Impacts of Rainfall Variability on Maize Production in Tongaren Sub- County, Bungoma County, Kenya

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https://doi.org/10.51867/ajernet.6.1.26

ABSTRACT

Maize crop farming in rain fed regions of the world is dependent on rainfall amount and distribution. In Kenya, most smallholder maize farmers depend on rainfall to grow the crop. The objective of this study was to evaluate rainfall variability and its impacts on maize production in Tongaren Sub- County, Kenya. The study applied the decision making theory and adopted the mixed methods research design. Cluster and proportionate sampling procedures were used to select 395 respondents selected out of a target population of 33,602 maize farmers. Primary data was obtained by use of questionnaires for households' interview, key informant interviews, focus group discussions (FGDs) and observation checklists. Secondary data was sourced from Kenya Meteorological Department comprising of monthly rainfall from 1985 to 2022. Maize yield data was obtained from Bungoma County Department of Agriculture. Analysis of data was done using SPSS and XL STAT statistical packages and results presented in form of pie charts, tables and bar graphs. Rainfall variability during MAM, JJAS and annual rainfall was found to be 20.7%, 20.6% and 14.3% respectively. Pearson's correlation coefficient between rainfall and maize yield for MAM, JJAS and March to September was computed as 0.05, 0.53 and 0.4 respectively. Further results reveal that rainfall probability of exceedance ranges from 60% to 100% during MAM period while that of March to September ranges from 70% and 100%. The study also established that rainfall variability impacts maize production in various ways such as influencing choice of maize variety (63.5%), maize yield and cropping cycle (100%). Regression of maize yield and time yielded an R^2 value of 26.7%. These results provide a useful guide on formulating adaptation policies aimed at making maize production resilient to adverse effects of climate change which may help to improve food security. The study concluded that there was significant rainfall variability which could be linked to fluctuations in maize yield and had the potential to affect future maize production in the study area. The study recommends the need for closer collaboration between the agencies responsible for provision of rainfall information and maize producers in order to address the issue of rainfall variability and manage climate related risks through appropriate adaptation strategies. To achieve this the study further recommends that climate information providers improve on the availability and dissemination of timely and accurate weather and climate information especially rainfall forecasts to the maize farmers so as to enable them make informed farm –level decisions in order to boost maize production.

Keywords: Climate Change and Variability, Climate Information Services, Rainfall Probability of Exceedance, Rainfall Variability, Seasonal Rainfall Forecasts

I. INTRODUCTION

Tongaren Sub –County leads in maize production in Bungoma County most of which is rain-fed. This study looks at an assessment of rainfall variability in the Sub-County across the years and its effects on maize production. Because of rainfall variability caused by climate change, maize production in the area is likely to be affected adversely.

Most agricultural systems depend on rainfall as the main source of water therefore knowing rainfall characteristics is vital in decision-making (Ebuhuoma & Simatele, 2017). Rain-fed agricultural systems are highly sensitive to spatial-temporal rainfall variability. As observed by Wang et al. (2020), rainfall variability is a worldwide phenomenon which exhibits notable spatial and temporal variability. In a study by Lehman et al. (2015) it was found that global warming has so far enhanced the number of record- breaking rainfall events in terms of extremes. These studies intimated that extreme rainfall on daily timescales is increasing in frequency over most land areas. Other researchers too have underscored the need to understand existence and impact of rainfall variability. For instance, Jamal et al. (2017) found that knowledge of climate and rainfall variability is vital for urban planning and rural land use. Similarly, a study done in Ethiopia by Lewis (2017) found that apart from rainfall amount, its distribution in a given season is very critical in crop growth and yield. Every area on the globe has a distinct period in which rainfall is received. For instance, Bangladesh has rainy monsoon season running from June to September (Islam & Uyeda, 2007). However, other study in that country has shown that there is a decrease in dry months in monsoon and pre-monsoon and an increase in the wet months (Shamsuddin, 2009). Similarly, it has been found out that in Bundelkhand region of India, precipitation during summer and winter seasons exhibited high precipitation variability (Som & Dey, 2022). A study conducted in South-West USA by Karanja et al. (2023) has revealed that there exists rainfall variability across various seasons mostly brought about by various atmospheric systems such as El Nino Southern Oscillation (ENSO). Seasonal precipitation variability in Europe has also been studied and the results show that there is rainfall variability across the seasons brought about by both natural and anthropogenic forces (Nikolaos & Stott, 2022). Rainfall in Kenya exhibits variability on year to year and season to season basis. Most parts experience two rainfall seasons that alternate with dry seasons. The two rainfall seasons are the long rainfall season which is concentrated between March to May (MAM) and the short season which occurs from October to early December (OND) (Gitau et al., 2012). A study by Palmer et al. (2023) has revealed that precipitation trends in Kenya are projected to remain highly variable and uncertain. It has also been observed that uneven seasonal distribution of rainfall exposes crops to frequent dry spells that may lead to reduced productivity (Barron et al., 2003). In another study, analysis of spatial variability in rainfall trends in Baringo, Kenya. Ednah et al. (2018) found that there was year to year rainfall variability across different agro-ecological zones. According to the report by The Ministry of Agriculture, Livestock, Fisheries and Co-operatives (MoALFC, 2021), most farmers in Bungoma County are reliant on rainfall, which can be unreliable and erratic. The rainfall and temperature fluctuations have led to increased incidents of pests and diseases, which in turn contribute to low crop yields and post-harvest losses.

Different sectors have specific climate information needs. For instance, in the agricultural sector, farmers may need information on the onset and cessation of the rainfall season in order to make informed decisions at the farm level (Vaughan & Dessai, 2014). It is because of this that climate information service (CIS) has in the recent past gained attention as a result of challenges brought about by climate change and variability (Diouf et al., 2019). A study conducted in Sub- Saharan Africa has revealed that climate information services are generally inadequate characterized by poor coordination and poor observational infrastructure (Harvey et al. 2019). Furthermore, the research noted that uptake of climate information (CI) in Sub- Saharan Africa (SSA) is still low as compared to other regions of the world.

In addition to the two major rainfall seasons in Kenya; namely the long rain season covering the months of March, April and May (MAM) and the short rainfall season covering the months of October, November and December (OND), there is also an intermediate season in the study area covering the months of June, July, August and September (JJAS) where substantial amount of rain is received (Koech, 2015). Just like many other crops, maize is mainly produced under rain-fed conditions which results in many farmers vulnerable when the rains fail (Vanschoenwinkel & Van Passel, 2018). However, the level of devastation due to drought, dry spells and floods are becoming increasingly severe with loss of livelihoods and negative impacts to key sectors such as maize farming.

Since most maize produced by smallholder farmers is rain-fed, changes in rainfall and temperature affect maize production in numerous ways including changes in the yields (Baffour- Ata et al., 2022) for instance under watering deprives the plant of water, which can lead to crop death or low yield (Omoyo et al., 2015).

1.1 Statement of the Problem

Agriculture is the main economic activity in Bungoma County where majority of the households are involved in rain-fed farming. Due to climate change and variability which causes fluctuations in rainfall, agricultural production has drastically declined leading to low maize crop yield. This has posed a threat to food security rendering a big portion of the population to be faced with food scarcity (MoALFC, 2021). According to Niang et al. (2014), climate variability is projected to increase rainfall variability in East Africa. As a result of this, Kenya is projected to experience a further decrease in the yield of cereals. Moreover, inconsistent rainfall patterns may lead to total maize crop failure (Omoyo et al., 2015) thus exacerbating the situation. Most studies in the past have only used quantitative way of analyzing the impact of rainfall variability on maize yield. This has led to limited knowledge on the qualitative aspects of the impacts. Addressing this knowledge gap is crucial for effective water resource management and adaptation to climate change in regards to maize production and this is what the study will do.

1.2 Research Objectives

i. To determine the trends of seasonal rainfall variability in Tongaren Sub-County.
ii. To assess the impacts of rainfall variability on maize crop production in Tongaren Sub-County.

1.3 Research Questions

i. What are the trends of seasonal rainfall variability in Tongaren Sub-County?
ii. What are the impacts of seasonal rainfall variability on maize crop production in Tongaren Sub-County?

II. LITERATURE REVIEW

2.1 Decision Making Theory

In studying the impact of seasonal rainfall variability on maize production, the decision-making theory was applied. Decision making theory is a theory of how rational individuals should behave under risk and uncertain situations. Deciding is making a choice between alternative courses of action. A rational farmer can decide on farm operations based on the prevailing or expected weather and climatic conditions and availability of climate information services becomes handy. Climate change is characterized by high levels of uncertainty, and this uncertainty can influence farmers' decision making. Agricultural decision making has historically been dominated by economists who tended to rely on normative mathematical models and behavioral theories driven by assumptions of human rationality that emphasized utility maximization (Camerer et al., 2005). According to Kurt et al. (2020), given that agricultural decision making is central to the economic livelihood of the farmers making these decisions, an economic approach is commonly used in studying this domain. Using a traditional economic framework, individuals are assumed to be rational actors with perfect information about choice alternatives that make decisions that will maximize their utility (or a related objective such as profit, income or yield), using all the information they can access to attain that goal. In this study, the main independent variable was the seasonal rainfall variability whereby the amount of rainfall forecasted in a season directly determines maize yield which was the dependent variable. A maize farmer will thus make a decision on what to do in the farm based on the expected rainfall in a cropping season.

2.2 Empirical Review

Most agricultural systems depend on rainfall as the main source of water. This is according to United Nations Educational, Scientific and Cultural Organization (UNESCO, 2019). The amount of rainfall received in an area is very important as it determines the kind of human activity that may be carried out (Wada et al., 2017). As observed by Reda (2015), rainfall variability is a worldwide phenomenon which exhibits notable spatial and temporal variability. Furthermore, in a study by Donat et al. (2016) it was found that global warming is already driving increases in rainfall extremes. Their results resonate well with the study by Lehman et al. (2015) which found that global warming has so far enhanced the number of record- breaking rainfall events in terms of extremes. These studies intimated that extreme rainfall on daily timescales is increasing in frequency over most land areas. Other researchers too have underscored the need to understand existence and impact of rainfall variability. For instance, Jamal et al. (2017) found that knowledge of climate and rainfall variability is vital for urban planning and rural land use.

Similarly, a study done in Ethiopia by Lewis (2017) found that apart from rainfall amount, its distribution in a given season is very critical in crop growth and yield. Every area on the globe has a distinct period in which rainfall is received. For instance, Bangladesh has rainy monsoon season running from June to September (Islam & Uyeda, 2007). However, it has been shown that there is a decrease of rainfall in dry months in monsoon and pre-monsoon while there is an increase in the wet months (Shamsuddin, 2009). Similarly, it has been found out that in Bundelkhand region of India, precipitation during summer and winter seasons exhibited high precipitation variability (Som & Dey, 2022). A study conducted in South-West USA by Karanja et al. (2023) has revealed that there exists rainfall variability across various seasons mostly brought about by various atmospheric systems such as ENSO. Seasonal precipitation variability in Europe has also been studied and the results show that there is rainfall variability across the seasons brought about by both natural and anthropogenic forces (Nikolaos & Stott, 2022). Rainfall in Kenya exhibits variability on year to year and season to season basis. Most parts experience two rainfall seasons that alternate with dry seasons. The two rainfall seasons are the long rainfall season which is concentrated between March to May and the short season which occurs from September to early December (Gitau et al., 2012). A study by Palmer et al. (2023) has revealed that precipitation trends in Kenya are projected to remain highly variable and uncertain. In another study, analysis of spatial variability in rainfall trends in Baringo, Kenya (Ednah et al., 2018) found that there was year to year rainfall variability across different agro- ecological zones.

The effect of climate change on agriculture has been studied widely and it has been found out that most of the tropics and equatorial regions of the world have their agricultural yields determined more by the amount of rainfall received and stored by soil than by the air temperature (Adamgbe, 2013). However, according to Mukiibi (2001), the magnitude of rainfall is less critical to farmers' production than distribution through a season. Already, there has been a decline in the long rainfall season between March and May, and the resultant moisture deficit has resulted in decreased crop yield of long-life grains, such as maize, across the East African region (Adhikari et al., 2015).

According to (Adamgbe et al., 2013) variability in rainfall characteristics has a greater potential to crop failure and majorly in food crop yield including maize and hence food insecurity in most Sub Saharan (SSA) countries in Africa. Kenya is adversely affected by climatic variability and change because of her dependency on rain-fed agriculture, with variability in rainfall and temperature directly affecting crop and livestock yields. Study by Kabubo-Mariara and Karanja (2007) found that, precipitation was positively correlated with net crop yield. Similarly, Wilfrey et al. (2018) while investigating the effect of climate change on maize productivity in Kenya found that precipitation and temperature affects maize production. Furthermore, Nyandiko et al., (2013) observed that in Lower Eastern Kenya region, inter annual rainfall variability had caused a major stress to farming and crop production resulting into famine and hunger to the poor and vulnerable rural population. Although most studies found major results on the effect of climate change on agricultural production, they failed to point out exactly how a specific crop had been affected by comparing pre-climate change and post climate change productions. This study addressed that knowledge gap by investigating the effect of seasonal rainfall variability on maize production in Tongaren Sub-County in Bungoma County, Kenya.

III. METHODOLOGY

3.1 Study Area

This study was conducted in Tongaren Sub- County which is found in Bungoma County, Kenya. The Sub-County is located to the far East of Bungoma County (Figure 1) and it lies between latitude 0.66394°N to 0.88603°N and longitude 34.80166°E to 35.06785°E covering an approximated area of 378.4 Km^2. According to Kenya National Bureau of Statistics (KNBS, 2019), 33,602 people engage in maize growing. The Sub-County consists of six wards namely; Mbakalo, Naitiri/Kabuyefwe, Milima, Ndalu, Tongaren and Soysambu/Mitua. The Sub-County is also the bread basket of Bungoma County since it is endowed with fertile land that supports agricultural production with maize being the main crop grown. In terms of climate, the Sub-County has a warm tropical climate with mean maximum temperatures ranging between 24 °C and 30 °C and mean minimum temperatures ranging between 14.0 °C and 18.5 °C. The area receives over 1000 mm of rainfall per year most of which falls in the afternoons and evenings.

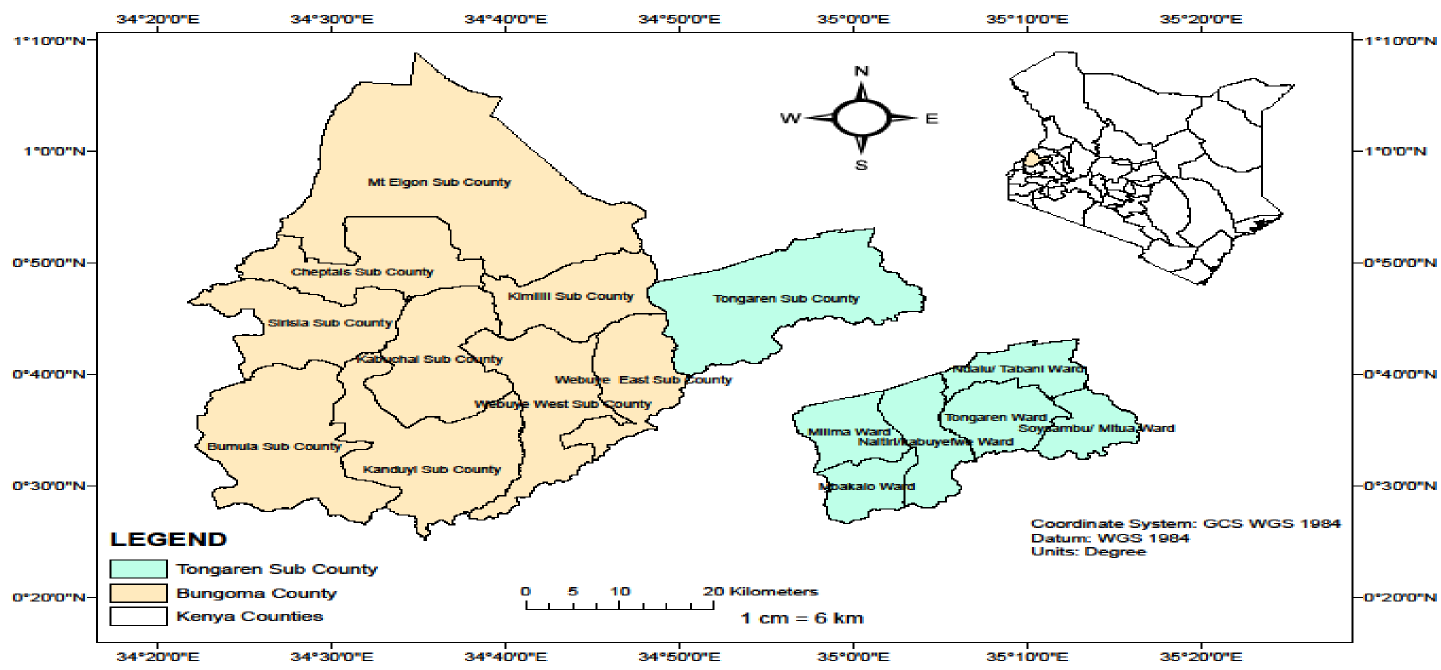

Figure 1
Map of the Study Area

3.2 Research Design

The study used a mixed methods research approach whereby both quantitative and qualitative methods were applied. Descriptive Survey was then used to evaluate the impacts of rainfall variability on maize production in the study area. Mixed methods research design was preferred because it enabled the study to integrate quantitative data with non- numerical qualitative data thus allowing for a deeper exploration and understanding of the research objectives and research questions.

3.3 Sampling Procedure

This section presents the method or procedure that was used in the study to determine a suitable sample which represents the whole population. The study used cluster sampling to reach out to the subjects and proportionate sampling technique (Etican & Bala, 2017) to determine sample size for each ward. In cluster sampling (Gravettter & Forzano, 2012), the individuals living in a particular village formed a distinct cluster from the others. After clustering the villages, simple random sampling technique was applied in order to get respondents in each village. Proportionate sampling technique was then applied in order to ensure that the number of individuals chosen per ward represented the study population proportionally. The formula applied in proportionate sampling is given in "Eq.1".

$$nh = \left(Nh/N\right)n \qquad (1)$$

Where,

nh = Sample size of stratum

Nh = Population size of the stratum

N = Total population size

n = Total sample size

The study then used Yamane (1967) as given in "Eq.2" to determine the sample size.

$$n = \frac{N}{1+Ne^2} \qquad (2)$$

Where,

n= sample size

N= Population size

e = Level of precision which is 0.05%

Based on a population of 33602, the desired sample size for the households was:

$$n = \frac{33602}{1+33602*0.05^2}$$

$$= 395$$

Out of a sample size of 395 respondents, 356 participated representing a response rate of 90.1 per cent as shown in Table 1.

Table 1

Distribution of Sample Size

Ward	No. of households	Sample size	Sample size response
Ndalu	5000	59	52
Soysambu/Mitua	9102	107	101
Tongaren	4000	47	40
Naitiri	4800	56	51
Milima	5200	61	54
Mbakalu	5500	65	58
Total	**33602**	**395**	**356**

Table1 shows how the participants were distributed proportionately in all the six wards of the study area.

3.4 Data and Data Collection

The study used both primary and secondary data which was further categorized as either quantitative or qualitative.

3.4.1 Questionnaire Survey

A questionnaire survey was used to collect information on the demographics and also on the impacts of rainfall variability on maize production.

3.4.2 Key Informant Interview

In addition to the questionnaire survey, key informant interview schedules were conducted in order to collect information relating to climate change, rainfall variability and maize production from Bungoma County Government officials drawn from the Department of Agriculture and other stakeholders.

3.4.3 Focus Group Discussions (FGDs)

A focus group discussion is a qualitative research method of data collection where selected groups of people discuss given topics or issues in-depth. Two focus group discussions were held with the aim of validating information collected during household survey. In this study the topical issues under discussion were the rainfall trends and the influence of rainfall variability on maize crop production in Tongaren Sub-County. During the discussions, participants were asked to give their perceptions on the changing rainfall patterns as well as the impact it has had on maize production and productivity.

3.4.4 Secondary Data

Secondary data comprising of monthly rainfall totals from 1985 to 2022 was sourced from Kenya Meteorological Department while annual maize yield data running from 1985 to 2022was sourced from Bungoma County Department of Agriculture.

3.5 Data Analysis and Presentation

The study used qualitative and descriptive statistical analysis using SPSS version 20. Inferential statistics were then used in order to draw conclusions. On the other hand, the rainfall and maize yield analysis was done through time series analysis and Mann Kendal trend analysis at 95% confidence level and significance level of 0.05. In time series analysis, the rainfall anomalies were plotted against the period (time). Graphs, frequency tables and pie charts were used to present the results. Coefficient of variation (v) was computed using the relationship below:

$$V = \frac{SD}{\bar{\bar{X}}} X\ 100 \qquad (3)$$

Where:

V = coefficient of variation

SD = standard deviation

$\overline{X}$= is the mean

Reliability of rainfall was then computed as shown in formula (4).

$$Reliability = 1 - v \qquad (4)$$

Where:

v is coefficient of variability.

IV. FINDINGS & DISCUSSION

4.1 Inter-Annual Rainfall Variability

Rainfall anomalies for the years from 1985 to 2022 were computed and plotted as shown in Figure 2. A positive anomaly indicates more precipitation (wetness) as compared to long-term precipitation mean whereas a negative anomaly indicates less precipitation (dryness) as compared to the long- term precipitation mean.

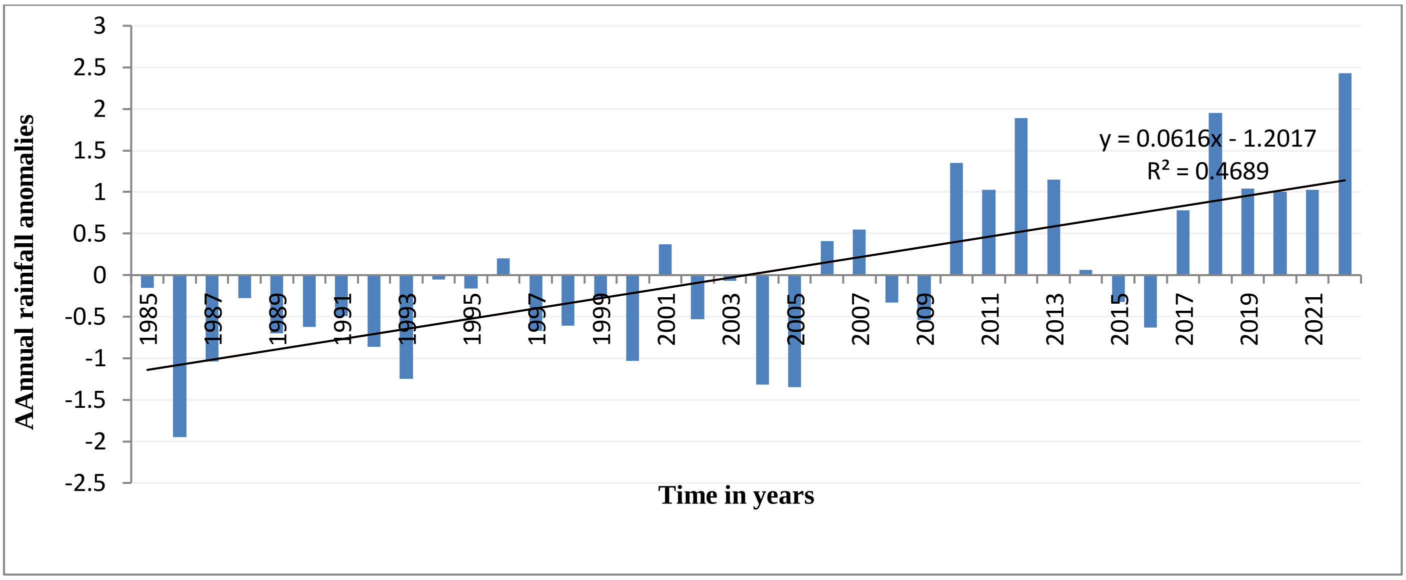

Figure 2
Standardized Annual Rainfall

The smallest anomaly was -0.05 registered in 1994 while the largest anomaly was 2.4 registered in 2022. This implies that the year 1994 recorded the least drop in the annual rainfall compared to the long term mean whereas the year 2022 recorded the highest rainfall increase as compared to the long term mean. Further analysis of results reveal that there were more years (23 years) that recorded less rainfall than the years that recorded more rainfall (15 years) in relation to the long- term mean. It can be seen that 1997 was an El Niño year yet the anomaly had a negative (-0.67) value. This can be explained due to the fact that earlier in the year, low amounts of rainfall had been recorded and therefore the actual total amount received (1302.7mm) in that year was below the annual mean (1424.0mm) recorded for the period running from 1985 to 2022. Furthermore, the result shows that there has been a general increase in the annual rainfall especially from the year 2010. Figure 2 also shows a general increasing trend in rainfall over the years. The findings of this study concur with those of Muthoni et al. (2019) that found a significant increasing trend in the annual rainfall over most parts of East Africa. Analysis of the rainfall show that most of the years registered over 1000mm of rainfall. This amount can support the growing of maize in the study area.

Table 2 gives an average annual variability of 14.3% which is significant. This means that there was a variation from the mean of up to 14.3% of rainfall received between the years. The results of this study resonates well with those of Andrew et al. (2015) that found rainfall in Kenya vary on annual basis. This variation in rainfall amount is likely to impact the maize output since amount of rainfall and its distribution in a given season is critical in affecting crop growth and its production. The high inter-annual variability signifies that the study area is likely to experience instances of extreme events such as droughts and floods. Mann Kendall's trend analysis yielded a p- value of <0.0001 (alpha=0.05) for the annual rainfall trends. Since this p-value was less than the alpha-value, it was concluded that inter-annual rainfall variability exhibited a significant trend. The computed R^2 implies that up to 46.9% of the information on rainfall anomalies is attributed to the time meaning that 46.9% of variability in rainfall which was the dependent variable was as a result of the time factor. The modest R^2 value explains the fact that rainfall does not depend on time alone but rather on the systems that cause it for instance the Inter-Tropical Convergence Zone (ITCZ) which occurs at specific times of the year. A summary of rainfall computations is given in Table 2.

Table 2
Rainfall Summaries

Variables	March to May (MAM)	June to September (JJAS)	Annual
Lowest rainfall (mm)	338.7	398.9	1039.0
Highest rainfall (mm)	822.7	851.2	1944.3
Mean rainfall (mm)	488.7	594.5	1442.1
Standard deviation	101.28	122.8	206.7
Coefficient of variation	0.207	0.206	0.143

4.2 Seasonal rainfall variability during MAM

Rainfall variability across March, April and May (MAM) rainy season show there is a general increasing trend in rainfall in Tongaren Sub- County during the rainy season. This result seems to be in agreement with studies done by Otte et al. (2017) that show an increase in MAM rainfall over East African region but contradicts the recent research results which show that MAM rainfall in most places is showing a reduction. However, computed p-value (alpha=0.05) was 0.127 indicating that the increase in rainfall during MAM season was insignificant. Results from analysis of rainfall data during the March, April, and May (MAM) season imply that the increasing rainfall trend though small is likely to enhance production of maize in the study area with the yield expected to increase in future. Figure 3 illustrates a plot of MAM rainfall anomalies against time.

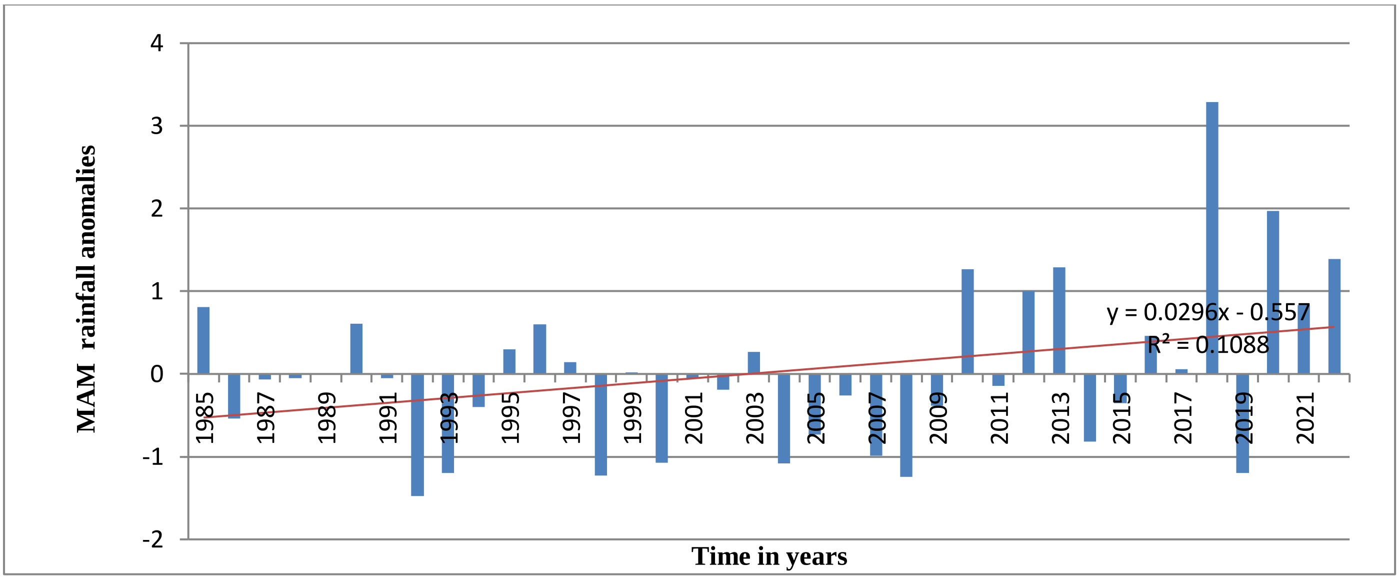

Figure 3
Standardized MAM Rainfall

From the anomalies the plot in Figure 3 exhibits a slight general increase in the MAM rainfall in Tongaren Sub- County for the period from 1985 to 2022. The results show that there were many years (22years) that recorded lower rainfall compared to the long term MAM seasonal mean. On the other side, 16 years recorded more rainfall as compared to the long term MAM mean for the season. Although some years recorded lower rainfall amounts as compared to the seasonal mean, the rainfall was still sufficient to support maize growing in the study area. It is to be noted that the horizontal axis represents time (independent variable) whereas the vertical axis represents the dependent variable (rainfall variability). Scrutiny of the Figure 3 further reveals that inter-annual rainfall variability across the MAM rainfall season is a regular occurrence which is likely to affect maize production. The derived trend line shows an increasing trend in rainfall variability with a computed R^2 value of 0.1088. This implies that only approximately 10.9% of variation in rainfall can be linked to time meaning that variation in time could only explain 10.9% of variation in rainfall during MAM rainfall season. Thus the model was poor in predicting rainfall variability during MAM as rainfall shows irregular variation that depends on various predictors and atmospheric forces other than time. The negative values indicate the years when the observed rainfall was below the long term seasonal mean whereas the positive values indicate when the observed rainfall was higher than the long- term mean.

The smallest anomaly was -0.003 recorded in 1989 whereas the largest anomaly was 3.29 registered in 2018. This implies that the year 1989 recorded the least drop in the MAM rainfall compared to the long term mean of 488.7mm whereas the year 2018 recorded the highest rainfall increase compared to the same long term mean. The lowest rainfall recorded during the season was 338.7mm in 1992 whereas the highest rainfall recorded during the season was 822.7mm recorded in 2018. Variation of rainfall within MAM had a modest coefficient of variation of 0.207. This implies that variation amongst the observed data was 20.7%. This is a significant variability according to Araya and Stroosnijder (2011) who observed that a coefficient variation (CV) of greater than 30% signifies a high variation. Variation of rainfall across the years of 20.7% has the potential to distort maize growing thus affecting the yield. Using the same data, a standard deviation of 101.28 was computed. The standard deviation of 101.28 is a large value and this implies that the MAM rainfall data is more spread out hence each value or score is far from the mean.

4.3 Seasonal Rainfall Variability during JJAS

The rainfall that falls during June, July, August and September (JJAS) season is very important as it supports the subsequent growth stages of maize; hence this rainfall determines whether maize yield will be good or poor. Analysis shows that there is a general increase in rainfall in Tongaren Sub- County during the June, July, August and September (JJAS) rainy season. The seasonal totals across the years range from a low of 398.9mm in 1986 to a high of 851.2mm in 2007. The mean for the entire period was found to be 594.5mm while a standard deviation of 122.8 was computed for this season. These values imply that rainfall within JJAS also varies and a variability of 20.6 % was computed. Since maize grown in this area is majorly rain-fed, maize yield is likely to be affected with years that have high rainfall values within JJAS season having likelihood to record high maize yield and vice versa. Figure 4 gives a plot of rainfall anomalies during the JJAS rainfall season.

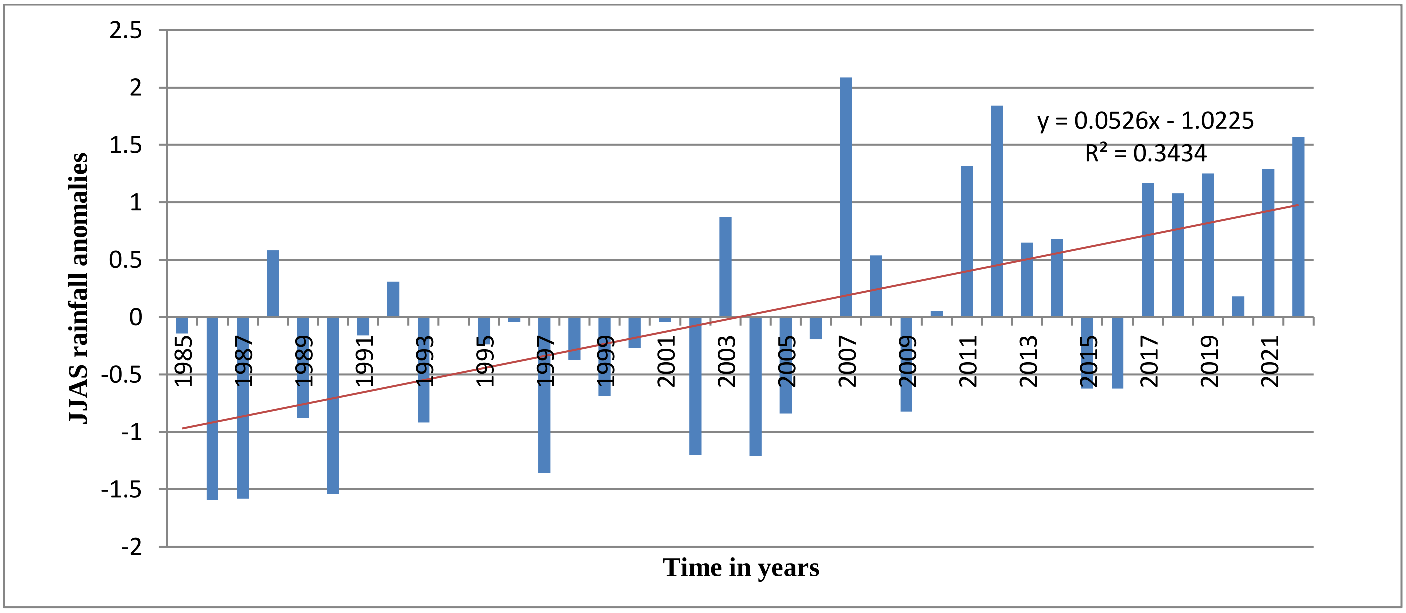

Figure 4
Standardized JJAS *Rainfall*

Figure 4 depicts a general increasing trend of rainfall amount during JJAS rain season. However, computed p-value (alpha=0.05) was 0.000 implying that there was a trend but was not significant. Similarly, computed R^2 value was 0.3434 meaning that 34.34% of rainfall anomalies experienced were associated with time factor. The low R^2 value during JJAS could be explained by the fact that rainfall during this period is as result of atmospheric systems such as Madden Julian Oscillation (MJO) which plays a major role and not just by variation in time. The regression model in Figure 4 only used time variation and excluded other factors and this could be the reason for the low R^2 posted by the model. Furthermore, the low R^2 value attests to the fact that there is low linear relationship between rainfall amount and time. However the positive slope suggests that rainfall anomalies increased with time for the period under study (1985 – 2022) and this is a sign that there is likely to be more variation in rainfall in future probably due to climate change. Figure 4 also shows that across the period under review, rainfall was either above normal or below normal. Above normal rainfall was recorded in 1988, 1992, 1994, 2003, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2017, 2018, 2019, 2020, 2021 and 2022. During the above normal episodes the lowest anomaly was 0.00 in 1994 while the highest was 2.09 in 2007. Below normal rainfall lowest anomaly was -0.04 recorded in 1996 and 2001 whereas the highest anomaly in this category was -1.58 in 1987. The computations show that there were more years (21) which had below normal rainfall especially between 1985 and 2006. This finding agrees with that of Hillier and Dempsey (2012) who had found that there was a reduction in the JJAS rainfall in the recent decades in the Horn of Africa.

4.4 Rainfall Probability of Exceedance

The probability of exceedance defines the probability that the actual rainfall received during a particular season is equal or higher than the estimated seasonal rainfall. It is to be noted that a season is considered wet when the probability of exceedance is equal to or above 80% whereas a dry season has probability of exceedance equal to or below 20% which denotes below normal rainfall (Zinyengere et al., 2011). Figure 5 shows MAM rainfall probability of exceedance. From Figure 5 the probability of exceedance of rainfall between 360mm to 460mm in the study area lies between 60% and 100%. This implies that the rainfall received in the study area during MAM is sufficient to support growth and development of maize. In a similar study by Mzezewe et al. (2013), it was established that seasonal rainfall amount of 450mm is indicative of a successful growing season and described it as a threshold rainfall amount.

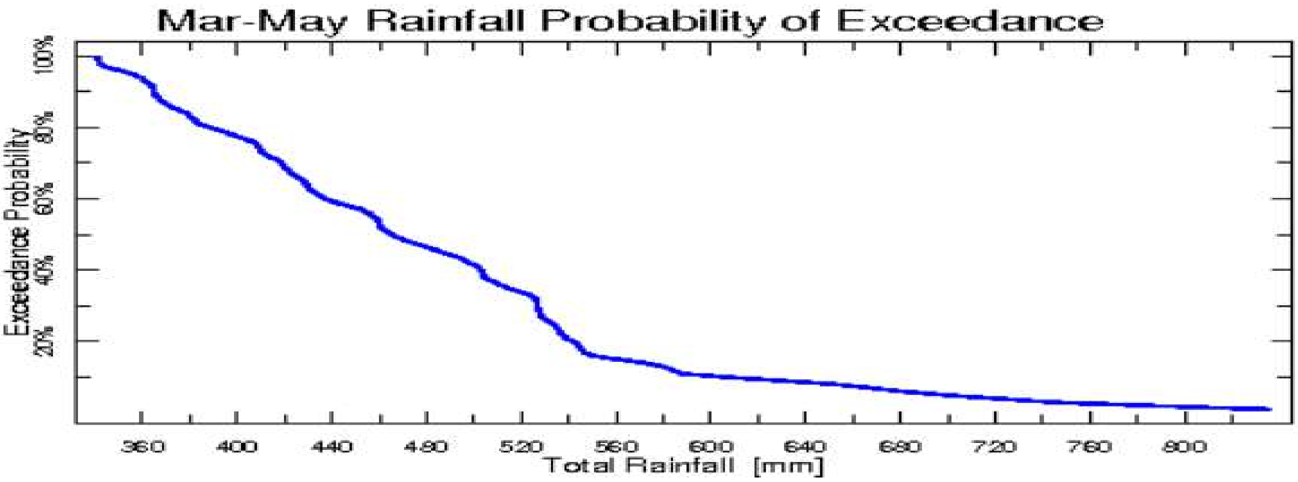

Figure 5
MAM Rainfall Probability of Exceedance

Based on this, the results as depicted in Figure 5 implies that maize can do well in Tongaren Sub-County as the threshold amount of 450mm of rain is met. Figure 5 also shows that there is an inverse relationship between the rainfall expected during MAM and rainfall probability of exceedance. As the expected rainfall during MAM increases, the rainfall probability of exceedance reduces and vice versa. The findings of this study agree with that of Butu et al. (2020). Rainfall exceedance for June, July, August and September (JJAS) rainfall season is given in Figure 6.

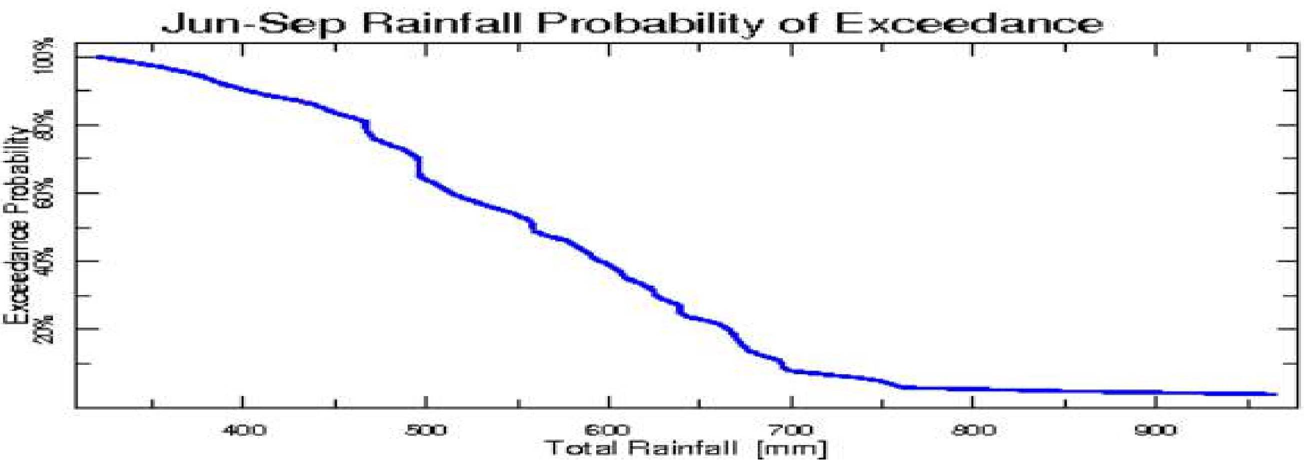

Figure 6
JJAS Rainfall Probability of Exceedance

From Figure 6, the probability of exceedance of rainfall between 320mm and 500mm lies between 70% and 100%. This implies that there was a high likelihood that the study area was to receive rainfall ranging between 320mm and 500mm between 1985 and 2022. From the rainfall analysis in the study area, the rainfall received during JJAS season is normally less as compared to the MAM rainfall. However, this amount of rainfall received during JJAS is still sufficient to support growth of maize in the area. Thus based on these results, smallholder farmers who depend on rain- fed agriculture are assured of growing maize in the area in any given year. Further scrutiny of Figure 6 reveals that the rainfall probability of exceedance reduces as the expected rainfall amount increases.

4.5 Impacts of Rainfall Variability on Maize Production

This study sought to assess the impacts of rainfall variability on various aspects of maize production and productivity. The respondents were asked to state whether they agreed or disagreed with the statements given to them. The findings are presented in the sub- sections below:

4.5.1 Perception of Maize Farmers on Rainfall Variability

Respondents were asked to state their perception in regards to recent rainfall variability relative to the past ten years.Table.3 shows the responses.

Table 3
Perception on Rainfall Variability

Perception	Yes	No
Rainfall has increased	55	201
No change in rainfall	30	326
Rainfall onset is earlier	18	338
Rainfall cessation is earlier	210	146

Results in Table 3 show that respondents perceived changes in the rainfall patterns in different ways. For instance, majority of the maize farmers (n= 301) representing 84.6 % felt that rainfall in the recent times has decreased as compared to (15.4%) who stated that rainfall has increased. The findings of this study are in agreement with those of Cudjoe et al. (2021) who carried out a study in Ghana and found that maize farmers are aware of and have recognized the changes in rainfall over the years. The results confirm the fact that farmers tend to perceive the severity of climate variability differently. Results also show that only 8.4% (n=30) of the respondents were of the opinion that there has been no change in the amount of rainfall in the recent times as compared to the past ten years. This implies that the majority of the maize farmers (91.6%) felt that rainfall amount has changed. Since majority of the smallholder maize farmers acknowledge that rainfall patterns and amounts have changed, this means that their farm-level decisions are likely to be influenced by prevailing weather conditions and they need to adapt to the new climatic conditions if they are to realize good maize yields. Table 3 also show that minority of the farmers (n=18) representing 5.1% reported that the onset of rainfall comes earlier than the past ten years whereas 94.1% who were the majority (n=338) felt that the rainfall onset delays. Furthermore, majority (59%) of the maize farmers said that cessation of rainfall comes earlier than the past ten years and 41% of the farmers were of contrary view. All these could be attributed to climate change. It can be inferred from these findings that maize farmers have to adjust to the new reality of climate change and adopt a new cropping calendar. A study by Klutse et al. (2013) observed that the onset and cessation of rainfall decreased maize production, which poses a serious threat to household food security, since maize is the staple food of most of the citizens. With this result in mind, maize farmers in the study area are likely to encounter food insecurity unless good adaptive strategies are put in place.

4.5.2 Selection of Maize Variety

The study sought to know whether rainfall variability had an influence when making a choice on the maize varieties to be grown. Figure 7 gives the outcome from the respondents.

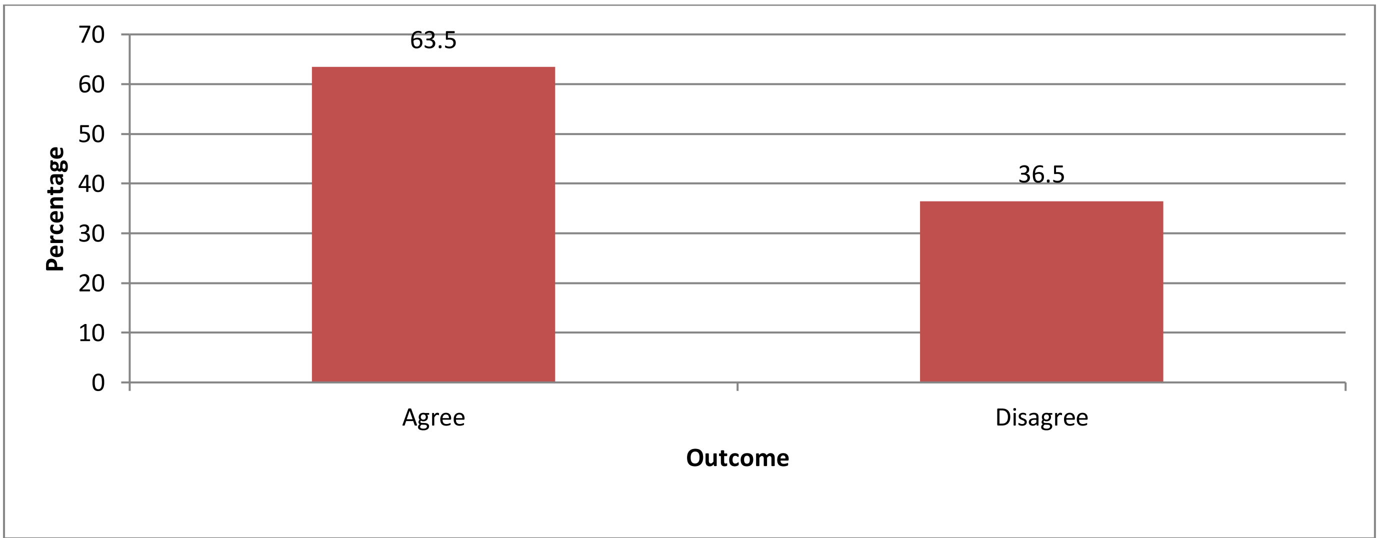

Figure 7
Response on Selection of Maize Varieties

A significant percentage of the respondents (63.5%) felt that variability of rainfall influences the choice of maize variety to be planted. This finding concurs with that of Guido et al. (2020), that the selection of seed varieties and when to plant them are two of the more consequential decisions based on climatic factors which farmers make each cropping season. This is very important because different maize varieties do well in certain weather conditions. Some maize varieties thrive when there is plenty of water whereas others still do well when there is just a little rainfall since they are drought resistant. This outcome clearly shows that a good number of maize farmers (36.5%) do not care much about the weather conditions when choosing maize varieties to be grown yet weather information could help them select maize varieties such as early – maturing or late- maturing to be planted. This is likely to compromise the maize yield, which may contribute to food insecurity since inability to use climate information such as seasonal rainfall variability characteristics may reduce their ability to manage climate risks.

4.5.3 Land Preparation

Preparation of land is an important farm activity prior to planting. Maize farmers in the study area were asked to indicate whether land preparation activity is impacted by variation in rainfall during planting season. The respondents were asked to indicate whether they agreed or disagreed with the fact that rainfall variability was a determinant on when to prepare land for planting maize. Figure 8 gives the results of the survey.

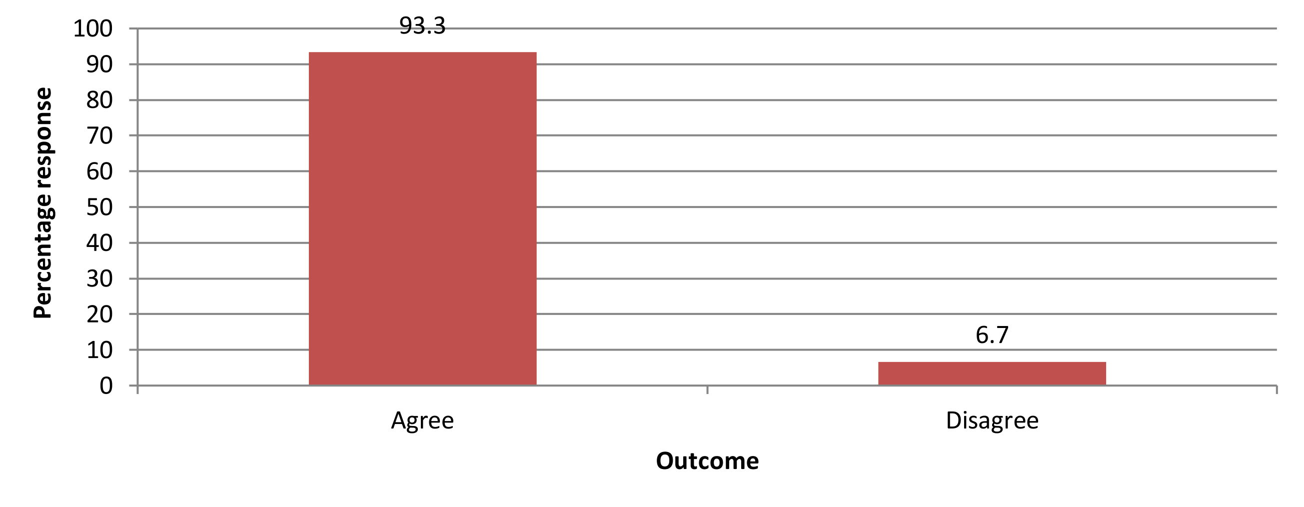

Figure 8
Response on Land Preparation

The results in Figure 8 show that 93.3% of the respondents agreed that rainfall variability influences when to prepare their land in readiness to grow their maize whereas 6.7% disagree. The finding of the study concur with that of Philip et al. (2021) which found that a significant number of farmers use climate information such as rainfall variability in making decisions related to land preparation. Most of the farmers in the study area prefer using tractors to plough their land since this is faster and saves time. Good timing to prepare land is important because this is an activity that should be undertaken before the onset of the seasonal rains. This is preferable because farm machinery can be deployed and maneuvered well when the land is still dry as opposed to when the land is wet as this makes deployment and use of machinery cumbersome.

4.5.4 Planting and Harvesting Time

Most of the farm activities are dependent on the availability of rainfall. In regards to when to plant maize, 100% of the respondents agreed that seasonal rain determines when to plant their maize crop. This is so because the amount of rainfall received plays a big role in determining whether they will achieve good germination of the seeds or not. Furthermore, the forecasted onset date of the seasonal rains is significant because this will help the farmer to plant maize in good time. Planting maize at the right time is desirable as this will eventually determine the yield. Thus, the amount of rain received when seasonal rains set in is very crucial. These findings corroborates with Reche et al. (2008) who observed that determination of planting dates was an important farm management strategy that reflected the application of knowledge on the behaviour of rainfall patterns. Moreover, Guido et al. (2020) in the study on impact of seasonal rainfall variability and forecasting in Sub- Saharan Africa found that seasonal forecasts had high usage for choices related to planting dates. In another study by Fisher et al. (2015), it was found that farmers, who plant too early, risk the failed germination of seeds from insufficient soil moisture, while farmers who plant too late, risk having their seeds washed away during intense rains. Although farmers in the study were of the opinion that seasonal rainfall variability plays a major role, in decision –making as to when to plant, farmers could also decide when to plant as the weather unfolds. This was affirmed during FGD when a famer said "*nowadays, it is becoming* *more difficult to predict the future rains in our area due to climate change*". Another farmer also said that "*The rains do not come early as they used to a few years ago and nowadays we wait until early April to plant our maize unlike in the past when we used to plant in February*". These sentiments expressed by the maize farmers affirmed the fact that rainfall patterns have shifted. Similarly, all the respondents (100%) felt that knowledge on seasonal rainfall variability is very crucial in determining when to harvest their maize. The finding of this study is in agreement with those of (Hansen, 2002 and White et al., 2017) which found that farmers use climate forecasts to reduce their vulnerability to the impacts of climate risks such as droughts and floods. This is because weather prevailing at the time of harvesting will determine the amount of maize that will be destroyed because of rotting due to excess water. Most farmers prefer to harvest their maize during the dry weather. This will reduce post- harvest losses. The dry weather will also enable the farmers take their maize produce to the market. When there is a lot of rain, most of the rural roads where most farmers live are rendered impassable hence; it makes transportation difficult and cumbersome.

4.5.5 Fertilizer Application

An impressive portion of the respondents (86.8%) reported that application of fertilizer on their maize farms is dependent on the seasonal rainfall. The finding concur with the studies carried by (Belay *et al*., 2017; Dewi and Whitbread, 2017) who intimated that farmers who rely on climate information to carry out farm management activities such as application of fertilizer are better placed to improve their crop yield and adapt well to climate change shocks. Application of fertilizer especially the organic type at the right time is crucial as this is one way in which fertility of the soil is conserved and maintained. Timing on when to apply fertilizer to crops is important as this enables the maize plants to fully utilize the applied fertilizer. It is preferred to apply the fertilizer when there is less rain as this will reduce the leaching of the fertilizer. Seasonal rain forecast is therefore critical since information on when there will be more or less rainfall is given and this may help the farmers in making the right decision on farm management activities.

4.5.5 Influence on Maize Yield

Respondents were asked to state whether seasonal rainfall variability affects their maize yield or not. Figure 9 shows the outcome of the survey.

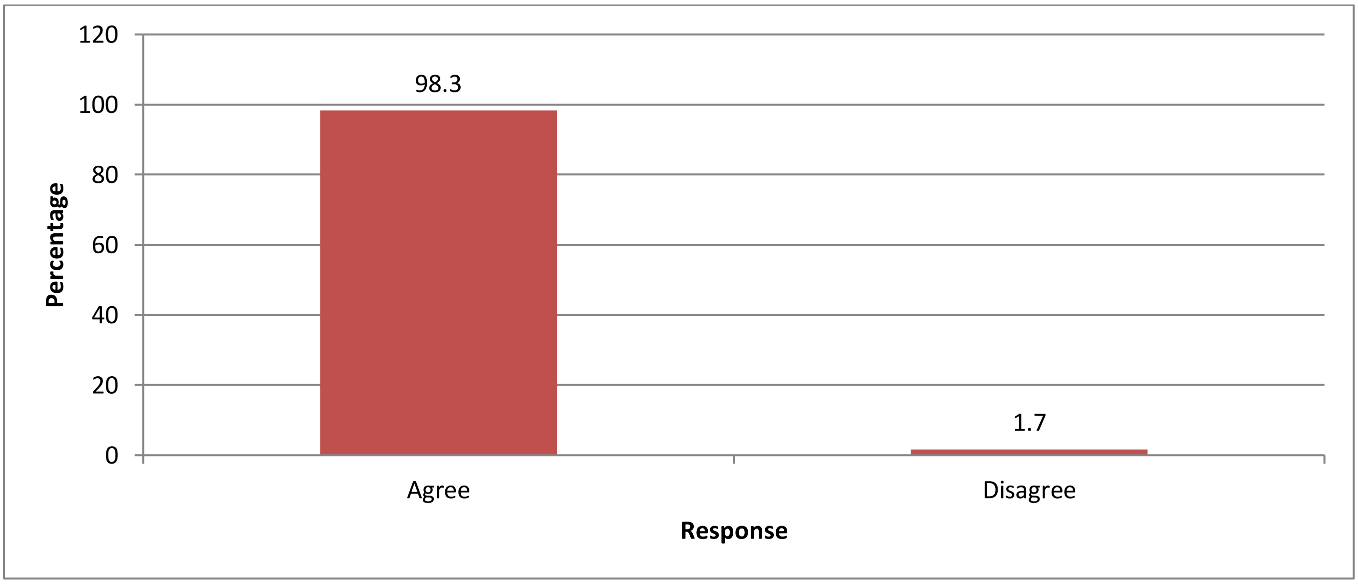

Figure 9
Influence on Maize Yield

An overwhelming majority of the respondents (98.3%) agreed seasonal rainfall received plays a big role in determining maize yield while 1.7% of the respondents disagreed with that statement. All the maize growth stages require enough water amounts in order to have a good yield. This result corroborates well with those of Bahiru *et al.* (2020) that rainfall variability over growing season adversely affects rain-fed crop production due to its associated risks such as delay on onset, early cessation and dry spells. The results show that most of the years when we had high rainfall recorded during the rainy season also recorded high maize yield and vice versa. This finding explains the fact that seasonal rain forecast when applied by the farmer is likely to help such a farmer in decision- making for instance in choosing the right maize varieties and when to plant. The right choice of maize varieties to be planted and when are crucial as these will determine the yield.

4.5.6 Weeding and Application of Herbicides

The study sought to know whether seasonal rainfall variability affected weeding and application of herbicides activities in maize production. Figure 10 below shows how the farmers responded.

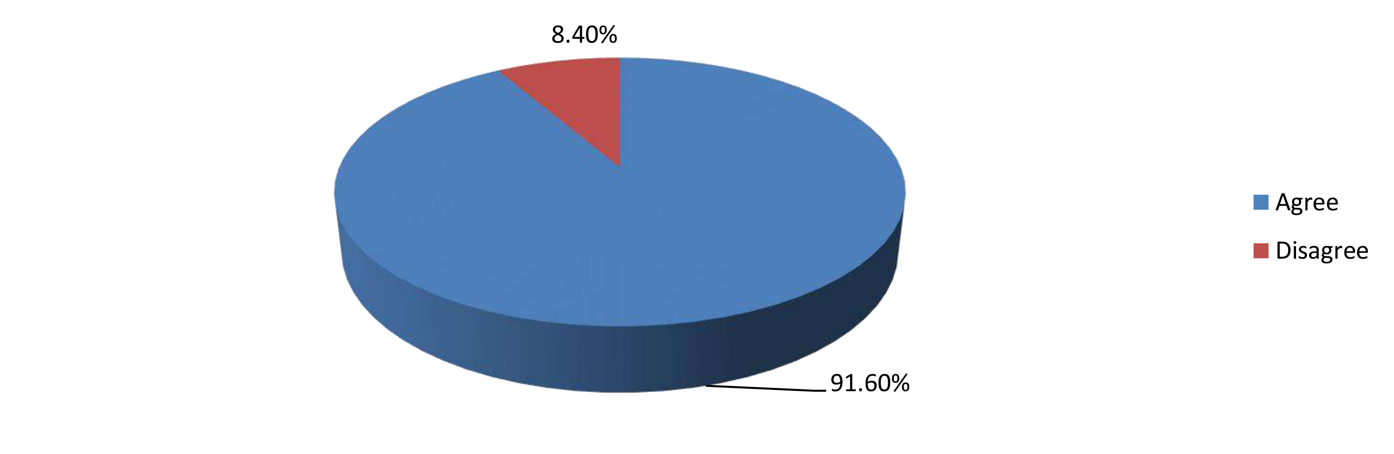

Figure 10
Response on Weeding and Application of Herbicides

Weeding and application of herbicides are farm activities that are dependent on the prevailing weather conditions. A high percentage of the respondents (91.6%), were of the opinion that seasonal rainfall determines when to carry out these activities. Another 8.4% of the respondents were of contrary opinion. Weeding and application of herbicides are normally carried out during the time when we have little rain as this ensures that we do not have re-emergence of weeds and also to ensure that the herbicides are not washed away by the rain water. The finding concur with that of Reche *et al*. (2008) which found that application of fertilizers, herbicides and other farm activities at particular times were some of the farm management practices that reflected use of seasonal forecasts in Kenya. Farmers are normally cautious on what farm activity to undertake in order to take full advantage of the prevailing weather. For instance, they would prefer to weed or apply herbicides when there is little rainfall as opposed to when there is heavy rainfall. Weeding done during the time of light rain ensures that there is low re-emergence of weeds. Likewise, application of herbicides during the time of light rain ensures that the herbicide is not washed away by the rain.

4.5.7 Delivery of Maize Produce to the Market

Few maize farmers (19.9%) were of the opinion that seasonal rainfall variability is important when it comes to determining when to take their maize produce to the market. This implies that majority (81.1%) of maize farmers do sell their maize at any given time of the year irrespective of the prevailing weather as maize is the staple food in this area and its market is readily available within them and does not necessarily need to be taken to the market which may be far. This finding is in agreement with that of Andersson *et al*., (2016) and Barnett (2019) which found that producers and suppliers of various commodities may not consider the impact of weather and climate risks on their operations. Seasonal rain forecasts give information whether there will be above normal, normal or below normal rainfall. The amount received will determine the state of the rural roads which are mostly not tarmacked. Too much rainfall will render most of these rural roads impassable and this may significantly impact transportation of the harvested maize to the market. However, the finding of the study seems to suggest that most farmers are unperturbed by weather conditions. It was mentioned during the FGD that most of the smallholder maize farmers transport their maize produce using motor cycles, the -so-called 'boda-boda'. 'These 'boda-bodas' can manoeuver their way even when the roads are bad and this could be the reason why they are preferred. They are also cheaper as compared with other means of transport.

4.6 Correlation between Rainfall Seasonality and Maize Yield

Seasonal rainfall amounts were related to total annual maize yield across the study area for the maize growing period between March and September. The result indicates that there was a significant positive correlation of 0.53 between the JJAS rainfall and the maize yield whereas the correlation between March to September rainfall and the maize yield was 0.4. Analysis of correlation between total rainfall during MAM season and maize yield posted a weak positive correlation coefficient of 0.05. The result of this study agrees with those of Ifabiyi and Omoyosoye (2011) which found that total rainfall amount determines the overall maize yield.

The result of this study shows that the rainfall received between June and September counts more in regards to overall maize yield than the March to September rainfall. Most of the growth stages such as maize flowering and tussling occur between June and September and these growth stages require good rainfall amounts. This could be the reason why the correlation between maize yield and rainfall amount is higher in this period. Analysis conducted on the maize yield trend gave a p-value (alpha=0.05) of 0.001 implying that there is a slight increasing trend in the maize yield in the study area over the years. With the increasing rainfall trend from the analysis, it is predicted that the increasing maize trend will be maintained in future. However, it is to be noted that maize yield does not depend only on rainfall amount but also on other factors. Figure 11 shows how maize yield compares with the rainfall amount for the period between 1985 and 2022.

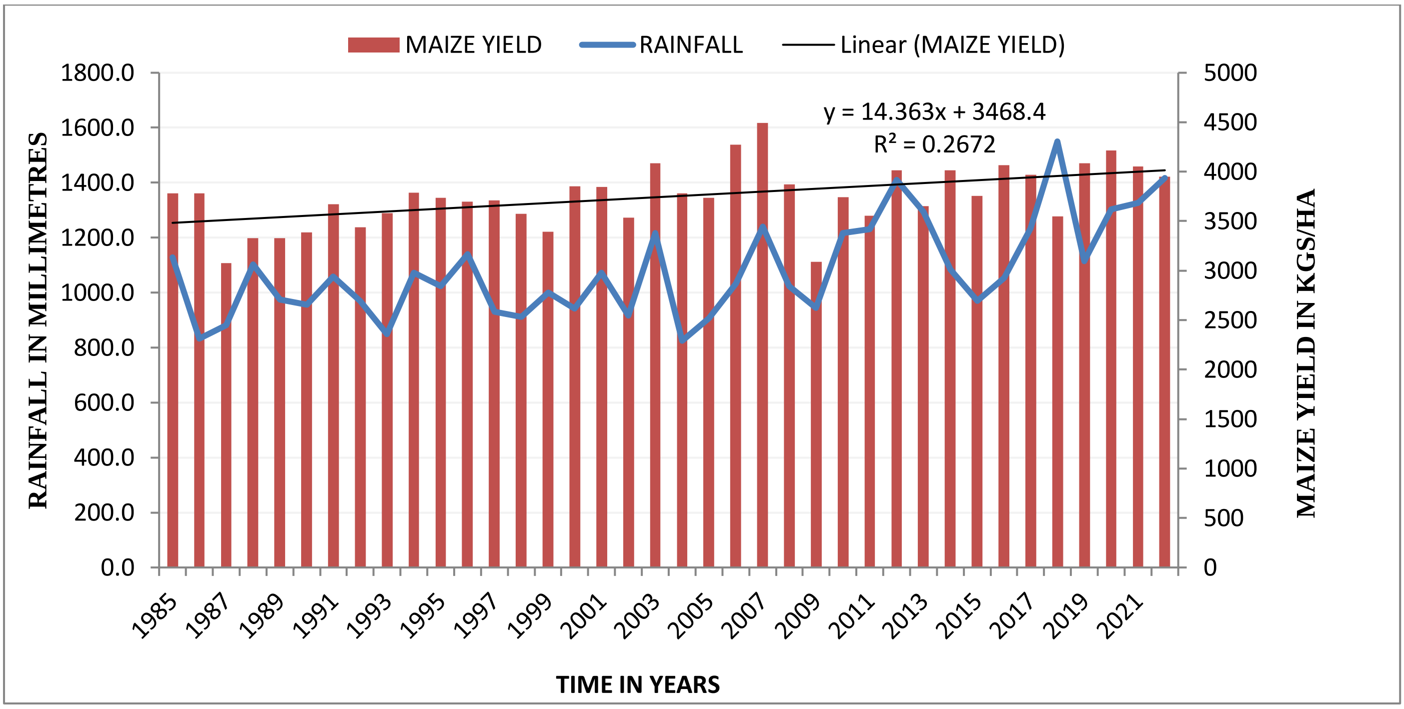

Figure 11

Correlation between maize yield and rainfall

Figure 11 shows a close relationship between maize yield and rainfall amount. It can be seen from the graph that some years that recorded high rainfall amounts also recorded high maize yields. However there were some instances when there was high rainfall but the maize yield was low for instance in 2018. Similarly some years with low rainfall amounts recorded high maize yield for instance in 2002 and 2004. This year- to- year fluctuation in yield can have major impacts on the livelihoods of farmers as observed by Frieler et al. (2017). This could have been caused by some other factors such as change in the acreage put under maize growing, pests and disease infestation, farm inputs and other agronomic practices.

4.7 Maize Yield Trends

The study sought to establish the views participants had in regards to the maize yield trend amidst rainfall variability at the individual level. They were asked to state whether maize yield over the years had decreased, increased or remained the same. Table 4 gives the results from the survey.

Table 4

Perception on Maize Yield Trends

Trend	Frequency	Percentage
Increased	12	3.4
Decreased	297	83.4
Not Changed	47	13.2
Total	**356**	**100**

It can be seen from Table 4 show that 83.4% of the respondents reported that maize yield at the individual level had decreased over the years while 3.4% were of the view that maize yield had increased. Another 13.2% felt that maize yield over the years had not changed. Thus, respondents who were of the view that maize yield had decreased formed the majority. This finding is concordant with Barimah et al. (2014) who reported a decline in maize yields across some parts of Ghana and cited increasing temperatures and irregularity in rainfall as the primary causes of the reduction in yields. This result also corroborates well with those of Bahiru et al. (2020) that rainfall variability over the growing season adversely affects rain-fed crop production due to its associated risks such as delay on onset, early cessation and dry spells. Results of rainfall variability which, have been reported in the study area indicate that maize farmers need to adapt to the changes in climate and adopt new ways of growing maize such as planting the right varieties so as to reverse the decreasing trend of maize yield.

Results in Figure 11 show that over the years as from 1985 to 2022, there has been a slight increasing trend of maize yield. This result seems to agree with that of Epule et al. (2022) which found that, there has been a general rise in the yield of maize across Africa. This is contrary to the perceptions maize farmers held that there had been a decreasing maize yield trend. However the trend had an R^2 value of 26.7% meaning that the variation in maize yield could be explained by time difference. Low R^2 value was due to the fact that the model used only considered time as a contributing factor to the maize yield and excluded other contributing factors such as soil fertility, extension services and new farming technologies such as new improved maize varieties among others. Future studies on the same need to consider these factors. Generally maize yield during the study period (1985 to 2022) has been different from year- to-year oscillating around the mean value of 3748.5 kg/ha. The lowest value (3078kg/ha) of maize yield was recorded in 1987 while the highest value (4491kg/ha) was recorded in 2007. This contrasts with the yearly rainfall totals where the year 2007 had a lower rainfall total of 1366.1mm as compared to 1987 which had annual rainfall total of 1431.4mm. This mismatch in maize yield and rainfall amounts could be attributed to other factors that affect maize production such as farm inputs which, were not considered in the regression.

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

This study investigated the rainfall variability and its impact on maize production in Tongaren Sub- County, Bungoma County, Kenya. Results show that both MAM and JJAS rainy seasons had increasing rainfall trends though insignificant. Similarly, results for annual analysis of rainfall trends also showed an insignificant increasing trend. However rainfall variability for MAM, JJAS and annual was found to be significant for the period under study (1985 to 2022).Rainfall variability for MAM, JJAS and annual were; 20.7%, 20.6% and 14.3% respectively. The rainfall variability is linked to climate change. This variability in rainfall is likely to affect maize yield due to the fact that majority of the smallholder maize farmers wholly depend on the rainfall to grow their maize. Findings of the study show that there has been a slight increasing trend of maize yield over the years which were however contrary to the perception held by the smallholder maize farmers. Results also indicate that rainfall variability influences maize production in various ways including choosing maize varieties to grow (63.5%), when to prepare land (93.3%), planting and harvesting time (100%) in addition to influencing the maize yield (98.3). These high percentages imply that most maize farmers make their farm decisions depending on the weather and climate and that rainfall is very crucial in their planning. It was established that maize yield has a significant correlation with rainfall received during JJAS (0.53) while the correlation with MAM rainfall is insignificant (0.05)**.** This shows that rainfall received between June and September plays an important role in determining maize yield since this period is when most development stages of maize crop take place.

5.2 Recommendations

The study recommends the need for closer collaboration between the agencies responsible for provision of rainfall information and maize producers in order to address the issue of rainfall variability and manage climate related risks through appropriate adaptation strategies. To achieve this the study further recommends that climate information providers to improve the availability and dissemination of timely and accurate weather and climate information especially rainfall forecasts to the maize farmers so as to enable them make informed farm –level decisions in order to boost maize production.

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