VARIATIONS IN ONSET, CESSATION OF THE LONG RAINFALL (MAM) SEASON AND IT'S IMPACT ON MAIZE YIELDS IN IGANGA DISTRICT, UGANDA

BY

WAGUBI ANDREW PETER

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DECLARATION

I Wagubi Andrew Peter, hereby declare that this dissertation titled "***VARIATIONS IN ONSET, CESSATION OF THE LONG RAINFALL (MAM) SEASON AND ITS IMPACT ON MAIZE YIELDS IN IGANGA UGANDA***" is authentic, original, and has never been submitted to any higher institution or university for an academic award.

Signed: …………………………………………….. Date: …………………………

APPROVAL

We the undersigned verify that this dissertation entitled ***"VARIATIONS IN ONSET, CESSATION OF THE LONG RAINFALL (MAM) SEASON AND ITS IMPACT ON MAIZE YIELDS IN IGANGA DISTRICT UGANDA"*** was done by Wagubi Andrew Peter, under our supervision and is ready for submission with our approval.

Date: ……………………………Signature ……………………….

Francis Wasswa N. Nsubuga (PhD)

Date: ……………………………Signature ……………………….

Turyabanawe G. Loy (PhD)

DEDICATION

This dissertation is fully committed to my family and friends, who contributed greatly to seeing me through this journey.

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Praise be to God for providing me with the fullness of life and well-being that enabled me to finish my course. I thank God for having brought me this far, so far.

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LIST OF ACRONYMS

SSA	Sub-Saharan Africa
SAI	Standardized Anomaly Index
NEMA	National Environmental Management Authority
MAM	March- April-May Season
IPCC	Intergovernmental Panel on Climate Change
GHACOF	Greater Horn of Africa Regional Climate Outlook Forum
IGAD	Intergovernmental Authority on Development in East Africa
SST	Sea Surface Temperature
RMSE	Root Mean Square Error
ENSO	El Niño Southern Oscillation
WAA	Worob Ong Agro-ecological Area
PCI	Precipitation Concentration Index
FAO	Food and Agriculture Organization
CORDEX	Coordinated Regional Downscaling Experiment
CV	Coefficient of Variation
UNMA	Uganda National Meteorological Authority
MK	Mann-Kendall
SON	September October November

ABSTRACT

Variations in rainfall patterns has an impact on rainfall dependent sectors especially those in agricultural production. Knowledge on variations in rainfall patterns and its impact on yields is vital in agriculture. The specific objectives of this study were on the assessment of rainfall and maize trends, variations in the onset and cessation of rainfall in the March, April, May (MAM) season and the effect of start and end of the long rains on crop yield product (maize) in Iganga district. To achieve the objectives, gridded rainfall point data (secondary) from 1990 – 2022 for Iganga district and Annual MAM maize yield data (secondary) from 2013-2022 in Iganga was obtained from Iganga district agricultural office. Climate data tool (CDT) software, which considers the methodology of a Pentad approach of wet days, Evapotranspiration and a regression using Pearson's correlation coefficient in SPSS, were the methodology employed to achieve the changes in the onset, cessation dates and the correlation between rainfall onset, cessation and maize yields respectively. Trend's significancy of the MAM rainfall and maize yields were tested using the Mann-Kendall trend test, the P-Value approach and level of significancy. Likewise, onset, cessation, length of the rainfall season significancy on maize yield using P-value approach were further re- evaluated using the Mann-Kendell tau statistic. Results showed an increasing trend in rainfall for March, April, while May was decreasing with P-values 0.64,0.49,0.35, respectively that were not statistically significant yet the MAM long rainfall season showed an increasing trend with a P-value of 0.35 that was statistically insignificant. The MAM maize production (2013-2022) showed an increasing trend in maize yields with a Sens's slope of 92.863 tons and a significant P-Value (0.043) showing a positive trend over the years. Study findings regarding variations in rainfall onset showed 26th February as the earliest and 8th April as the latest onset date. Rains started 24 times in March which accounted for 75% of total occurrences. 1st May was the earliest date while 26th June was the latest cessation date. The rains ended 21 times in May which accounted for 66% of the total occurrences. The relationship between onset, cessation and maize yields was analyzed using Pearson correlation showed (-0.091 with a P- value of 0.420), (0.188 with a P- value 0.960) respectively, which is a negative (inverse) relationship for onset and a positive relationship for cessation. While Mann-Kendall tau statistical analysis showed onset results (-0737, P-value 0.3293), cessation results (0.1345, P-value 0.0746), length of season results showed (0.1585, P-value **0.0355).** The results showed that the time of cessation of the rains and length of the growing season have more effect on maize yields than onset in the study area. UNMA should therefore collaborate with the local farmers and give timely information about when the rains will start and end to avoid food insecurity.

CHAPTER ONE: INTRODUCTION

1.1 Background

Globally climate change and variability are impacting crop yields especially in Africa. Yield quantity and quality, crop growth and development are among the aspects impacted by climate variability especially associated variables of rainfall and temperature (Abdisa et al., 2022). Climate essentially determines agricultural productivity, this has been of great interest since crop yields are affected by change in rainfall and climate (Sowunmi et al., 2020).An analysis on variations in rainfall amounts of the transition months at the start and end of the wet season was done to ascertain a change in rainfall commencement and end dates(Sylla & Wisser, 2016)

The dates of the start and end of rainfall are crucial characteristics to the rainfed agriculturalists in the majority of the sub-Saharan tropical regions. Especially considering that significant alterations and fluctuations to the climate are predicted for many parts of the world. It is anticipated that these modifications would impact the beginning and end of the rainy season, which has changed over time to become erratic. Putting forward a dilemma for farmers with relation to optimizing seed planting and the necessity of adjusting to how long the growth season is (Mosunmola et al., 2020a).

In Nigeria, the Nigerian Meteorological Agency (NIMET 2015) published research stating that there have been notable anomalies with regard to the beginning and cessation of rains, particularly between 1971 and 2000. With a few exceptions, the beginning of the rainy season was generally typical throughout 1941–1970. However, between 1971 and 2000, over 80% of Nigeria experienced variability in both the beginning and end of the rainy season (Patrick et al., 2019).

In East Africa farmers who completely rely on rainfall for agriculture, depend on the main rainfall seasons, the long rainfall season (MAM) March-May and (OND) October-December the short rainfall season. The pressure gradient lying between the Atlantic and Indian ocean has led to high inter-annual onset variation of the MAM and OND seasons. The MAM rains are more dependent on onset than cessation dates (Camberlin et al., 2009).

Crop yields have been greatly affected by the fluctuations in the rains and user needs assessments in the region have continuously requested early warning of the beginning and start of rains, because it would be of great help to farmers to ably control possible risks during planting and harvesting (MacLeod, 2018).

The scientific community has generally paid less attention to onset and cessation across east Africa. Across Kenya and Tanzania, the (MAM) i.e., March-May and the October-December (OND), the mean dates, changes of the commencement and end of the rains have been determined by (Nicholson, 2017).Farmers in east Africa would greatly benefit from knowing when the rainy seasons will start or end early, and this is a common request from regional stakeholders (Bwambale & Mourad, 2022).

For a growing nation like Uganda, the choice of growing a crop, preparing of land for a crop type to be planted, to the time of harvest, is dependent on rainfall. Food security could be threatened by a change in rainy season onset and cessation posing developmental and social-economic problems like induced poverty. In order for crop-growing activities to be effective, it’s important to understand the beginning and end of rains especially within the MAM season. This is because irregular and severe delays in rainfall have an impact on the nation's overall food output, especially grains (rice, beans, millet, soya bean, maize), that makes up the nation's major diet (Amekudzi, Yamba, Preko, Asare, et al., 2015).

Maize being mainly rain-fed and grown for home consumption, there is a great deal of uncertainty over how well it will perform in various climatic conditions (Bwambale & Mourad, 2022). Currently, considering its distribution, amount, cessation and onset, rainfall has been very variable and unpredictable, which sometimes results in poor agricultural yields or complete crop failure. Smallholder farming is problematic due to the use of crude instruments, inadequate crop growing techniques, and absence of data on the beginning, duration, and end of rainfall (Mubiru et al., 2012).

In some parts of Uganda today there has been a change in the commencement of rainfall by a month which has changed the cropping patterns. Most Ugandan farmers are still practicing subsistence and small-scale agriculture. Most times rainfall patterns have been unpredictable thus threatening food security since most staple crops over rely on rainfall (Bwambale & Mourad, 2022).

In Uganda rainfed crop growing accounts for more than 95% making it vulnerable to climate change. Despite this, the country’s economic foundation is in farming and is essential to many people's livelihoods. So, even a small variation in rainfall could affect the farming systems’ productivity and a large variation could impact the economy, society and generally the environment negatively (Babel & Turyatunga, 2015).

This study therefore sets out to establish if there are changes in the commencement and end of the rains during the long rainfall MAM season and its impact on maize yields in Iganga Eastern Uganda.

1.2 Statement of problem

Rainfall is the most important parameter for crop production, crop water for proper yield depends mainly on rainfall patterns of onset, cessation, length of the season, amount and distribution. Globally variability in rainfall onsets, cessation, and length of the season affects soil water availability to crops and pauses a serious risk to crop yields. The burden of variability is big on rainfed agricultural farmers in Sub–Saharan Africa causing food insecurity.(State et al., 2016a). In Sub–Saharan Africa maize which is rain fed is the most vital and widely consumed food crop, it's a staple food crop for most of the people in Africa and in Iganga district.

Recently, there are indications that the start and end of rainfall seasons has changed in Uganda specifically in the East. This has caused a problem of irregular onsets and cessation dates, a delay by one week or false start may negatively affect crop germination, growth and yield. Farmer's planning and decision making regarding when to plant their crops is influenced by their ability to determine when the rains will start. Growth and yield of crops are essentially influenced by distribution, start and end of the rains (Getachew & Teshome, 2018).

Small holder farmers in Iganga today are not certain of when the rains start or end and the impact it has created on maize yields, this has caused uncertainty on when to till, plant, with raised interest. They therefore need to establish if there is a change in onset, cessation and length of the rainfall season and how it affects Maize yields in Iganga district. This is a challenge among climatologists and researchers who would wish to establish whether rainfall start and end has changed or it's rather the variability? The knowledge of the rainfall parameters is very vital for planning and determining the effect of rainfall onsets, cessation and length of the rain season on maize yield. This can provide alternatives for achieving an adaptive capacity by the local rain fed maize farmers (State et al., 2016a).

This study therefore aimed at determining if there are changes in the commencement and cessation of the long rainfall season, their variation and impact on maize crop yields in Iganga district, Eastern Uganda.

1.3 General Objective

This study mainly aims at investigating if there has been a change in the days when the rain begins or ends during the long rainfall MAM season and its effect on yields so that farmers especially those growing maize in Iganga district, Eastern Uganda are advised in time for implications and ensure food security.

1.3.1 Specific Objectives

i) To assess the trends of rainfall (1990-2022) of the long rainfall (MAM) and maize yields (2013-2022) in Iganga district, Eastern Uganda.
ii) To establish variations in onset and cessation dates, of long rainfall (MAM) season in Iganga district, Eastern Uganda.
iii) To examine the effect of variation of start, end and duration of the growing season of the long rainfall (MAM) season on maize yields in Iganga district, Eastern Uganda.

1.4 Research Questions

i) What are the trends of the rainfall (1990-2022) of the long rainfall (MAM) and maize yields (2013-2022) in Iganga district Eastern Uganda?

ii) What are the variations of the start and end of the long rainfall (MAM) season in Iganga, Eastern Uganda?

iii) What is the effect of variations in onset, cessation and the duration of long rainfall season (MAM) season on crop yields in Iganga, Eastern Uganda?

1.5 Justification of Study

Sub-Saharan Africa (SSA) is likely to have a decline in the yield of crops by the year 2050 as indicated by the IPCC Fifth Assessment Report (2013). Recently, there are indications that the start and end dates of the rainfall seasons have changed in Eastern Uganda. Some seasonal rains come early and end when it’s still expected, yet sometimes the rainfall onset and cessation is late (Mubiru et al., 2012).This study will therefore determine if there has been changes in onsets and cessation dates of the MAM rain long season and how it affects maize yields in Iganga.

In Africa, most people depend on staple crops like maize (Zea mays L.). Most academic studies predict that sub-Saharan Africa's output of rain-fed maize will decline due to climate change (Ramirez-villegas, 2015).The actual yield of maize per hectare in Uganda has been decreasing from 2014-2018 yet the area under the crop is increasing (NEMA, 2019). Ugandan crop yields have been significantly affected by changes in precipitation due to irregular and uneven distribution of precipitation during the cropping season (Epule et al., 2018).This study targeted Iganga district in Eastern Uganda to find the effect of rainfall onsets ,cessations onto maize yields.

Maize that is mainly grown in the rainy season normally has its yields determined by the distribution of seasonal rainfall, onset timing, and end of seasonal rains. Apart from the agriculture sector, to manage dams and release water back into rivers, hydroelectricityproducing companies should have knowledge of when the rains begin and end. The tourism sector needed information on the beginning and end of the rains to plan for outdoor activities, the road works sector also needs this information to plan a schedule for the road works. For farmers to make important decisions on when to start planting, they need knowledge on how rainfall variability will affect onset and cessation. Therefore, Uganda and Iganga district farmers in particular, that practice rainfall dependent agriculture will determine yields by early or late onsets and cessation dates. Such a scenario, raises interest among farmers, researchers, and climatologists who would wish to establish whether the start and end dates of the rains have changed or whether it's rather the variability? It's upon this basis that this study will determine the effect of the changes in start and end dates of rainfall on maize yields, which intends to contribute to specific knowledge for dependable planning and maintaining rainfed agriculture, as well as the construction of drainage systems and irrigation systems, which relies on having an understanding of reliable rainfall amounts, year-to-year variability, and its distribution pattern (Dunning et al., 2016).

It is also very vital for local farmers to be knowledgeable on rainfall onset and cessation impact on maize yield to effectively decide when to begin planting as well as other farm tasks. Iganga being an area that is rainfall dependent for agriculture production, together with other social economic activities, early or late onset, and cessation determine the production of crops and growth of other sectors that survive on rainfall. To propose solutions, address the food security problem in Iganga District, and pave the road for socio-economic developments, appropriate information on rainfall onset and cessation is essential.

1.6 Significance of the Study

Numerous teleconnections between weather patterns and seasonal variability have led to false starts in the commencement of the rains in the growing season. Due to these onset variabilities and uncertainties, farmers are urgently in need of information regarding when the growing season begins and ends. As a result, they are unsure of what to expect, and the question "When do rains commence or end during the growing season?" keeps resonating in their heads (Ocen et al., 2021).

Rainfall agriculture in eastern Uganda will have a basis for this study, both now and in the years to come. To be certain of crop production, farmers need information on the onset, cessation, and length of rainfall season. It’s vital to develop proper adaptation methods since they have a big impact on crop growth & production.

1.7 Scope of Study

Iganga district where maize is the main cash crop, was the main area of focus. The study covered a period of 10 months, that is, from January 2023 to September 2023. Daily observational gridded rainfall data recorded from weather stations in the district, for the period 1990 – 2022 was used. The study also used data collected on maize production and yield for the same district for the last 10 years (2013-2022). Determining start, and end, of the long rainfall season and its variations were independent variables while maize yields was the dependent variable using Iganga district in Eastern Uganda. Conducting the research with quite good daily rainfall gridded data from 1990-2022 enabled better outcomes of the research. The study was mainly carried out in Iganga district. This is due to limited time; resources and logistical problems encountered which could not allow carrying out the research countrywide.

1.8 Limitations of the Study

Scarcity of data, both rainfall and maize yield data was a serious limitation that would not allow scaling up. A few years of data records and the issue of station data including limited financial and logistical problems were also encountered.

The study mainly concentrated on maize yields in relation to rainfall parameters of onset, cessation, and length of the growing season from 2013 – 2022 using rainfall data from 1999-2022. Maize yields also depend on other factors like Temperature, humidity, prevailing winds soil moisture, and other non-climatic factors like application of fertilizers which were not considered in this study.

In this study, my delimitations were that rainfall data was availed by UNMA after gridding and because of scarcity of data only 10 years of maize yield data were availed by the production department of Iganga. Financial limitations were overcome by making part payments at every necessary level.

1.9 Conceptual Framework

The interrelationship between the study variables and how they relate to achieving the expected goals were illustrated in this framework. The focus was on determining the impact of the changes in the start and end of the long rainfall season (MAM) on maize yields in Eastern Uganda. Observed daily rainfall gridded data was analyzed to determine variation in seasonal rainfall onset and cessation.

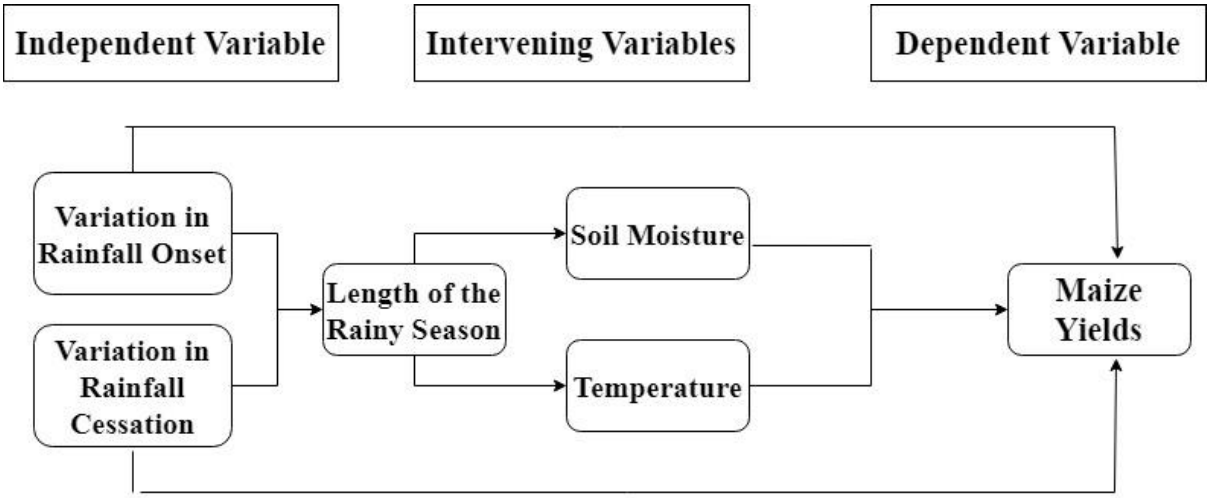

Figure 1.1: Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Literature by current scholars on onset and cessation dates was comprehensively reviewed in this chapter. Studies of different regions were examined.

2.2 Rainfall Variability

The variance in yearly or seasonal rainfall above or below a long-term average value is known as rainfall variability. Rainfall in a place may vary throughout a certain time of the year, either being above or below average; this variation is called variability (Metz, 2011). Rainfall is the most important climatic factor in developing countries because it supports life especially in the agricultural sector (Wagesho & Claire, 2016). Rainfall variability in Africa is anticipated to rise just like in other parts of the world, since extreme weather events have increased (Thornton et al., 2009, Lal et al., 2012).

In a study investigating the various agroecological zones in Ghana for differences in rainfall commencement, and end, length of the season, wavelet analysis was used to evaluate the standard deviation in the annual precipitation totals considering the start and end dates of the rain season for each climatic zone. Wavelet power spectra across Ghana and their notable peaks showed indications of variation in the dates of rainfall commencement and end. While the beginning and end of rains differences in the transition zone was 2-4 years whereas savannah zone was within 4-8 years, the start and end of rain variances of the coastline showed 2-8 while forest zones showed 2-4-year variability (Amekudzi, Yamba, Preko, & Asare, 2015).This variation is in line with Iganga rainfall onset and cessation changes over the years of study yet it was done in a district.

The Greater Horn of Africa Regional Climate Outlook Forum (GHACOF) commenced reception of onset and cessation projections from Climate Predictions and Applications Centre, although no evaluation of expected competence has been provided (MacLeod, 2018).

East African rainfall variance has been well studied, and the amount of yearly precipitation as a whole has increased. (Thornton et al., 2009 and Nicholson, 1993 Nimusiima, et al, 2013). However, because the rainfall in East Africa's equatorial regions is so complicated, influenced at the regional level, it is impossible to rely on generalizations based on global climatic trends.

The failure of the rainy season can have a significant impact on a nation's economy, as agriculture depends on it. Due to its high-water stress vulnerability, maize, a typical staple crop, frequently displays a remarkable inter annual variation. This study therefore considered mainly rainfall characteristics and their impact on maize yields (Lala et al., 2021).

The rains in Uganda start and stop differently during the course of the year. In some cases, they begin early and end early. This has prompted studies to determine whether rainfall patterns have altered. While the bulk of these studies frequently employ data that has been aggregated to monthly, seasonal, or annual time periods, very few of them use long-term series that include daily observations (Nsubuga, 2018). This study used daily gridded data to find out if there has been an impact by the variations in onset and cessation dates on maize yields in Eastern Uganda.

2.3 Methodologies of studying onset and cessation

In Ghana, a study was conducted to determine how the output of important crops and the pattern of rainfall in the Worobong Agro-Ecological Area (WAA) relates climate change to food security. The pattern, water availability, and intensity of the association between agricultural output in the WAA were identified by analyzing local rainfall data variations and using precipitation concentration index PCI to examine the irregular rainfall distribution during a normal year, (main and minor). Results demonstrated that rainfall variations within the three groups' main seasons was less than that of the minor seasons. It also showed that three crops' yields had decreased over the time period (Kyei-Mensah et al., 2019). On the contrary this study found a variation in the long-time rainfall series of the season but with an increasing trend in the maize yields.

The Pearson product-moment correlation coefficient, coefficient of variation, and precipitation concentration index (PCI) were utilized in a study by Kyei-Mensah et al. (2019) to produce statistical indices and analyze the interannual and intraseasonal rainfall variability. More importantly, PCI can be used to describe annually distributed rainfall (that is, if it is concentrated in one month or rather evenly distributed), which was the study's main objective. A pattern in the (major and minor) variations in distribution of rainfall was revealed by the results. The coefficient of variation (CV) results for the (major and minor) seasons throughout the 30 years revealed remarkable fluctuation in both seasons, with the minor season showing the most variation when compared to the major (Kyei-Mensah et al., 2019). My study findings were in line with this study, using Pearsons’s correlation the results showed variations in the interannual variability in the study period though the study considered one season.

According to a study done to determine the impact of the beginning and end of the rainfall season on crop yields in Lafia, Nigeria, regression analysis was used. Study results revealed that the end of the rainfall season has a greater effect on crop yield than the beginning of the rainfall season (Iortyom et al., 2017). This finding corroborated with my study findings in Iganga district.

The start and finish timings of the rainfall season in a study, were determined by daily rainfall data 1981 - 2010. By dividing each year into pentads, the pentad calendar yields 72 pentads in total. Rainfall was computed and accumulated for each pentad. Pentads of rainfall for the study area are displayed alongside the number of pentads, providing an estimate for each individual year. Both the exact start date and the first date of the cessation are given by the latest day of the beginning of the pentad. Pentad provides the day that the rainy weather occurred (Dates et al., 2016). The pentad methodology was also used to determine the onset dates of the long rainfall season in this study.

Analysis techniques that use threshold values for cumulative rainfall are applied when calculating onset-based rainfall (Segele & Lamb, 2005). A cut off from the percentage of accumulated rainfall (Odekunle, 2006). A total of all accumulated anomalies (Camberlin et al., 2009, Dunning et al., 2016). An accumulation of at least 1 mm was considered to be a rainy day. On the first day of the rainfall season, the start will be defined as when there has been at least 20 mm of rain in 3 straight days of accumulation without a dry spell lasting at least 7 days in the subsequent 20 days. Threshold values are commonly used in determining onset and cessation date, this study equally applied a threshold for onsets and cessation dates.

2.4 Models for Assessing Crops and Rainfall onset and cessation

In Brazil, a study utilized hierarchical Bayesian modeling of daily rainfall incidence from multiple sites, it was possible to determine the commencement and end of the rains in the (MAM) season. This was accomplished by locating the first day of the year during which the estimated likelihood of rainfall is greater than the stated value, such as 0.5 (Lima & Lall, 2009).

In Uganda, a study used the Aqua crop model to examine how possible climate change would affect maize yields in the region of Victoria Nile basin. With the help of data from the Coordinated Regional Downscaling Experiment (CORDEX) and the Hadley Centre Global Environmental Model version 2-Earth System (HadGEM2-ES) (2071-2099), maize production was projected for the near future (2021-2040), mid-future (2041-2070), and distant future (2071-2099). According to their research, depending on the agroecological zone, maize yield could decrease by up to 1–10%, 2-42%, and 3–39% in the short-, medium-, and long-term futures, respectively. Since maize is a staple crop, this yield reduction might have a significant effect on both socioeconomic and regional food security (Bwambale & Mourad, 2022). Contrarily this study focused on rainfall onsets, end and the duration of the rainfall season using long term gridded rainfall data to examine effect on maize yields.

According to most studies done (Gunathilaka et al., 2016,Patrick et al., 2019) predictive models, projections and assessments of crop yield impact on rainfall have dominated the Literature it’s for such reasons that this study focused on daily long term gridded data to assess and determine onset and cessation of rainfall.

2.5 Conditions for maize growth

(Udom & Kamalu, 2019) in a bid to determine maize water requirements for growth, using the Blaney-Criddle and Pan Evaporation data, the average daily consumption rate was 4.22 mm, whereas the growing season’s total water requirement for maize was 456.9 mm. Tasseling (5.66 mm of rain on day-1) and formation yield (6.31 mm day-1) were shown to be the crop's greatest water usage periods.

Development stages, the expansion of the crop canopy, the maize species, amount of evaporation in the environment, planting density, crop's growth to maturity all affect how much water is needed for maize (or any other crop). Environmentally, water would be required to maintain sufficient moisture for the crop to grow in the root zone on sandy soils, yet with limited storage capacity. The ideal maize yield may be negatively impacted by moisture stress starting around tasseling and continuing to setting of cobs and filling. An excessive amount of water loss in the root zone will leave many cobs empty or with little grains. Consequently, the pattern of water use during the developmental stages (Udom & Kamalu, 2019).

Water of 400-600 mm is required for a maize plant to grow in a season and is mainly soil moisture reserve. If a crop is not managed well, amounts of water above 600mmt can lead to lower yields. Soil and weather conditions normally determine a farm’s total yield, hence called a farm’s yield possibility. For every millimeter of water used about 10-16 kgs of grain is produced (Mapfumo et al., 2020).

Maize grows best under rainfall conditions of 600-1000 mm. It needs a pH range of 5.5-8.0 and thrives best in high water holding capacity fertile soils, that are well drained, deep with medium texture (Durodola, 2020).

Where the mean of the summer month temperature is less than 23° C or less than 19° C mean daily temperature, maize cannot be grown because it’s a warm weather crop. At 16°-18° C temperatures germination will be faster and less variable, although minimum germination temperature is 10° C. Between 5-6 days maize should sprout, at 20° C. 32°C is the temperature that is affecting yields critically. To prevent damage to the crop 120-140 frost free days are needed because it damages at any stage of growth. Grain filling and leaves of mature plants can be severely affected. Apart from rainfall (water) stress, maize is also affected by temperatures (Nkonya et al., n.d.).

2.6 Assessing rainfall and maize trends

In the dry plains of Ethiopia, where seasonal rainfall variability is large, an analysis of trends in rainfall events, such as start, cessation, dry period, wet spell, and number of rainy days, was found to be more significant than annual and seasonal totals. Previous research in many regions of Ethiopia focused on analyzing trends in seasonal and annual rainfall totals, ignoring intra-seasonal variability in rainfall, which includes the length of dry spells, the number of rainy and dry days, and other crucial factors for agricultural planning. However, disaggregated analyses showed that stations in the country's northwest, north, and center showed varying (positive, negative, or no) trends. This study ignored intra-seasonal variability in rainfall, something that my study has clearly analyzed (Getachew & Teshome, 2018).

In study using trend analysis, the decadal and interannual variability in the annual temperature and rainfall time series were examined. The statistical program Minitab was utilized for the investigation. The coefficient of variation (CV) was used to determine the decadal and interannual variability in the commencement, end and length of the rainfall season. The parameters of the time series trends were determined by a simple regression and correlation analysis.

The basic regression analysis, in which rainfall was regressed on time, was used to ascertain the annual rainfall trends in the time series, duration of the rainy season, start and end in all the stations evaluated during the period 1978/80–2010/12. The statistical program Minitab was then used to calculate the equation of the line of best fit. Data on annual rainfall in the studied area indicated a trend toward increase. The annual rainfall statistics at Gasol Station indicated a rising tendency for all the months of July, August, September. This study corroborated with my study where the seasonal (MAM) trend was generally increasing in the March and April, yet on the contrary decreasing in May on an annual basis (State et al., 2016a).

According to a Nigerian study, the annual or temporal distribution of rainfall varied from a minimum of 1026.4 mm in 2001 to a maximum of 1903.3 mm in 1991. This means that while 1991 offered the possibility of a higher food yield, it also carried the greatest danger of flooding and environmental damage. With an average annual rainfall of 1428.4 mm and a standard deviation of 108.6 mm, it is possible to anticipate an annual rainfall fluctuation of 108.7 mm over this place in any given year. Although there is a minor decrease trend in the parameter's values over time, it is not statistically significant at any of the selected significance thresholds (0.01, 0.05, and 01) based on the calculated p-value (0.6925). The study's modest declining tendency is consistent with the findings of Dunning et al., (2016) who noted that rainfall in the West African region has been declining over the previous three decades. More significantly, though, is that this pattern is becoming increasingly complex.

It demonstrated that over the research period, corn yield over Akure had increased. With a yield value of 465.7 tons in 2008, the highest yield statistics were recorded; in 2000, the lowest yield value recorded was 144.2 tons. At the 10% level of significance, the test results for significance at all levels of significance for the observed increase revealed a significant upward trend in yield values in the study region. The positive rainfall values previously noted from the research carried out while holding other yield-related parameters constant may not be unrelated to this rise. Atiah et al., (2021) noted that precipitation has a greater effect on crop productivity than temperature.

There were 297.6 tons in the mean yield value. The mean value of the maize yield was greater in years 2006–2016, with the exception of 2010 and 2015, which had values below the mean yield value. The low yields of maize in years 2000–2005, 2010 and 2015 were below the mean value. Moderately high rainfall values were depicted in most years with higher maize yields yet 2000,2002, and 2004 all had low maize yield values despite the high rainfall observed in the season. This suggests that at different growth stages requirements such as rainfall, properties of soil other yield factors, could be considered for future studies. This study is consistent with my findings where the trend indicated increasing maize yields in relation to an increase in precipitation in that the period 2013-2022 (Mosunmola et al., 2020b).

The duration of the rainfall season, the dates of its beginning and end, and the number of wet days all showed a declining trend in the meteorological variables. This suggests that as time has gone on, the rainfall season's dates of the beginning and ending have gotten later. In the meantime, there was an increase in rainfall amount, the temperature annual average, and the mean annual sunlight. This suggests that they have been growing over time. However, out of all the crops examined, the trends for cassava, yam, groundnut, sorghum, and soy beans were upward, whereas the trends for rice and maize were downward. This demonstrates how the yield of rice and maize declines with rising temperatures, more sunshine, and heavy rains. On the contrary Iganga district Maize trends were on the increase with increasing rainfall (Adamgbe & Ujoh, 2013).

2.7 Determining variations in rainfall onset and cessation

In various places around the world, the rainfall starts and end dates have been determined by numerous approaches in different studies(Dodd & Jolliffe, 2001) in West Africa, defined the beginning of a rainfall season as the first five days in a row with at least 25 mm of precipitation, provided that there are no dry spells (seven days or longer) in the 30 days that follow.

In comparison to seasonal totals, the scientific community has traditionally given less attention to onset and cessation across East Africa (Nicholson, 2017). October-December (OND) short rains and March- May (MAM) long rains are two rainfall seasons whose average dates and variations of the beginning and end of the seasons has been determined in Kenya and Tanzania. For these nations, beginning and cessation have been demonstrated to be strongly in agreement with the totals of the season and with one another during the short rains, not the prolonged ones (MacLeod, 2018). This study therefore addressed the change in commencement and end of long rains (MAM) and its impact on maize yields particularly in Iganga, Eastern Uganda.

The coming of the (MAM) rains in East Africa is influenced by zonal winds; abnormal easterlies (westerlies) might result into a late, or early start and later on a wet (dry) season. MAM rains have been connected to the beginning of the monsoon winds (Mugo et al., 2016a). Despite West African onset forecast skill having been evaluated, It has been shown that short rains start earlier and are more likely to reoccur than the long rains especially when the atmospheric model is used forced by sea surface temperature (SST), in the scientific literature East Africa has not described her level of forecast skill (MacLeod, 2018).

Principal component analysis (PCA) was used to assess the onsets and cessations of a specific areas in Tanzania, East Africa. The correlation matrix is subjected to a PCA (S-Model). Following the division of the time series of the leading principal component (PCI), which represents the predominant mode of variability in the research region, into subsets, one for each year, cumulative series are calculated beginning on February 1st of each year. A series was carried out for 150 days and it showed a steady downward trend at first, followed by a rising trend (the rainy season, or above-average precipitation) and then another downward trend (the northern summer dry season). The start (stop) of rain is then determined by the minimum (maximum) point values. The commencement and cessation of the rainfall season are not the same, as seen by the differences in regional patterns for the commencement and cessation of rainfall (Camberlin & Okoola, 2003).

A five-day average (or pentads) of daily rainfall was used to define the beginning of a rainy season. If the rainfall average was significantly below the criteria for various pentads before commencement and significantly above the threshold for numerous pentads after onset, they determined the start of the rains to be a five-day total in which precipitation surpassed a particular threshold (Marengo et al., 2001).

In an investigation, a study used the cumulative pentad (five-day total) to pinpoint when rainfall started to fall. Beginning dates for a 5-day period of rain (a "pentad") with at least 25mm of rain and three days of wet weather were totaled. The specified values are entered into the onset-generating INSTAT program. Elgon's onset was missed by the approach, but late onset was detected at other Kenyan locations. 372 onsets, or 76% of the maximum 492 that might have been recorded during the research period, were recorded (Mugo et al., 2016b).

The effective end of the raining season is what shows the end of rain in a season. Walter (1967) defined end of rains date as the last date on which a threshold reached (Dates et al., 2016). This study differently used the Evapotranspiration methodology with a threshold to determine end of rains.

Regarding historical fluctuations in rainfall in Africa, a number of hypotheses have been made, including the long rains season's start and end changes and the occurrence of the periodic cycle changes (Oguntunde et al, 2014; Timit et al., 2022 Camberlin & Okoola, 2003). Anecdotal evidence suggests that the south Sahel region of West Africa's commencement of the rain season shifted earlier according to farmers there (Dunning et al., 2016).

Methodology for determining the variations in the onset and cessation dates of the long rain season can be split into two broad categories: those that take atmospheric dynamics into account and those that use water balance, such as how much or how often it rains (Amekudzi, Yamba, Preko, & Asare, 2015). To identify the commencement and cessation of the rains in the season a study that used models that considered atmospheric dynamics (Kerandi & Omotosho, 2008). Evapotranspiration and rainfall relationship was used to construct a model to forecast the onset and cessation dates of the rainy season (Omay et al., 2022).

Others methods use only rainfall data to determine the beginning and end of the rainfall season; this percentage of cumulative mean rainfall method determines the beginning and ending dates (Amekudzi, Yamba, Preko, Asare, et al., 2015) .This study used daily rainfall gridded data to determine the rainfall dates.

There are several methods for determining when the rainy season begins and ends, and many of them have been applied just in the West African region. Most call for the definition of thresholds, such as the first two days that follow each other with at least 1mm of rain and a total of more than 20mm being defined as the beginning. An extra criterion is introduced to prevent inaccurate onset detection: no seven-day period with a total rainfall of less than 5mm occurred in the ensuing 20 days (MacLeod, 2018). This study used the climate data tool, to determine onset using a pentad approach a threshold of three consecutive wet days with at least 1mm of rain was used.

A study adopted the (Walter, 1967) method, which typically uses only the rainfall record that is measured directly from ground stations, to analyze the effect of when rainfall starts, ends, and the growing season's duration and impact of variations on crop yields in Benue State. Instead of the first day that rain falls, this technique says that the beginning of the rainfall season is when a location receives more than 51mm of cumulative rainfall. While the termination date is the day after which it is not anticipated that 51mm of rain will fall, In order to determine the exact day when the rains finish, the formulas are therefore used in reverse order, accumulating the entire rainfall backward from December (Patrick et al., 2019).

In Ethiopia, the beginning of the rains in a season was defined as the day on which 20 mm or more of rain fell over three consecutive rainy days following a starting date (the first of June in regards to the short rain season while the first of February for the long rain season), with no longer than seven dry days of weather to occur in the next 30 days. Any day after the first of September for the SON season and the first of May for the MAM season when the soil water balance hits zero is considered the cessation date (District & Eastern, 2020). On the contrary Evapotranspiration with a threshold was used to determine cessation in Iganga district, Eastern Uganda.

In East Africa, the scientific community and even academics have paid little attention to onset and cessation; therefore, additional research should be done to close the knowledge gap. When compared to long rains(MAM), the commencement and finish of short rains (OND) in Kenya and Tanzania are closely correlated (MacLeod, 2018).

A study investigated if the primary growth season did not start in the expected time. The false start of the rainfall season (Fsos) was found to be related to the phenomenon known as the season's false onset, which occurs when a dry spell occurs before the rainy season normally begins (Sivakumar, 1988).

A study interpreted the day the rains begin as the start of the growing season for crops. A threshold approach, which is crucial for rainfed farming in identifying when the rainfall season genuinely begins, formed the basis of the definition of a false start (Ocen et al., 2021).

In a study investigating the variations in the start, end of rainfall and duration of Ghana's Agro-ecological zone's rainfall season, the onset and end of rainfall were calculated using rainy day's numbers and rainfall amount from cumulative curves. Findings of this study showed that zones of transition began in the second decade of March and ended in the third decade of April. The Savannah zone has been linked to late rainfall commencement, which occurs between the second decade of April and the first decade of May. In the entire country less than ten days separated the duration, end, and start of the season and the root mean square error's (RMSE) range was five to twenty-five days. The findings indicated a variation in the start, end dates and duration of the rainfall season. (Amekudzi, Yamba, Preko, Asare, et al., 2015).

A study in Nigeria determined the growing season end by doing the same thing as for the beginning, with the exception that here it was calculated going backward from December. It is calculated by dividing the first month's total rainfall with a cumulative monthly rainfall of more than 51mm by the number of days in the first month following December with a cumulative monthly rainfall of more than 51mm. While Walter (1967) stated that the long growing season would be got by subtracting the beginning and end of rain dates, and this would be the length of the growing season (Dates et al., 2016).

The scientific community, for example (Nicholson, 2017) has traditionally paid far more attention to seasonal totals in East Africa than just beginning and cessation. In Kenya and Tanzania, the seasonal rains' MAM and OND mean start and finish dates have been established. It was discovered that the short rains' beginning and termination were closely connected (Camberlin & Okoola, 2003).

According to a study in Kenya, the cessation of the MAM rains preceded the start of the Indian monsoon. Anomalist easterlies and westerlies, or zonal winds that control the advent of protracted rains, have caused a dry or wet season and a late or early seasonal beginning overall (Camberlin & Okoola, 2003, Camberlin et al., 2009).

Due to the heterogeneity of station records, there aren't many studies in Uganda that use daily records. A study found out that aspects like initiation and cessation require the use of daily records for research. It is necessary to identify changes in rainfall's beginning and cessation in order to predict potential impacts. Dates have been linked to the commencement and end of large-scale processes that affect local weather , such as the El Ninio Southern Oscillation (ENSO), cyclones, and monsoons (Mubiru et al., 2012). This study therefore differently used daily data as an existing gap.

2.8 Impact of Onset and Cessation on crop yields

Rainfall discrepancy will reduce worldwide yields of main crops such as maize, wheat, rice (Rowhani et al., 2011). The world's second-largest cereal food crop after wheat is maize, that can be grown in a wide range of agro-ecological zones. Depending on the seed diversity, maize grows in different parts through long and short seasons, it can mature in 90–190 days (Epule et al., 2017).

In Sri Lanka, a study used monthly panel data from various tea farms for more than 15-years to gauge how the weather affected tea production. To investigate how Sri Lankan tea output is impacted by both weather fluctuations and climatic changes, they primarily used a two-stage panel data approach. They discovered that a hotter, rainier climate would be detrimental to tea production. Therefore, their forecasts indicate a negative proportionate impact with increasing mean temperatures and greater rainfall (Gunathilaka et al., 2016).

In Lafia, Nigeria, regression analysis was performed to determine the impact of the commencement and end of the rainfall season on crop yields. Regression analysis showed that the end of the rainfall season had a greater effect on crop output than the beginning of the rainfall season (Iortyom et al., 2017). This finding corroborates with the impact of end of rains in Iganga district that had a greater effect on maize yields than the onset dates in the study.

In West Africa, a study used a Pearson correlation technique to evaluate rainfall indices against crop yields in the region, and there was a perfect correlation of rainfall with the yield of yam, sorghum and maize. Wrong start and end of rainfall that characterizes the length of the growing season, may contribute to low agricultural yields (Patrick et al., 2019).

Most people in Africa depend on maize (Zea mays L.), a staple crop whose impacts on output have been thoroughly studied. According to vast academic studies in Sub-Saharan Africa (SSA), less rain-fed maize will be produced due to climate change. (Ramirez-villegas, 2015, Adhikari et al., 2015) . In rain-fed Africa, extreme climatic conditions like drought are expected to have an impact on maize production (FAO 2009). Drought is likely the most recognized issue as an extreme weather occurrence in the agricultural industry, having significant implications for rain-fed crop output (Chimonyo et al., 2019, Mabhaudhi et al., 2019)

Over 95% of the land in Sub-Saharan Africa (SSA) is used for rainfed farming systems and rainfed crop cover (FAO, 2011). Planning for agriculture and crop production has been significantly impacted by a shift in rainfall patterns brought on by climate change impact (Sowunmi et al., 2020).

Early notice of beginning and cessation is frequently requested in the greater Horn of Africa region, and rainfall fluctuations has had a substantial effect on agriculture since it allows farmers to better manage planting activity and associated risks (Dunning et al., 2016).

A study depicted the rainy months of March, April, and May (MAM) to have higher intraseasonal variability. The nature of the significant variability that has been observed in the beginning and ending dates of MAM rains has been the subject of numerous studies(Camberlin & Okoola, 2003). Variations in the start and end of prolonged rains have disturbed agricultural activities and resulted in poor yields (Mugo et al., 2016b).

In a study analysis from 2022, the majority of Uganda's staple crops are rain-fed, making it the country in East Africa most in danger of a decline in crop yield., over all plant's growth and production has a remarkable effect due to water stress at particular growth stages, even though maize can be grown with as little as 200 millimeters of average annual rainfall. The frequently unpredictable rainfall patterns puts a country's food security in danger since they over rely on rains during the growth of staple crops (FAO 2016).The main determinant of an area's rain-fed agricultural yield is the pattern of rainfall during the growing season (Bwambale & Mourad, 2022).

In tropical countries, especially East Africa, rainfall has the greatest regional and temporal variability of all the climatic elements. Due to the significant degree of rainfall unpredictability, early or delayed starts and cessations of rainfall are frequent. Even when rainfall amounts were above average, considerable departures from the mean in the timing of the rain's arrival and cessation could occasionally lead to subpar crop yields (Mugo et al., 2016b).

Temperature and rainfall (water stress) both affect maize development. Up to 29°C, maize yield grows with temperature but falls sharply as the temperature climbs. 25 °C is the most excellent temperature for maize growth. The output of maize is reduced by 1% for every degree above 30°C per day, even in the best rain-fed conditions. Additionally, it was found that with an increase of 1°C above the maximum there would be a maize decline in output by as much as 10% for every optimum. When soil moisture levels are appropriate, temperatures as high as 37.8°C will favor maize production These results imply that the variables limiting maize output at high temperatures include moisture stress as well as temperature stress (Raza et al., 2019).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The chapter outlines how the study was conducted. It covers the data required and their sources, research design and methodology, method of data collection, data analysis, and tools for analysis.

3.2 Study Area

The area of study is Iganga district particularly covered by the sub counties of Bulamagi, Nabitende, Nakalama, Nakigo, Nambale, Namungalwe, Nawandala, Nawanyinji, located in the eastern part of Uganda. It's located between Latitude 0^{o}degree 00 minutes and 2^{o}degrees 30 minutes E and Longitude 32^{o}degrees 30 minutes E and 34^{o}degrees 30 minutes E. It is found in the zone, east of the river Nile. Iganga occupies a total surface area of about 1.019 km$^{2.}$ Iganga shares its southern boundary with Mayuge district, eastern boundaries with Bugiri district, while it shares its northern boundary with Kaliro district and the western boundary with Luuka district **(Figure 3.1).** It had a total population of 53,870 people during the 2017 population and housing census (Population & Profiles, 2017) (*I.e . " Mountain Slope*, n.d.) .

3.2.1 Precipitation

The western and southern part of the district receives an annual average of 1200 mm of rainfall , whereas the drier northwest receives 900 mm. Rainfall in the wetter south ranges from 1000 to 1200 mm, peaking in March through May and October through November. This kind of pattern of rainfall with lows and peaks reveals that rainfall varies in the study area (*I.e . " Mountain Slope*, n.d.) as envisaged by the current study.

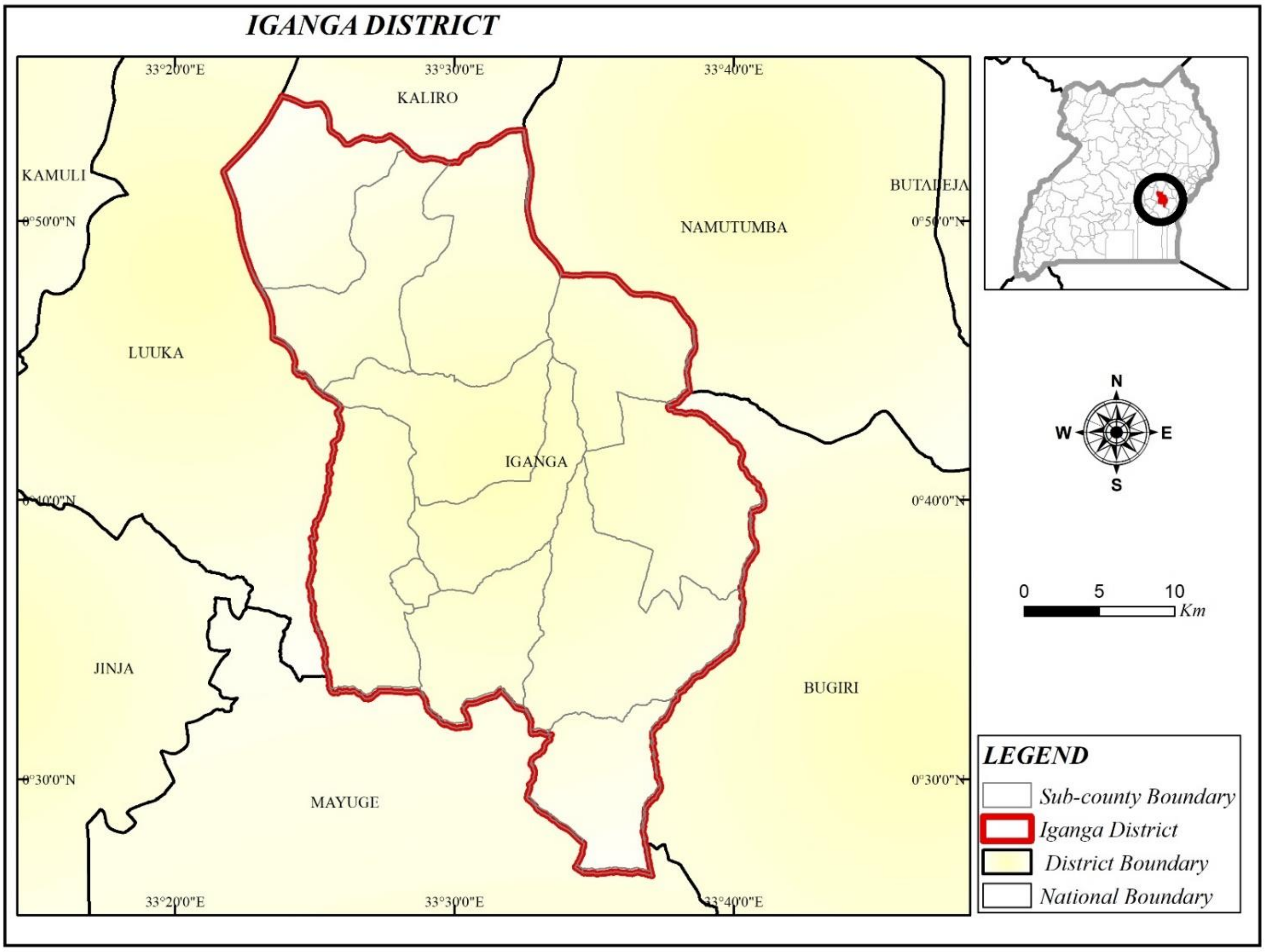

Figure 3.1: Location of Iganga district in Uganda
(Source Q G.I.S)

3.3 Research Design

This study was a correlation research study that undertook correlations and regressions that investigated the impact of onsets, cessation and length of the rainfall season on maize yields. It adopted a qualitative research approach that was descriptive in nature.

Research design involved a reconnaissance survey, obtaining data, data quality control, data analysis, establishing trend and analysis in order to achieve the objectives. To assess the trends of rainfall (1990-2022) of the long rainfall (MAM) and maize yields (2013-2022) in Iganga district Eastern Uganda, to determine variations in onset and cessation dates, of long rainfall (MAM) season in Eastern Uganda. To examine the effect of variation of start, end and length of the growing season of the long rainfall (MAM) season on maize yields in Iganga, Eastern Uganda.

During the reconnaissance survey, familiarization of the study region was achieved by physically visiting the eight sub-counties and the district main production department.

This later was followed by obtaining data from the National Meteorological Authority in Kampala and data for maize yield was got from the production department of Iganga district. This was done using a flash disk through a soft copy data request. Because of issues that are related to data, it was necessary to do data quality control like homogeneity test was done for maize data, while climate data being gridded point data it was already cleaned data without missing gaps from UNMA using the climate data tool.

This step enabled the study to proceed with data analysis. Data had to be arranged in series of months that is March, April, May, seasonal MAM, and annual, then establishing correlations with the overall area series. Man-Kendall trend test was used to determine monthly, MAM seasonal and inter annual variability trends with moving averages for the period of study.

R studio programming software, using the component of climate data tool software through the pentad criterion methodology based on rainy days with thresholds, determined onset dates, while the Hargreaves methodology which considered a fraction of evapotranspiration and thresholds determined cessations dates. Climate data tool software, Microsoft office excel 2010, were used to create frequency tables, graphs, scatter plots alongside moving averages.

Rainfall and Maize data was examined using Microsoft office excel 2010, SPSS software using the Pearsons correlation and Man - Kendall tau statistic for association between the two variables considering the P- value with a significancy level of 0.05. In order to establish the kind of relationship that existed between MAM maize production and MAM rainfall performance between the years 2013-2022, a standardized anomaly index of maize yields during the MAM rainfall season was done.

Descriptive statistical tools like bar and line graphs, tables were used to describe the effect of the variations in onset and cessation dates on Maize yields. Report writing then commenced. The design of the study is summarized in figure 3.2 below.

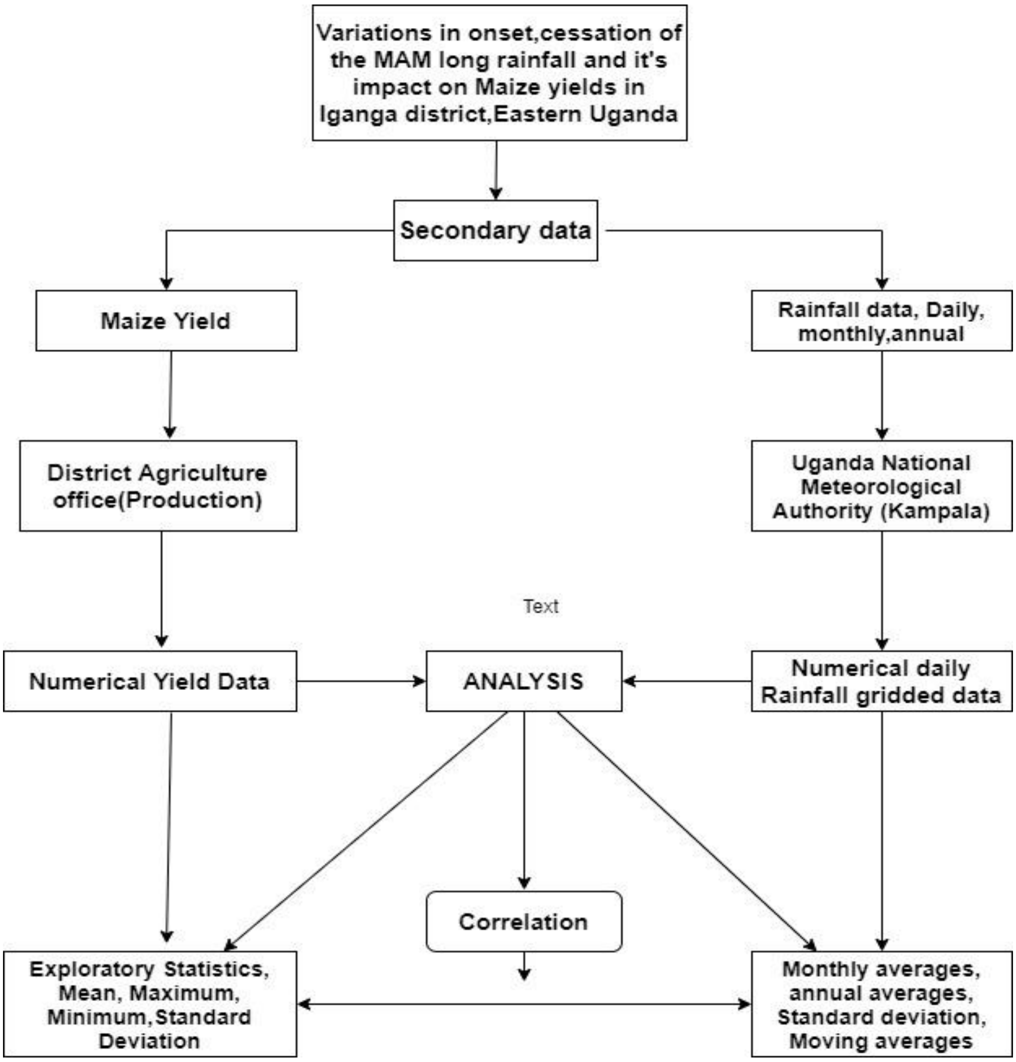

Figure 3.2: A flow of the research design

3.4 Data

The data used in this study was mainly secondary data, which was collected from the National Meteorological Authority Kampala. The National Meteorological Authority, Kampala provided a soft copy of the time series daily rainfall gridded point data. covering a period of 1990-2022 (32 years) were attained. Climate data tool CDT was used to download CHIRPS daily rainfall dataset for eastern region

https://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/.v2p0/.dailyimproved/.global/.0p05/.prcp/dods during the study time. Data inventory at UNMA showed that Jinja (Station id 89330430), Tororo (Station id 89340190), Soroti (Station id 88330060) had complete data. Grid-based interpolation method using nearest – neighbor was used. Like any other reanalyzed climatic products, the dataset possessed a few limitations, such as bias and random errors. A bias correction to ensure that outlier errors are sorted was done, since the resolutions were different, regridding was done and merged the two datasets to have a near reality dataset.

Still using CDT, a point in Iganga Nawandala sub county was identified, extracted its rainfall data and used it for analysis

https://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/.v2p0/.daily-improved/.global/.0p05/.prcp/Y/%28**0.6046N**%29VALUES/X/%28**33.4720E**%29VALUES/T/%281%20Jan%201981%29%2831%20Dec%202022%29RANGEEDGES/

The data was summed up into daily, monthly, and annual rainfall database of eastern Uganda and Iganga district in particular for a period from 1990-2022 (i.e., the length of data is thirty-two years for the region). The period of thirty- two years will be enough time to cover a variety of noteworthy weather abnormalities that have happened in Iganga district. The period was carefully chosen because it’s in line with the conventional way of characterizing an area’s climate data using 30 year’s weather data as adopted by the

World Meteorological Organization. The data was used for computing intra-seasonal and inter-annual rainfall, linear regression, Mann-Kendall test, and correlation coefficient. Rainfall is the climate variable chosen for this investigation. This is because it is the only variable where farmers may find strategies to optimize the farming process for the best yield (Mapfumo et al., 2020).

Secondary data on maize yield was obtained from Iganga agriculture offices in the production department, this data was reportedly collected and obtained from farmers in Iganga district particularly covering the sub counties of Bulamagi, Nabitende, Nakalama, Nakigo, Nambale, Namungalwe, Nawandala, Nawanyinji through different surveys in the district for a period 2013-2022. The crop selected for the study was mainly a food crop whose yields were documented by the Iganga agricultural production department for the period 2013-2022. The maize yield data was used to determine the impact of change in the start and end of the long rain season (MAM) on maize yield in Iganga.

Table 3.1: Collection Instruments, Variables and Sources

Variable	Data required	Source of Data	Data type	Data collection instruments
Onset **Cessation**	Daily rainfall in mm	National Meteorological Authority, Kampala.	Secondary	Soft copy from UNMA
Maize Yields	Maize yields in tones	National Agricultural Organization of Uganda, Maize grower's associations any cooperative group and buyers of maize. Iganga District agriculture office.	Secondary	Soft copy from Iganga District agriculture office

3.5. Data Quality control

Long-time series meteorological data has issues and to get reliable, quality, complete, and homogenous data analysis results, homogeneity tests were run.

3.6. Data Analysis

Rainfall and maize yield data were examined using Microsoft Office Excel 2010, SPSS, and the Climate data tool, to create frequency tables, scatter plots, and graphs, alongside moving averages. The Climate data tool, which uses monthly rainfall data, was used to determine the start and end dates of rain. The climate data tool was used. It is relatively simpler to carry out, more cost-effective, and novel because it relies solely on rainfall records that are measured directly for computation (State et al., 2016b).

The Climate Data Tools (CDT), created and maintained by Columbia University's International Research Institute for Climate and Society (IRI), is an open-source R package. Data organizing, quality assurance, merging satellite data with station data and reanalysis data, assessing merged and input datasets, conducting various studies, managing Network Common Data Format (NetCDF), and visualization are all possible uses for the CDT (Dinku, 2022). CDT offers all of its features in graphical user interface (GUI) mode, which is publicly accessible (Omay et al., 2022).

3.6.1 Assessing the trends of the long MAM rainfall season (1990-2022) and maize yields (2013-2022)

To achieve the first objective of assessing the trends of rainfall (1990-2022) of the long rainfall (MAM) and maize yields (2013-2022) in Iganga district Eastern Uganda. First Temporal Characteristics of trends and moving averages of Iganga MAM long rains, Interannual variability of March, April, May, and for MAM long rain season, in the time series of annual rainfall was analyzed using the trend analysis. Maize production trends of the interanual variation of the MAM average maize production 2013-2022 was also analysed. The non-parametric Mann-Kendall test was used during trend analysis to assess whether there has been a remarkable change in the rainfall pattern and maize production trends. This test was chosen because of its advantages and it's not like previous tests that need to be normally distributed (Baffour-ata et al., 2021b, Bwambale & Mourad, 2022).

The mathematical expression in Equation (i) that will be used to calculate the standardized MK trend statistics.

$$\boldsymbol{S} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n-1}} \sum_{\boldsymbol{j=i+1}}^{\boldsymbol{n}} \boldsymbol{sgn}(\boldsymbol{x_j} - \boldsymbol{x_i}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\boldsymbol{i})$$

Where x_i and x_j are sequential data for the i_{th} and j_{th} terms, n is the sample size.

In detecting the trend, a hypothesis was set as follows; null hypothesis (H_0), signify no trend. Alternative hypothesis (H_1), indicate the presence of trend, either increasing or decreasing trend. The variance of S calculated using Equation (ii);

$$\boldsymbol{Var}(\boldsymbol{S}) = \frac{\boldsymbol{n(n-1)(2n+5)}}{\boldsymbol{18}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\boldsymbol{ii})$$

To determine the significance of the trend, the probability related to S and the sample size, n, were computed. Z values are used to determine the trend's significance, with negative and positive Z scores indicating downward and upward trends, respectively.

For a two-tailed test, at a given α level of significance, (H_1), was accepted if $|Z| > Z_{1-\alpha/2}$ where $Z_{1-\alpha/2}$ is calculated from the standard normal distribution tables. The importance of the trend was then statistically measured by computing the probability related to MK and sample size n. Equation was utilized to determine the normalized test statistic, Z.

(iii);

$$\boldsymbol{Z = \frac{S-1}{\sqrt{Var(S)}}\ If\ S} > 0$$

$$\boldsymbol{= 0\ \ If\ S = 0}$$

$$\boldsymbol{= \frac{S+1}{\sqrt{Var(S)}}\ If\ S} < 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (\boldsymbol{iii})$$

The trend is deemed downward if Z is negative and calculated is bigger than the level of significance.

Understanding the pattern and broad changes in these climate factors is crucial. An area's current climate and its historical variability are evaluated using rainfall data in a trend analysis. The non-parametric Mann-Kendall test was used during trend analysis to determine whether there has been a remarkable change in the rainfall pattern. The test also has a very low sensitivity to unexpected peaks brought on by irregular time series.

By giving them a common number lower than the least measured value in the dataset, it includes any non-detectable data.

S is initially assumed to be zero (0) in the M.K. statistic, suggesting the absence of a trend. If the previously sampled data value is less than that from a later period, S is increased by one (1). Also, if the data value from the earlier period is greater than the data value from the past era, S is decreased by one (1). This test compares the alternative hypothesis (H1), which assumes that there is a trend (S = 0), to the null hypothesis (H0), which assumes that there is no trend (S = 0). In the event when there are n data points and the data point is at time j, the Mann-Kendall statistic (S) can be written as; (Bwambale & Mourad, 2022).

$S\ = \sum n - 1 \sum n\ i = 1\ j = k + 1 sgn\ (xi\ - xi)$………………………….. **(iv)**

3.6.2 Determining the variations of onset and cessation dates

The most commonly used methods in determining onset and cessation dates are those that consider several wet days, rainfall spell lengths, and a fraction of evapotranspiration as thresholds on total rainfall amounts (Gudoshava et al., 2020)

Onset and cessation dates criterion in this study were determined by creating a combination of thresholds of wet or dry spells, number of wet days, and accumulated or total rainfall. While the length of the growing season will be attained by subtracting the cessation dates from the onset dates (Baffour-ata et al., 2021a).

To achieve objective number two of determining if there is a change in rainfall starting dates, of the long growing season (MAM), This study used the CDT software tool and considered a Pentad Criterion based on rainy days of a number of 3 consecutive wet days each exceeding 1mm of rainfall totaling to 20mm and a dry period less than 10 days, in the 21 days that follow (Omay et al., 2022). This was used to determine the rainfall onset dates (Adelekan & Adegebo, 2014) The first day of March for long rains and October 1st for short rains, respectively, with a minimum total rainfall of 20 mm is considered the onset.

To further achieve objective number two, which is to determine if there is a change in the rainfall end dates of the long growing season (MAM). The study used the climate data tool (CDT) software tool to determine cessation dates and considered cessation of the season as adapted from the Hargreaves Method which considers a fraction of Evapotranspiration and a threshold of accumulated 10 days rainfall with less than 0.5 mm of Evapotranspiration (Omay et al., 2022)

A study defined the cessation as the date after 1st May for MAM and 1st December for SON when there is no water supply to the soil and without rains in the next 10 days,60mm was the soils water holding capacity (Tadross et al., 2009). In Machakos County Kenya, a study embraced the concept of stoppage dates to examine climate variations and trends and how they affect crop productivity (Bosire, 2019).

3.6.3 The effect of variation of onset, cessation and length of the rainy season on maize yields

To achieve objective three, At Bivariate level, the Pearson correlation was used with SPSS software to examine the association between variation in onset, cessation, and maize yields.

The Pearson correlation coefficient measures the strength of relationship between onset, cessation and maize yield with a limit of -1 and 1, -1 indicates an inverse relationship between the independent and dependent variable, while 1 indicates a positive association between independent and dependent variable. According to (Ruigar & Golian, 2016), a value of 0 indicates that the independent and dependent variables do not have a linear connection. Additionally, the correlation between the independent and dependent variables was ascertained by computing the P-values at a significance threshold of 0.05.

The Pearson coefficient of correlation was calculated as shown below:

$$r = \frac{\Sigma(xi-\bar{x})(yi-\bar{y})}{\sqrt{\Sigma(xi-\bar{x})}^2(y\grave{\imath}-\bar{y})^2} \quad \text{……………………………………..(v)}$$

Where, x is the onset and cessation dates and y is the maize yield data

The analysis of the data involved the use of a statistical computer package for social scientists (SPSS) to determine the relationships between variables. The independent variables were regressed against the dependent variable in the quest to explore whether maize yield is sensitive to the onset and cessation of rainfall. The analysis values for the dependent variable maize yields were transformed into natural logs rather than the original raw values. The reason for using log transformation was because logarithmic transformations help in pulling outlying data closer to the bulk of the data in a quest to have the variables normally distributed. In other words, log transformation is effective for data whose residuals increase with increasing values. For the larger values, taking logs thereby "pulls in" the residuals.

Ordinary Least Squares (OLS) regression was utilized for estimation. Maize yield data was transformed into natural logs rather than original raw values. It reduces the discrepancy between the observed value of your dependent variable and the value predicted by your line of best fit

$$\text{min } \sum_{i1}^{n}(\text{yi} - (\text{a} + \text{bx}))^2 \text{……………………………….} \textbf{(vi)}$$

Here:

- refers to the observed value of the dependent variable,
- xi is the value of the independent variable,

- a and b are parameters to be estimated that represent the intercept and slope of the regression line respectively

The simple correlation coefficient (r) was utilized to evaluate if the trend line in the time series under analysis is moving upwards or downwards. In which the following values are present: x (time in years), y (observation in the series), r (correlation coefficient), N (total number of observations in the series), and σx (standard deviation of x). When the value of (r) is positive, the time series under study is trending upward; when the value of (r) is negative, the time series under study is trending downward. Tables, frequency distributions, graphs, numbers, were be used to present the data.

$$r = \frac{\frac{\Sigma xy - x\bar{y}}{N}}{\sigma x - \sigma y} \text{...} \textbf{(vii)}$$

The second component of the analysis involved using Mann-Kendall tau statistic and correlation analysis, the variations in the time series of these factors (start, end, and length of the rain season) were identified, and their impact on maize yields in Iganga district 2013-2022.

The Mann-Kendall test calculates a Kendall correlation between the time series and time (up to a constant scaling factor) If S is the usual Kendall statistic, then r= $D2$ Where ti is the number of values tied at the $i\text{-}th$

$$\mathbf{D2} = \mathbf{(}n2\mathbf{)}((n2\mathbf{)} - \sum i\ (ti2)) \text{..} \textbf{(viii)}$$

The Mann-Kendall statistic was calculated to show if there is a correlation between onset, cessation, length of the growing season, and maize yields in the study area. Descriptive statistical tools such as bar and line graphs, and tables were used to describe the effects of the variations in the start and end dates of long rainfall season on maize yields.

Table 3.2: Table of Data Analysis

OBJECTIVE	VARIABLE	ANALYSIS
To assess the trends of long rainfall MAM season and maize yields	Rainfall • Onset • Cessation • Maize	Descriptive statistics: - Moving averages, Trends Interannual variability of March, April, May, MAM, long rains of Iganga
To determine the variations in rainfall onset, cessation		-Measures of central tendency and dispersion e.g. mean -Mann- Kendall for trends
To determine the impact of variation in onset, and cessation on maize yields	• Maize yields in Tones • Rainfall variations	Descriptive statistics: -Inferential statistic: -Pearson's correlation -Mann-Kendall for correlation

3.7 Validity and Reliability

Pre-testing the data-gathering tools was done to confirm the validity and reliability of a test (Recha et al, 2017). Pre-testing the data collection instruments was part of the process to evaluate the research validity reliability and suitability before actual administration.

3.8 Data Management and Ethical Considerations

Obtaining multiple authorizations to guarantee effective entry into the field was one of the logistical considerations. The researcher first sought permission from the university administration to collect data from National Meteorological Authority Kampala, Iganga district Agricultural Offices.

CHAPTER FOUR: RESULTS

4.1 Introduction

Results from the analysis were done concerning the objectives of the study area as presented in this chapter. The results address the question of rainfall and maize trends and the effect of the start and end of the MAM long rain season on maize yields in Iganga district.

4.2 Assessing the trends of Iganga MAM long rains 1990-2022 and maize yields (2013-2022) in Iganga district Eastern Uganda

4.2.1 Rainfall Trends

The study assessed the trend of Iganga MAM rainfall of March for the given period and the results of the inter-annual variability are presented in Figure 4:1

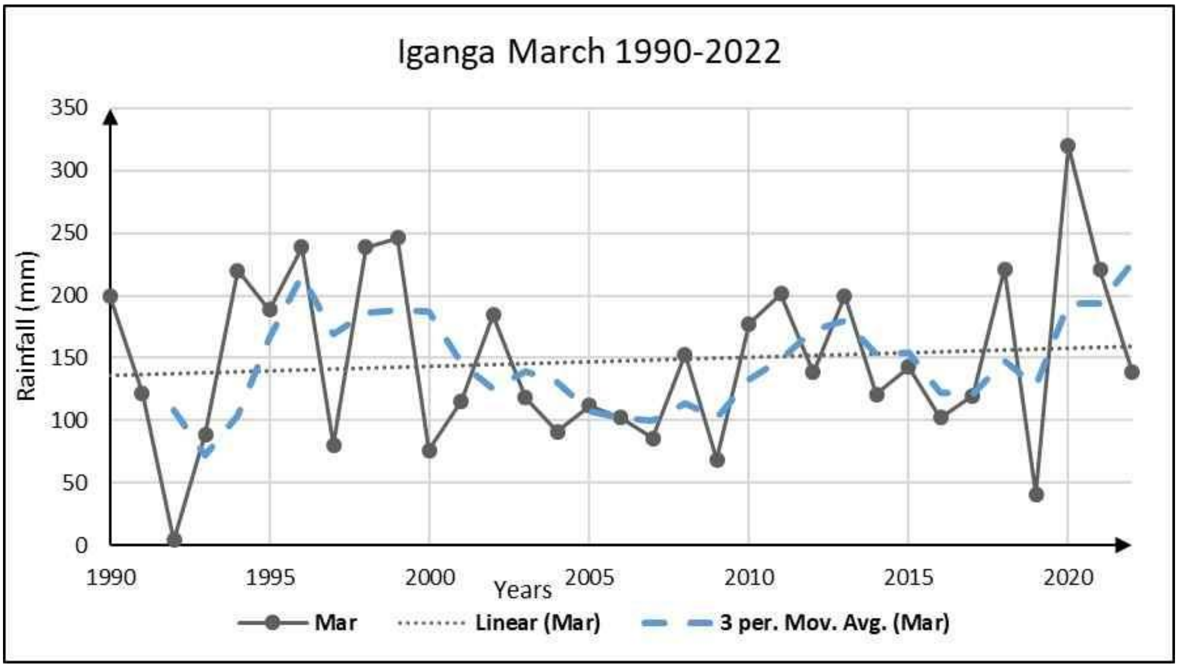

Figure 4.1:Iganga inter-annual variability of March rain from 1990-2022
Source: Researcher 2024

Figure 4.1 shows the inter-annual variability of March rainfall, moving average, and trend during the period 1990-2022. It depicts rainfall received in Iganga between 1990 and 2022. During these 32 years, high amounts of annual rainfall were seen in 1996, 1998, 1999 and 2020, and the lowest annual rains were observed during 1992 and 2019. Generally, the rains were below 150mm for most of the years in the study period. These results however were subjected to further analysis to establish the significance of the trend and the results are presented in the table 4.1.

Table 4.1: Iganga rainfall Mann - Kendall Results

MK- Test	March	April	May	MAM
Z	0.47	0.70	- 0.95	0.95
Sen's	0.67	075	-1.09	0.12
P-Value	0.64	0.49	0.35	0.35
Tau	0.05	0.09	- 0.12	0.12

The Mann-Kendall results in Table 4.1 reveal a P-value of (0.64) for March rainfall trends which is an indication that the trend was insignificant.

In order to assess the trends of rainfall in April, the study engaged in establishing the interannual variability of April rainfall, moving averages, rainfall performance during the 1990-2022 period in Iganga and results are presented in Figure 4.2.

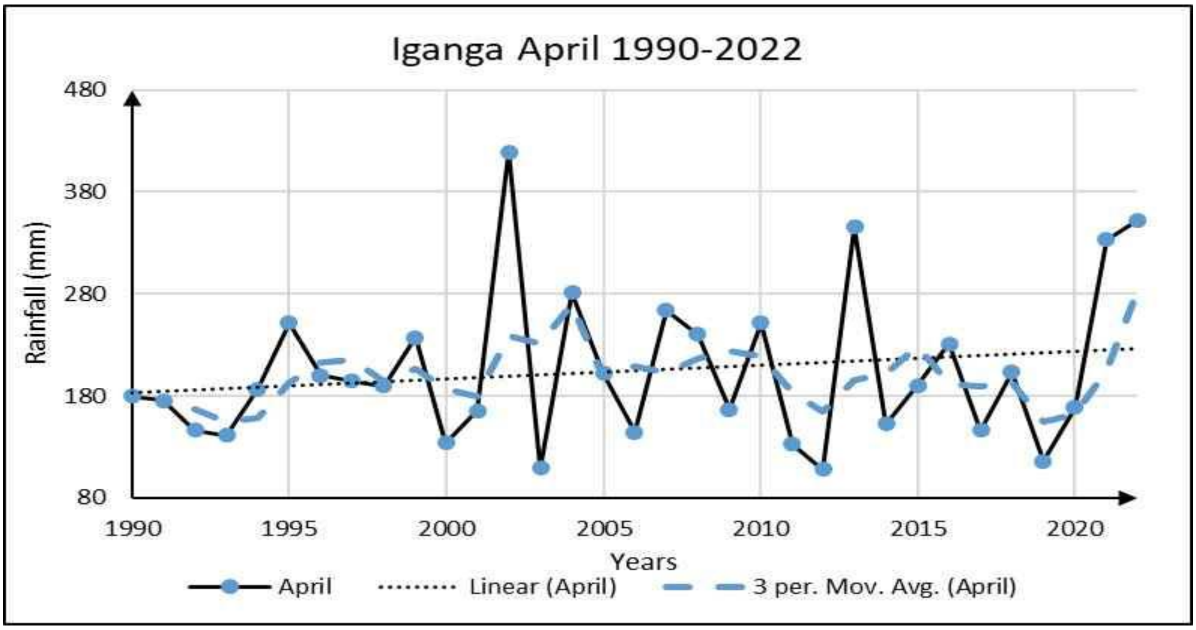

Figure 4.2: Iganga inter-annual variability of April rain from 1990-2022
Source: Researcher 2024

Figure 4.2 shows that Rainfall was low at 180mm in 1990 but it increased slightly to 260mm in 1995. There was a sharp increase in the rainfall received in Iganga in 2002 from 100mm to 430mm but this drastically dropped to 100mm in 2003 and kept fluctuating from 2003 to 2012. A sharp rise in rainfall in the study area is depicted between, 2012-2013 from 100mm to 360mm, 2020-2021 from 180mm to 330mm although according to the Mann-Kendall results in Table 4.1, the P-value (0.49) indicates that the trend was insignificant.

The study also engaged in assessing the trends of May rainfall as well and established the inter-annual variability of May moving averages, and trends during 1990-2022 and results are depicted in Figure 4.3.

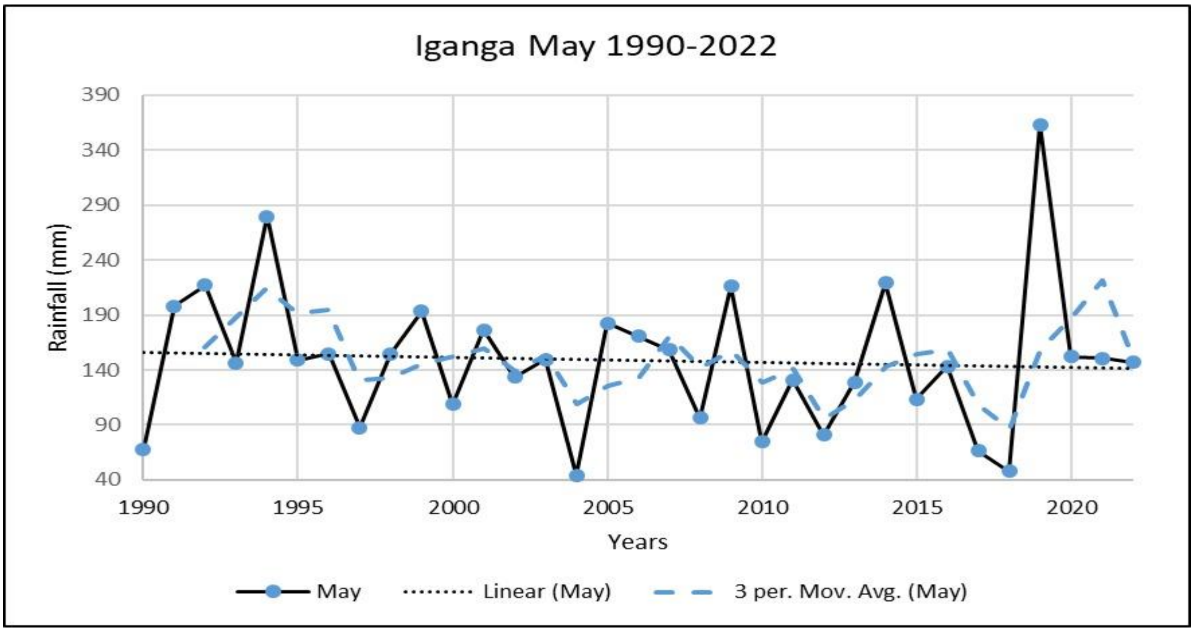

Figure 4.3: Iganga inter-annual variability of May rain from 1990-2022
Source: Researcher 2024

Figure 4.3 shows the inter-annual variability of May rainfall, moving average, and trend during 1990-2022. The results revealed that there was a general decrease in the rainfall received in Iganga especially in 1990, 1997,2000, 2004, 2010, 2018, although it increased in 1992, 1994 and sharply increased in 2019 from 40mm to 365mm. In 2020, rainfall dropped drastically from 365 to 150mm, although according to the MK results in Table 4.1, the P-Value (0.35) indicates that the trend was insignificant.

The study advanced to assessing the trend and established the interannual variability of the MAM long rainfall season from 1999-2022 in Iganga Eastern Uganda and results are depicted in Figure 4.4.

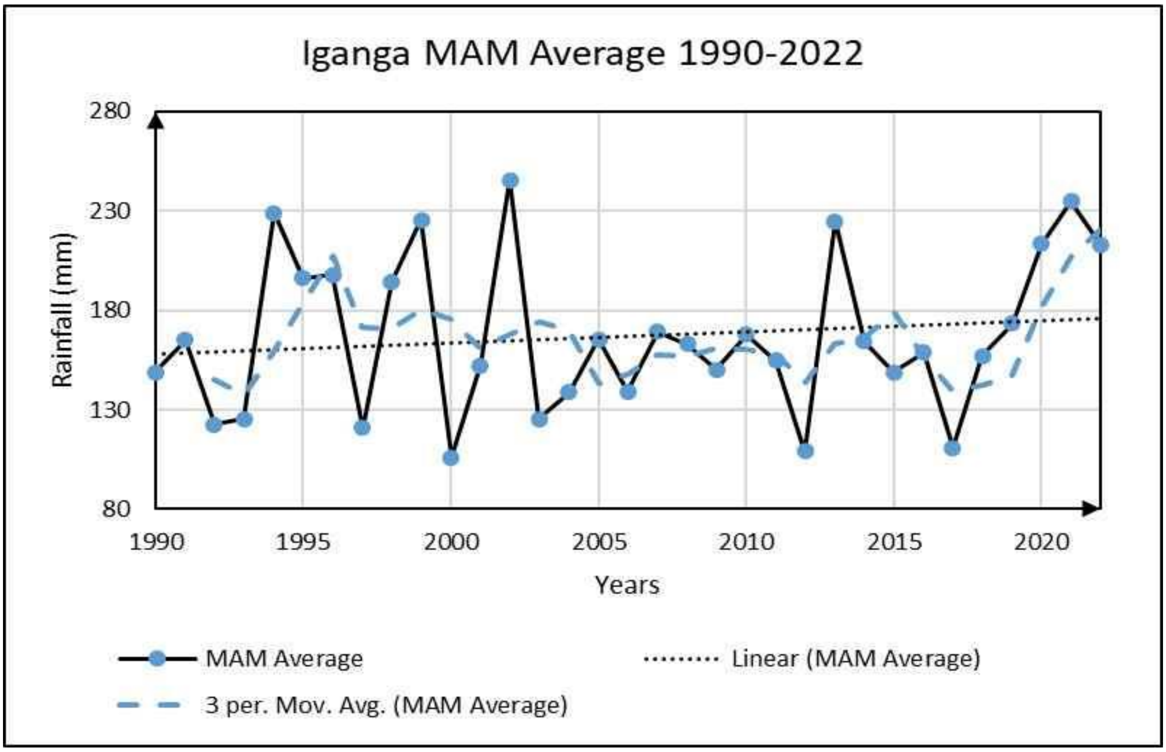

Figure 4. 4: Iganga inter-annual variability of March, April, and May rain from 1990-2022
Source: Researcher 2024

Figure 4.4 shows the inter-annual variability of MAM rainfall, moving averages, and trends during 1990-2022. The results presented reveal that there was a sharp increase in the rainfall received in Iganga in 1994 from 125mm to 230mm, 2000 from 105mm to 245mm in 2002, 2013 from 105mm to 230mm, and 2021 from 105mm in 2017 to 240mm. while the moving averages show a rise and fall in the performance of the MAM rains. However, according to the Mk results in Table 4.1, the P-value (0.35) shows that the trend was insignificant.

4.2.2 Maize Trends

For purposes of determining the interanual variation of the MAM average maize production 2013-2022 was determined and the results are portrayed in Figure 4.5

In a bid to determine the trend of the MAM maize production, the researcher conducted a Mann Kendall trend test on the MAM maize production in Iganga district from 2013-2022 and the results are presented in table 4.5 below.

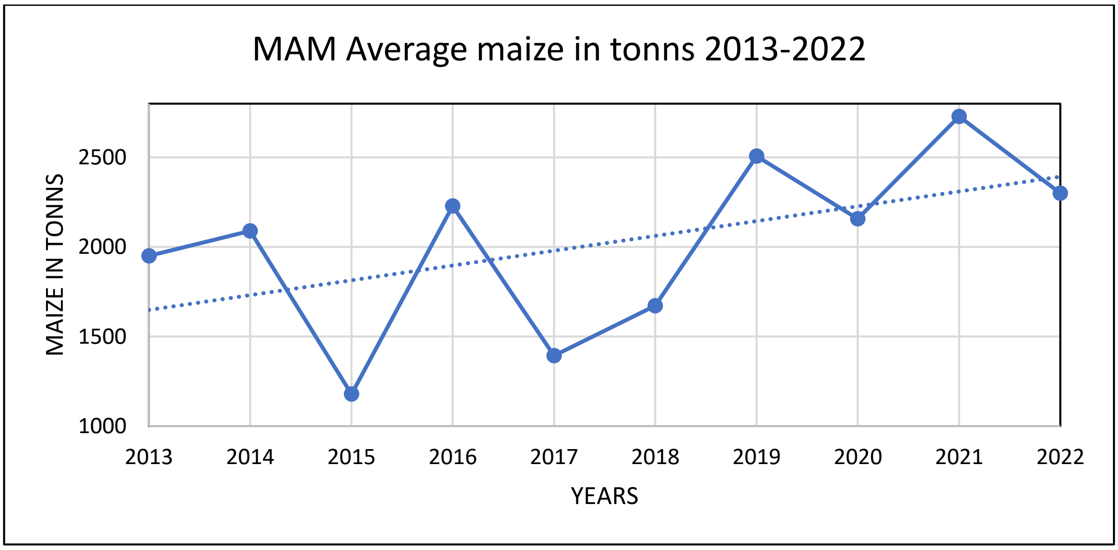

Figure 4.5 Iganga Maize production in tons during March, April, May 2013-2022
Source: Iganga Agricultural Department 2024

Figure 4.5 shows that there was an increase in the maize production in 2014, 2016, 2019, 2021 with notable reduction in yields in 2015,2017. This therefore shows that there is a steady increase in maize yields in the study area.

Table 4.2 MAM Maize MK results 2013-2022

Data	Maize
N	10
P-value	0.043 (Significant)
Z value	1.760
Tau	0.467
Sen’s slope	92.863
Confidence interval	-17.9625 to 195.7000

Table 4.2 confirmed that there was an increasing trend in maize yields with a Sen’s slope of 92.863 tons and a significant P-Value (0.043)

4.3. Determination of the variation in onset and cessation dates of the MAM long rain season of the Iganga district using gridded data:

The study set out to determine the variation of onset and cessation of the MAM rainfall season and results are summarized in Table 4.2 below.

Table 4.3: Rainfall onset and cessation dates

YEAR	ONSET	CESSATION	YEAR	ONSET	CESSATION	LGS
1990	8th March	1st May	**2007**	16th March	26th June	
1991	28th Feb	25th June	**2008**	22nd March	3rd May	
1992	8th April	25th June	**2009**	17th March	25th May	
1993	7th March	13th June	**2010**	4th March	10th May	
1994	3rd March	25th June	**2011**	5th March	30th May	
1995	6th March	20th May	**2012**	28th Feb	25th June	
1996	14th March	24th June	**2013**	1st March	24th May	65
1997	24th March	27th May	**2014**	12th March	18th June	99
1998	9th March	24th May	**2015**	28th Feb	16th May	78
1999	27th Feb	15th May	**2016**	8th March	19th May	73
2000	5th March	29th May	**2017**	16th March	14st May	59
2001	7th March	22nd June	**2018**	26th Feb	14st May	78
2002	28th Feb	13th May	**2019**	6th March	21st June	106
2003	23rd March	20th June	**2020**	3rd March	25th May	84
2004	13th March	10th May	**2021**	1st March	18th May	79
2005	27th Feb	8th June	**2022**	14th March	18th May	65
2006	27th Feb					

Source: Researcher 2024

Table 4.3 shows the derived onset, cessation dates over the period under study and length of the growing season (LGS) for the 10-year period of availed data from 2013-2022.Results show early onset on 27th February in 1999, 2005, 2006, 28th February in 1991, 2002, 2012, 2020, while onsets in March varied from 1st March 2021 to 24th March in 1997 for most of the period of study. 8th April 1992 was the latest onset date. Cessation dates ranged from 1st May in 1990 to 30th May 2011, for 21 times and rains ceased in from 8th June 2005 to 26th June 2007 for 12 time over the period of study. This indicates that there has been a continuous change in the start date and end dates of the MAM long rain season in Iganga from 1990 to 2022.

The study endeavored to establish the onset and cessation dates variations of the MAM long rain season in Iganga using the climate data tool with the Pentad criterion for onset and the Hargreaves Method which considers a fraction of Evapotranspiration and a threshold for cessation and results are depicted in figures 4.6,4.7, and 4.8, 4.9.

4.3.1 Onset

In an effort to establish the onset dates of Iganga MAM long rain season 1990-2022 the results derived are depicted in Figure 4.6 below:

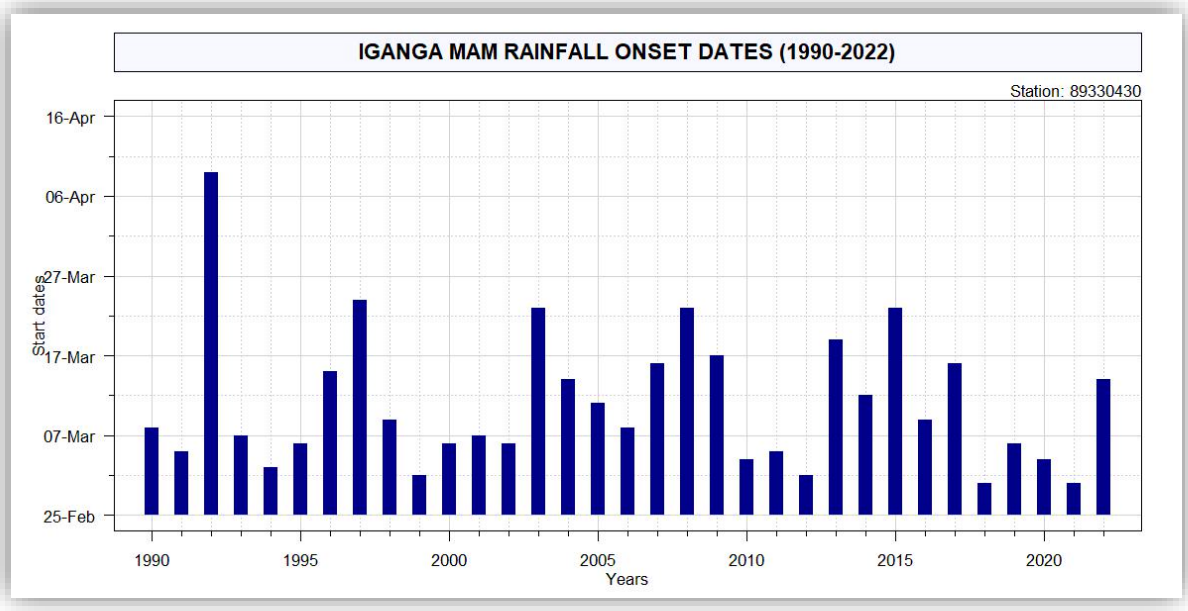

Figure 4.6: Iganga MAM onset rainfall dates from 1990-2022
Source: Researcher 2024

The results in Figure 4.6 reveal that there was a variation in onset days, though during certain years it was consistent. The earliest onset date recorded was 26th February 2018. The MAM rains started early in February for eight different years, 1991, 1999, 2002, 2005, 2006, 2012, 2015, and 2018, while the rains started in March for 24 different years in the period of study which accounts for about 75% in terms of occurrences. It is revealed that rain onsets happened more often in March although it was also recorded in February and only once in April. 1st March which is the perfect onset date for the local farmer occurred only twice in the period of study namely in 2013 and 2021.10th March was recorded as the mean onset date of occurrence in the study area and local farmers can rely on this date for planting. The year 1992 was the only one where the onset was extremely late with rains starting on 8th April.

Figure 4.7 further reveals the results of the onset dates of the Iganga district's long rainfall season from 1990-2022. The variation in start dates of the rains is varied as seen in the scatter plot. 1990 was an early onset year followed by 2019, 2002, 2005, 2006, 2015, and 2018. 2021, and 2013 were onset days that were near to normal. April 8th, 1992 shows the biggest variation in onset of the study area. 1997, 2003, 2008 also varied greatly in onset.

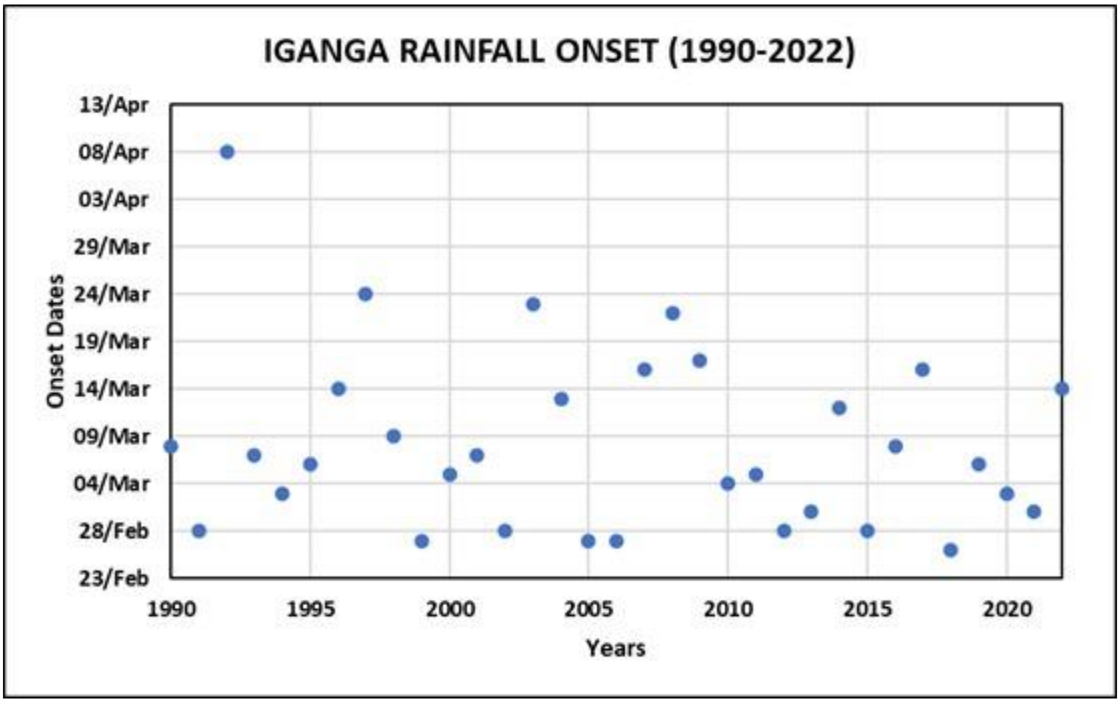

Figure 4.7: A scatter plot on onset dates of Iganga 1990-2022
Source: Researcher 2024

4.3.2 Cessation

In pursuit of the cessation dates of Iganga MAM long rain season 1990-2022 results derived are depicted in Figure 4.8 below

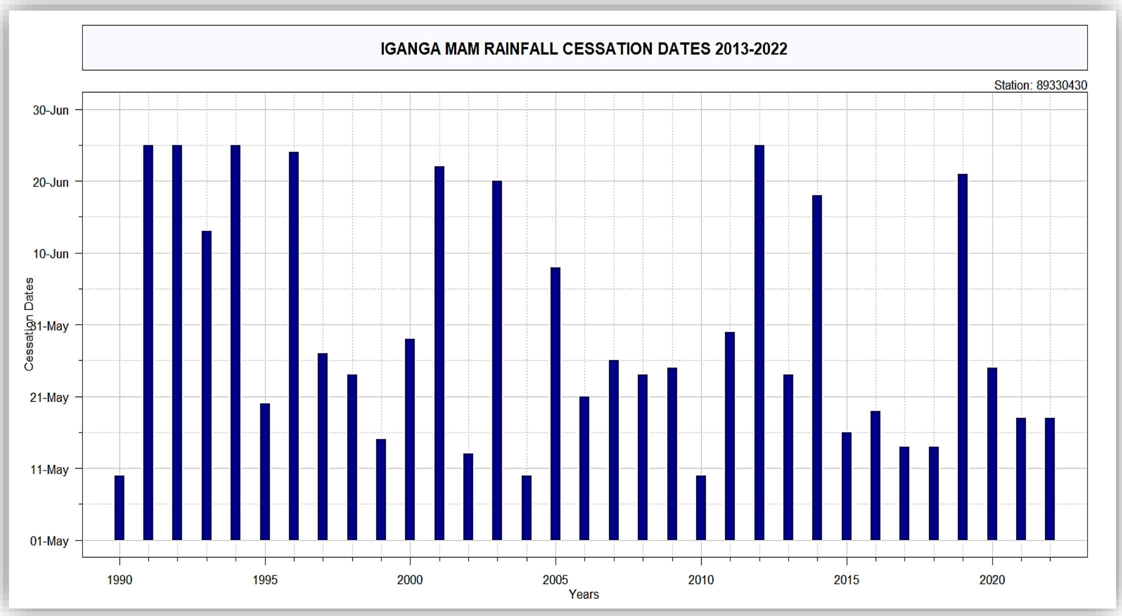

Figure 4.8: Iganga MAM cessation rainfall dates from 1990-2022
Source: Researcher 2024

Results in Figure 4.8 further indicate that there has been a fluctuation in cessation dates of the MAM rains in Iganga from 1990 to 2022. 1990 1st May is reflected as the earliest cessation date for the period investigated while 26th June 2007 was the latest date of cessation for the MAM long rain season. 30th May 2011 was the only year that registered a normal cessation date, an implication that the variation in cessation dates was high. The cessation dates of the MAM long growing season ended 21 times in May accounting for 66% of the total occurrence of cessation dates and ended 11 times in June.

The study also endeavored to establish the variation in end dates of the rains and results are presented in Figure 4.9 below. The results of variation in end dates of the rains as seen in the scatter plot revealed 1st May 1990 and 3rd May 2008 as the earliest cessation dates that were normal end dates. 2007, 1991, 1992, and 2012 were all years of late cessation and occurred in June.

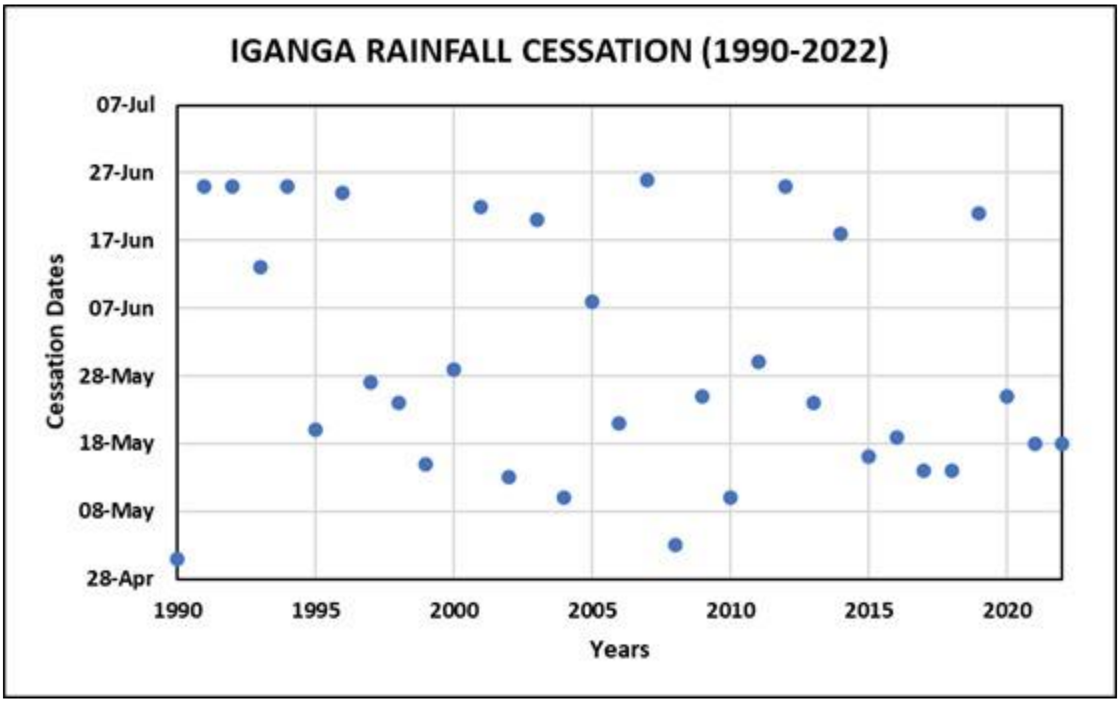

Figure 4.9: A scatter plot on cessation dates of Iganga 1990-2022
Source: Researcher 2024

Figure 4.9 further reveals the results of the cessation dates of Iganga district MAM long rainfall season from 1990-2022. The results of variation in end dates of the rains as seen in the scatter plot revealed 1st May 1990 and 3rd May 2008 as the earliest cessation dates that were normal end dates. 2007, 1991,1992, and 2012 were all years of late cessation and occurred in June.

For clarity of the variations established to exist in onset and cessation dates the researcher depicted the trend in Figure 4.5 and 4.7 respectively. The results from the study show that onset dates concentrate more in March while cessation dates tend to concentrate in May. Figures 4.6 and 4.8 indicate that there was a great variation in the onset and cessation date. This therefore depicts that the start and end of rains are no longer predictable. This has greatly affected the length of the growing season which in turn affects maize production in the growing season.

4.3.3. Length of the growing season

Table 4.2 further reveals that the length of the growing season was only calculated from 2013-2022 mainly because it was the period of study in which maize data was available in the study area. Table 4.2 further indicates that the shortest growing season lasted 59 days in 2017 while the longest growing season was 106 days in 2019. 2014, 2015, 2016, 2018, 2020, and 2021 equally had fairly long seasons with 99, 78, 73,78,84,79 days respectively.

Under rainfed conditions, the amount and distribution of rainfall, onset, and cessation have affected maize yields and food security. The start of the rains in the long rain season determines the beginning of the growing season and the date of planting for the farmers. If there is a delay in planting, it will result in maize crop farmers extending the growing season when there is a postponement of the rainy season's arrival which affects maize crop yields.

However, the growth season of crops is shortened when the rains stop early in the season, and as a result, maize crops do not reach their maturity stage. The length of the season is determined by the difference between onset and cessation dates.

Maize grows best under rainfall conditions of 600-1000 mm. It needs a pH range of 5.5-8.0 and thrives best in high water holding capacity fertile soils, that are well-drained, and deep with medium texture (Durodola, 2020).

4.4 Determining the impact of variation in onset and cessation on maize yields

The researcher endeavored to establish the impact of the variation in onset of MAM rains and maize yields and the results are presented in Table 4.4 below.

Table 4.4: Onset dates and associated Maize Yields

Iganga	Year	Onset dates	Maize Yields
	2013	1st March	15.60
	2014	12th March	16.72
	2015	28th Feb	16.77
	2016	8th March	17.83
	2017	16th March	11.14
	2018	26th Feb	13.37
	2019	6th March	20.6
	2020	3rd March	15.16
	2021	1st March	18.50
	2022	14th March	12.04

Table 4.4 indicates that early onsets in Iganga district which were 26th February 2018, 28th February 2015, yielded 13.37 tons, and 16.77 tons of maize respectively. This reveals that when rains came earliest, production was low at 13 tons and increased with later onset in 2018. While late onset 14th of March 2022, and 16th of March 2017 yielded 12.04 tons, and 11.14 tons of maize respectively, an indication that as rainfall set in late yields reduced as depicted in the study period.

The researcher also went ahead to establish the impact of the variation in cessation of MAM rains on Maize production and the results derived are presented in table 4.5 below.

Table 4.5: Cessation dates and associated Maize Yields

Iganga	Year	Cessation dates	Maize Yields (Tons)
	2013	24th May	15.60
	2014	18th June	16.72
	2015	16th May	16.77
	2016	19th May	17.83
	2017	14th May	11.14
	2018	14th May	13.37
	2019	21st June	20.6
	2020	25th May	15.16
	2021	18th May	18.50
	2022	18th May	12.04

Table 4.5 reveals that early cessation in Iganga district, 14th May 2017, and 14th May 2018 yielded 12.04 tons, 11.14 tons, and 13.37 tons of maize respectively. This indicates that when rains ceased early, yields were low at 12.04,13.37, and 11.14 tons. While late cessation 18th June 2014, 21st June 2019 yielded 16.72 tons, and 20.6 tons of maize respectively. This result indicated that the longer it took the rains to cease the higher the maize yields produced in the study period.

In order to determine the impact of variation in onset, cessation on maize yields, the researcher conducted a homogeneity test of maize production of Iganga from 2013-2022 and the results are presented in Table 4.6 below:

Table 4.6: MAM maize homogeneity test 2013-2022

Data	**Maize**
N	10
P-value	0.195 (Not Significant)
T value	4.609
Change Point (K-value)	6

Table 4.6 above reveals that there was a P-value of (0.195) and a change point value of 6 which was insignificant.

In order to establish the kind of relationship that existed between MAM maize production and MAM rainfall performance between the years 2013-2022, the researcher did a standardized anomaly index of maize yields during the MAM rainfall season and the results are presented in figure 4.10 below.

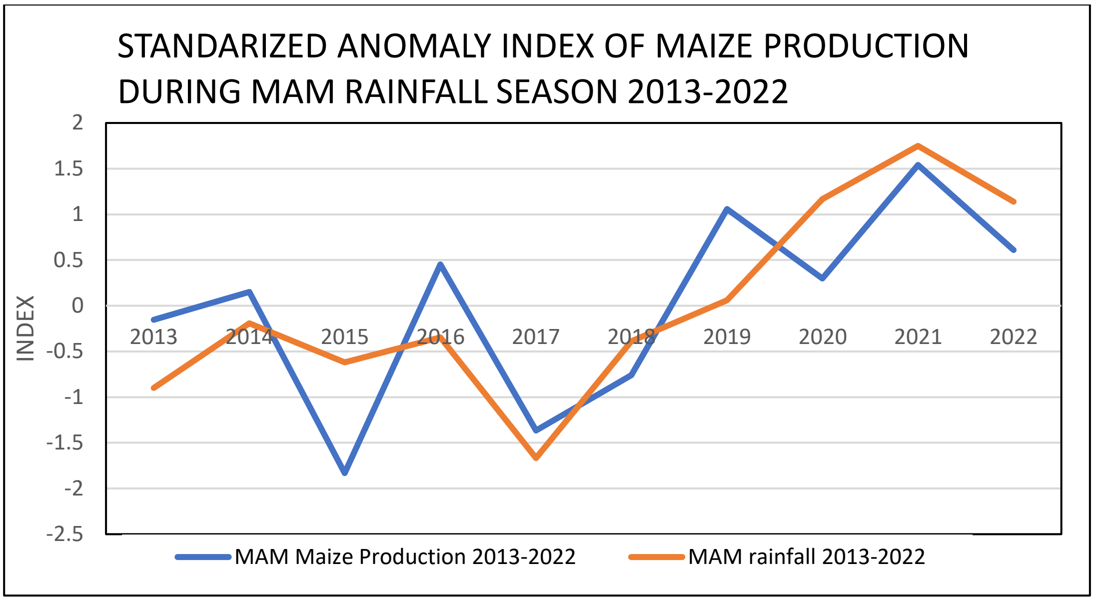

Figure 4.10: Standardized maize and rainfall performance during March, April, and May 2013-2022
Source: UNMA and Iganga Agricultural Department 2024

About the SAI table 4.7 below and figure 4.10, results indicate that in 2013 MAM rainfall was near normal, 230mm with 2000 (tons) of maize yield, while in 2016 rainfall was also near normal, with 170mm with 2300 (tons) of maize yield, 2017 had moderately less production of maize 1400 (tons) and rainfall performance of 120mm, 2019 MAM rainfall was moderately high with 180mm with 2500 (tons) of maize, while 2021 MAM had extremely high maize production of 2700 (tons) and severely high rainfall performance of 240mm.

Table 4.7:Standardized Anomaly Index (SAI) value and their interpretation

SAI Value	Interpretation
≥ 2.0	Extreme high
1.5 to 1.99	Severe
1.0 to 1.49	Moderate
- 0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderate
-1.5 to -1.99	Severe
≤− 2.0	Extremely less

Source: Adapted from McKee *et al*. (1993)

In a bid to interpret the results of Figure 4.10 showing the standardized anomaly index of maize yields during the MAM rainfall season 2013-2022 in Iganga district, the researcher used the contents of Table 4.7 showing SAI standardized anomaly index values and their interpretation as adapted from McKee *et al*. (1993).

At bivariate level of analysis, Pearson correlation was employed to determine whether a linear relationship existed between the maize yields and onset results are depicted in Table 4.8. To achieve the desired objective of estimating the effect of time of onset of rainfall on the quantity of maize produced, the Ordinary Least Squares (OLS) regression was applied for estimation purposes.

Table 4.8: Pearson's correlation results for rainfall onset and maize yields

		Onset of rainfall	Maize yield (in Tons)
Onset of rainfall	Pearson Correlation	1	-.091
	Sig. (2-tailed)		.420
	N	80	80
Maize yield (in Tons)	Pearson Correlation	-.091	1
	Sig. (2-tailed)	.420	
	N	80	100

The results of the Pearson correlation showed a negative relationship between onset of rainfall and quantity of maize produced. This is given by -0.091 which suggests an inverse relationship between the two variables onset of rainfall and maize yields. That is, the longer it takes to start raining, the lesser the yields.

Pearson correlation was also employed to determine whether a linear relationship existed between the maize yields and cessation of MAM rains and results are presented in table 4.9.

Table 4. 9: Pearson's correlation results for rainfall cessation and maize yields

		Cessation of rainfall	Maize yield (in Tons)
Cessation of rainfall	Pearson Correlation	1	.188
	Sig. (2-tailed)		.096
	N	80	80
Maize yield (in Tons)	Pearson Correlation	.188	1
	Sig. (2-tailed)	.096	
	N	80	100

Regarding the relationship between cessation of rainfall and maize yields, table 4.9 reveals that the correlation is positive (0.188) which implies that the longer rainfall takes to cease, maize yields tend to rise although not to a statistically significant level since the sig-value of 0.096 is way above the level of significance 0.05.

In order to determine the influence of onset rainfall dates on maize yields in Iganga district an ordinary least square regression analysis was carried out and results are presented in table 4.10 below.

Table 4.10: Results of the ordinary Least Squares for the influence of onset of rainfall on maize yields (Tons)

	Coef.	Std. Err.	t	P>t
Onset	-0.04	0.03	-1.42	0.160
Cessation	0.05	0.03	2.12	0.040
Constant	14.30	0.15	93.77	0.000

The results of the regression show a negative coefficient for onset of rainfall (β=-0.04). Although statistically insignificant (0.16>0.05), the results suggest that holding other factors in the model constant, for each additional day for rainfall onset, the expected maize yields tend to decrease by 4 percent. Whereas, for cessation, the coefficient is positive and statistically significant (β=0.05, p=0.04) which signifies a positive relationship between the period it takes for rainfall to cease and the volume of maize output. The more the number of days it takes for rainfall to cease, the higher the volume produced. Specifically, the findings show the more the number of days it takes for rainfall to cease, is associated with a 5 percent increase in the volume of maize produce.

To show the significance and influence of rainfall onset, cessation, and length of the growing season of Iganga district a Mann-Kendall tau statistic was further carried out and the results are presented below in Table 4.11

Table 4.11: Rainfall onset, cessation, length of rainfall, and their influence on maize yields (Tons)

	-Mann- Kendall stat	p-values
Rainfall onset	-0.0737	0.3293
Rainfall cessation	0.1345	0.0746
Length of rainfall	0.1585	0.0355

From the Mann- Kendall statistic results for the influence of the start, end, and length of the growing season 2013-2022 above, the negative rainfall onset value of -0.0737 implies an inverse relationship between the number of days it takes for the rains to begin and the overall maize yields. Although statistically insignificant (p=0.3293>0.05), the longer the period it takes the rain to start, the lower the maize output. For rainfall cessation however, the Mann- Kendall statistics are positive (0.1345) which suggests that the longer the days it takes rainfall to cease, the higher the output although not statistically significant (0.0746>0.05). As for the Length of rainfall, a longer length of rainfall is associated with increased output level.

In a bid to show the relationship between maize yields (tons) and onset days in Iganga district, the average output of maize by onset rainfall days was carried out in Figure 4.11.

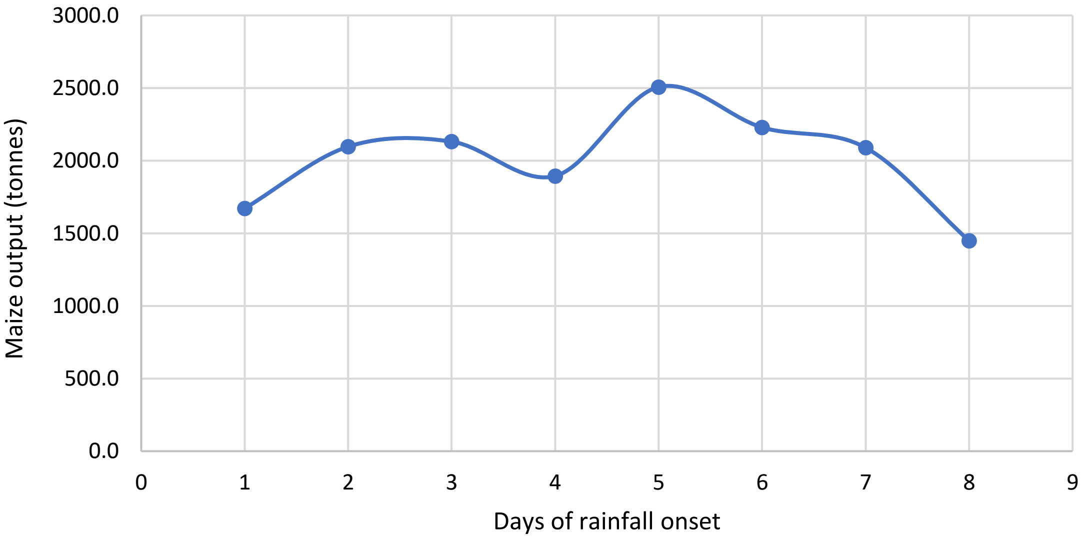

Figure 4.11: Average output of maize (in tons) by onset of rainfall

Figure 4.11 shows the Mann-Kendall statistic results of days of onset against maize output in the period of study 2013-2022 in Iganga district. From the 1st day of onset, it shows a low maize yield of 1600 tons, the maize yield increases slightly after the 2nd and 3rd day when days of onset take longer by 5 days, we see an increase in maize output of about 2500 tons, After the 7th - 8th day of rainfall onset crop yields drop drastically to 900 tons. This implies that as the onset of rainfall takes longer the maize yield outputs of Iganga district reduce.

In a bid to show the relationship between maize yields (tons) and cessation days in Iganga district, the average output of maize by cessation rainfall days was carried out as seen in Figure 4.12

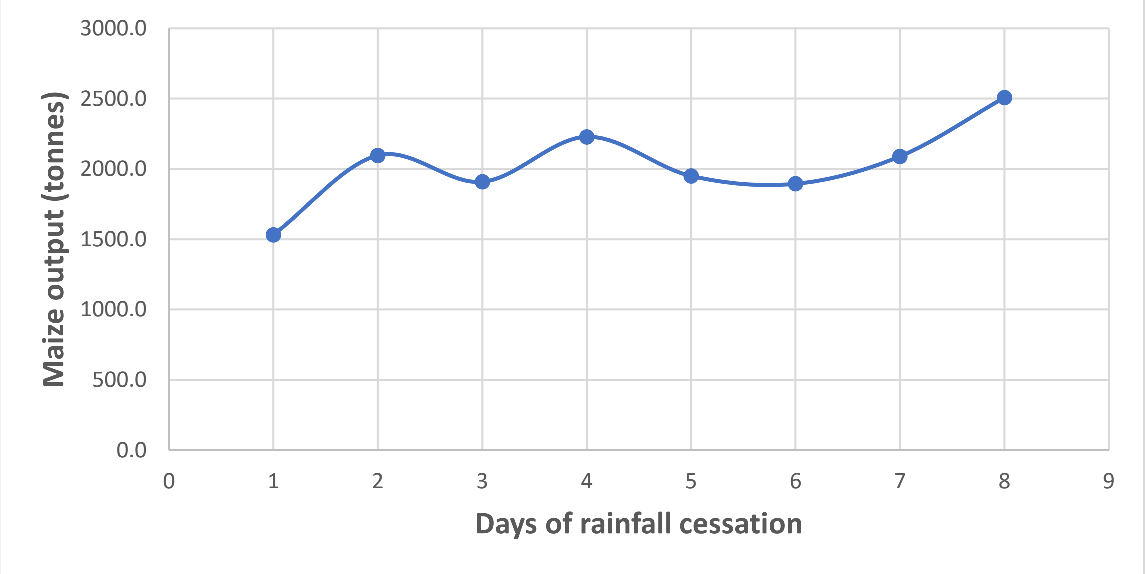

Figure 4.12: Average output of maize (in tons) by cessation of rainfall

Figure 4.12 shows the Mann-Kendall statistic results of days of cessation against maize output in the period of study 2013-2022 in Iganga district and it shows that from 1st day of cessation, crop yields were 1500 tons and as the days of cessation took longer than is 2nd day the crop yields increased up to 2000 tons while 3rd of cessation recorded a decline in yield, with an output of 1900 and from 4th – 8th day average output increased up 2500 tons in the study for the period 2013-2022.

In a bid to determine the influence of the length of the rainfall season on maize yields in Iganga district, the average output of maize by the length of the rainfall season was carried out as depicted in Figure 4.13

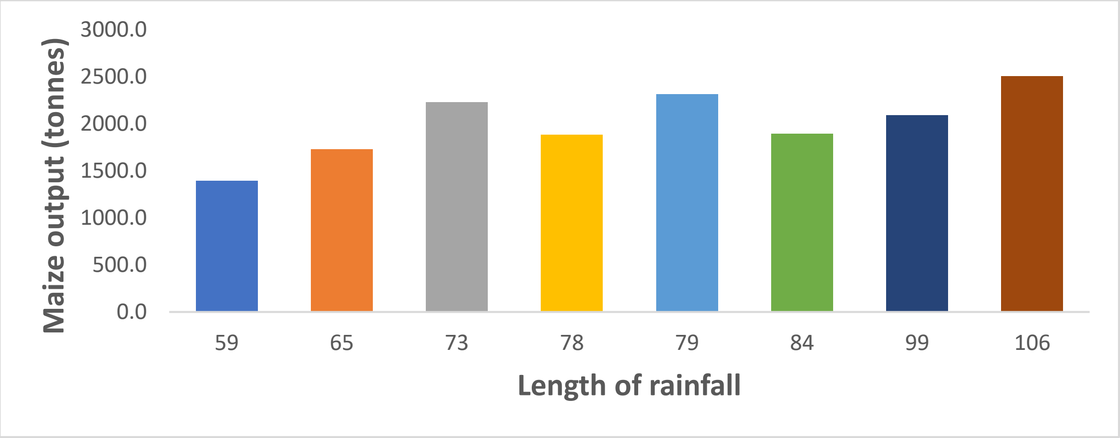

Figure 4. 13: Average output of Maize (in tons) by length of the rainfall season

Figure 4.13 shows the Mann-Kendall statistic results of the growing season length against maize output in the period of study 2013-2022 in Iganga district. The growing season length was attained after subtracting the cessation date from the onset date**.** The results show the rainy season length of 2013-2022 ranging from 59 days in 2017 to 106 days in 2019. When the length of the rainfall season was lowest at 59 days the maize yield output was equally low at 1400 tons, while maize yields steadily increased with increasing length in the rainfall season with 73 days 2200 tonnes,79 days 23000 tons, and 106 days where 2500 tons were produced. Fluctuations in the maize yield production occurred with length of rainfall season at 78 days 1800 tons, 84 days 1800 tons.

CHAPTER FIVE: DISCUSSION

5.1 Introduction

The study findings are discussed in this chapter in accordance with the study's goals and in light of earlier research.

5.2 Assessing the trends of Iganga MAM long rains 1990-2022 and maize yields (2013-2022) in Iganga district

The rainfall trends of Iganga's MAM long rainfall season from 1990 to 2022 align closely with findings from various studies examining trends. In the dry plains of Ethiopia, where seasonal rainfall variability is large, an analysis of trends in rainfall events, such as start, cessation, dry period, wet spell, and number of rainy days, was found to be more significant than annual and seasonal totals. Disaggregated analyses showed that stations in the country's northwest, north, and center showed varying (positive, negative, or no) trends. This is in agreement with my findings where by during the 32 years period rainfall for March and April varied in performance, high amounts of annual rainfall were seen in 1996, 1998, 1999 and 2020, and the lowest annual rains were observed during 1992 and 2019. Generally, the rains were below 150mm for most of the years in March while in April Rainfall was low at 180mm in 1990 but it increased slightly to 260mm in 1995. There was a sharp increase in the rainfall received in Iganga in 2002 from 100mm to 430mm but this drastically dropped to 100mm in 2003 and kept fluctuating from 2003 to 2012. A sharp rise in rainfall in the study area is depicted between, 2012-2013 from 100mm to 360mm, 2020-2021 from 180mm to 330mm. However, according to the Mann-Kendall analysis results they were not significant. The rains showed a generally increasing trend in March and April because it’s mainly the period when the rains set in.

While May showed a generally decreasing trend with rains as low 40mm in 2018 and this could be attributed to the fact the rainfall is ceasing during that period.

This study ignored intra-seasonal variability in rainfall, something that my study has clearly analyzed (Getachew & Teshome, 2018)

In a study carried out in Nigeria, it demonstrated that over the research period, corn yield over Akure had increased. With a yield value of 465.7 tons in 2008, the highest yield statistics were recorded; in 2000, the lowest yield value recorded was 144.2 tons. At the 10% level of significance the yield values in the study region showed a substantial rising trend, according to the test findings for significance at all levels of significance for the observed increase.

This study corroborates with my findings of Maize yields trends of Iganga district for the period of study. This increase in yields may be attributed to the increasing trends in the match April inter annual rains in relation to other factors in the area of study like Temperature (Mosunmola et al., 2020b)

5.3 Determination of variations in onset and cessation dates in Iganga district

Iganga district saw a significant degree of fluctuation in the length of its long rainfall growing season throughout the study period, which may be explained by the district's high variation in the rainfall onset and low variance in the cessation trend. This finding is in line with a previous study by (Baffour-ata et al., 2021a) suggesting that variation in the onset of rains and cessation trends may significantly affect the length of the long rainfall growing seasons.

5.3.1 Onset

The variations in the onset dates of Iganga's MAM long rainfall season from 1990 to 2022 align closely with findings from various studies examining climate variability across East Africa.

A study by Olatunde & Love showed that the Onset of MAM rains started on the 16th of February in 1988, contrary to this finding where the onset was on the 26th of February 2018, while their study reveals that early onset occurred twice on the 26th of February this was in line with this study where early onset on 26th of Feb occurred once, the onset date also occurred in April once in this study while on the contrary it occurred 11 time in April with the latest being 17th April 1992.

Generally, onset dates occurred eight times in February, twenty-four times in March, one time in April, this contravenes with Olatunde & loves study where onset occurred one time in February & May, 6 times in March and 24 times in April. The onset dates in Iganga are more in March contrary to Olatunde's April (Olatunde & John, 2019).

For instance, a study by Camberlin and Okoola (2003) highlights that stronger equatorial anomaly, influenced by SST anomalies in the Indian Ocean, can significantly affect the timing and intensity of rainfall seasons in East Africa. Their study suggests that these anomalies contribute to delayed onsets of the "long rains," impacting agricultural planning and water resource management (Camberlin & Okoola, 2003).

Similarly, (Sagero et al., 2016) documented shifts towards delayed onset dates of seasonal rains for example Kenya, attributes delayed onsets to mechanisms involving SST-driven changes in atmospheric circulation patterns affecting regional rainfall dynamics as asserted by (Obaigwa, 2019).

It is noted that the assessments by the Intergovernmental Panel on Climate Change (IPCC) emphasize the critical role of SST anomalies in modulating regional climate variability, IPCC reports indicate that warmer SSTs can intensify evaporation and alter atmospheric circulation, thereby influencing rainfall distribution in regions like East Africa (IPCC, 2021;). However, it should be noted that factors particularly sea surface temperature (SST) anomalies and equatorial dynamics, play a vital role in regional weather patterns (Ayugi et al., 2022).

The extreme statistics of the variations in the climatic parameters from 1986 to 2010 were presented in a study conducted in the Northern Nigerian state of Benue. The findings showed that the rainy season began on April 2, 1999, the earliest date being April 2, 1987, the latest date being May 2, 1987, and the mean date being April 16. The results also revealed that the mean date of the rainy season's end was October 10 and the earliest date of cessation was September 1, 2001. The latest date of cessation was October 16, 1987. Comparably, the rainy season's longest period was 194 days (2008), its shortest was 139 days (2001), and its average was 177 days. The mean duration was 77 days, with the highest number of rain days being 95 days (1999) and the lowest being 59 days. The mean rainfall was 1208.1 mm, with the maximum amount of 1617.6 mm occurring in 1999 and the lowest amount of 841.1 mm in 1988. Contrary to my study where onset dates were only for the long rain season, the earliest onset date was 26th February and varied over 24 times in March over the period of study (Adamgbe & Ujoh, 2013).

5.3.2 Cessation

Cessation dates have changed over the years as result of several factors and this has been supported by several studies. For instance, a study by Olatunde & John, (2019) had their earliest cessation date as 1st September and latest cessation date as 20th October 1995 and

1994, which is for the SON season that is contrary to this study that specialized in the MAM season. (Olatunde & John, 2019)

Generally, the cessation date of Iganga within the study period 1990 - 2022 occurred in two months, 21 times in May which is 66% of the total occurrence, and 12 times in June. The cessation dates of rainfall in Iganga occurred most often in the month of May. The results showed that Iganga district area in Eastern Uganda has had fluctuating start and end dates constantly. This has increasingly made it harder for the local farmers to effectively identify a particular date for onset and cessation of rainfall.

The impact of variations in the commencement and cessation dates of rainfall on crop yields in the research area is well-supported by various studies. For example, research by(Adamgbe & Ujoh, 2013) emphasizes that changes in rainfall timing significantly influence agricultural productivity, stressing the importance of timely rains for optimal crop growth and yield outcomes. Delayed onset or early cessation of rains on planting schedules and crop development stages, can lead to reduced yields (Res et al., 2014). Additionally, (Wakjira et al., 2021) discovered that a late-onset and shorter rainy season leads to ~1.5% and 1.1% crop production in Ethiopia. Similarly, Kotir, (2011) emphasize that variations in seasonal rainfall can result in water stress during critical growth periods, thereby affecting crop production and food security in the region. Moreover, global assessments by the World Meteorological Organization (WMO) reports highlight how climate variability, including changes in precipitation patterns, poses challenges to global food production and agricultural sustainability (Baffour-ata et al., 2021a).

Contrarily, while rainfall timing does impact crop yields, the relationship is not universally straightforward. For example, studies by (Araya et al., 2011) argue that in certain agro-ecological zones with efficient irrigation systems, farmers can mitigate the effects of erratic rainfall patterns on crop production. Technological advancements and water management strategies can sometimes offset the negative impacts of delayed or irregular rainfall on agricultural productivity. Moreover, in regions where crops are less reliant on seasonal rainfall, such as areas with extensive irrigation networks or where drought-resistant crop varieties are cultivated, the direct impact of rainfall timing on yields may be less pronounced (Altieri et al., 2015). These contrasting perspectives underscore the complexity of the relationship between rainfall variability and crop yields, emphasizing the need for context-specific research and adaptive agricultural practices to sustain food production in diverse environmental conditions. Thus, the relationship between the time of rainfall and agricultural output highlights the necessity of flexible policies and methods to lessen the effects of climate variability on livelihoods and food security.

5.3.3 Length of the growing season

The rainfall-specific start and end dates are very vital in determining the onset and cessation of the growing season in an area. The beginning, end of rains and its variability importantly results into efficient crop production. This is because the potential of several crops is determined by vital components of moisture resources that are created by the start, end, and length of the season (State et al., 2016a). The specific start and end dates of rainfall are crucial in delineating the onset and cessation of the growing season as observed by the study is also in agreement with a study by Lobell et al. (2012) which emphasizes that timely rains at the beginning of the growing season are essential for seed germination and early crop development, which can ultimately impact yield outcomes (Lobell & Gourdji, 2012). Furthermore, a study by (Oguntunde et al., 2018) in Nigeria, elaborates on how variations in rainfall onset and cessation dates can influence agricultural planning and management strategies. Moreover, global assessments by the United Nations Food and Agriculture Organization (FAO) report that changes in precipitation patterns can impact crop growth stages, pest outbreaks, and overall agricultural productivity worldwide (FAO, 2020). Therefore, the specific timing of rainfall onset and cessation plays a critical role in shaping the agricultural calendar and productivity in various regions. These studies collectively highlight the importance of integrating climate information into agricultural planning and management strategies to enhance resilience and sustainability.

5.3. Effect of variation of onset, cessation of MAM rainfall season on maize crop yields:

The results of the study indicate that early rainfall onset generally leads to higher maize yields by providing optimal planting conditions and favorable crop development stages, whereas late onsets are associated with reduced yields. This finding aligns with (Iortyom & Kargbo, 2023) who reported that early onset improves yields for crops like sorghum and yam, with higher yam yields in years of early onset compared to late-onset years. Similarly,(Rashid & Rasul, 2009) found that maize planted at the onset of the monsoon in July, reaching maturity as the monsoon recedes in September, showed increased yields in Pakistan. Conversely, delayed onset of rains can lead to water stress during critical growth phases, adversely affecting maize yields. (Rashid & Rasul, 2009) also noted that delayed monsoon onset can result in insufficient soil moisture, hindering seed germination and reducing yields. Moreover, Adikuru et al, (2021) emphasized that delayed rainfall onset threatens food security by shortening the growing season and forcing farmers to delay planting (Adikuru et al., 2021).

Contrarily, some studies suggest that the impact of rainfall onset on crop yields is not universally significant. For example, research by(Lala et al., 2021) in regions with advanced irrigation systems found that timely irrigation can mitigate the effects of delayed rainfall, maintaining stable maize yields. Similarly,(Simelton et al., 2013) argue that crops in certain regions have adapted to variable rainfall patterns, showing resilience despite changes in rainfall onset. In some cases, farmers' adoption of drought-resistant crop varieties and improved soil management practices have reduced the dependency on early rainfall for successful crop yields Additionally, highlights that technological advancements and precision agriculture can offset the adverse effects of erratic rainfall, ensuring consistent yields regardless of natural rainfall variability(Alemayehu & Bewket, 2016). These perspectives suggest that while early rainfall onset can be beneficial, effective agricultural practices and technologies can significantly buffer against the negative impacts of delayed rainfall. Unlike these studies, the current study mainly focused on maize yield production.

The results linking rainfall cessation timing to maize yields suggest that later cessation is associated with increased maize yields. This relationship has been observed in several studies across different agricultural contexts for example, Adejuwon (2006) in Nigeria highlights that a delay in the cessation of rainfall can extend the growing season, providing more time for maize plants to mature and increase grain yield. Similarly, the study emphasizes that optimal moisture availability during the critical stages of grain filling contributes significantly to higher yields when rainfall cessation occurs later (Adejuwon, 2006). Additionally,(Tack et al., 2017) in the United States demonstrated that prolonged soil moisture availability and favorable temperatures during the late growing season can enhance maize yield potential. Moreover, global assessments by the International Food Policy Research Institute (IFPRI) reports suggest that late cessation of rains can mitigate the risks of moisture stress during critical growth stages, thereby supporting higher maize yields in various agro-ecological zones (IFPRI, 2019). In contrast, the relationship between rainfall cessation and maize yields is not universally positive. For instance, Araya et al., (2011)highlight that extended rainfall periods can lead to waterlogging, which adversely affects maize growth and reduces yields. Excessive moisture towards the end of the growing season can create conditions that are detrimental to crop health, such as increased susceptibility to diseases and pests (Araya et al., 2011). Similarly, a study in Europe found that while late rainfall cessation can sometimes benefit maize yields by extending the growing period, it can also lead to harvesting difficulties and post-harvest losses, thereby reducing overall yield quality and quantity. The benefits of late rainfall cessation are context-dependent, and extended rainy periods can sometimes pose significant challenges to agricultural productivity (Samberg et al., n.d.). These insights underscore the significance of climate variability in agricultural production and highlight the potential benefits of adaptive strategies that consider optimal timing of rainfall events.

Farmers in the study area face considerable challenges in accurately forecasting the true beginning and cessation dates of rainfall, which significantly impacts crop production. The evident pattern of inconsistency and unpredictability in the onset and cessation dates in Iganga district has profound implications for agricultural activities, affecting various stages such as preparation, clearing, planting, weeding, harvesting, and storing of agricultural land. This is consistent with Omay et al., (2022) which indicated the difficulty farmers encounter in predicting rainfall patterns, emphasizing the resulting uncertainties that disrupt farming schedules, leading to suboptimal practices and reduced crop yields in agricultural production. Moreover, Wakjira, (2021) elaborates on how variability in rainfall onset and cessation complicates decision-making processes related to crop selection, planting dates, and water management strategies, ultimately impacting farm profitability (Wakjira et al., 2021). Global assessments by organizations reports highlight that unpredictable rainfall patterns can hinder food security, increase production costs, and reduce farmers' incomes, particularly in regions reliant on rain-fed agriculture (World Bank, 2020). Addressing these challenges requires improved climate forecasting, adaptive agricultural practices, and supportive policies to enhance resilience and sustainability in agriculture. For rainfall cessation, the analysis reveals a positive and statistically significant coefficient, indicating a direct relationship between the duration of rainfall cessation and maize output volume. Specifically, the longer it takes for the rains to cease, the higher the volume of maize produced. The findings suggest that each additional day of rainfall delay in cessation is associated with a 5 percent increase in maize yield. A study by Adamgbe & Ujoh, (2013) supports these findings, demonstrating that extended periods of favorable soil moisture resulting from late rainfall cessation can enhance and maximize maize productivity. Similarly, Res et al., (2014) asserted that delayed cessation of rains can extend the period for crop development, allowing for optimal growth conditions and higher yields.

However, some studies suggest that while unpredictable rainfall patterns pose challenges, they do not always result in negative agricultural outcomes. For instance, a study by Nabikolo, (2014) in semi-arid regions of Kenya and Zimbabwe found that farmers have successfully adopted adaptive strategies such as conservation agriculture, which improves soil moisture retention and enhances resilience to rainfall variability. Similarly, research by Sultan et al., (2013) in West Africa indicates that access to climate information and early warning systems can significantly improve agricultural decision-making, allowing farmers to better cope with unpredictable rainfall patterns and maintain or even increase yields.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter concludes and recommends based on the objectives of the study. The conclusions were used to understand the variations in onset and cessation dates and their impact on maize yields in Iganga district. The recommendations are to inform local farmers and other sectors that rely on the start and end dates of the rainfall season for their activities.

6.2 Summary of Major Findings

This study investigated the impact of the start and end of the MAM long rain season on the maize yields in Iganga district, eastern Uganda. Findings attained in determining the variations in onset and cessation showed that there were great variations in onset and cessation dates from 1990 -2022. Findings on onset showed that the earliest onset date recorded was, 26th February 2018. The MAM rains started early in February for eight different years, 1991, 1999, 2002, 2005, 2006, 2012, 2015, and 2018, while the MAM rains started in March for 24 different years in the period of study which accounts for about 75% in terms of occurrences, this means that rain onsets happened more often in March although it was recorded in February, March, April.1st March which is the perfect onset date for the local farmer occurred twice in the period of study2013 and 2021, 10th March was recorded as the average onset date of occurrence.1992 was the only year where the onset was extremely late with rains starting on the 8th April

Findings in the ending dates of the rains of the MAM long rain season in Iganga from 1990 to 2022 showed that 1990 1st May was the earliest cessation date for the period investigated while 26th June 2007 was the latest date of cessation for the MAM long rain season. 30th May 2011 was the only year that registered a normal cessation date, an implication that the variation in cessation dates was high. The cessation dates of the MAM long growing season ended 21 times in May accounting for 66% of the total occurrence of cessation dates and ended 11 times in June.

In the study area, the effect of changing onset and cessation dates was analyzed using descriptive statistical tools like bar and line graphs, and tables. A homogeneity test finding for maize production 2013-2022 in Iganga showed an insignificant P-value of (0.195) yet the inter-annual variability of maize production in Iganga district 2013-2022 showed an increasing trend and significant P-value of (0.043). A standardized anomaly index of maize production during the MAM rain season of 2013 -2022 had extremely high maize production and rainfall performance which showed that there is a Correlation between maize production and rainfall performance during the March, April, and May seasons of 2013-2022 was 0.75 significant at 95% (C.I). Meaning that with increasing rainfall variations during the MAM season there was equally an increase in maize yields.

The regression results show a negative coefficient of onset of rainfall, the result suggests that holding other factors constant for every additional day of rainfall onset the expected maize yields tend to decrease by 4%. In other words, the longer the onset the lower the yields for that season.

Mann-Kendall's statistic findings for the influence of the start, end, and length of the growing season on maize yields 2013-2022, the negative rainfall onset value of -0.0737 implies an inverse relationship between the number of days it takes for rains to begin and the overall maize yields. Although statistically insignificant ($p=0.3293>0.05$), the longer the period it takes the rain to start, the lower the maize output. For rainfall cessation however, the Mann- Kendall statistics are positive (0.1345) which suggests that the longer the days it takes rainfall to cease, the higher the output although not to a statistically significant extent (0.0746>0.05).

As for the Length of rainfall, the longer length of rainfall is associated with increased output level. This is indicated by a positive value of the Mann-Kendall statistics equal to 0.1585 and a corresponding p-value of 0.0355 which implies a statistically significant influence of the length of rainfall growing season on maize output.

6.3 Conclusion

Based on the findings of this research there is a clear variation and inconsistency in the start and end of rains in Iganga district something that affects the farmer's growing season in terms of preparation or tilling of the land up to harvesting and post-harvesting activities. Other rain-fed agricultural activities and activities like road construction and infrastructural developments, will be informed by the study findings.

Finally, the impact of the start, end, and length of the growing season is that late-onset leads to low maize yields while late cessation leads to high maize yields in the study area. This consequently determines the length of the growing season which significantly influences maize yields in the area of study.

These results will help with planning to prevent issues related to climate factors in the research region. Local farmers involved in Maize growing will learn from this research results that rainfall onset and cessation dates continue to vary year after year and that they should try alternative options for watering the maize plants to avoid losses.

Then to researchers, the results of this study create a study gap for a much wider area that involves different climatic zones.

Maize production is influenced by several factors, including fertility of the soils, adequate temperatures, existence of sufficient amounts of water for crop growth, size of land under cultivation, scientific agricultural practices like proper spacing, application of fertilizers, spraying herbicides to prevent pests, weeds, diseases, appropriate planting time and use of improved varieties of maize.

6.4 Recommendations

This study recommends that UNMA should work with district agriculture officers and disseminate information at the right time on a village level and also educate farmers about the variations in the start and end rainfall dates for current and future seasons to come, for appropriate planning and timely tilling, sowing, weeding and harvesting.

The study recommends that more weather stations be set up in several districts areas in Uganda to cater to the impact of fluctuations in climate on different activities This would help capture data for several climate parameters, to be used in the future.

This study also recommends that farmers in Iganga and Uganda at large should integrate soil management techniques to mitigate the increasing changes in onset and cessation in the face of increasingly an unpredictable climate.

Future research should also deal with the effective dissemination of information pertaining to onset and cessation date variation to farmers at a local level

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APPENDIX

Appendix I: Maize Production Data for Iganga

	MAIZE PRODUCTION DATA FOR IGANGA DISTRICT									
YEARS	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Sub Counties	A	A	A	A	A	A	A	A	A	A
Bulamagi	1296981	1389623	1445207	1482264	926415	1111698	1667547	1259924	1537849	1000528
Nabitebde	2345372	2512898	2512898	2680425	1675266	2010319	3015478	2278361	2780941	1809287
Nakalama	1336319	1431771	1431771	1527222	954513.9	1145417	1718125	1298139	1584493	1030875
Nakigo	1083546	1160942	1160942	1238338	773961.1	928753.4	1393130	1052587	1284775	835878
Nambale	4220772	4522255	4522255	4823739	3014837	3617804	5426706	4100178	5004629	3256024
Namungalwe	1924776	2062260	2062260	2199744	1374840	1649808	2474712	1869782	2282234	1484827
Nawandala	2574747	2758658	2758658	2942568	1839105	2206926	3310389	2501183	3052914	1986233
Nawanyingi	818771.6	877255.3	877255.3	935739	584836.9	701804.3	1052706	795378.2	970829.2	631623.8
Average	1950.161	2089.458	2096.406	2228.755	1392.972	1671.566	2507.349	1894.442	2312.333	1504.41
Total (kgs)	15601284	16715662	16771246	17830039	11143774	13372529	20058794	15155533	18498665	12035276
yield in tonns	15601.28	16715.66	16771.25	17830.04	11143.77	13372.53	20058.79	15155.53	18498.67	12035.28
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	1950	**2089**	**2096**	**2229**	**1393**	**1672**	**2507**	**1894**	**2312**	**1504**

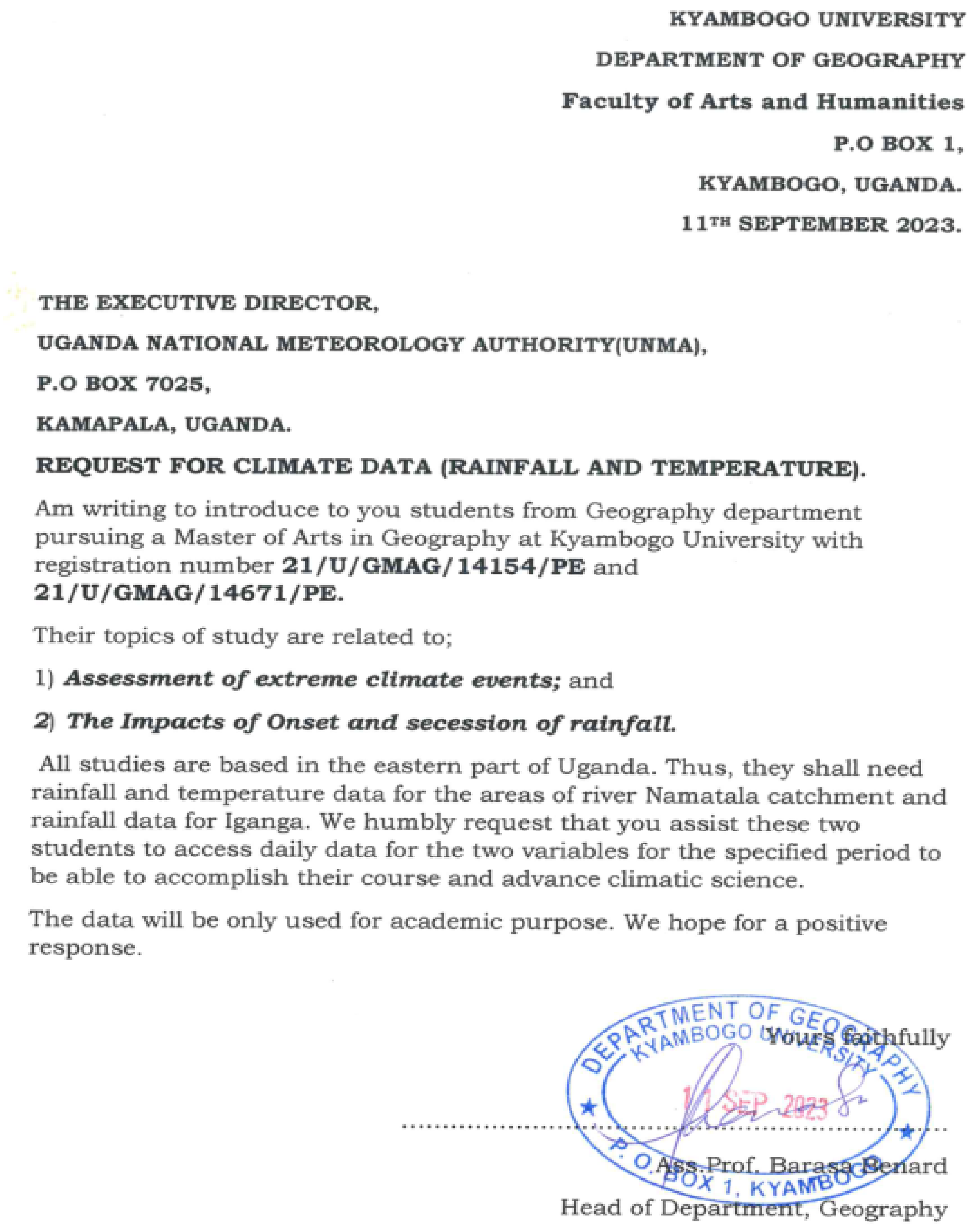
Appendix II: Analysis of Onset, Cessation, Length of the Season and Maize Yields of Iganga

Sub county	Year	Onset date	Cessation date	Onset	Cessation	Length	Yield
Bulamagi	2013	1st March	24th May	3	5	65	1296981
Nabitebde	2013	1st March	24th May	3	5	65	2345372
Nakalama	2013	1st March	24th May	3	5	65	1336319
Nakigo	2013	1st March	24th May	3	5	65	1083546
Nambale	2013	1st March	24th May	3	5	65	4220772
Namungalwe	2013	1st March	24th May	3	5	65	1924776
Nawandala	2013	1st March	24th May	3	5	65	2574747
Nawanyingi	2013	1st March	24th May	3	5	65	818771.6
Total_kgs	2013						15601284
Total_tonns	2013						15601.28
Bulamagi	2014	12th March	18th June	7	7	99	1389623
Nabitebde	2014	12th March	18th June	7	7	99	2512898
Nakalama	2014	12th March	18th June	7	7	99	1431771
Nakigo	2014	12th March	18th June	7	7	99	1160942
Nambale	2014	12th March	18th June	7	7	99	4522255
Namungalwe	2014	12th March	18th June	7	7	99	2062260
Nawandala	2014	12th March	18th June	7	7	99	2758658
Nawanyingi	2014	12th March	18th June	7	7	99	877255.3
Total_kgs	2014						16715662
Total_tonns	2014						16715.66
Bulamagi	2015	28th Feb	16th May	2	2	78	1445207
Nabitebde	2015	28th Feb	16th May	2	2	78	2512898
Nakalama	2015	28th Feb	16th May	2	2	78	1431771
Nakigo	2015	28th Feb	16th May	2	2	78	1160942
Nambale	2015	28th Feb	16th May	2	2	78	4522255
Namungalwe	2015	28th Feb	16th May	2	2	78	2062260
Nawandala	2015	28th Feb	16th May	2	2	78	2758658
Nawanyingi	2015	28th Feb	16th May	2	2	78	877255.3
Total_kgs	2015						16771246
Total_tonns	2015						16771.25
Bulamagi	2016	8th March	19th May	6	4	73	1482264
Nabitebde	2016	8th March	19th May	6	4	73	2680425
Nakalama	2016	8th March	19th May	6	4	73	1527222
Nakigo	2016	8th March	19th May	6	4	73	1238338
Nambale	2016	8th March	19th May	6	4	73	4823739
Namungalwe	2016	8th March	19th May	6	4	73	2199744
Nawandala	2016	8th March	19th May	6	4	73	2942568
Nawanyingi	2016	8th March	19th May	6	4	73	935739
Total_kgs	2016						17830039
Total_tonns	2016						17830.04
Bulamagi	2017	16th March	14st May	8	1	59	926415
Nabitebde	2017	16th March	14st May	8	1	59	1675266
Nakalama	2017	16th March	14st May	8	1	59	954513.9

Nakigo	2017	16th March	14st May	8	1	59	773961.1
Nambale	2017	16th March	14st May	8	1	59	3014837
Namungalwe	2017	16th March	14st May	8	1	59	1374840
Nawandala	2017	16th March	14st May	8	1	59	1839105
Nawanyingi	2017	16th March	14st May	8	1	59	584836.9
Total_kgs	2017						11143774
Total_tonns	2017						11143.77
Bulamagi	2018	26th Feb	14st May	1	1	78	1111698
Nabitebde	2018	26th Feb	14st May	1	1	78	2010319
Nakalama	2018	26th Feb	14st May	1	1	78	1145417
Nakigo	2018	26th Feb	14st May	1	1	78	928753.4
Nambale	2018	26th Feb	14st May	1	1	78	3617804
Namungalwe	2018	26th Feb	14st May	1	1	78	1649808
Nawandala	2018	26th Feb	14st May	1	1	78	2206926
Nawanyingi	2018	26th Feb	14st May	1	1	78	701804.3
Total_kgs	2018						13372529
Total_tonns	2018						13372.53
Bulamagi	2019	6th March	21st June	5	8	106	1667547
Nabitebde	2019	6th March	21st June	5	8	106	3015478
Nakalama	2019	6th March	21st June	5	8	106	1718125
Nakigo	2019	6th March	21st June	5	8	106	1393130
Nambale	2019	6th March	21st June	5	8	106	5426706
Namungalwe	2019	6th March	21st June	5	8	106	2474712
Nawandala	2019	6th March	21st June	5	8	106	3310389
Nawanyingi	2019	6th March	21st June	5	8	106	1052706
Total_kgs	2019						20058794
Total_tonns	2019						20058.79
Bulamagi	2020	3rd March	25th May	4	6	84	1259924
Nabitebde	2020	3rd March	25th May	4	6	84	2278361
Nakalama	2020	3rd March	25th May	4	6	84	1298139
Nakigo	2020	3rd March	25th May	4	6	84	1052587
Nambale	2020	3rd March	25th May	4	6	84	4100178
Namungalwe	2020	3rd March	25th May	4	6	84	1869782
Nawandala	2020	3rd March	25th May	4	6	84	2501183
Nawanyingi	2020	3rd March	25th May	4	6	84	795378.2
Total_kgs	2020						15155533
Total_tonns	2020						15155.53
Bulamagi	2021	1st March	18th May	3	3	79	1537849
Nabitebde	2021	1st March	18th May	3	3	79	2780941
Nakalama	2021	1st March	18th May	3	3	79	1584493
Nakigo	2021	1st March	18th May	3	3	79	1284775
Nambale	2021	1st March	18th May	3	3	79	5004629
Namungalwe	2021	1st March	18th May	3	3	79	2282234
Nawandala	2021	1st March	18th May	3	3	79	3052914
Nawanyingi	2021	1st March	18th May	3	3	79	970829.2
Total_kgs	2021						18498665
Total_tonns	2021						18498.67
Bulamagi	2022	14th March	18th May	8	3	65	1000528
Nabitebde	2022	14th March	18th May	8	3	65	1809287
Nakalama	2022	14th March	18th May	8	3	65	1030875

Nakigo	2022	14th March	18th May	8	3	65	835878
Nambale	2022	14th March	18th May	8	3	65	3256024
Namungalwe	2022	14th March	18th May	8	3	65	1484827
Nawandala	2022	14th March	18th May	8	3	65	1986233
Nawanyingi	2022	14th March	18th May	8	3	65	631623.8
Total_kgs	2022						12035276
Total_tonns	2022						12035.28

Appendix III: A Data Request Letter to UNMA



KYAMBOGO UNIVERSITY
DEPARTMENT OF GEOGRAPHY
Faculty of Arts and Humanities
P.O BOX 1,
KYAMBOGO, UGANDA.
11TH SEPTEMBER 2023.

THE EXECUTIVE DIRECTOR,
UGANDA NATIONAL METEOROLOGY AUTHORITY(UNMA),
P.O BOX 7025,
KAMAPALA, UGANDA.

REQUEST FOR CLIMATE DATA (RAINFALL AND TEMPERATURE).

Am writing to introduce to you students from Geography department pursuing a Master of Arts in Geography at Kyambogo University with registration number **21/U/GMAG/14154/PE** and **21/U/GMAG/14671/PE.**

Their topics of study are related to;

1) ***Assessment of extreme climate events;*** and

2) ***The Impacts of Onset and secession of rainfall.***

All studies are based in the eastern part of Uganda. Thus, they shall need rainfall and temperature data for the areas of river Namatala catchment and rainfall data for Iganga. We humbly request that you assist these two students to access daily data for the two variables for the specified period to be able to accomplish their course and advance climatic science.

The data will be only used for academic purpose. We hope for a positive response.

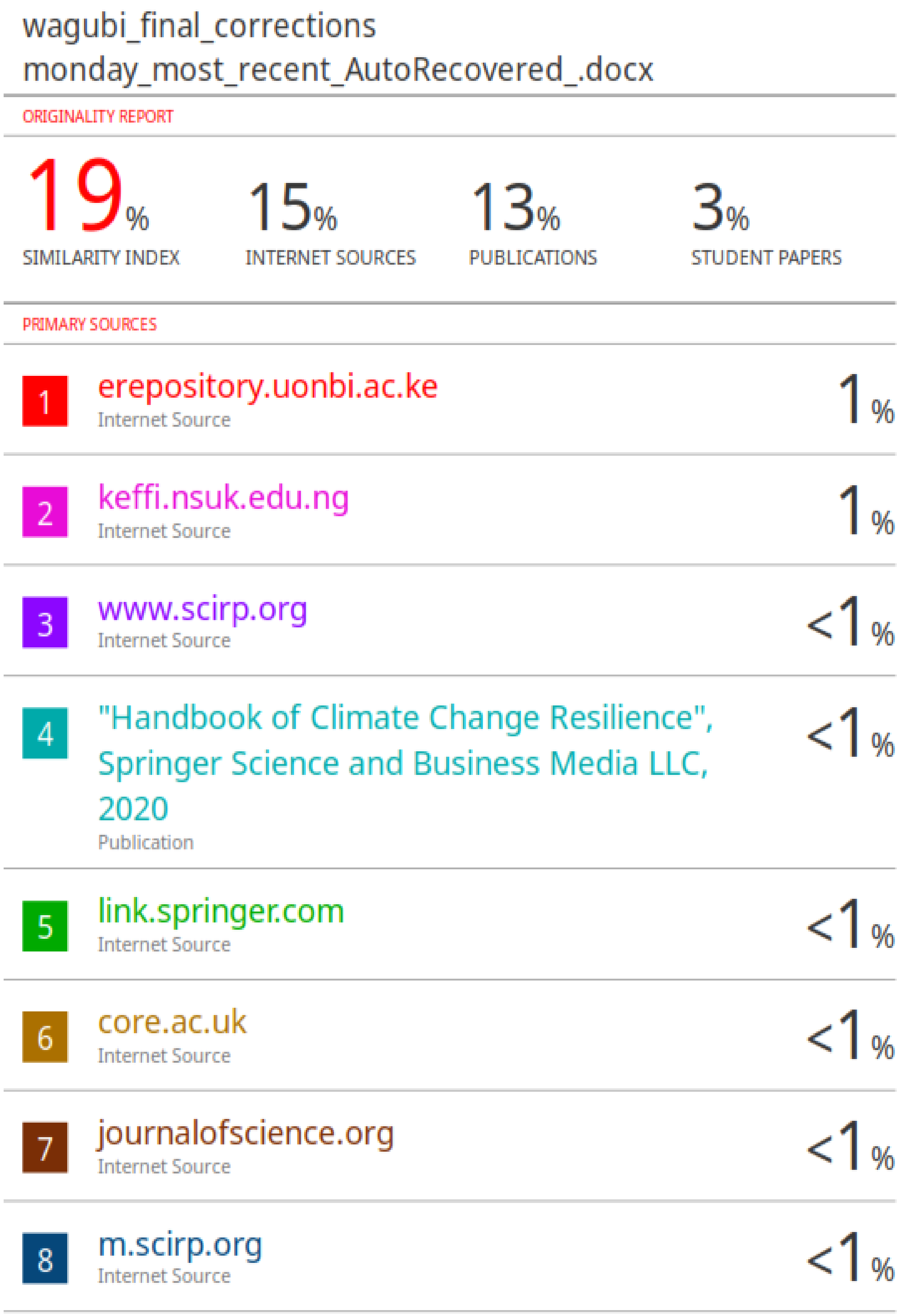
Yours faithfully

11 SEP 2023

....

Ass.Prof. Barasa Benard
Head of Department, Geography

Appendix IV: Plagiarism Test Results



wagubi_final_corrections monday_most_recent_AutoRecovered_.docx

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