cane biomass yields.

In a study done by Bewket, (2009) on long term rainfall variability in Amhara, Lalibela Ethiopia between 1975 and 2003 a departure by 0.3 from the mean annual and annual coefficient (CV) for the 28 years was recorded which was relatively high. Over Tanzania, Liwenga (2012),reported drought being extreme in 1995/ 2000, severe in 1993 and 1997, moderate 1996 and 2005, normal years were 1989/ 1990,1992 and 1995/1996, and the wet years were 2002, 2003 and extremely wet ,1998 and 2001.Studies that have been done focusing on the larger Great Horn of Africa have contradicted each other on the causes of extreme events especially drought, such that some have associated drought to reduction in the March–May (MAM; 'long rains') (Lyon and Dewitt, 2012).

The drought is reported in the aforementioned studies to have caused immense damage to agricultural crop production. Studies done in Vhembe, South Africa, Shandukani and Tibangayuka, (2013) reported a decline of -3.95mm and 18.3mm per year between 1970 and 2009. The African continent has been noted to be affected by rainfall variability. Food and Agriculture Organization, (FAO) (2014) reported that the continent has a long history of rainfall fluctuations, the worst being in 1910s which affected East and West Africa alike resulting in diverse effects on agricultural crop production. Floods and droughts are the common extreme events in the region. The two are associated with devastating socio-economic losses in the region (Funk et al., 2013; Lyon et al., 2014; Nicholson, 2016). These aforementioned studies done in Africa focused on inter annual rainfall variability and its effects on agricultural crop production and socio economic activities in general, however there was need for a study focusing on the effects of inter annual rainfall variability on sugar quantity.

A study by Camberlin and Okoola,(2003) observed total rainfall during the March to May seasons from 1968 to 1997 appeared to increase in Kenya stating that the highest rainfall fluctuation for the MAM season was statistically recorded between the year 1998 and 2000.In overall, although the MAM season records higher rainfall than OND, studies by (Clark *et al.,* 2003) show that the OND season experiences higher degree of inter-annual rainfall variability than MAM.Similar studies suggest that, the total annual precipitation projection in Kenya will increase by approximately 0.2- 0.4 % per year and this will affect sugar production (GoK, 2009). In related studies, Herrero *et al*, (2010), reported that seasonal rainfall amounts and annual rainfall over the whole country will increase by 0.2% to 0.4% per year for the long rains season (March, April and May).Studies by Williams and Funk, (2011), indicate recent La Nina years are tending to be drier, whereas El Nino, March, April, May and June seasons are tending more towards average, rather than above-average rainfall trends. According to Congressional Research Service (CRS, 2012) report, the 2010-2011drought has been proved to be the worst in Kenya. Kisaka *et al*., (2015), in a study over sub humid regions of eastern Kenya reported that the annual total rainfall is unpredictable and poorly distributed over time resulting in poor yields as crops suffer from stress. The aforementioned studies contradicted each other with some suggesting an increase in rainfall amounts while others indicating an increase in drought events, since they did not focus on long term variations in total seasonal rainfall amounts. Long term variations may have an impact on total annual rainfall amounts that can provide a trend of predicting future seasonal and annual rainfall pattern, a gap that the present study attempts to address.

2.3 Seasonal and annual rainfall variability effects on sugarcane yields

According to a study by Di Bella *et al.,* (2008), in Herbert District, Australia, it was reported that varieties of sugar cane that are harvested late in the growing season are at great risk of poor yield response due to high probability of significant rainfall events that cause damage to soil nutrients such as leaching. In another contrasting study by Salter and Schroeder (2012) in MacKay (Australia) it was reported that high total seasonal rainfall variability had an effect on sugar cane production by high rainfall amounts leading to high yields in 2008-2010. In their report it was indicated that sugarcane variety Q124 out-performed other varieties, across most soil types, in the Mackay region. However, weather conditions during that period may also have been more favorable for cane production, they noted. Further they stated that, the 1994–1998 period experienced on average, 118 mm more effective rainfall, 682 mm lower than the annual total rainfall well distributed within the seasons that resulted in high sugarcane biomass yields due to likelihood of lower incidence and severity of water logging than that recorded in (2008–2010). Zhao and Yang, (2015) in their studies found out that variation in moisture content in the soil takes a period of almost a year to be seen in variation of sugar cane yields. In a study over Brazil, Teodoro, *et al.*, (2015) revealed that sugarcane planted during the main rainy season grew faster and had better yields. The aforementioned studies focused on the variety of sugarcane grown and the water table level rather than analyzing the trend in changes in seasonal and annual rainfall amounts that cause major changes to the soil water level and their effects on these yields.

In studies by Hurney,(1992) a number of factors contribute to the variation in ratoon yields during the rainy season among them bud development in ratooning stubble indicated in early ratoon that ensure a ratoon crop. Similarly Chapman *et al.*,(1992), also suggested that the number of buds per stem piece that decrease in older ratoons and damage at harvest time could affect ratooning ability. In related studies by Gomathi*et al.*, (2013), in India where the production of sugarcane was analyzed in terms of tiller production, annual rainfall amounts and it was reported to be highly associated with the yield of the first ratoon (r=0.630), second ratoon (r=0.553).Hussan *et a*l., (2017) in a study over Pakistan revealed that the time of harvesting sugarcane ratoon crops affects their yield in that those harvested during seasons with less rainfall produce higher yields. These factors put together may explain the relationship in variation of ratoons yields to seasonal and annual rainfall amounts. In the studies mentioned sugarcane ratoon yields were not studied to ascertain whether there is a certain threshold for optimum production under rain fed conditions due to variations in total seasonal and annual rainfall amounts or the type of ratoon. Though a variation in rainfall amounts was suggested to be increasing or reducing the yields, no rainfall trend was worked out so as to lead the stakeholders review their harvesting patterns.

The past 30 years in Africa have seen unusually severe or prolonged dry spells which has seriously affected agriculture, thus resulting in many deaths and severe malnutrition (UNEP, 1992). A study done in South Africa by Deressa*et al*., (2005), revealed that increasing precipitation by 4mm beyond the average seasonal rainfall was damaging sugarcane production According to a similar study by Binbol*et al.,* (2006) over Numan, Nigeria it was noted that rainfall variability correlated strongly with sugarcane yields with low seasonal amounts leading to low cane yields. He reported that sugarcane yield correlate strongly with rainfall in that too much rainfall at germination stage was detrimental to sugar yields. The study looked further at inter annual rainfall variability. Boko *et al*, (2007) predicted that yields from Africa's rain fed farm productions could decrease by 50% by the year 2020 as a result of inter annual rainfall variability. Rainfall variability and extreme events such as drought are expected to adversely affect agricultural production and food security (Christensen *et al,* 2007). In another study, Masavya *et al,* (2009) reported that rainfall variability affects crop yields and alter planting dates, though the study did not specifically focus on sugar cane. A study done in Kuta (Nigeria) by Yahaya et *al.*, (2014) showed a continuous increase in yield of yams from 2001 having 11.26tons/ha to 2009 having 16.91tons/ha; a general explanation that with the increase in the amount of rainfall received, so was a corresponding increase in tubers yield. This study focused yams which take six months to mature unlike sugarcane which takes 12—18 months. In a similar study over Ghana Kyei-Mensah, *et al.*, (2019) elucidated a decline in terms of yields of key agricultural cash crops such as cocoyam due to reduced rainy days throughout different seasons. The aforementioned studies focused on the quantity of crops harvested. However, they did not analyze the quality of yields harvested especially when the crop takes a long period to mature such as sugarcane that this study intended to explore.

Kenya experiences major and minor droughts, major ones every decade and three to four years, respectively (UNEP, 2000). Studies by Amissah-Arthur *et al*., (2000) linked the local short rainy season (October to December) to reduced crop yields, despite the fact that, increased seasonal rainfall amount is associated with high yields. A report (Anyah and Semazzi, 2007) from Lake Basin region (inclusive of Mumias sub county), shows an analysis of high rainfall intensity, impacting negatively to the subsistence farming. Related studies by Thornton *et al*., (2007) indicated dramatic fluctuations in inter-seasonal rainfall projecting a reduction in maize yields by 20% in semi-arid regions; resulting to losses in the range of 200kg/ha to 700kg/ha. The 1998‒2000 drought, for example, was estimated to have economic costs of $2.8 billion from the loss of crops and livestock, forest fires, damage to fisheries, reduced hydro-power generation, reduced industrial production and reduced water supply in Kenya (Stockholm Environmental Institute, Project Report, 2009). The 2010–2011, drought period, has been proved to be the worst in 60years, with more than 12 million people in need of emergency relief (CRS Report, 2012). However these studies mainly focused on subsistence crops, with no attention on sugarcane despite its social-economic benefits. Further, the studies did not critically analyze effects of seasonal rainfall variability on perennial crops, a weakness the present thesis attempted to address.

2.4 The effects of inter annual rainfall variability on sugar quantity (Sucrose)

Kettlewell *et al*., (1999) in studies over UK showed how rainfall variability can affect the quantity of wheat harvested. They reported that high rainfalls in August led to reduced supply of quality wheat from 45% to 25% as a result of North Atlantic Oscillation (NAO). Studies by Porter and Semenov (2005) elucidates that crop quality is a multi-faceted and complex subject involving growth, storage, processing, pre- and post- harvest and environmental aspects such as rainfall variability. A study by Santos and Sentelhas (2005) in Brazil revealed that apart from temperature, inter annual rainfall variability is the main cause of sugarcane quantity yield fluctuation since it affects the soil water balance. In a study over Brazil, Teodero *et al*., (2007) found that the early dry season affected end of crop growth, resulting to low sucrose accumulation (76.2tons of sugar/ha to 10tons of sugar/ha).Over South East United States, rainfall amounts recorded in 1988 were 500mm and maize yield harvested was 500kg/ha whereas in 1989 there was a harvest of 10,000kg/ha of sugarcane with similar seasonal rainfall amounts, the difference was attributed to inter annual rainfall variability (Baigorria *et al.,* 2008). In studies over China, Zhao and Yang-Rui, (2015), reported that less rainfall amounts during the main rainfall season mainly reduces cane yield leading to low sucrose yield. In these studies sugarcane production the variation in inter-annual rainfall was not studied to ascertain its effects on sugar quantity.

Rainfall variability and changes in frequency of extreme events are important for yield, its stability and quality. Studies by Jorio*et al.,* (2006) over Charb, Morocco revealed that the rainy seasons which normally begins in January disrupts harvesting, transporting and crushing operations of sugarcane. They pointed out that the sugar mills set the harvest schedule based on crop yield and sugar content, however, the plan is compromised by the onset of rain that prevents infield access of transport vehicles, they assert. Further they state, with this difficult in vehicle transport, farmers opt for hand loading, an operation that is difficult and expensive. Jorio *et al*.,(2006) concludes that, the long delays occasioned by rainfall variability between harvesting and delivery and between delivery and crushing sugarcane reduces quantity of juice extracted as well as quality produced. In a study over Uganda, Orianga, (2013), noted that annual rainfall amounts affected the quantity of millet yields. The few studies that have been done in Africa show how rainfall amounts affect the tonnage and quantity of sugar (sucrose); however they did not pinpoint the effects of variation inter-annual rainfall on sugar (sucrose).

A study done by Fabio *et al.,* (2013) over Southern Brazil reported that early and late planted cultivars showed low sucrose concentration than those planted in the middle circles. Related studies in Coimbatore, India (TNAU; www.tnau.ac.in, 2014), found that the ideal time of harvesting sugarcane is when the Pol% value is 16. In a study over sub-tropical Guangxi, China, Xiao (2017) reported the quantity of sucrose increased with the increase of the March rainfall that enhanced photosynthesis in sugarcane crops. Some of these studies found out that yield variability reduced as rainfall was increased. Notably, these studies focused on early and late planting or harvesting and not on how water stress affects the general production stages of sugarcane. These studies did not take into consideration areas receiving bimodal seasonal rainfall and experience high variation in inter-annual rainfall amounts, a gap that the present study examines.

A study by Deressa *et al.,* (2005) identified effects of high level precipitation on sugarcane production in South Africa. The findings were on winter precipitation where up to 94 mm increased net revenue per acre and increasing it beyond its normal by 4 mm in summer damages sugarcane production. This finding agreed with the fact that sugar cane production requires low level precipitation during ripening and harvesting for high sucrose accumulation (Hunsgi, 1993). Studies by Yahaya *et al*., (2014) over Kuta (Nigeria) revealed drop of 14.19 tons/ha in yam yields during the period 2001 to 2009 despite minimal variability in the annual rainfall variability. A study done in Tendaho, Ethiopia (Hagos, *et al*., 2014) recommended a Pol% value of 16% to be an ideal level of harvesting sugarcane. In a study over Eastern Rwanda, Nahayo, *et al.,* (2018) reported a drop in quality of crop yields especially rain fed maize during 2015 and 2016 which was attributed to a reduction in MAM rainfall. However, these studies did not analyze the effects inter-annual rainfall variability.

The effects of rainfall variability on crops yield quality in Kenya has been done in a few studies. Studies by Jamoza (2005) pointed out that erratic and low seasonal rainfall was the main cause of low cane yields in the highlands western of Kenya. In her study, she examined various varieties of sugarcane that produced better quality yields. Other studies by Herrero *et al,* (2010) observed that increase in rainfall lead to increased productivity in maize and beans in specific areas. This study looked mainly on staple foods at seasonal rainfall variability scale; no focus was done on effects of rainfall variability on sugar (quantity) at inter annual rainfall variability scale. In another study, by Lugaria, (2016) over western Kenya, it was revealed that there is an increment in OND rainfall amounts making the growth of rain fed maize sustainable for both the long rains season and the short rains season. However this study did not analyze the quality of the maize harvested during the short rains season.

2.5 Theoretical Framework

The study was guided by Cob-Web theory as advanced by Sillah, (2014). In line with this Sillah, (2014), used the Cob-Web theory to clarify that the planting behavior is adjusted based on the past information of the market price, which is adaptive expectation. The farmers do speculate about the future market price from the previous year's earnings, which may influence how much sugarcane planting acreage to be undertaken within the year. In sugarcane production, rainfall is one of the main climatic elements required and changes in total seasonal and annual rainfall amounts will bring about fundamental changes in sugarcane yields and pricing. For Sillah, sustained rainfall amounts will give predictable prices for sugarcane yields. Rainfall amounts vary and they result in poor yields. According to Zhao and Yang-Rui (2015) suggests that due to rainfall variability, sugarcane hectarage in Guangxi, the largest cane producing province, is expected to drop 6% in 2014/15 as farmers grow the fast-growing tree species for industrial use. Similarly, cane hectarage in Hainan is estimated to decline 11% in 2014/15 due to low profits.

The potential negative impact of climate change, especially rainfall on sugarcane production in Zimbabwe has been reviewed by Chandiposha (2013) that indicate poor yields discourage farmers to plant more sugar cane. The little seasonal rainfall amounts give rise to stunted sugarcane plants while heavy rainfall amounts interfere with agronomic activities on the farms. Sillah therefore suggested that the environment should be protected and sustained by practicing proper farming methods that do not bring about climate change such as use of environmentally friendly fertilizers and suitable crop varieties. For instance, a study done in Kenya by Kenya National Bureau of Statistics, (KNBS, 2015), suggests that rainfall variability will adversely affect agriculture in 2020, 2030 and 2040 if policies that prevent destruction of natural environment are not put in place. A sugarcane farmer should protect the environment so that changes in climatic elements are sustained. He must understand that variations in rainfall amounts affect sugarcane yields. This kind of farming provides avenues for Kenyan sugarcane farmers to revitalize the sugar industry.

2.6 Conceptual Framework

Rainfall variability in Mumias Sub County may result into below average or above average rainfall. This may affect sugarcane biomass yields and sugar quantity yield in the figure below;

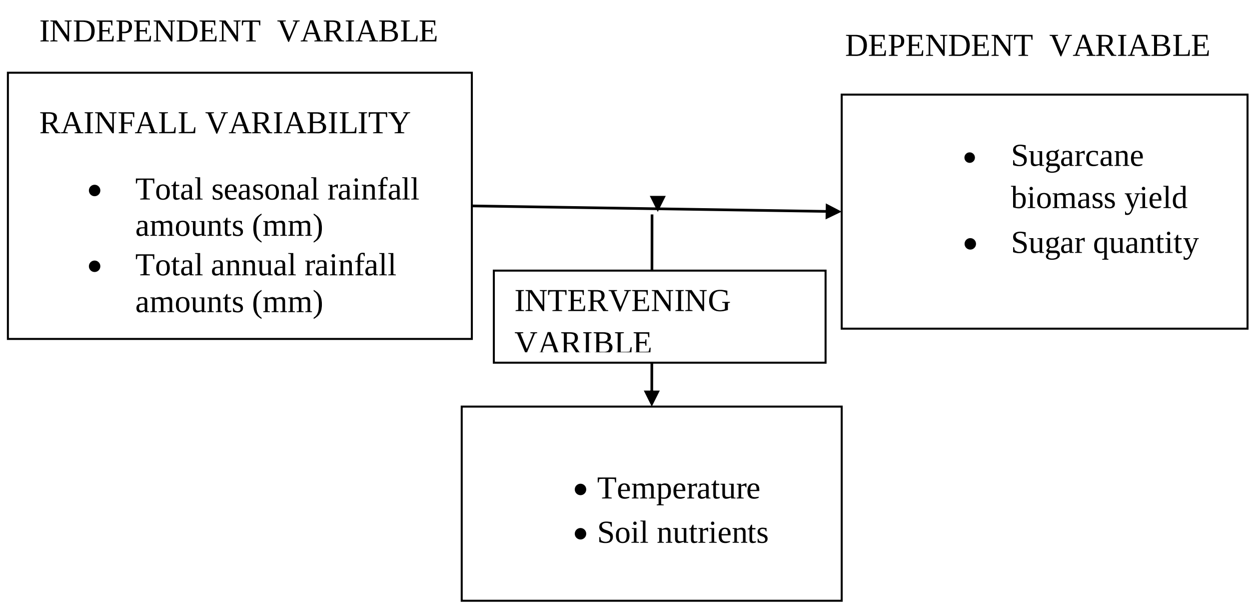

Figure .1 Conceptual Framework

Source: - Author's work, 2015

Rainfall is a very important factor in crop yields. The variability in seasonal and inter annual rainfall can fall either below or above average and may affect crop production and yields. Total seasonal rainfall below average may lead to dry spells or drought which devastates sugarcane yields through planting, shortening nodes, the size of stems and dry cane. This reduces the sugarcane biomass yields.

Total annual rainfall above average increases water logging in farms which affect the time of planting, weeding, harvesting and increase fiber content thereby reducing sucrose accumulation. In addition, due to leaching the soil loses nutrients which are vital for plant growth and it also leads to small sized cane with shortened nodes. This affects the sugar quantity negatively. Average seasonal rainfall may increase sugarcane yields by increasing the biomass content of sugarcane, hence improving sugarcane yields. These variations in rainfall amounts taking place over a period of time lead to variations in sugarcane biomass yields and also the sugar quantity. Temperature also affects sugarcane yields in that low temperatures reduce the photosynthesis processes. In addition, soil nutrients affect the growth of sugarcane crops. In this study temperatures were assumed to have less variation since the study area lies within the tropics and close to the equator. Similarly soil nutrients were taken to have had minimum effect since Mumias sugar company supplied farmers with fertilizers for sugarcane farming during the study period

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter is a description of the procedures that will be used in collecting data for this study. First, the study site is described. Later the research design, study instruments and methods of data analysis are also explained.

3.2 Description of Study Area

The study was based in Mumias Sub County one of the major sugarcane producing sub-counties in Kenya. This is a sub county in Kakamega County in western part of Kenya. Formerly, it was known as Mumias District before the promulgation of the 2010 Constitution of Kenya. It covers a total area of 586.2sq.km and lies between latitude 1˚30´N and 0˚05´N, longitudes 34˚and 35˚45´E. The altitude ranges from 1240 m to 1641m above sea level. There were 5 rain gauge stations (Kenya Meteorological Department, Gok,2019) .The population was approximated 340,774(Republic of Kenya, 2009).

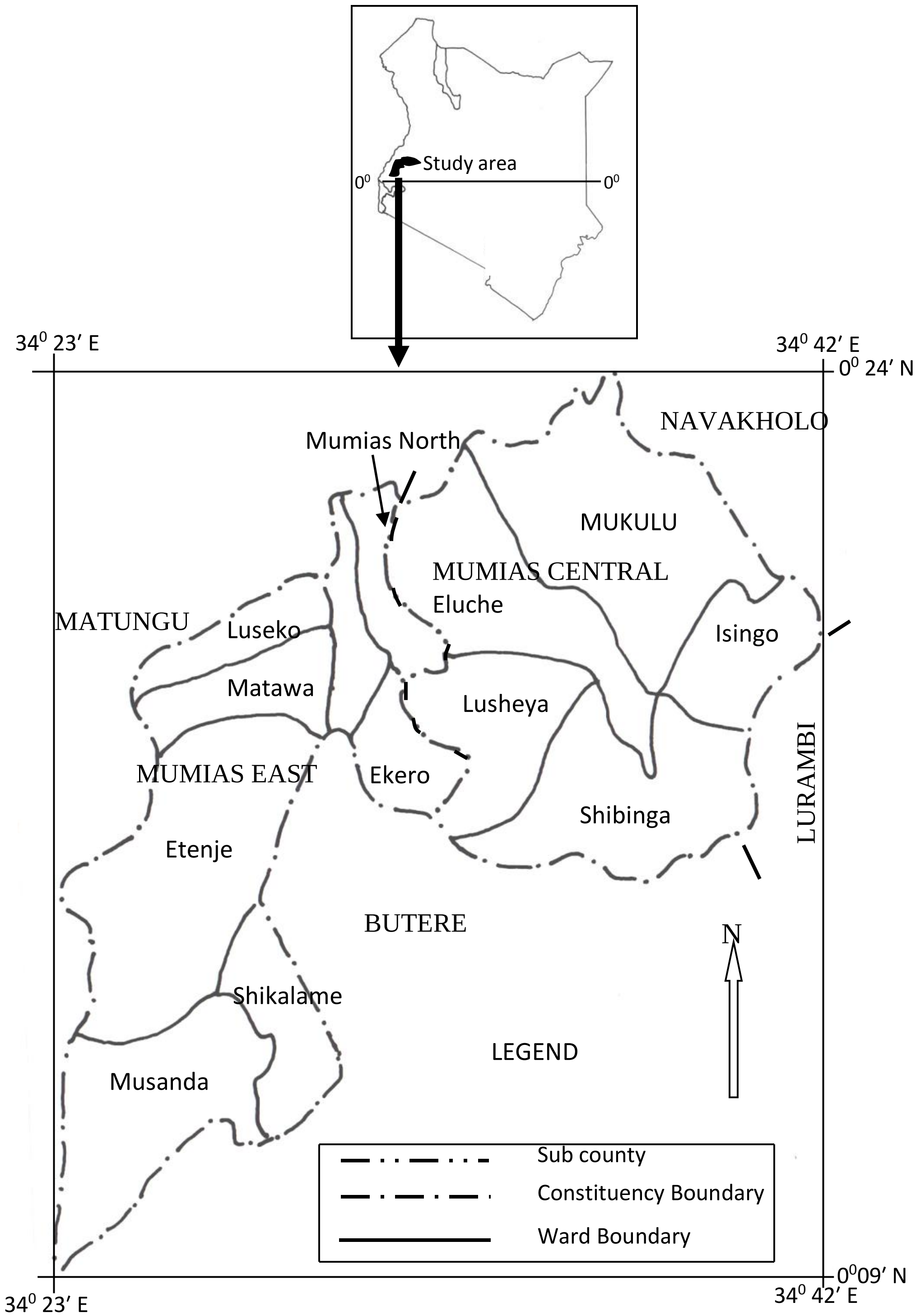

Figure 2: Map of Kenya showing location of Mumias Sub County

Source: Modified from Mumias District Development Planning, 2010

3.2.1 Climate

Mumias sub county is mainly tropical humid, characterized by day temperatures varying between 18˚C and 22˚C. The sub county receives rainfall almost throughout the year, with minimum rainfall being received between December and February. Mean annual rainfall varies from minimum of 600mm to 700mm and maximum of 1520mm and 2400mm, (See table 1).

Table 1: Long term mean monthly figures for rainfall and temperature 1993 to 2002

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RAIN (mm)	700	600	1700	2400	2200	1900	1200	1700	1520	1530	1520	700
TEMP (∘ C)	19	20	21	22	20	19	20	20	19	19	18	21

Source: Meteorological Department, Nairobi.

3.2.2 Soils

The study area has soils from post Kavirondian granites, pre-Cambrian volcanic and sedimentary rocks as parent material (Kenya Agricultural Research Institute, 1991). The soils are dominantly black cotton sandy loamy acrisols, clay loam and sandy clay suitable for sugarcane farming. The soils are suitable for sugar cane farming.

3.2.3 Sugar Production

Majority of people living in Mumias Sub County depend on sugarcane farming. The main planting period is in the months of March to July, and harvested after 12 to 18 months. The main plant seed is supplied to farmers by MSC and the yields from this are viable up to the third ratoon after which fallowing is recommended before a new seed crop is planted.

3.3 Research Design

The present work used cross sectional descriptive research because it was possible to collect large rainfall and sugarcane production data at one point at a time. This made it to be inexpensive in terms of time needed to complete the research and finance to collect data. In this study the rainfall amounts recorded in a rain gauge station was the unit of analysis of which the rainfall data were surveyed because this is the data that gives the rainfall distribution in the area. The rainfall data collected from Mumias rain gauge stations covered a period of 31 years and was assumed to be representative of the entire population within the time span of the research period.

3.4 Study Population and sample size

According to Mumias synoptic weather station, (2017) the number of rain gauge stations within Mumias Sub County was 5 and which were not distantly located. Therefore, the sample study was drawn from the target 5 rain gauge stations. In a study in Ghana, Nyatuame,*et al.*, (2014),to find temporal disparity of three different rain fall zones analysis of variance (one way ANOVA) test was used . Asare-Nuamah, (2019) used one way ANOVA to address the aspect of homogeneity across six agro ecological zones in Ghana. Similarly in this study to ascertain whether there were any differences between the means for five rainfall data regions, ANOVA test was used. This was done using the one way ANOVA test on rainfall amounts for 31 years with their corresponding rain gauge stations to ascertain whether there is consistency in the rainfall amounts pattern and minimize biasness in the rainfall data recorded in the study area. A null hypothesis was stated as: There is no significant variation in means of annual rainfall received in any of the five rain gauge stations (H_0: $\mu_1 = \mu_2 = \mu_3 \ldots = \mu_k$); i.e. $\mu_{1\ldots,}$ μk=mean of annual rainfall for each rain gauge station; Alternative hypothesis as: There is a significant variation in means annual rainfall amounts in the five rain gauge stations (H_1: Means are not all equal), at 0.05 significance level. If the static value fails to reject the null hypothesis, then one data set of rainfall amounts from the five rain gauge stations will be used, in that the rainfall pattern within the study area will be taken to be similar. The importance of this test is to assess whether there exists any variance in groups of data collected from a wide area, if no variance exists then the outcome variables are of the same magnitude in each of these groups (i.e. the rainfall data).

Table 2: ANOVA showing Annual rainfall amounts for 31 years from five rain gauge Stations in Mumias Sub County

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	582884.78148	4	145721.19537	1.38	0.24334
Within Groups	1.58319E7	150	105546.2977		
Total	1.646148E7	154			

Source: Mumias Synoptic Weather Station, 2017

Table 2 shows Analysis of variance (ANOVA) table extracted from 31 years total annual rainfall amounts from five rain gauge stations located apart in Mumias Sub County. The corresponding data values are depicted in Appendix 1.The results indicated that there is no difference between the means of annual rainfall amounts among the five rain gauge stations for 31 years ($F=1.38$ and $p=0.24334$, which is non significant, that is, there is no significant difference in the means of annual rainfall amounts. The null hypothesis failed to be rejected at 0.05 significance level. This implies that the rainfall pattern over Mumias Sub County is similar in the areas covered by the five rain gauge stations and this made it prudent to use recordings from one rain gauge station to analyze the historical rainfall trends at seasonal and annual scales as well as its effects on sugarcane production.

3.5 Data collection methods

3.5.1 Secondary data

The present research utilized secondary data. Secondary data was obtained using document analysis where by published and unpublished reports were sourced from Mumias synoptic weather station, Mumias Sugar Company and Mumias sub county Agricultural Offices. It also comprised of thirty one year (1982 to 2012) rainfall data provided by Mumias synoptic weather station from five rain gauge stations in the study area. In addition to this, sugarcane yields comprising of quantity of cane harvested in terms of tons as well as sugar quantity recovered from the canes in terms of POL (%) for the out grower farmers and the nucleus estate was also provided by Mumias sugar company. Also a sugar technologist from Mumias Sugar Company provided records of sugarcane yields in terms of tons per hectare and processed sugar quantity in terms of POL (%) received for the same period. Data on land acreage under sugar cultivation during the study period was obtained from Mumias Agricultural sub county offices. Document analysis was used to analyze the data. According to Bowen, (2009), one of the types of documents is public records that show events, yearly reports and organizations activities. The sugar cane yield data and the rainfall data formed the basis for regression analysis.

3.6 Methods of Data Analyses

Quantitative data on rainfall amounts was analyzed using descriptive statistics such as means, percentages, line graphs and linear equations, Coefficient of variation, standard deviation and linear regression analysis. Line graphs were used to show trends in total seasonal and annual rainfall amounts as well as sugarcane yields. Linear regression was used to show the effects of rainfall amounts at seasonal and annual scales on sugarcane biomass and quantity yields. Coefficient of Variation (CV) was used to calculate seasonal and annual rainfall variability on rainfall data for the period 1982 to 2012.In relating rainfall amounts to sugarcane yields, a six months lapse period was observed for accumulated effective soil moisture content. Statistical Packages for Social Science (SPSS version 20) and OriginLab software version Origin Pro 8 were used to process the data.

Seasonal rainfall amounts data and annual rainfall amounts were taken as an independent variable and sugarcane yields as the dependent variable. According to a study over Ghana by Nyatuame *et al*., (2014) linear regression was used to analyze rainfall trends, similarly a line graph and a linear equation were used to measure the trends in historical total seasonal and inter annual rainfall amounts for purposes of predicting rainfall patterns.

3.6.1 Results Presentation

The results were presented in the form of description, tables and graphs. The graphs which were in the form of trend lines and line graphs were used to show rainfall variability at various temporal scales and sugarcane yields. Scatter graphs were used to show the relationship between rainfall and sugarcane yields.

3.7 Reliability and Validity

In a research, reliability means that if a research instrument is used and the results of the study can be reproduced under a similar methodology, then the research instrument is considered to be reliable (Golafsheni,2003).Conversely, validity refers to the ability of a research measuring what it is expected to measure, in that it is trustworthy and accurate (Bond, 2003).In this study, the research is expected to measure how rainfall variability affects sugarcane yields.

3.7.1 Reliability

To ensure reliability, internal consistency method was used to assess the correlation between multiple items in a test that are intended to measure the same construct. In this regard to get a high positive correlation, document analysis was used to ascertain the recorded information and the corresponding data from other sources that stretched within the same timelines as a triangulation method, Corbin and Strauss, (2008).

3.7.2Validity

In this study criterion validity was used. According to Fink, (2010), criterion is an external measurement of the same thing as it compares responses to those obtained from well established surveys. This means that the researcher went through the documents collected from rain gauge stations as well as Mumias sugar factory and ensured they correlated with the criterion so as to answer the specified objectives. Expert opinion helps to establish the criterion, Bellamy, (2015). The supervisors expert opinion helped improve the criterion.

3.8 Research Ethics

Considering that the research process is built on trust, it was essential to consider some ethics. For this study, research ethics was observed in different ways. First, the researcher got approval from the Maseno University School of Graduate Studies after presenting the proposal. A letter of authorization to collect data from Mumias Sugar Factory was given by Maseno University after which the researcher presented it to the management of Mumias Sugar Factory which in turn authorized the researcher to collect data. The researcher acknowledged the source of secondary information. This avoided plagiarism. Second, the data was only used for purpose of the study alone. The data was stored in a computer with a password that is only in possession of the researcher. The data will not be used in any other way. The researcher operated under Kenya's laws and the area given laws. In government offices the researcher had to seek for permission in advance.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter has been divided into two parts; the first part presents the analysis of rainfall variability at seasonal and inter annual scales, and the second part presents the effects of rainfall variability on sugarcane production in Mumias sub county between 1982 and 2012.

4.2 Historical trends in Seasonal and annual rainfall amounts

The historical trends in seasonal and inter annual rainfall amounts were analyzed to see their variations between 1982 and 2012.

4.2.1 Analysis of rainfall pattern over 31 years

Figure 3 shows the monthly long term mean rainfall recorded at Nucleus rain gauge station over 31 years. (Data depicted in Appendix 2).

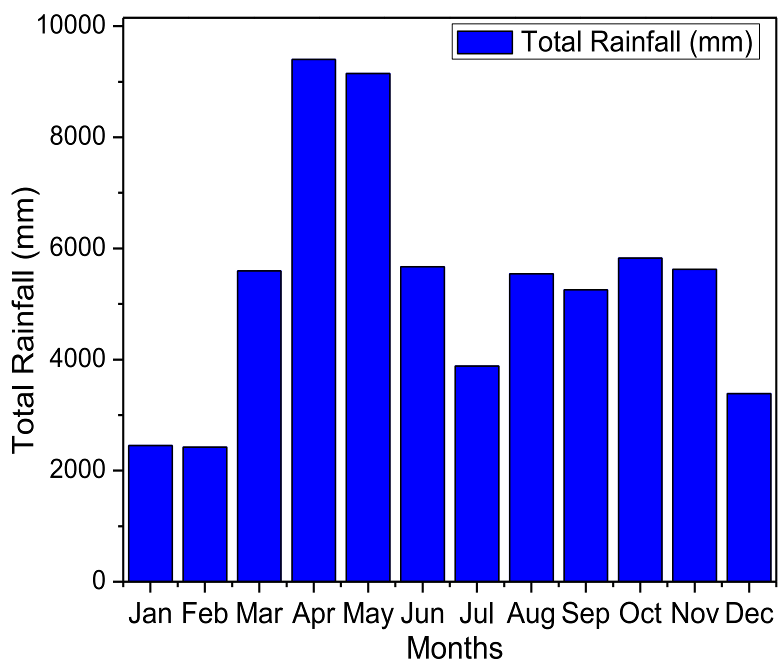

Figure 3: Annual cycle of total monthly mean rainfall amounts over Mumias sub county during1982-2012

The results from Figure 3 show that the major rainy season falls between March and May whereas the short rainy season falls between August and November. There were no distinct dry months in Mumias Sub County. The annual cycle of rainfall over Mumias Sub County reveals two distinct seasons: “long rains” during March-May (MAM) with peak in April and “short rains” October-December (OND) with peak in November. Lowest rainfall over the study domain is observed in January and February. The results from Figure 3show that it is almost dry from January up to February. The Figure 3 also shows that the long rains season commences in March with a peak being recorded in May. The rainfall amounts start to reduce towards July when low rainfall amounts are also recorded. Another rainfall season picks up starting in August with a peak period in October .It was evident from Figure 3 that the rainfall distribution is bimodal in nature which conforms with the rainfall patterns in tropical humid areas in Kenya as previously confirmed by a number of authors (Zhao and Yang, 2015; Ogwang*et al.,* 2016; Kerandi *et al*., 2016; Ongoma *et al*., 2017; Ayugi *et al.*, 2017) using different datasets.

These findings in Figure 3 concur with studies done by Clark *et al*., (2000) reported that the MAM season records higher rainfall than OND season. Degefu *et al.,* (2018), on seasonal trends of rainfall over tropical humid East Africa between 1963 and 2012 reported that rainfall was generally high in March to May and from September to December. Therefore, an analysis of monthly rainfall amounts was carried out to determine the seasonal totals and historical trends in the study area. The monthly long term rainfall amounts were analyzed to determine the total seasonal rainfall trend covering the study period of 31 years for the two rainfall seasons (MAM and OND).

4.2.2 Analysis of Total Seasonal rainfall amounts trends over 31 years

Figure 4 shows the trends in long rainfall season (MAM) and the short season (OND) recorded at the Nucleus rain gauge station over the last 31 years (1982-2012) while Appendix 3 represents the data values.

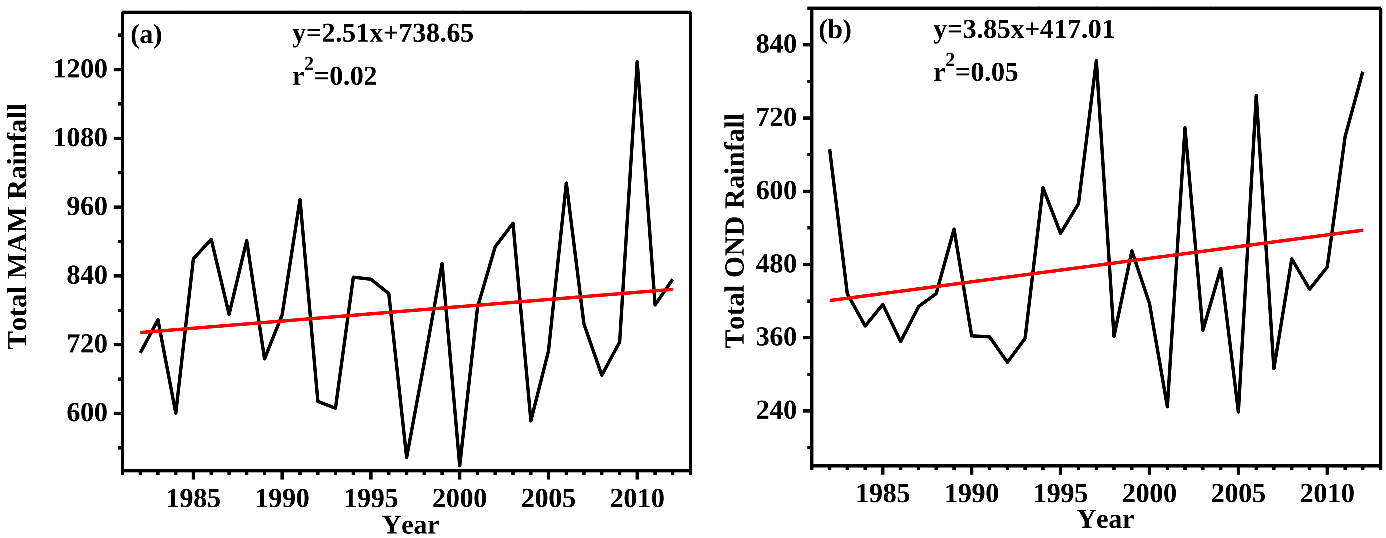

Figure 4: Rainfall trend for (a) MAM, (b) OND over Mumias Sub County during 1982-2012

Figure 4shows increasing trends in both the MAM and the OND seasons. The total rainfall within the two seasons in the sub county appeared to increase with a trend of (slope=2.51) at a non-significant (R^2=0.02, p>0.05) for the long rains (MAM) whereas (slope=3.85) at a non-significant (R^2=0.05, p>0.05) for the short rains (OND). The highest change in rainfall amount increment for the MAM season was recorded between the year 1996/1997and 2000/2003 as well as between 2008/2010 while the lowest change in rainfall amount was recorded in1995/1996. This change in rainfall amounts can be attributed to years that were linked to extreme events such as the *El Niño* of 1997/1998. Similarly, the OND rainfall amounts had the highest decrease in rainfall amount recorded between 1997 and 2001 and the highest increment between 2005 and 2007 while the lowest change in rainfall amounts was recorded between 1990 and 1993.

The analyses from Figure 4 show that historically, the rainfall trends have been increasing. The highest rainfall amount for MAM was recorded in 2011 while the lowest in 2000. The graph shows the period ranging from MAM cycle of 2002 to 2004 had high amounts of rainfall recorded consecutively which could have contributed to positive trends (+2.51 for MAM, +3.84 for OND). This was in consistent with results of Camberlin *et al.*,(2003)that observed total rainfall during the March to May seasons from 1968 to 1997 appeared to increase at a non-significant (R^2=0.39,P>0.05) in humid regions of Kenya and Uganda.

The results in Figure 4 concur with Gebrechorkos *et al,* (2019) who studied seasonal trends over humid and sub humid regions of eastern Africa between 1981 and 2016 and found out that generally rainfall amounts were highest in the months of September to December. Similarly, Kijazi and Reason, (2009) concur with these findings such that they observed that the heavy rainfall recorded during the OND in 2006 was as a result of warming over the western Indian Ocean that was also related to the *El Nino* phenomenon. In another study, Liebman *et al*., (2014) suggested that the high rainfall experienced in 2006 is a result of the season having a longer period from onset to the cessation period. In a similar study, Osbahr and Viner, (2006), reported that the highlands of western Kenya receive bimodal rainfall and its variability is experienced at onset which is unpredictable and also at times in extremes, for example the *El Nino* of 1997/1998 and the drought of 2000/2001. The MAM seasons of 1997 and 1998 recorded the wettest period which coincided with the *El Nino* events highlighted by (Schreck and Semmazi (2004); and Shongwe *et al.,* 2009); this was also evident in 2002/2003 period. From the analysis the driest seasons were recorded in 1984, 2000, 2001 and 2009. This dry period coincided with the *La Nina* phenomenon recorded in 2000/2001, (Schreck and Semazzi, (2004); and Shongwe *et al*., (2009).

From the analysis the study area conforms to a bimodal rainfall pattern that is common in humid regions of East Africa. Shongwe *et al.,* (2009) report concurs with these findings where positive trends for (MAM) and (OND) seasons over the wet and humid agro climatic regions of East Africa were recorded. The coefficient of variation for MAM seasonal rainfall was 0.3 (30%) and for the OND was 0.5(50%) which shows high rainfall variability. A number of rainfall variability modeling studies provide contrasting evidence in East Africa, for instance, time series plots of Shongwe *et al.*, (2009) over the region during the 20th and 21st centuries and in each rainy season provided substantial evidence in support of an increasing trend. However, results by Funk *et al*., (2013) and Omondi *et al.*, (2014) reported mixed trends in precipitation over the wet and humid region of East Africa. They reported that in some locations during certain seasons an increase in rainfall is observed while elsewhere a decrease in rainfall is observed.

In general, trends are weak in East Africa, (Daron, 2014).The changes in seasonal rainfall amounts contributed immensely to the rain fed agricultural activities in Mumias. Sugarcane growth takes a longer period spanning over the two specified rainy seasons. It therefore requires a stable rainfall regime. Sugarcane growth transcends over a period of two rainy seasons. It therefore requires an analysis of inter annual rainfall variability.

4.2.3 Analysis of annual rainfall trends in Mumias Sub County over the last 31 years (1982-2012

Figure 5 shows annual rainfall trends over Mumias during the period between 1982 and 2012

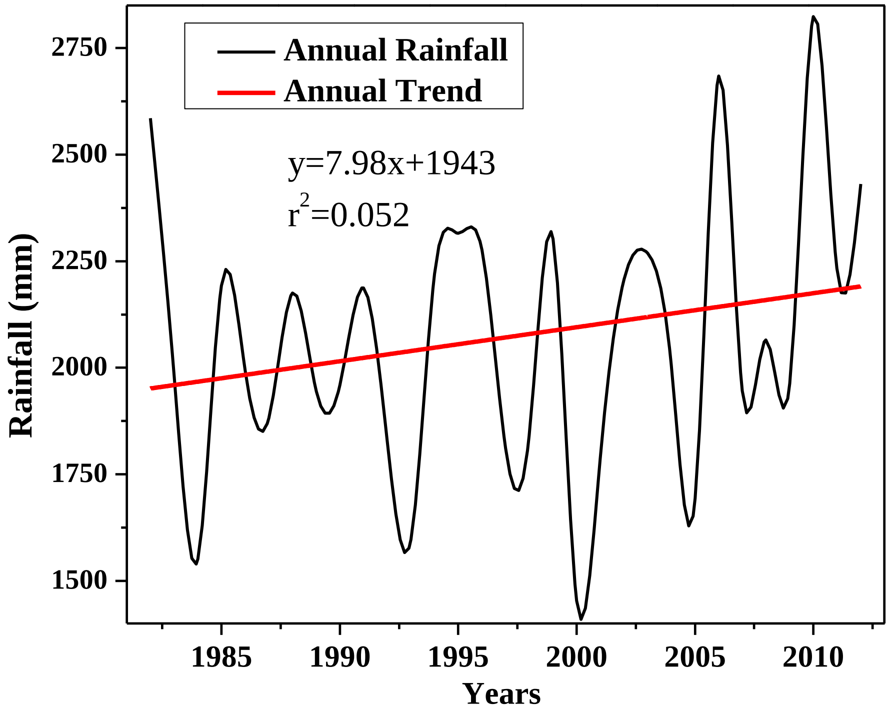

Figure 5: Annual rainfall distribution over Nucleus zone in Mumias sub county from 1982-2012

Figure (5) shows the annual distribution and annual rainfall trends (mm) over Nucleus zone in Mumias Sub County while the corresponding data values are represented in Appendix 4. It is evident that, there is a general variation in total annual rainfall amounts during the study period. The total annual rainfall amounts in Mumias sub county shows an increasing trend of a general positive slope of 7.98 of R^2=0.052 for the 31 year period. From the analysis only 5% of variation in total annual rainfall amounts can be explained for in terms of the period of years which can be attributed to climate change. From Figure 5, the years with extreme low rainfall were 1984 and 2000; moderate rainfall amounts 1985 and 2004, high rainfall amounts 1982and 2006 .Notable decrease in the amount of total annual rainfall was recorded in 1994 and 2000.The analysis from Figure 5 show that out of 31 years, Mumias sub county recorded 10 years above normal.

The results from Figure 5 confirm to a similar study in warm and humid Southern Africa regions by Philips *et al.*, (1999) where in the years 1982/1983, 1991/1992, 1994/1995 and 1997/1998 rainfalls had an increasing trend in total annual rainfall amounts. Similarly, the enhanced rainfall amounts were recorded in 2006 and 2012 which conform to the trends in tropical regions of East African as suggested by a number of authors (Zhao and Yang, 2015; Ogwang *et al.,* 2016; Ayugi *et al*., 2017; Ongoma *et al.,* 2017). The results derived from the present analysis imply that there is a general increase in total annual rainfall amounts over the study domain.

The results derived from the study as in Figure 5 are in line with similar studies by National Aeronautical Space and Administration (NASA), space flight center (2007) that indicated a 5% increase in annual rainfall in the tropics In studies over Tanzania, Liwenga (2012), reported an increment in rainfall trends highlighting specifically drought being extreme in 1995/ 2000, severe in 1993 and 1997, moderate 1996 and 2005, normal years were 1989/ 1990, 1992 and 1995/1996, and the wet years were 2002, 2003 and extremely wet, 1998 and 2000. In Vhembe, South Africa, Shandukani and Tibangayuka, (2013) reported a decline of -3.95mm and 18.3mm per year between 1970 and 2009 which indicated some regions in Africa were facing declining annual rainfall trends. The African continent has been noted to be affected by rainfall variability as indicated in a report by (IPCC, 2013). In their study Zhao and Yang, (2015) demonstrated that an increment or a decrease in annual rainfall amounts for at least a year affected sugarcane biomass yields. Similarly, Kisaka *et al*., (2015), in a study over sub humid regions of eastern Kenya reported that the annual total rainfall is unpredictable and poorly distributed over time which leads to crops suffering from stress. From Figure 5, therefore the variation in total annual rainfall amounts could have affected sugarcane production. From these analyses to compare the degree of variation of total rainfall amounts between years, the Coefficient of variation trend for inter annual rainfall was calculated for the 31 years of study. The trend of coefficient of variation for the period between 1982 and 2012 is presented below in Figure 6.

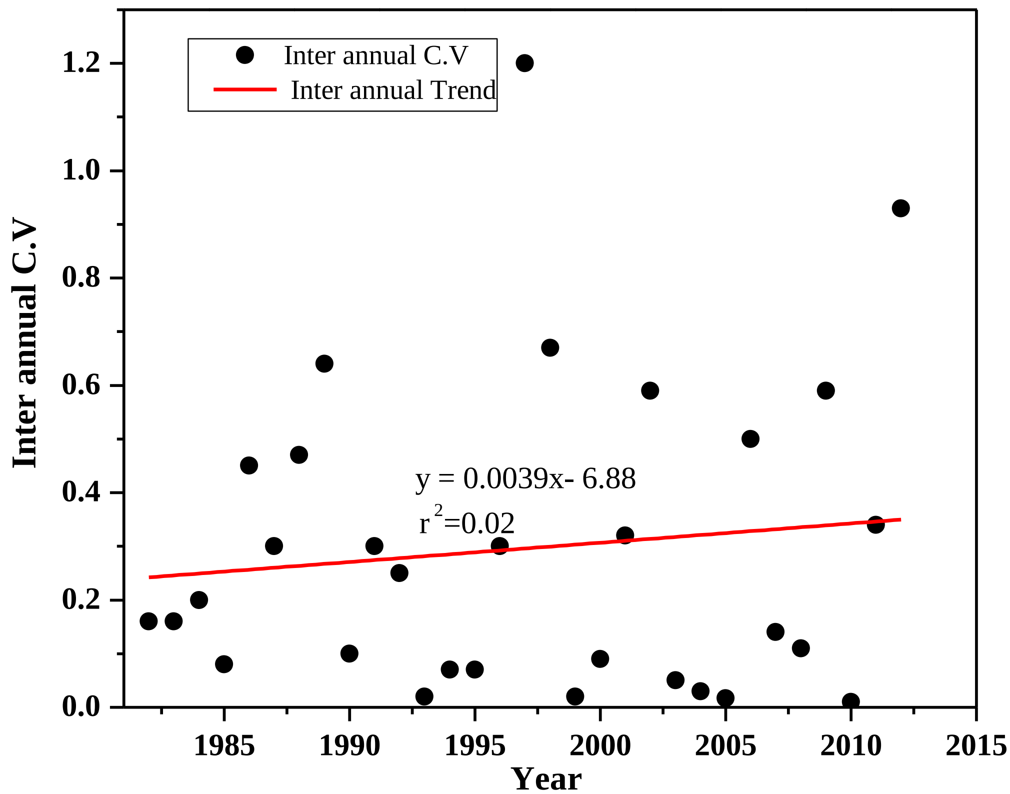

Figure 6: Inter annual Coefficient of Variation trend over Nucleus zone in Mumias sub county from 1982-2012

From Figure 6, shows the annual rainfall coefficient of variation (CV) for 31 years period. The Coefficient of Variation slope shows an increasing trend in inter-annual rainfall variability of positive slope 0.0039 of r^2 =0.02. The analysis presented in Figure 6 show that only 2% of variation in CV can be explained for in terms of years. The analysis shows that there was a general increase in coefficient of variation in the study area of which out of the 31 years of study, 17 years had a coefficient of variation above 20%. The year 1998 and 2009 show one of the highest CV values of above 0.9. These are years when the area was experiencing the *El Niño/La Nina* phenomenon. However, there are a number of years that the CV value was high (CV of 0.6) for instance in 1989 and 1994, which could be attributed to complex interactions of forced and free atmospheric variations within the study region. There are a number of years when the CV value was almost zero, such as 2005 and 2010. This could be attributed when the previous year's rainfall amounts versus the preceding year's rainfall amounts had similar patterns since the region lies close to the equator and it is in a modified warm and wet region sometimes referred equatorial region. The findings in Figure 6 indicate presence of inter annual rainfall variability in the study area.

A number of studies have suggested that rainfall data that has a coefficient of 0.2 (20%) or above, indicate high rainfall variability (Doorenbos, (1976), Kisaka, *et al.*, (2015)). In a similar study done by Bewket, (2009) on long term rainfall variability in Amhara, Lalibela Ethiopia between 1975 and 2003 a CV of 0.2 (20%) was recorded which was a departure by 0.1 from (CV of 0.3) for the 28 years and it was cited to be relatively high. In humid region of East Africa, Lyon, (2014) and Schmocker, (2016) suggest existence of high levels of inter annual rainfall variability which is consistent with the results obtained in Figure 6.

In results from Figure 6 the high inter annual variability was not only experienced during the years of extreme events such as *El Niño* or *La Nina*. Inter-annual, seasonal and variability of rainfall is also as a result from complex interactions of forced and free atmospheric variations as suggested by Khasandi, (2016). She states that, these include several synoptic systems such as monsoons, trade winds, tropical cyclones, subtropical anticyclones, easterly/westerly wave perturbations and the extra-tropical weather systems that influence the rainfall distribution. Other causes of inter annual rainfall variability in the region have been suggested such as existence of teleconnections between rainfall variability over the EA and other global climate indices such as QBO as in studies by Ogallo *et al*., (1994) that are winds contributing to the *El Nino* rains. Another contributor to the variations in annual rainfall amounts the Southern Oscillation Index (SOI) as stated by Ropelewski and Halpert(1987) which causes fluctuation of atmospheric pressure over Indo-Pacific region. This atmospheric component is the cause of *El-Nino* rains. From the findings, the annual rainfall amounts that were recorded within the entire study period vary such that they show an increase or a decrease in quantity due to these phenomena. Therefore Mumias sub county experiences inter annual rainfall variability which may have an effect on sugarcane production.

4.3 Analysis of historical trends in Sugarcane yields from out grower farmers in Mumias

An analysis on the trends of sugarcane yields was done with a view of assessing the production of total sugarcane biomass yields and the quality of sugarcane produced. This was in connection with the fact that sugar production is one of the main agricultural activities in western Kenya and the importation of sugar seems to be on an increasing trend in the country. The total biomass sugarcane yields in tonnes per hectare (TCH) by Mumias Sugar Company were analyzed along the study period in Figure 7.

Figure 7 shows the trend of sugar cane biomass yields for the period between 1982 and 2012.

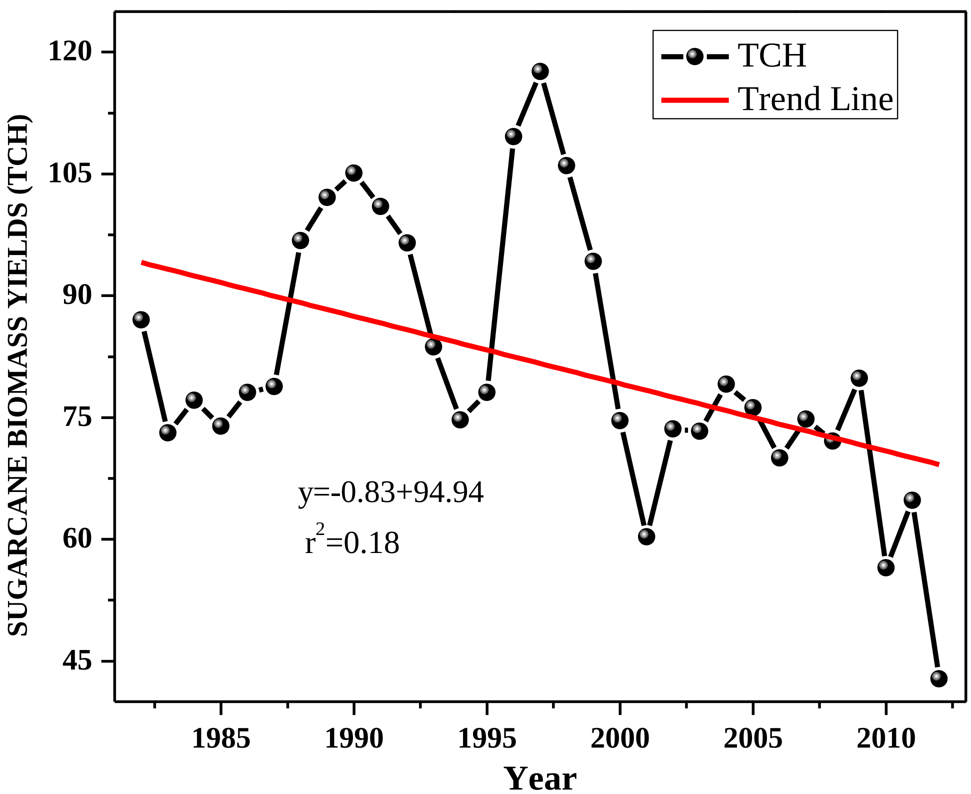

Figure 7: Total sugarcane biomass yields versus the year of harvesting during 1982-2012

From Figure 7 the total sugarcane biomass yields show a declining trend in Mumias sub county with a slope = -0.83 while R^2=0.276 implying that only 27.6% of the variation in production can be explained for by time in terms of the number of years such as changes in pricing of sugarcane biomass yields and changes in land use. The results in Figure 7 show sugarcane biomass yields have generally been decreasing from 1982-2012. The highest sugarcane biomass yield was realized in 1997 and this is the period that followed a stable rainfall regime from 1994 up to 1996 and other factors not considered in this study such as the sugar price that could have attracted more farmers to plant sugarcane. The lowest sugarcane biomass yield was recorded in 2011. This low yield could be attributed to a high CV value of above 0.3 (30%) recorded in 2009 and 2011.Within the same period the total annual rainfall CV has been increasing which suggests this to one of the underlying factors that are leading to poor yields such as leaching of soil nutrients, poor weeding and interference with agronomic activities as reported by a number of authors such as Santos and Sentelhas, (2005) .The highest decrease is recorded 1998 and 2001.This period corresponds to years when total annual rainfall amounts dropped drastically, (See Figure 5).

Studies done by a number of authors such as Salter and Schroeder, (2012) attribute low sugarcane yields to low annual rainfall amounts recorded. Conversely, stable production of sugarcane biomass yields were realized between 1994 and 1995 due to stability in annual CV (See Figure 6) as suggested by Binbol, *et al.*, (2006). However, there was a decline in yields from 2011 to 2012 despite the same period recording high rainfall amounts. This concurs with similar studies done by related studies Kirungu, (2011) over western Kenya who suggested that water stress as a result of inadequate rainfall at the late canopy development stage affects yields. In another study Sillah, (2014) attributed low yields to farmers' behavior whereby investment in production is highly related to predictability of returns. In this connection rainfall variability that lowered yields over the period could be affecting further investment from both large and small scale farmers in sugarcane production. This is in contrast with other sugarcane growing areas in the world that have recorded a positive trend such as Pakistan where economic returns are high in sugarcane farming, as revealed in studies done by Saira *et al.*,(2015) . In these countries sugarcane farmers are provided by new varieties of sugarcane so as to cushion them from challenges of variations in rainfall amounts. This positive trend was attributed to an increment in land acreage under cane. Another study done by Ibrahim *et al.*, (2010) over Nigeria during the period 1980 to 2007 revealed a compound increase by 2.10% in sugarcane yields with a good fit and R^2=0.17 signifying that 17% of the production would be explained for by the number of years. This increase was attributed to farmers growing better sugar cane varieties.

Apart from total sugarcane biomass trend being analyzed, sugar quantity is an integral product in sugarcane production. This therefore requires a trend analysis for the sucrose quantity to be done. In this case the POL value (sucrose %) was correlated with the study years as shown in Figure 8. Figure 8shows sugar quantity (sucrose) trends in Mumias sub county over the last 31 years (1982-2012).

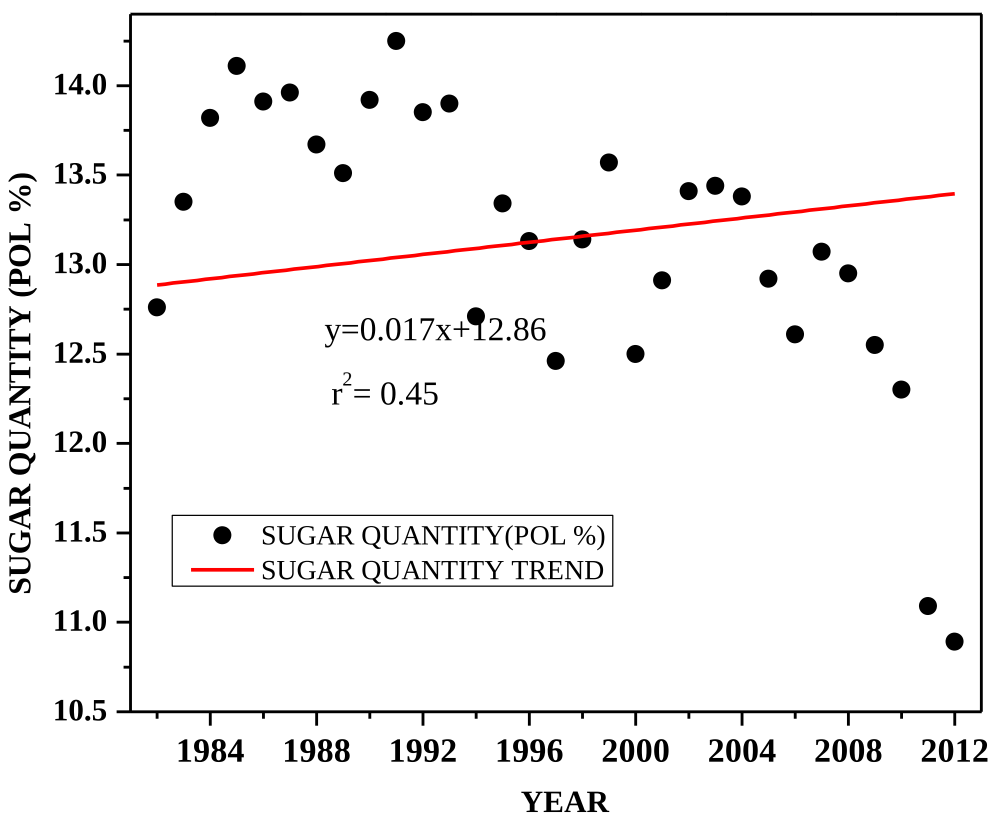

Figure 8: Sugar quantity (Sucrose) trends over Mumias sub county during 1982-2012

Figure 8 shows that the sucrose trend in Mumias sub county is generally increasing positively with a slope of 0.017 and R^2=0.45 implying 45% of the production factors can be explained for by time in terms of the period years. Other factors that could have contributed to slight increment of sugar quantity levels could be the improvement in factory sugar recovery procedures, temperatures and soil nutrients, though they were not considered under this study. From Figure 8, the Pol value for 2010 and 2011 was extremely low (10.75 and 11.00) in comparison to the rest of the years during the study period. Notably, the same years correspond to low sugarcane biomass yields harvested. This could be attributed to among other factors the increased total annual rainfall amounts that led to leaching of soil nutrients and other factors not considered in this study such as dwindling returns from sugarcane farming. In this case poor quality cane could have been harvested. The time factors are quite substantial since they contribute to almost 50% of the other production factors. Harvesting of sugarcane which is immature will yield low Pol value sugar whereas mature cane will yield high Pol value sugar as suggested by Zhao and Yang-Rui, (2015). Similarly, Fabio, *et al*., (2010) noted that, it is very important to quantify time as a production factor because the ratoons' yield which is part of the sugar quantity produced take time to grow as they reengineer the quality of their produce.

This analysis indicates that though the relationship between the sugar quantity and the number of years shows a positive trend, there are other factors contributing to the slight increment in sucrose sugarcane produced. A study done in Coimbatore, India (TNAU; www.tnau.ac.in, 2014) suggested that, the time of harvesting sugarcane such as during rainy period or dry season affected the Pol value. According to Xiao (2017), increased March rainfall enhances photosynthesis in sugarcane crops and therefore there has been an increase in (MAM) seasonal rainfall amounts which could have contributed to the increase. Changes in Pol value could as well be attributed to most farmers in Mumias starting to harvest their cane at the right time such as during dry times.

4.4 Analysis of effects of total seasonal and annual rainfall amounts on sugar cane biomass yields.

The effect of the rainfall amounts variation within the long rains season (MAM) was analyzed with a view of assessing its impact on sugarcane yields. This was due to the fact that the main planting period of sugarcane in the study area falls within this season because there is sufficient rainfall to support good germination. Total seasonal rainfall amounts were analyzed along total sugarcane yields that are the tonnage (TCH) of raw harvested cane. A six months interval between the rainfall amounts and the corresponding sugarcane yields was observed. Appendix 4 provides information of the total seasonal rainfall, sugarcane yields received by Mumias Sugar Company. The total seasonal rainfall amounts received were correlated to the sugarcane biomass yields from out grower farmers in Figure 9.

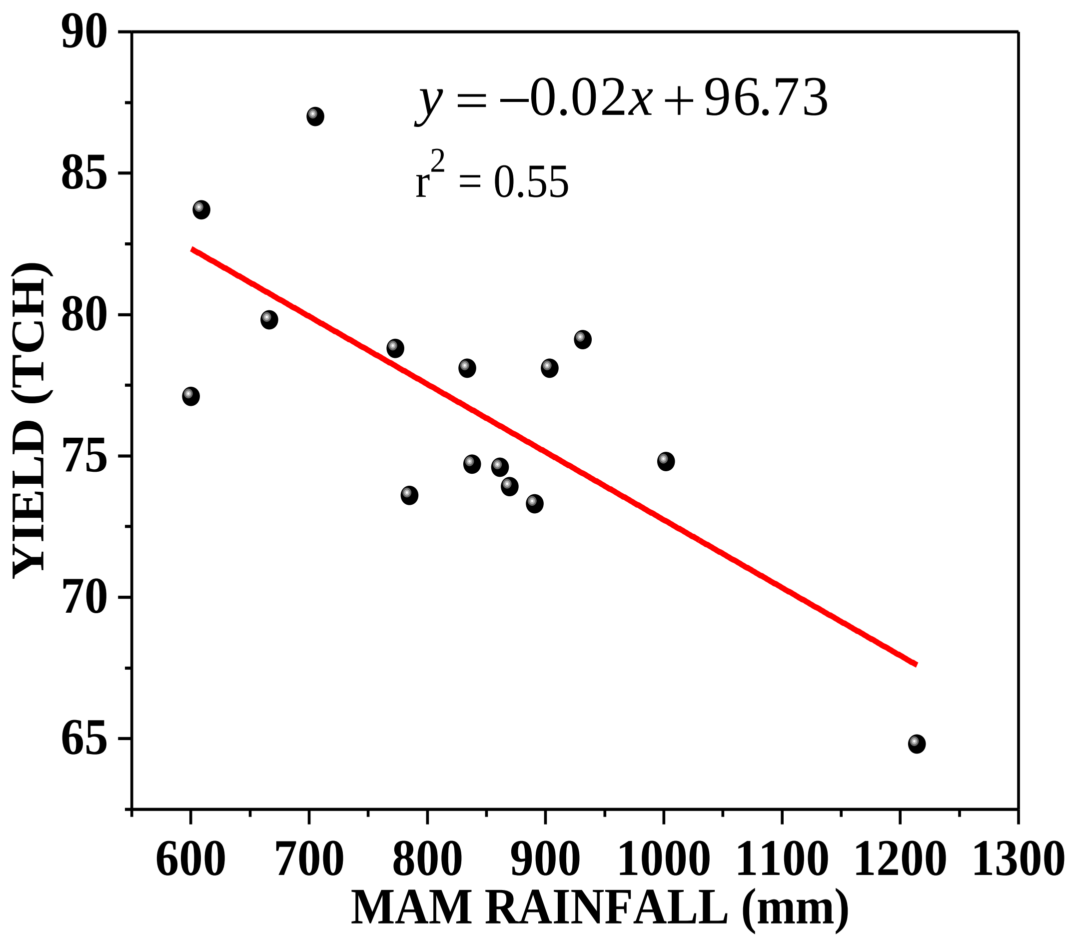

Figure 9: Total MAM rainfall amounts versus sugarcane biomass yields for the period 1982-2012

Figure 9 shows that an increase in total (MAM) seasonal rainfall amounts corresponds to a decrease in sugarcane biomass yields (slope= -0.02, R^2=0.55). The relationship between sugarcane biomass yield and MAM rainfall showed that 55% (r^2=0.55) of variation of sugarcane biomass yield can be explained by total rainfall amounts in March—May. These results demonstrate the total seasonal rainfall (MAM) is a very important factor affecting sugarcane yield because other factors accounted for 45% of variation of sugarcane yield. These other factors could be temperature, runoff water, intensity of rainfall and time of harvesting as suggested by Kirungu,(2011). Figure 9 also shows that relationship between total (MAM) seasonal rainfall and sugarcane biomass yields was decreasing at non-significant rate of (slope= -0.02) implying that when high long rains total amounts were recorded, sugarcane biomass yields decreased in that sugarcane elongation stage is affected. Further, from Figure 9, it is shown when the region of Mumias Sub County receives very high rainfall amounts during the long rains season (MAM), the corresponding yields for the period were decreasing. It is also shown from Figure 9, that moderate rainfall amounts ranging between 800mm and 900mm correspond to high sugarcane yields of tons harvested per hectare (above 75) being realized.

A number of authors such as Binbol, *et a*l., (2006) have suggested that sugarcane yields are affected during the main seasonal rainfall because of the germination rates of the crop and the elongation stage are affected. The results are in line with what Mortimore and Adams, (1999),Mulianga, *et al.*, (2013), Zhao and Yang, (2015) who found in their studies that variation in moisture content in the soil takes a period of almost a year to be seen in variation of sugar cane yields. They also indicated in their studies that the distribution and length of the period of rain during the elongation stage and the effectiveness of the rains in each rainfall event is the real factor that affects the yields of crops. Studies by Salter and Schroeder (2012) in MacKay (Australia) reported that total seasonal rainfall variability had an impact on sugar cane production. They established that well distributed or moderate seasonal rainfall amounts lead to high yields. In similar studies over Fiji, Zhao and Yang, (2015), reported a record sugar production (516,529 tons) in 1994 due to favorable main seasonal rainfall amounts, but sugar productions in 1997, 1998, and 2003 were 47, 50, and 43% of the average sugarcane biomass yields harvested respectively, lower than that in 1994 due to low main seasonal rainfall amounts. The analysis in Figure 9 conforms to other sugarcane growing zones whereby well distributed main seasonal rainfall amounts received lead to high yields as reported by a number of authors such as Salter and Schroeder (2012)

The region also receives enhanced rainfall in the months of October to December which is referred to as the short rains season (OND). An analysis of the relationship of this season rainfall amounts to sugarcane yields was done. Figure 10 shows the relationship between total OND rainfall amounts to sugarcane biomass yields during the period 1982 to 2012 in Mumias Sub County.

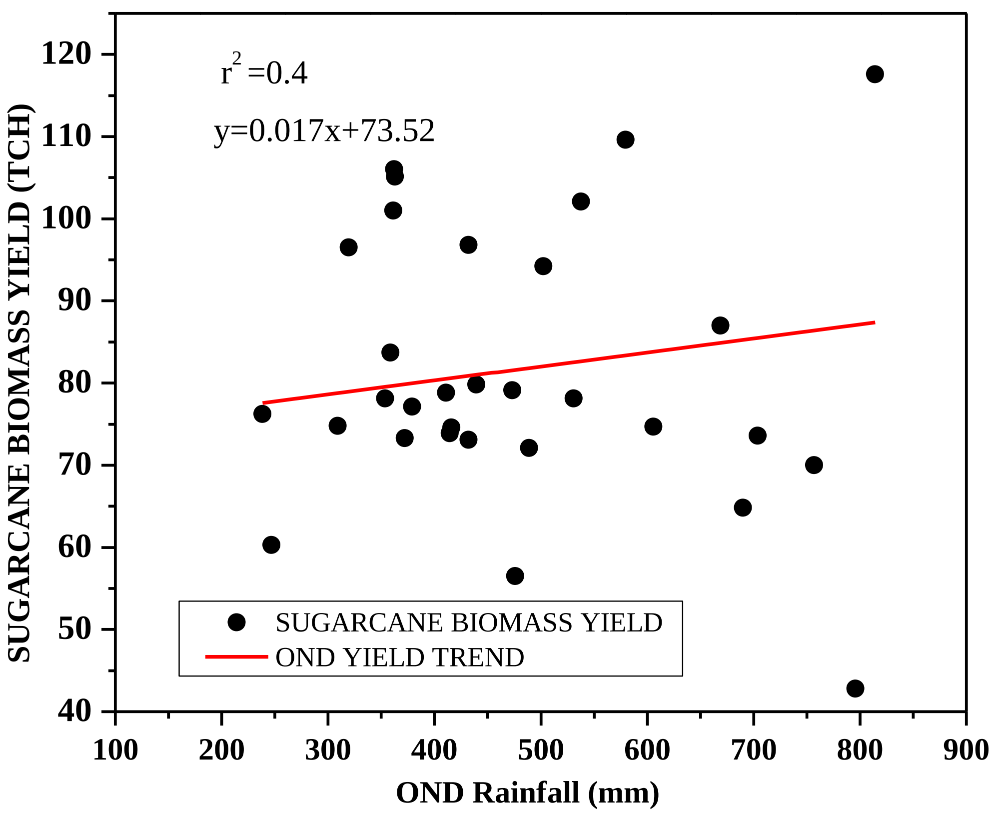

Figure 10: Total OND rainfall amounts (mm) in relation to sugarcane biomass yields for the period 1982-2012

From Figure 10 the relationship between total (OND) rainfall amounts and sugarcane biomass yields shows a slight increase in sugarcane biomass yields (slope= 0.017, R^2=0.4). This implies that 40% of the variation in sugarcane biomass yields can be explained for by total rainfall amounts in October—December. A slope of 0.017 indicates low variation in sugarcane biomass yields as attributed to variation in seasonal rainfall amounts during this season over the study period of 31 years. The results demonstrate that OND rainfall is not a very important factor affecting sugarcane yields because other factors accounted for 60% of the variation of sugarcane yield. These factors that were not considered in this study could temperature and soil nutrients. The temperature and soil fertility could have affected sugarcane biomass yields but the study did not analyze to what extend it could have had on the yields as suggested by Binbol, *et al.,* (2006). From Figure 10 analysis, the optimum total seasonal rainfall corresponding to high yields was when rainfall amounts were between 400mm and 800mm but not above 800mm.High OND total rainfall amounts could also converge with the long rains and this could create mixed results in the sugarcane yields of the preceding year. The sugarcane yields could also have not been affected during the (OND) season because during this period a number of studies have suggested that the high temperatures experienced contribute to high levels of Carbon dioxide that is essential in accumulation of biomass, Zhao and Yang, (2015).

From Figure 10 it can be noted that since the OND season is not the main planting season its effects on yields may be minimal as reported in a study by Masavya *et al,* (2009) who indicated that this could attributed to the alteration planting dates, though the study did not specifically focus on sugar cane. This implies that some farmers could have planted sugarcane during this period. The slight increase of sugarcane yields can be attributed to the high seasonal rainfall variability experienced during the OND season as suggested by Yahaya, *et al*., (2014) who attributed the increase in yams yield between 2001 and 2009 to an increase in the amount of rainfall received over Nigeria. The analysis from Figure 10 are in agreement with findings from a similar study in Kenya, Mulianga, (2018) who reported that when rainfall is normalized at seasonal level, its impact on sugarcane biomass yields is minimized. Since seasonal rainfall amounts affect the annual rainfall, it was prudent to find out the relationship between total annual rainfall amounts and sugarcane biomass yields using linear regression. The sugarcane yield was taken from the out grower farmers output since they are the key stakeholders in the industry and also most of the cane harvested in the study area is from the farmers. The information is depicted in Figure 11.

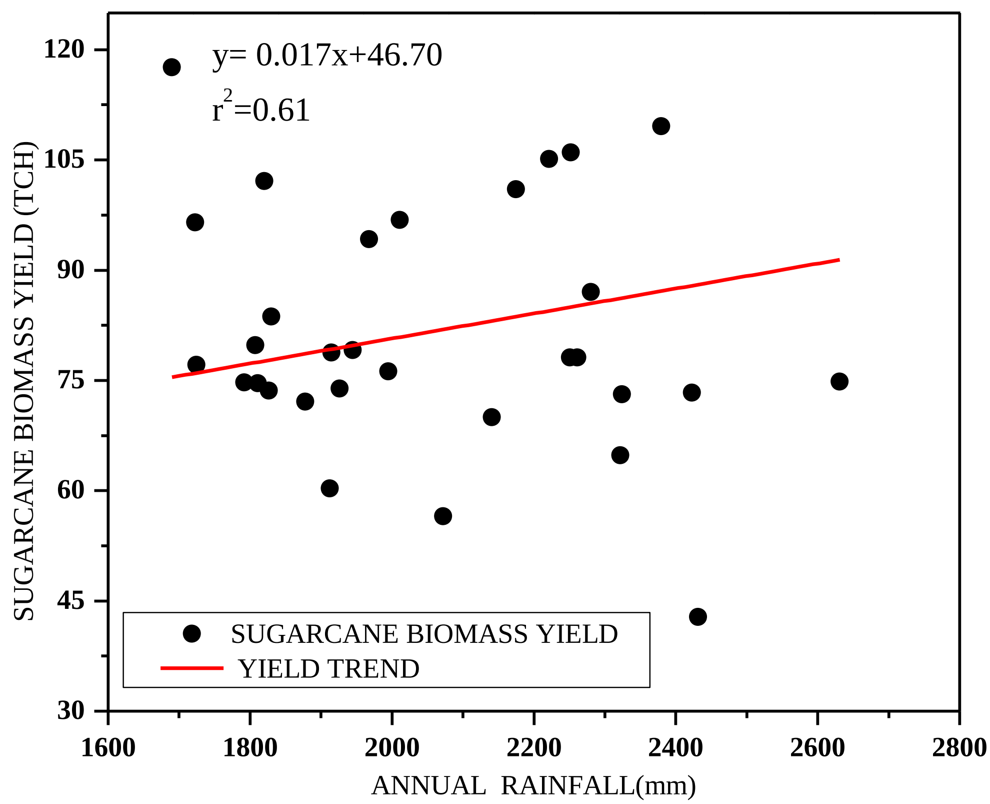

Figure 11: Total annual rainfall amount (mm) in relation to sugarcane biomass yields for out grower farmers during the study period of 31 years

From Figure 11 the analysis showed the relationship between total annual rainfall amounts and sugar cane biomass yields was increasing slightly (slope=0.017, r^2=0.61). This indicates that 61% (r^2=0.61) of the variations in sugarcane biomass yields can be explained by total annual rainfall amounts. These results demonstrate that total annual rainfall amounts is a very important factor affecting sugarcane biomass yields since other factors accounted for only 39% of variation of sugarcane biomass yield. From Figure 11, the analysis shows that in years where there was less annual rainfall amounts low sugarcane biomass yields were realized. This was in years receiving between 1700mm to 2300mm as depicted in Figure 11. Apart from the *El Niño* and *La Nina* years the production of optimum sugar cane yields is between 1700mm and 2300mm. The main outliers are falling within periods of global phenomenon the *El Niño* and *La Nina.* Rainfall amounts above or below this could be interfering with agronomic activities such as harvesting, weeding and even the soil fertility. From the analysis the sugar cane yield increased in relation to increase in total annual rainfall amounts. The total annual rainfall amounts are affected by the seasonal rainfall amounts hence the effect is translated to the sugarcane biomass yield. Therefore from Figure 11, sugarcane biomass yield is strongly affected by total annual rainfall amounts accounting for about 61% of the variations.

This result in Figure 11 is similar to a study by Shruti, *et al.,* (2017) over tropical India where it was reported that annual rainfall variations affected sugarcane growth and yields. In Pakistan, Hussain, *et al*., (2018) cited periodical variations in annual rainfall amounts as one of the factors affecting sugarcane biomass yields. Similarly, Deressa ,*et al.*, (2005) reported that total tonnage of sugar cane harvested appeared to increase per acre with an increase in rainfall amounts though increasing it beyond its normal by 4mm damages sugarcane production. This result is similar to a study done by Binbol, *et al*.,(2006), in Numam, Nigeria, reported that sugar cane yield correlate strongly and positively with climatic factors. Deressa, *et al.*, (2005) further reported that high level precipitation in winter increased net value per acre. Jamoza, (2005) concurs with these findings where it was suggested that erratic and low rainfall was the main cause of low cane yields in the highlands western of Kenya.

The study findings show that the availability of enough total annual rainfall amounts lead to high yields. The analyses were also done on sugarcane ratoons in relation to (MAM) rainfall amounts because it is the main planting season and the ratoon yields make part of the accumulative sugarcane biomass yield received by Mumias Sugar Company.

The analyses of effects of total seasonal (MAM) and annual rainfall amounts on plant, first ratoon, second ratoon, third ratoon yields and sugarcane varieties yields was done on the Nucleus yields so as to cater for farm management practices that cut across all the ratoons and thus minimizing chances of bias.

The Nucleus estate yields were analyzed for plant, first ratoon, second ratoon and third ratoon that are economically viable. Figure 12 shows analysis of the findings of the information on the sugarcane yields in relation to their ratoons and the main seasonal rainfall (MAM) amounts.

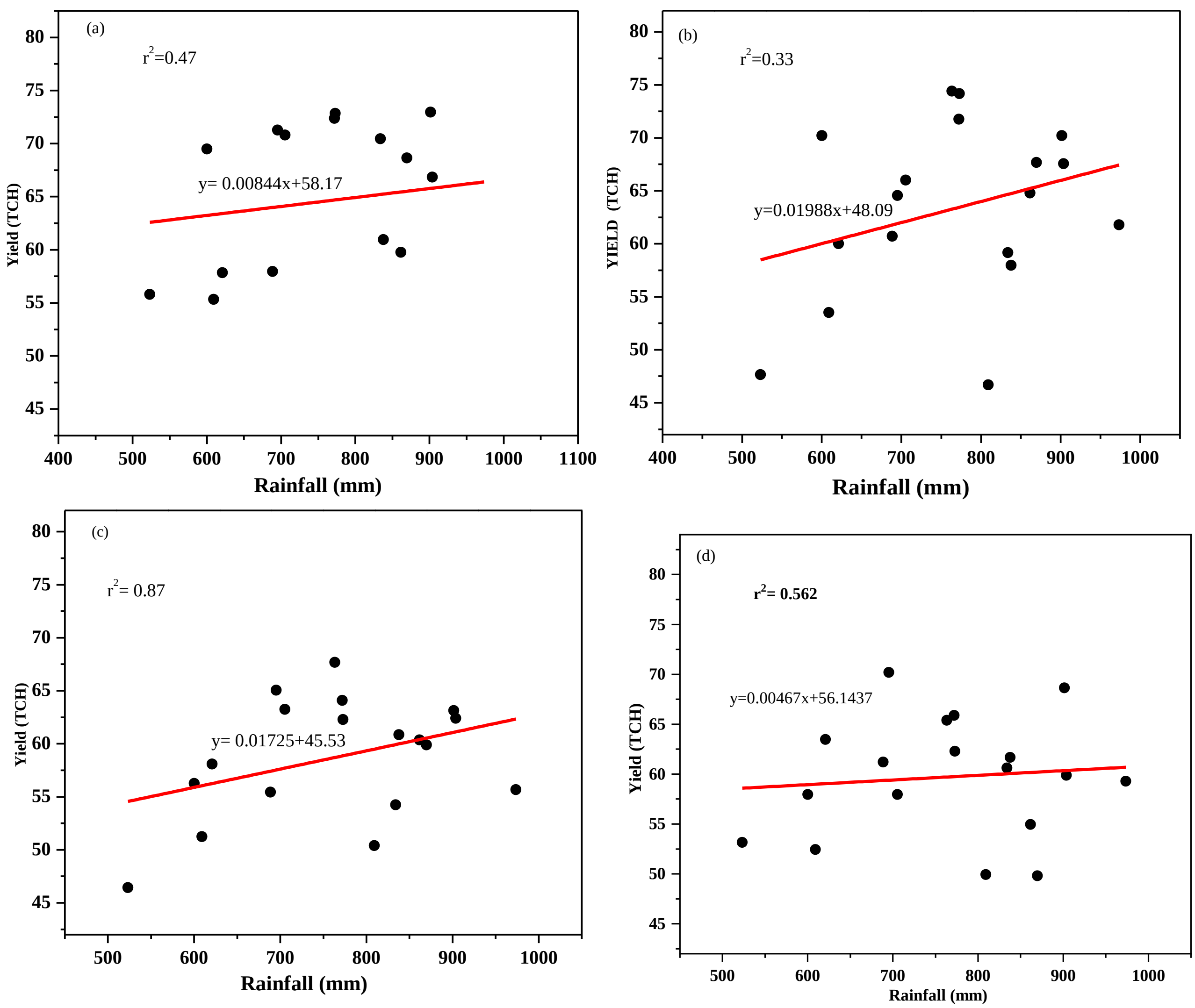

Figure 12: Scatter plots of Sugarcane biomass yield (TCH) versus MAM seasonal rainfall for (a) plant, (b) first ratoon, (c) second ratoon, (d) third ratoon.

From Figure 12, the scatter plots show the relationship of the main seasonal rainfall (MAM) amounts versus the ratoon yields. Figure 12(a), the plant yield appeared to increase at a significant rate (R^2=0.47, $p<0.05$). The Figure 12(a) shows that 0.47 (47%) of the variation in sugarcane biomass yields can be explained by total seasonal rainfall amounts. The relationship between the plant crop yields and the total seasonal rainfall shows that high seasonal rainfall amounts such as above 650mm correspond to high yields. In periods that the total seasonal rainfall amounts fell below 600mm the yields were low. There was an exceptional period when the rainfall amounts recorded were 850mmyet the yield was low. This could be attributed to a period when cane harvesting delayed due to the El *Nino* phenomenon and other factors not considered in this study such as the method of harvesting the ratoon crop. In Figure 12 (b), the yield of the first ratoon increased at a non-significant rate (r^2=0.33), implying that 0.33(33%) of variation in sugarcane yield can be explained in terms of main seasonal rainfall (MAM) amounts. The rest 67% could be other factors not considered in this study such as the first ratoon crop tillers could have been damaged during harvesting of the plant crop resulting in lower yields as suggested by Gomathi *et al.*, (2013) and the level of cutting which affects the stem number as indicated in a study by Sakaigaichi *et al.*,*(*2017).

In Figure 12(c), the second ratoon yield appeared to increase at a significant rate (R^2=0.87) implying that 0.87 (87%) of variation in sugarcane biomass yields can be explained for by total seasonal rainfall amounts. Other factors not considered in this study accounted for 0.13 (13%) indicating that total seasonal rainfall amounts is an important factor in variation of sugarcane biomass yields. This could be attributed to good establishment of the ratoons and sprouting of many tillers due to the available soil moisture as suggested by Smit, (2011). The increment was higher than the first ratoon. Total main seasonal rainfall amounts above 700mm gave rise to higher yields whereas those below 600mm gave rise to low yields. In Figure 12 (d), the third ratoon yield appeared to increase at a significant rate (R^2=0.562) implying 0.562 (56.2%) of variation in sugarcane yields can be explained for by total seasonal rainfall amounts. Other factors not considered in this study accounted for 0.438 (43.8%).Analyses in Figure 12 showed that the plant, first ratoon, second ratoon and third ratoon yields were all higher than their long term mean against high total seasonal rainfall amount of 600mm.

This result in Figure 12 conforms to a similar study over Australia An-Vo *et al.*, (2017), Australia; that concluded that the response of ratoons to precipitation was not the same. In another study, Leite, *et al.*,(2016) over humid Brazil reported that adequate main seasonal rainfall is one of the major climatic factors affecting the process of sugarcane biomass accumulation for both plant and ratoon cycles. In a related study over Coimbatore, India, Gomathi, *et al.*, (2013) indicated that cane length were highly associated with the yield of the first and second ratoon. From this study it implies that the variation of the first ratoon yield and the second ratoon is affected by the amount of the main seasonal rainfall and this concurs with studies by Ferraris and Chapman, (1991) in Australia.

A number of studies concur with findings in Figure 12 such as studies by Hurney,(1992) and Chapman *et al.*,(1992)who suggested that a number of factors contribute to the variation in ratoon yields during the main rainy season among them the number of buds per stem piece that develop during the main rainfall season contribute to sugarcane yields. In studies over Uttar Pradesh, India, Singh, et al., (2005), indicated that sugarcane ratoon yields correlated highly with the main seasonal rainfall period. This result is similar to result in Figure 12. It implies that better rainfall amounts enhance the sprouting and establishment of the ratoons that eventually give rise to better yields. Shruti, *et al.*, (2017) in a study over tropical India reported that variations in rainfall amounts affected sugarcane growth. Therefore the ratoon cycle yields were generally affected by variations in the main seasonal (MAM) rainfall amounts.

The main seasonal rainfall having been seen to be one of the major climatic factors affecting the sugarcane biomass yield, it was necessary to analyze the effects of total annual rainfall amounts on ratoons biomass yield since they are grown for a period spanning over a year. Figure 13 shows the analysis of total annual rainfall amounts versus the plant, first second and third ratoon biomass yields that are economically viable.

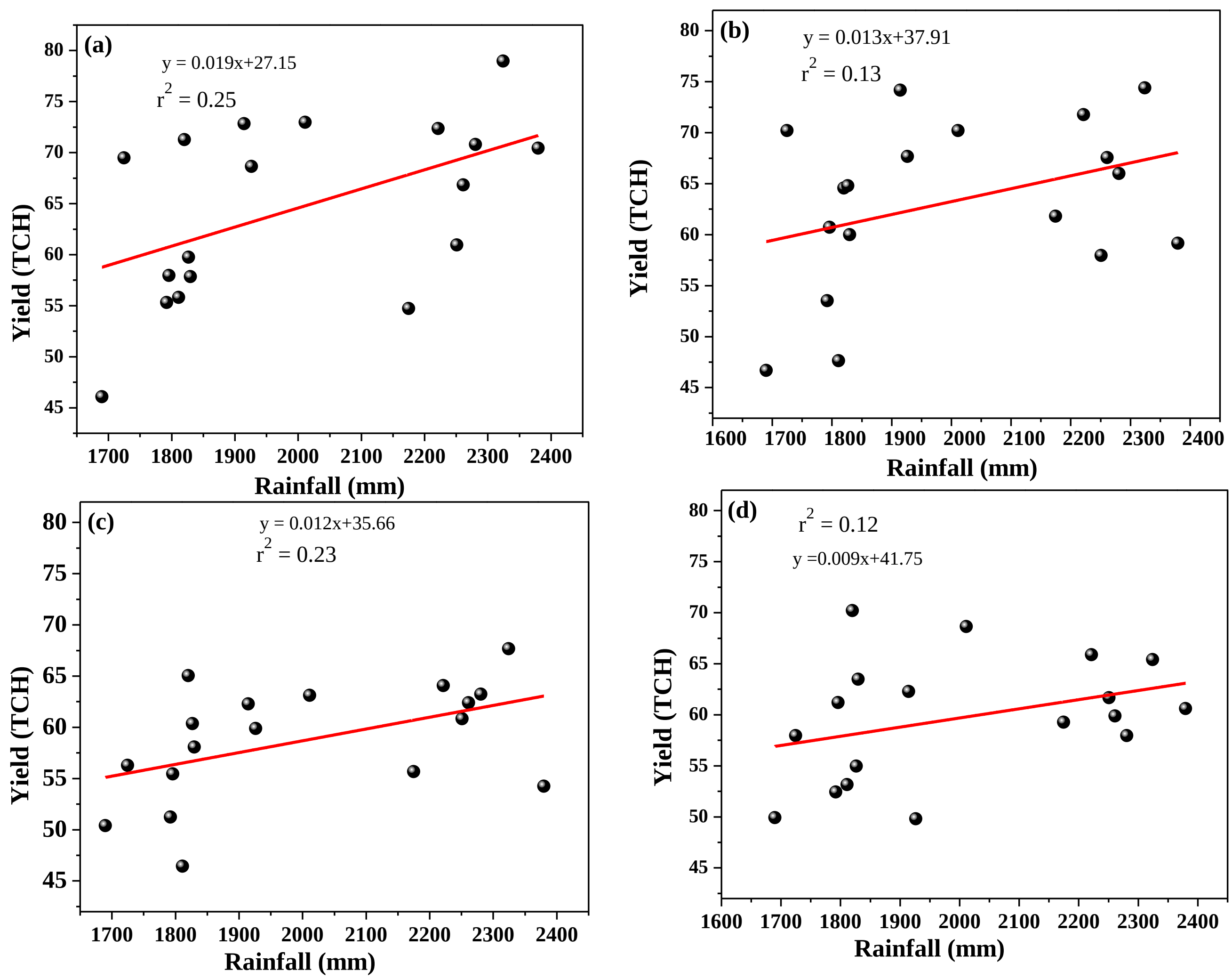

Figure 13: Scatter plots of yield (TCH) versus annual rainfall (mm) for (a) plant, (b) first ratoon, (c) second ratoon, (d) third ratoon during 1982-2012.

From Figure 13, the scatter plots show the relationship of annual rainfall amounts versus the ratoon yields. Figure 13(a), the plant yield appeared to increase at significant rate (R^2=0.25, $p<0.05$). The Figure 13(a) shows only 0.25 (25%) of the variation in sugarcane biomass yields can be explained by total annual rainfall amounts. The effect of total annual rainfall amounts on the plant crop yields shows mixed results, though there was a general increase of about 2% in sugarcane biomass yields. In years that the total annual rainfall amounts fell below 1900mm the yields were low or moderate. In Figure 13 (b), the yield of the first ratoon increased at a non-significant rate (r^2=0.13), implying that only 0.13(13%) of variation in sugarcane yield can be explained in terms of total annual rainfall amounts. The rest 87% could be other factors not considered in this study such as the first ratoon crop could have had more tillers than the plant crop resulting in higher yields and during this period total annual rainfall amounts were high as suggested by Gomathi *et al.*, (2013) and as indicated in a study over humid Japan by Sakaigaichi *et al., (*2017). This shows total annual rainfall amounts are not an important factor of variation in first ratoon crop biomass yields.

In Figure 13(c), the second ratoon yield appeared to increase at a significant rate (R^2=0.23) implying only 0.23 (23%) of variation in sugarcane biomass yields can be explained for by total annual rainfall amounts. Other factors not considered in this study accounted for 0.77 (77%) indicating that total annual rainfall amounts are not an important factor in variation of sugarcane biomass yields. The increment was lower than the first ratoon though still higher total annual rainfall amounts influenced the yield. Total annual rainfall amounts above 2200mm gave rise to higher yields whereas those below 1800mm gave rise to low yields. In Figure 13 (d), the third ratoon yield appeared to increase at a significant rate (R^2=0.12) implying only 0.12 (12%) of variation in sugarcane yields can be explained for by total annual rainfall amounts. Other factors not considered in this study accounted for 0.88 (88%).Further analyses in Figure 13 showed that the plant, first ratoon, second ratoon and third ratoon yields were all higher than their long term mean against high total rainfall amount of 2324.2mm and also against a total rainfall amount of 2011.3mm.

Similar results were observed by Gomathi *et al.*, (2013), in India where the production of sugarcane was analyzed in terms of tiller production and it was reported to be highly associated with the yield of the first ratoon (r=0.630), second ratoon (r=0.553). From Figure 13, in summary number of factors may contribute to the variation in ratoon yields among them bud development in ratooning , the amount of total seasonal rainfall and the roots of a sugar cane plant develop into a layer that covers the soil and this may not allow the penetration of water easily leading to differences in yields. However, above all these factors variations in total annual rainfall amounts accounts for at least 20% of the factors across all the major ratoons. The results confirm to studies done by various authors who suggested that a number of factors may also contribute to the variation in ratoon yields among them bud development in ratooning , (Chapman,*et al*., 1992), also the number of buds per stem piece that decrease with older ratoons and damage at harvest time could affect ratooning ability, (Hurney, 1992). He further stated that, these factors put together may explain the variation in yield output for various ratoons in relation to the effect of total annual rainfall amounts. The production of buds may also be as a result of genetic component because commercial cultivars have been selected to do well for the first three to four cultivation cycles and it is important to look at the varieties grown. There are other factors that could lead to differences in yields as sugarcane plant grows as reported by An-Vo *et al*.,(2017). The roots of a sugar cane plant develop into a layer that covers the soil and this may not allow the penetration of water easily leading to differences in yields from one ratoon to another, as further reported in a study by An-Vo *et al*., (2017), Australia; and they concluded that ratoons will therefore correlate differently to precipitation. They further indicated the largest yield gaps to have been recorded between the wet and dry conditions (up to 50tons/ha) specifically observed in the first ratoon crop, second ratoon crop and third ratoon crop.

A study done in India by Gomathi *et al.,* (2013), reported that the sugar yield production of ratoons was highly associated with the variation of growth and physiological factors. Another factor of yield gaps in ratoons is their root canopy at the ground that does not allow easy penetration of ground water. From Appendix 6, it was analyzed and in 1982, 1983 , 1985 and 1993 the yield of the plant crop was higher than the first ratoon crop, the yield of the first ratoon crop was higher than the second yield crop, and the yield of the second yield crop was higher than the yield of the third ratoon crop. During these years the amount of total annual rainfall is low suggesting that little damage is done to the plant buds when harvesting took place.

To analyze further, the yields from two key varieties of sugarcane grown in Mumias Sub County was done. As stated segregated data on sugar cane yields in relation to varieties and seasonal rainfall within the study period as availed is presented in Appendix . The agriculture office data revealed that most farmers preferred to plant varieties that offer higher yields which were Co 945 and CB38-22 varieties were grown within the period 1982 to 2012.

Figure 14 shows the relationship between the varieties CO 945 and CB38-22 versus total annual rainfall amounts for the period from 1996 to 2003. The information is presented in Appendix 7.

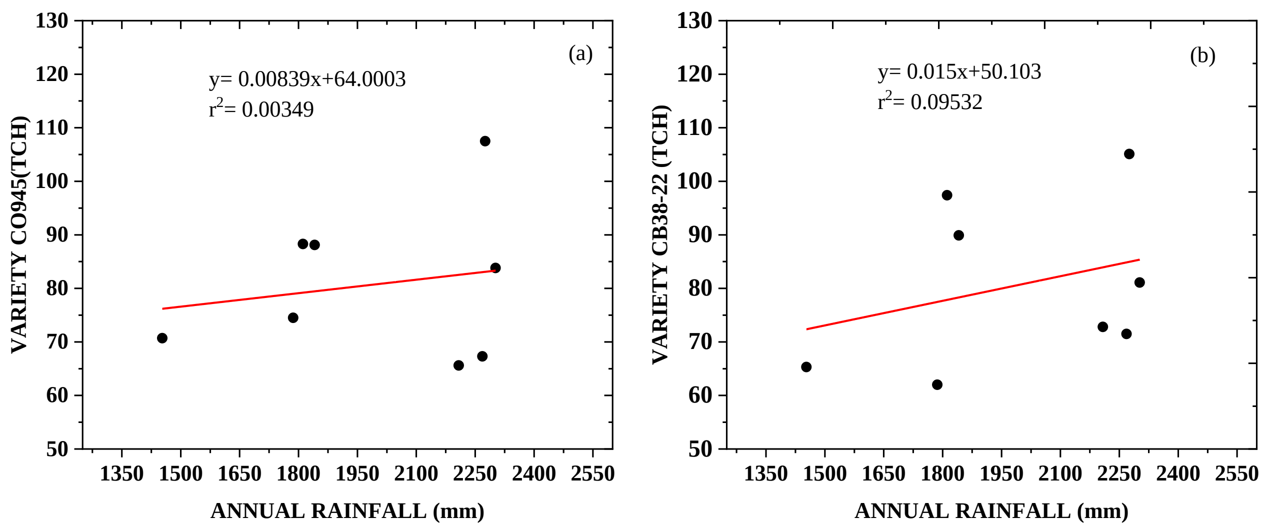

Figure 14: Scatter plots of sugarcane varieties (CO 945 and CB38-22) yield (TCH) versus rainfall amounts (mm) over Nucleus Zone during the study period.

Figure 14 shows the linear regression analysis of the most common planted sugarcane varieties C0 945 and CB36-22 by farmers in Mumias Sub County during the study period. Figure 14 (a) shows that sugar cane variety CO 945 yields increased at a significant rate (slope 0.00839, r^2=0.0349) implying that 3% of variation in sugarcane biomass yields in this variety can be explained for by total annual rainfall amounts. The slope 0.00839 implies that there was generally low increment in total sugarcane biomass yields. This means total annual rainfall amount as a factor contributed to variation of yield in this variety. In Figure 14 (b) the yields of sugarcane variety also increased as the total annual rainfall amounts increased, (slope= 0.0153, r^2=0.099). This implies that 9% of variation of sugarcane biomass yield in this variety can be accounted for by total annual rainfall 90% of variation in yields in this variety could be accounted for by other factors not considered in this study. Similarly a slope of 0.03998 means there was low increment in sugarcane biomass yields. The two varieties respond to total rainfall amounts almost in an equal measure such that their yields relate to the changes in rainfall amounts as seen especially when rainfall amounts are between above 2300mm. Similarly both varieties recorded low yields of TCH value of 70 when total rainfall amounts were below 2000mm.This is despite the fact that the crops were under the professional management of Mumias Sugar Company.

According to a study by Di Bella *et al.*, (2008), in Herbert District, Australia, it was reported that varieties of sugar cane that are harvested late in the growing season are at great risk of poor yield response due to high probability of significant rainfall events. Similar studies by Salter and Schroeder (2012) in MacKay (Australia) reported that total annual rainfall variability affected sugar cane production during the high rain period. Sugarcane variety Q124 out-performed other varieties, across most soil types, in the Mackay region. However, weather conditions during that period may also have been more favorable for cane production. The 1994–1998 period experienced, on average, 118 mm more effective rainfall, 682 mm lower total rainfall, better rainfall distribution, and likely lower incidence and severity of water logging than recently (2008–2010). In a similar study by Chapman (1997), he described the difference in crop yields of approximately (~ 10 t/ha) as being accounted for by total annual rainfall amounts. Rudd and Chardon (1977) also showed that yield declined by 0.46 t/ha each day the water table was within 0.5 m of the soil surface during the peak growth period (Dec- Jun). From this we may attribute some of the disparities seen in yields to different varieties hence the reason new varieties are developed to respond to environmental changes. In a related study, Jamoza, (2005) suggested that erratic and low rainfall was the main cause of low cane yields in the highlands western of Kenya where the response of various sugarcane varieties were analyzed. In similar studies over humid western Kenya Otiso, (2016) and Ogega, *et al.,* (2018) in studies over humid western Kenya associated the frequent dry spells over the region with poor yields in crops such as sorghum, millet and maize.

4.4 .1Analysis of relationship between inter-annual rainfall variability on quantity of sugar

The relationship between total annual rainfall amounts and sugar quantity was analyzed using the sucrose concentration percentage per ton of raw sugarcane harvested which is known as the POL percentage or POL value. The POL (%) is the sucrose percentage in the sugar juice. This is the quantity of sugar in the juice from the crushed cane and it is one of the parameters accounting for the quality of sugar cane harvested. Appendix 7 provides information on sugar quantity in cane harvested that is measured in terms of POL (%) and in relation to the amount of total annual rainfall from 1982 to 2012 in Mumias Sub County. A regression line of the information was plotted in Figure 15.

Figure 15 shows the regression analysis of sugar quantity versus total annual rainfall amounts during the study period 1982 to 2012.

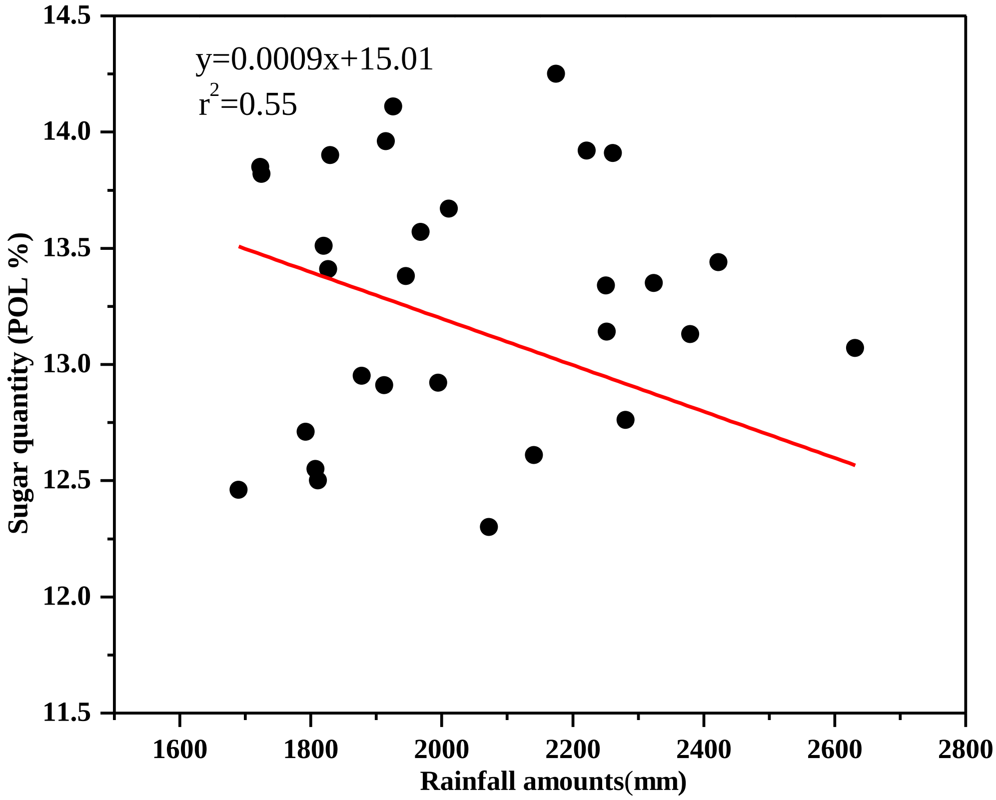

Figure 15: Sugar quantity versus total annual Rainfall (mm) for 31 years of study period

Figure 15 shows that 0.55(55%) of variation in sugar quantity (POL%) can be explained for by total annual rainfall amounts. The POL (%) appeared to decrease (slope= -0.0009) with an increase in the amount of total annual rainfall amounts at a non-significant (R^2=0.55, p >0.05). The findings conform to similar results by Sharma and Gupta, (1990) over India that reported drastic reduction in sucrose content with an increment in moisture content. The analysis shows that the Pol value of sugarcane harvested in Mumias Sub County was highest when rainfall amounts were ranging between 1800mm and 2000mm. This same rainfall amounts was also found to be ideal for the raw sugar tonnage per hectare. From Figure 15, the highest total annual rainfall recorded for the period was 2623.8mm while the lowest total annual rainfall recorded within the period was 1653.1mm.This translates to a range of 970.1mm. On the side of sugar quantity recovered from cane harvested the highest POL (%) was 14.25 while the least was recorded as 10.89 a range of 3.3. The periodwhen high total rainfall amounts of 2322.0mm and 2431.3mm were recorded, the sugar quantity realized was low, that is POL (%) of 11.09 and 10.89 respectively. High rainfall amounts lead to leaching of soils, inaccessibility to farms during harvesting and weeding resulting into low sugarcane biomass yields as well as sugar quantity. When high inter annual rainfall variability was recorded due to the *El Nino* phenomenon and low POL (%) were recorded consecutively as 12.46 and 13.14 during the same period.

The findings are in line with a report bySantos and Sentelhas, (2005), in a study in Brazil who suggested that low rainfall amounts lead to poor nodes formation. In a similar study done in Coimbatore, India (TNAU, 2014), it was found that the ideal POL value of sugarcane harvested is 16%. Teodero*et al*., (2007) found that the early dry season affected end of crop growth, resulting to low sucrose accumulation (76.2tons of sugar/ha to 10tons of sugar/ha).This was similar to results got in a study done by Hagos, *et al,* 2014 in Tendaho, Ethiopia. Moreover, sugarcane in rain fed areas increases stem fiber mass due to increase in soil moisture content. As noted by Hunsgi (1993), the harvesting of immature canes has led to low quality sugar of low sucrose content and this reduces the sugar prize. Quality of C4 crops yields was similarly done by Nahayo, *et al.,* (2018) attributed a drop in quality of crop yields especially rain fed maize during 2015 and 2016 to a reduction in rainfall amounts.

From the analysis it was evident that the Pol value of sugarcane harvested in Mumias Sub County was highest when rainfall amounts were ranging between 1800mm and 2000mm. This same rainfall amounts was also found to be ideal for the raw sugar tonnage per hectare. At low rainfall amounts the sugar quantity seemed to be high while at periods when rainfall amounts were high the sugar quantity decreased.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter presents three parts starting with the summary of the findings on rainfall variability and sugarcane production, the second part deals with key conclusions made from the findings and the third part presents the recommendations made based on the study and areas for further research.

5.2 Summary

This study analyzed rainfall variability over 31 years. The historical trends in total seasonal annual rainfall and sugarcane yields have been analyzed. The findings revealed that total seasonal and annual rainfall in Mumias Sub County has been increasing (positive slope=2.51 for “long rains” and slope=3.85 for “short rains”). The months of October to November that flow in the short rains season showed high levels of rainfall variability. The trends in sugarcane yields show a decrease. Coefficient of variation for seasonal and annual rainfall amounts was analyzed. Inter annual rainfall variability was noted with an increase in total annual rainfall amounts and a coefficient of variation of 20%. The variability at inter annual rainfall scale was a positive slope=7.98 and a mean coefficient of variation of 0.2(20%) was obtained which suggests low inter- annual rainfall variability. The variations in seasonal and inter annual rainfall were found to be 83.17 % and 67.7% respectively within the study period implying a high level of temporal rainfall variability.

Variability in total seasonal and annual amounts was noted to have affected sugarcane production in this study. The results indicated that 55% (r^2=0.55) of variation of sugar cane biomass yields can be explained for by increase in seasonal rainfall amounts during the long rains 'MAM'. Changes in the total seasonal short rains 'OND' amounts had little effect on sugarcane biomass yields. Likewise changes in total annual rainfall amounts affected sugarcane biomass yields such that 61% (r^2=0.61) of variation of sugar quantity can be explained for by total annual rainfall. It was observed that sugarcane biomass yields varied in relation to variation of annual rainfall totals in Mumias Sub County such that high sugarcane biomass yields were recorded when total annual rainfall amounts ranged between 1700mm and 2000mm.

Variations in total annual rainfall amounts were found to have affected the quantity of sugar recovered from sugarcane. The findings revealed that 55 % (r^2=0.55) of variation in sugar quantity (sucrose content) could be explained for by annual rainfall amounts. The findings showed that low sucrose content was recovered from the harvested cane when total annual rainfall amounts were high whereas with low total annual rainfall amounts sucrose content recovered was high. High sucrose yields were realized when total annual rainfall amounts ranged between 1800mm and 2300mm. The relationship between rainfall variability and sugarcane yields was significant, thus these results suggest that rainfall variability has an effect on sugarcane production in Mumias Sub County.

5.3 Conclusion

The characteristics of rainfall variability were assessed in detail in this study area and how this affected sugarcane production in terms of biomass yields as well as sugar quantity .High temporal rainfall variability is evident in the sub county. At seasonal and annual scales it has been observed that total rainfall amounts were increasing. The variation in total historical seasonal rainfall amounts showed a higher level of variability during the short rains season. This indicated that this is not the right time for farmers to apply fertilizers, weed their farms and plant new setts (sugarcane seedlings) due to unpredictability of rainfall. On the other hand the long rains seasons depicted an increasing trend. This shows that period is ideal for planting new crops but not the right time for harvesting the sugarcane. This implies that the ideal time for harvesting sugarcane is between December and March when transportation will not be interfered with and cane would be of high quality. There was a general increase of annual rainfall amounts in the study area recording a coefficient of variation at 20%, indicating high inter annual rainfall variability.

The high seasonal rainfall variability during the short rains seasons affected sugarcane production negatively for instance in (2000 and 2009) when the total seasonal rainfall amounts were low and this led to low yields from both the out grower farmers and the nucleus estate. Sugar cane yields increased in relation to increase in total annual rainfall amounts. In years where there was high total annual rainfall amounts high sugarcane biomass yields were realized and especially those years that received total annual rainfall amounts of between 1800mm and 2000mm. Since farmers may not be in control of variations in total seasonal and total annual rainfall amounts, those close to water bodies such as rivers or dams can arrange for irrigation measures incase rainfall amounts fall below the above mentioned range.

The high annual rainfall amounts also affected the sugar quantity such as in 2001 and 2012 where the POL (%) was low, this affected the amount of cane crashed. It was evident that total rainfall amounts of between 1800mm and 2000mm both at seasonal and annual scale were ideal for high yields in terms of raw harvested cane and POL value. If this problem of rainfall variability continues, it would put sugarcane production a loose making venture. Therefore, a number of strategies should be introduced so as to help small scale sugarcane farmers and sugarcane processing factories in coping with rainfall variation. This study therefore, recommended the following as strategies to be done.

5.4 Recommendations

In Mumias Sub County there are two rainy seasons, the long rainy season stretching from March to May and the short rain season stretching from October to November. During the short rain season rainfall is most unreliable and therefore farmers should plant their cane setts towards the end of the long rains season such that as the short rains period commences, tillering and node elongation period will coincide with the season thus translating into high yields. The millers should arrange for this to go hand in hand with planting dates so that uniformity is achieved during the harvesting process as per blocks to avoid harvesting immature or over mature canes.

The farmers should create mitigating measures against heavy rainfall amounts and dry spells so that the sugarcane biomass yields are cushioned against rainfall variability. The measures will assist farmers get enough yields and income as well as sugarcane millers will process sugar throughout the year. Projects in control of soil nutrient leaching and water harvesting and installation of modern irrigation systems should be done so that the growing season is maintained with adequate supply of soil nutrients and moisture content. Investment on the modes of transporting mature cane should be done especially during the long rains seasons so that the quality of cane delivered to the processing factory is of high quality.

Sugar research firms should carry out constant findings on yields of various varieties of sugarcane so as to come up with varieties that are tolerant to drought and heavy rainfall amounts.

5.5 Areas of further research

Further research may be required to analyze the impact of rainfall variability on agronomic activities involving sugarcane production in Mumias Sub County.

Another important area of research is to examine the effects of rainfall variability on sugarcane production using remote sensing in Mumias Sub County.

To add on this, another area is to examine the effects of rainfall variability and mixed cropping on sugar production in Mumias Sub County.

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APPENDICES

APPENDIX 1: TOTAL ANNUAL RAINFALL AMOUNTS FOR FIVE RAIN GAUGE STATIONS IN MUMIAS SUB –COUNTY (1982-2012)

YEAR	MATUNGU	NUCLEUS	KHALABA	MALAHA	SHIANDA
1982	2414.3	2585.8	1955.3	2081.2	2232.2
1983	2234.6	1976.9	2204.9	1993.4	1873.6
1984	1712.6	1551.0	1695.9	1364.2	1533.4
1985	1652.82	2192.5	1807.7	1865.6	1630.9
1986	1646.5	1991.1	2077.8	1809.1	2113.6
1987	1809.6	1881.9	1794.1	1869.4	1802.3
1988	1556.6	2175.2	2224.7	1883.3	1523.0
1989	2223.3	1944.0	2211.1	2498.2	2067.6
1990	1792.3	1960.2	1785.7	2003.1	1895.0
1991	2471.9	2186.8	2281.6	1843.3	1999.2
1992	2657.6	1831.0	1906.5	1880.0	2003.9
1993	1819.8	1596.8	1488.5	2012.1	1911.1
1994	2194.4	2220.7	1649.5	2160.8	1810.7
1995	2820.8	2315.6	2108.8	2384.1	1935.2
1996	2859.7	2275.6	1852.3	2311.1	1883.2
1997	2203.9	1811.4	2330.9	2586.3	2185.0
1998	1579.1	1841.1	1194.3	1869.6	1565.9
1999	1874	2301.9	1745.2	2080.1	2051.3
2000	1802.8	1453.1	1927.3	2010.5	2063.3
2001	1123.6	1786.4	1449.5	1589.8	1369.0
2002	1774.5	2208.0	1962	1921.8	2133.3
2003	1614.8	2268.5	1682.2	1818.6	1981.4
2004	1894.2	2007.5	1955.8	1869.3	1830.5
2005	1594.4	1693.7	1918.8	1248.9	1420.9
2006	2474.8	2684.4	2204.1	1821.3	1896.6
2007	1846	1945.9	1878.7	2088.5	2198.4
2008	1656.5	2065.1	1618	2328.0	1857.0
2009	1090.5	1962.7	1375.2	1799.2	1574.6
2010	2150.5	2823.8	2176.6	2088.2	2281.0
2011	1836.2	2233.3	1902.8	1993.4	2124.5
2012	1950.4	2431.2	2633.5	2041.2	2336.7

Source: Mumias Synoptic Weather Station, 2017

APPENDIX 2: MONTHLY RAINFALL AMOUNTS

Nucleus Rain station Monthly rainfall distribution totals, means, standard deviation and coefficient of variations from 1982 to 2012 in Mumias Sub County

Year	Monthly rainfall (mm)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1982	187.3	61.1	119.8	240.6	345.1	351.6	108.4	310.8	192.3	248.7	280.4	139.7	2585.8
1983	54.4	95.5	158.1	278.4	327.0	130.5	104.7	142.8	253.2	222.6	116.9	92.8	1976.9
1984	49.1	5.0	37.3	289.1	273.9	137.3	93.6	171.4	115.3	78.3	214.4	86.3	1551.0
1985	57.6	67.6	241.6	357.5	270.6	172.1	311.0	127.4	172.6	151.4	226.6	36.5	2192.5
1986	35.9	75.0	139.9	432.0	331.9	221.0	141.4	150.7	109.6	114.0	97.5	142.2	1991.1
1987	78.5	180.9	154.1	240.7	378.2	126.8	100.0	135.1	76.5	222.9	175.3	12.9	1881.9
1988	138.0	72.5	171.0	477.0	253.6	176.5	56.1	214.9	183.5	206.4	208.8	16.9	2175.2
1989	22.8	105.3	231.1	176.4	287.8	110.1	88.2	165.4	219.0	201.2	155.9	180.8	1944.0
1990	89.8	234.2	225.7	345.4	201.1	114.8	108.0	134.6	143.6	90.8	107.6	164.6	1960.2
1991	122.8	86.2	141.8	389.4	442.3	243.0	116.6	176.2	107.1	207.3	106.9	47.2	2186.8
1992	26.6	35.8	57.7	297.2	266.1	278.1	220.0	210.1	119.9	164.5	75.5	79.7	1831.0
1993	84.1	53.0	58.4	212.1	338.6	214.0	32.6	125.2	119.9	149.7	128.2	81.0	1596.8
1994	35.0	59.6	210.5	282.7	344.7	223.1	171.5	166.4	121.3	136.0	417.6	52.3	2220.7
1995	14.4	68.9	264.6	433.0	136.4	268.7	162.4	220.0	216.2	202.5	293.9	34.6	2315.6
1996	153.0	174.4	153.9	294.8	360.6	113.3	112.8	138.2	195.0	252.3	252.7	74.6	2275.6
1997	27.3	0.0	164.3	242.8	116.0	113.7	112.1	176.8	44.1	181.0	341.2	292.1	1811.4
1998	170.8	55.2	84.9	376.3	227.4	180.0	77.5	156.5	150.3	227.9	109.6	24.7	1841.1
1999	128.8	0.0	354.2	249.8	257.6	230.9	80.9	215.1	282.3	259.0	108.6	134.8	2301.9
2000	63.1	16.1	71.0	195.5	242.1	142.1	82.5	118.7	105.4	223.2	113.7	79.2	1453.1
2001	90.4	22.8	149.9	264.2	371.1	174.8	77.8	214.1	174.4	123.4	101.5	22.0	1786.4
2002	93.6	29.7	263.5	341.5	285.9	99.3	145.7	86.2	158.6	189.7	267.5	246.8	2208.0
2003	55.4	94.1	284.8	323.2	323.8	247.0	152.0	316.0	100.2	192.4	110.0	69.6	2268.5
2004	155.7	81.2	126.0	318.5	142.4	181.0	129.0	156.4	243.9	168.3	155.4	149.7	2007.5
2005	23.9	90.9	210.1	280.0	218.6	171.4	156.7	158.5	145.3	143.7	67.3	27.3	1693.7
2006	119.7	135.5	305.8	410.4	285.9	185.0	180.1	122.1	182.8	168.1	310.6	278.4	2684.4
2007	82.0	178.6	115.4	184.7	456.2	220.9	109.1	98.0	191.7	130.4	128.3	50.6	1945.9
2008	80.2	91.7	207.0	232.7	226.9	156.6	184.0	229.7	167.2	321.5	113.7	53.9	2065.1
2009	102.5	12,1	126.5	301.5	296.6	66.8	108.0	278.0	231.4	117.2	83.5	238.6	1962.7
2010	96.9	198.0	378.5	290.0	545.6	232.4	122.0	209.6	274.7	200.2	182.2	93.7	2823.8
2011	3.1	37.6	328.4	212.4	248.6	159.9	97.5	222.7	233.1	247.4	337.0	105.6	2233.3
2012	10.7	5.1	57.4	430.4	346.5	228.6	140.3	192.9	223.4	281.8	237.2	276.9	2431.2
Mean	**79.1**	**78.2**	**180.4**	**303.2**	**295.1**	**183.0**	**125.2**	**178.7**	**169.5**	**187.9**	**181.5**	**109.2**	**2071.1**
SD	**50.1**	**62.1**	**91.2**	**80.0**	**92.1**	**62.2**	**52.8**	**56.3**	**59.6**	**57.1**	**92.8**	**83.4**	
CV	**0.6**	**0.8**	**0.5**	**0.3**	**0.3**	**0.3**	**0.4**	**0.3**	**0.4**	**0.3**	**0.5**	**0.8**	**0.5**

Source: Mumias Synoptic Weather Station,(2017)

APPENDIX 3: LONG AND SHORT RAINS DATA

Rainfall distribution in terms of seasonal rainfall total and anomalies from 1981/1982 to 2011/2012 seasons Mumias Sub County

	Mar	**Apr**	**May**	**Jun**	**Oct**	**Nov**	**Dec**	**Rainfall total(mm)**
1982	119.8	240.6	345.1	351.6	248.7	280.4	139.7	1725.9
1983	158.1	278.4	327	130.5	222.6	116.9	92.8	1326.3
1984	37.3	289.1	273.9	137.3	78.3	214.4	86.3	1116.6
1985	241.6	357.5	270.6	172.1	151.4	226.6	36.5	1456.3
1986	139.9	432	331.9	221	114	97.5	142.2	1478.5
1987	154.1	240.7	378.2	126.8	222.9	175.3	12.9	1310.9
1988	171	477	253.6	176.5	206.4	208.8	16.9	1510.2
1989	231.1	176.4	287.8	110.1	201.2	155.9	180.8	1343.3
1990	225.7	345.4	201.1	114.8	90.8	107.6	164.6	1250
1991	141.8	389.4	442.3	243	207.3	106.9	47.2	1577.9
1992	57.7	297.2	266.1	278.1	164.5	75.5	79.7	1218.8
1993	58.4	212.1	338.6	214	149.7	128.2	81	1182
1994	210.5	282.7	344.7	223.1	136	417.6	52.3	1666.9
1995	264.6	433	136.4	268.7	202.5	293.9	34.6	1633.7
1996	153.9	294.8	360.6	113.3	252.3	252.7	74.6	1502.2
1997	164.3	242.8	116	113.7	181	341.2	292.1	1451.1
1998	84.9	376.3	227.4	180	227.9	109.6	24.7	1230.8
1999	354.2	249.8	257.6	230.9	259	108.6	134.8	1594.9
2000	71	195.5	242.1	142.6	223.2	113.7	79.2	1067.3
2001	149.9	264.2	371.1	174.8	123.4	101.5	22	1206.9
2002	263.5	341.5	285.9	99.3	189.7	267.5	246.8	1694.2
2003	284.8	323.2	323.8	247	192.4	110	69.6	1550.8
2004	126	318.5	142.4	181	168.3	155.4	149.7	1241.3
2005	210.1	280	218.6	171.4	143.7	67.3	27.3	1118.4
2006	305.8	410.4	285.9	185	168.1	310.6	278.4	1944.2
2007	115.4	184.7	456.2	220.9	130.4	128.3	50.6	1286.5
2008	207	232.7	226.9	156.6	321.5	113.7	53.9	1312.3
2009	126.5	301.5	296.6	66.8	117.2	83.5	238.6	1230.7
2010	378.5	290	545.6	232.4	200.2	182.2	93.7	1922.6
2011	328.4	212.4	248.6	159.9	247.4	337	105.6	1639.3
2012	57.4	430.4	346.5	228.6	281.8	237.2	276.9	1858.8
Mean	186.44	313.34	304.97	189.06	194.13	187.52	112.27	1488.22
Sd								234.95
Cv								0.2

Source: Mumias Synoptic Weather Station, 2017

APPENDIX 4: SUGARCANE YIELDS

Out grower farmers and Nucleus Estate Sugar cane yields in tons per hectare (TCH) versus Total seasonal rainfall (mm) and average age of cane harvested in months.

Year		Cane yield (TCH)	Total Seasonal Rainfall (mm)	Average age of can harvested in months	Year		Cane Yield (TCH)	Total Seasonal Rainfall (mm)	Average age of can harvested in months	Year		Cane yield (TCH)	Total seasonal rainfall (mm)	Average age of car harvested i months
1982	OG	87	1725.9	22	1992	OG	96.5	1218.8	19	2002	OG	73.3	1694.2	19
	NE	65.4				NE	58.68				NE	61.08		
1983	OG	73.1	1326.3	17	1993	OG	83.7	1182	18	2003	OG	79.1	1550.8	21
	NE	69.48				NE	58.92				NE	48.48		
1984	OG	77.1	1116.6	18	1994	OG	74.7	1666.9	16	2004	OG	76.2	1241.3	21
	NE	63.72				NE	45.48				NE	40.56		
1985	OG	73.9	1456.3	19	1995	OG	78.1	1633.7	16	2005	OG	70.0	1118.4	18
	NE	57.36				NE	60.84				NE	50.52		
1986	OG	78.1	1478.5	20	1996	OG	109.6	1502.2	23	2006	OG	74.8	1944.2	18
	NE	64.08				NE	60.36				NE	51.60		
1987	OG	78.8	1310.9	20	1997	OG	117.6	1451.1	26	2007	OG	72.1	1286.5	18
	NE	57.36				NE	49.32				NE	49.08		
1988	OG	96.8	1510.2	22	1998	OG	94.2	1230.8	30	2008	OG	79.8	1312.2	21
	NE	70.68				NE	39.48				NE	49.44		
1989	OG	102.1	1343.3	24	1999	OG	74.6	1594.9	27	2009	OG	56.5	1230.7	18
	NE	70.68				NE	42.12				NE	40.20		
1990	OG	105.1	1250	24	2000	OG	60.3	1067.3	16	2010	OG	64.8	1922.6	16
	NE	67.92				NE	51.36				NE	47.52		
1991	OG	101.1	1577.9	21	2001	OG	73.6	1206.9	16	2011	OG	42.8	1639.3	16
											NE	43.92		
	NE	66.48				NE	58.98			2012	OG	47.8	1858.8	16
											NE	45.12		

Source: Mumias Sugar company (2017 Key: OG (Out growers' yields); NE (Nucleus estate yields)

APPENDIX 5: SUGARCANE RATOONS YIELDS

Sugarcane yields in terms of tons per hectare (TCH) of the plant, first ratoon, second ratoon and third ratoon in relation to seasonal rainfall from 1982 to 1999.

Year	Plant yield(TCH)	First ratoon yield(TCH)	Second ratoon yield (TCH)	Third ratoon yield (TCH)	Rainfall amounts (mm)
1982	70.8	66.0	63.24	57.96	2280.6
1983	78.96	74.4	67.68	65.4	2324.2
1984	69.48	70.2	56.26	57.96	1724.7
1985	68.64	67.68	59.88	49.8	1926.3
1986	66.84	67.56	62.4	59.88	2261.2
1987	72.84	74.16	62.28	62.28	1914.6
1988	72.96	70.2	63.12	68.64	2011.3
1989	71.28	64.56	65.04	70.2	1820.1
1990	72.36	71.76	64.08	65.88	2221.5
1991	54.72	61.8	55.68	59.28	2174.7
1992	57.84	60.0	58.08	63.48	1829.7
1993	55.32	53.52	51.24	52.44	1792.2
1994	60.96	57.96	60.84	61.68	2251.1
1995	70.44	59.16	54.24	60.6	2379.6
1996	46.08	46.68	50.4	49.92	1689.7
1997	55.8	47.64	46.44	53.16	1811
1998	57.96	60.72	55.44	61.2	1795.9
1999	59.76	64.8	60.36	54.96	1826.7

Source: Mumias Sugar Company (2017)

APPENDIX 6: SUGARCANE VARIETY YIELDS

Sugar yields in terms of tons per hectare (TCH) of CO 945 and CB38-22 varieties in relation to total seasonal rainfall amounts for period 1996 to 2002

YEAR	VARIETY		Total Seasonal rainfall (mm)
	CO 945	CB38-22	
1996	107.5	105.1	2203.5
1997	88.3	97.4	1651.4
1998	88.1	89.9	2418.3
1999	83.8	81.9	1980.6
2000	70.7	65.3	1614.7
2001	74.5	62.0	1912.5
2002	65.6	72.8	1826.7
2003	67.3	71.5	2422.8

Source: Mumias sugar company, 2017

APPENDIX 7: SUGAR QUANTITY PRODUCTION

Sugar quantity in terms of POL (%) in relation to total annual rainfall amounts for the period 1982 to 2012.

Year	Sugar quantity (POL %)	Rainfall amount (mm)	Year	Sugar quantity (POL %)	Rainfall Amount (mm)	Year	Sugar quantity (POL %)	Rainfall Amount (mm)
1982	12.76	2280.6	1992	13.85	1722.8	2002	13.41	1826.7
1983	13.35	2324.2	1993	13.90	1829.9	2003	13.44	2422.8
1984	13.82	1724.7	1994	12.71	1792.2	2004	13.38	1945.1
1985	14.11	1926.3	1995	13.34	2251.1	2005	12.92	1995.1
1986	13.91	2261.3	1996	13.13	2379.6	2006	12.61	2141.1
1987	13.96	1914.6	1997	12.46	1689.7	2007	13.07	2631.3
1988	13.67	2011.3	1998	13.14	2251.9	2008	12.95	1878.1
1989	13.51	1820.1	1999	13.57	1967.8	2009	12.55	1807.4
1990	13.92	2221.5	2000	12.50	1811.0	2010	12.30	2072.4
1991	14.25	2174.7	2001	12.91	1912.5	2011	11.09	2322.0
						2012	10.89	2431.3
Mean							**13.14**	
sd							**0.784**	
C.V							**0.0596**	

Source: Mumias Sugar Company, 2017