Assessing the Impact of Climate Variability on Maize Production in Rwanda: A case of Gakenke District

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Abstract— *The changes in climatic variables is a challenge for the humanity as they affect different ecosystems important for life. This study assessed the impact of climate variability on maize production from 2012 to 2021. Specifically, this study 1) assessed the pattern of precipitation and temperature variability, 2) analysed the production of maize, and 3) investigated the relation between climate variability and maize production in Gakenke district. This study was conducted in three sectors, with a sample of 322 maize farmers. Climatic data were obtained from the Rwanda Meteorological Agency. Both descriptive statistic and regression and correlation analysis were performed in RStudio. The results show a remarkable variability in the annual mean temperature and annual rainfall. The mean temperature and amount of rain have increased by +1.34°C and 1.74 mm in Cyabingo, by +1.47°C and 1.997 mm in Gakenke, and by +1.52°C and 3.389 mm in Gashenyi. An overall increase in maize yields was highlighted and much dependent on temperature variation than precipitation variability. A strong correlation was between the temperature and yields, with r values of 0.98 for Cyabingo, 0.90 for Gakenke, and 0.94 for Gashenyi. The regression analysis indicates that maize yields were significantly influenced by temperature variability, with R-squared values of 0.960 (p-value = 0.000), 0.815 (p-value = 0.000), and 0.885 (p-value = 0.000) respectively in Cyabingo, Gakenke, and Gashenyi. On the other side, a mild positive correlation (r = 0. 43), a moderate negative correlation (r = -0.59), and a weak negative correlation (r = -0.1) were between precipitation and maize yields in Cyabingo, Gakenke, and Gashenyi, respectively. The regression analysis also indicates that maize yield of was not significantly influenced by precipitation variability. Although this study shows the temperature as an important factor for maize production, its continuing rise could bring to heavy rains and unexpected strong weather events, with ultimate negative impacts. Thus, adaptation strategies on climatic variability should be enhanced in order to minimize its disastrous effects on maize production.*

Keywords- Climate variability, Climate change, Maize production, Gakenke district, Rwanda.

I. INTRODUCTION

The global development has encountered a significant challenge in the form of climate. This is primarily resulting from the effect of worldwide climate change, variation in rainfall patterns, and the rising average temperatures, which have introduced new hurdles and risks to all human and world wide. Changes in the climate are the result of both natural and human-induced factors occurring across continents and oceans [1]. These changes extend beyond typical atmospheric conditions and can be attributed to natural influences like the Earth's orbital variations, volcanic activities, and crustal movements, as well as human activities such as the accumulation of greenhouse gases and aerosols, deforestation, intensive farming, waste disposal, transportation, industrial operations, and overconsumption [2]. Global warming, indicated by the overall increase in the planet's temperature, has emerged as a predominant trend that will usher in significant global transformations in the future. Recent studies highlight important information on the expected problems of food insecurity as consequence of climate change [3], [4], with particular effect on local communities that depend on rain-fed agriculture [5].

Agriculture makes up roughly 39% of Rwanda's total gross domestic product (GDP) and provides livelihoods for about 88% of the whole population, particularly in rural parts of the country, where the majority of Rwandans reside [6]. More than 65% of Rwandan population depend on agriculture, forestry and tourism resources for income generation and food security [7]. Among the four key sectors, agriculture stands out as a major factor accelerating the economic development and significantly improving the livelihoods in Rwanda. However, the sector is much prone to the weather and climate-related hazards, including unusual rainfall patterns, hail, floods, landslides, and extended periods of drought, all of which are consequences of climate variability, particularly in terms of temperature and rainfall patterns [8]. Recent incidents have shown the severe consequences of extreme weather events on agricultural output accross different parts of the country.

Therefore, it is critical to understand the extent of the effects of climate variability as an option for sustaining crop production and meet the countrywide food demand. In the light of this concern, this study assessed the impacts of climate variability on maize production in Gakenke district, northern part of Rwanda. Specifically, it provides important data of climate variability (especially on precipitation and temperature pattern) during the past 10 years (from 2012 to 2021), provides data on maize production and its trends in the study area during this study period, and also analyses and predicts the impact of climate variability on maize production in the study area. This provides information that is required to facilitate farmers for their adaptation to climate change thereby reducing their vulnerability to climatic crisis.

II. MATERIALS AND METHODS

2.1 Study site description:

This study was conducted in Gakenke district, one of the five districts of the Northern Province of Rwanda. The climate in Gakenke district is generally humid climate, with the average annual temperature varying between 16ºCand 29ºC and annual rainfalls ranging from 1100 mm to 1500 mm [9]. As it is the case for the entire country, Gakenke district experiences four different seasons: The small dry season: January-February, the high rain season: March- end May, the high dry season: June-end August, and the small rain season: September- December. This climate makes Gakenke district to be a favourable region of agricultural activities. Gakenke district is characterized in general by high inclined hills separated by rivers and marshlands. These marshlands are generally exploited during the dry season [9] . The map showing the sectors selected for this study is presented below:

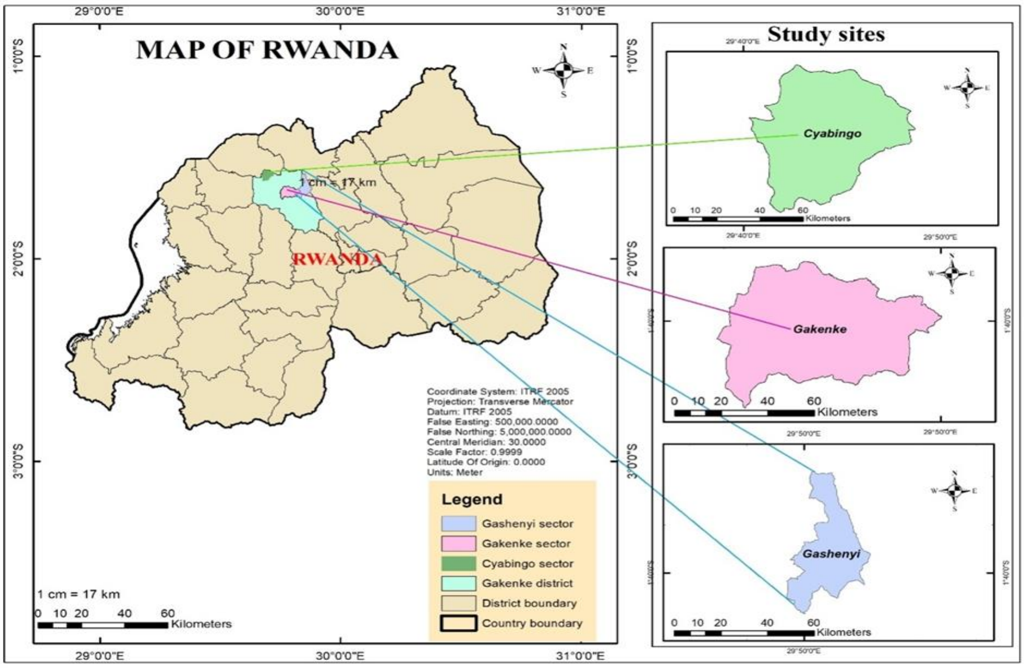

FIGURE 1: District map showing the selected sectors for sampling

2.2 Study population and sample size:

This study focused on farmers living in three sectors of Gakenke district, namely: Gakenke, Gashenyi, and Cyabingo sectors. These sectors were selected due to their accessibility and because they are under the some agro-climatic conditions, rendering Gakenke district a prime location for agricultural activities. The target population consisted of farmers who are organized into land consolidation cooperatives. Among these farmers, only those who have been growing maize for, at least, the past ten years were considered as respondents. Their total number is 1648 with 689 located in Gakenke ,539 in Gashenyi and 420 in Cyabingo sector. A sample of n is the numbers of maize's farmers that were interviewed, and was determined using this formula: $\boldsymbol{n} =$

$\frac{N}{1+N(e)^2}$ Where n = Sample size, N= study population which is the total number of farmers in Gakenke, Gahenyi, and Cyabingo sectors and e = margin of error that was 5% meaning that the confidence level was 95%. Hence, $n = \frac{1648}{1+1648\,(0.05)^2}$= 321.8~322.

Proportionate sampling method was used to determine the number of maize farmers who were interviewed in each of the three sectors. The following formula was used: $= \frac{Ni \times n}{N}$, where ni = the sample size proportion to be determined, Ni = the population proportion in the stratum, n = the sample size, and N = the total population

TABLE 1
PROPORTION OF POPULATION IN EACH SECTOR

Farmers in land consolidation groups/ cooperatives Sector	Number of households	The proportion of population to be interviewed per sector	The proportional percentage (%)
Gakenke	689	135	42
Gashenyi	539	105	33
Cyabingo	420	82	25
Total	1648	*n*= 322	100

2.3 Data collection:

This study applied a non- probability sampling technique. Purposive sampling method was used to select three sectors. The proportionate sampling method was also applied as a non- probability sampling to determine the number of maize farmers to be interviewed in each of the three sectors. Primary data of maize production were gathered through semi-structured interviews, face to face, with maize farmers (n = 322) as respondents. These interviews explored a range of perspectives concerning the implications of climate variability and its impact on maize production in Gakenke district. The data were collected in a face to face interview and were recorded using a detailed schedule with open and closed questions. For the secondary data, the literature review encompassed pertinent climate-related scientific publications, reports, and policy documents collected from various locations. In order to obtain rainfall and temperature datasets, meteorological data recorded at the nearest Cyabingo, Paroisse Nemba, and Minazi meteorological stations were accessed from the RMA. The ArcGIS 10.8 software was used to draw a study area location map, and required (administrative boundary) shapefiles were accessed form Gakenke district.

2.4 Data Analysis:

Data were analysed to assess the impact of climate variability on maize production in Rwanda: a case of Gakenke district. For the first and second objectives, descriptive statistic was performed to assess the pattern of precipitation and temperature variability and to analyse the production of maize over the past 10 years in Gakenke district. For the third objective, regression and correlation analysis were performed to relate climatic data with maize yields in order to find out the relationship between climate variability and maize production in the study area. This was also to provide information for future prediction regarding the impact of climate variability on maize production. Both descriptive statistic and regression and correlation analysis were performed in RStudio.

III. RESULTS AND DISCUSSION

This study has investigated the impacts of climate variability on maize production in Gakenke district. These impacts were analysed in three dimensions, specifically by: 1) assessing the pattern of precipitation and temperature change over the past 10 years in Gakenke district, 2) analysing the production of maize over the past 10 years in Gakenke district, and 3) finding out the relation between climate variability and maize production in Gakenke district. All respondents answered all questions. The majority of respondents (72%) were females while 28% were male 72% of respondents attended primary school. Among them, 90% did only agriculture and 10% added small business during the study period. The analysis results showed that agricultural sector encompasses mainly the persons with lower level of formal education.

3.1 Status of climate variability (rainfall and temperature pattern) over the past 10 years in Gakenke, Gashenyi and Cyabingo sector:

3.1.1 Trend of Temperature Patterns:

Temperature variations in the study areas (Fig. 2, Fig. 3, and Fig. 4). Temperature trend lines in wetland of Gakenke, Gashenyi and Cyabingo sector indicate the similar since 2012 to 2021 there is increase in mean temperature. In Gakenke the average maximum temperature was 18.86ºC whereas the minimum was 17.39ºC since 2012 to 2021 making increase of 1.47ºC, In Gashenyi the average maximum temperature was 20.52ºC whereas the minimum was 19.00ºC since 2012 to 2021 making an increase of 1.52ºC. In Cyabingo the average maximum temperature was 20.24ºC whereas the minimum was 18.90ºC since 2012 to 2021 making an increase of 1.34ºC.

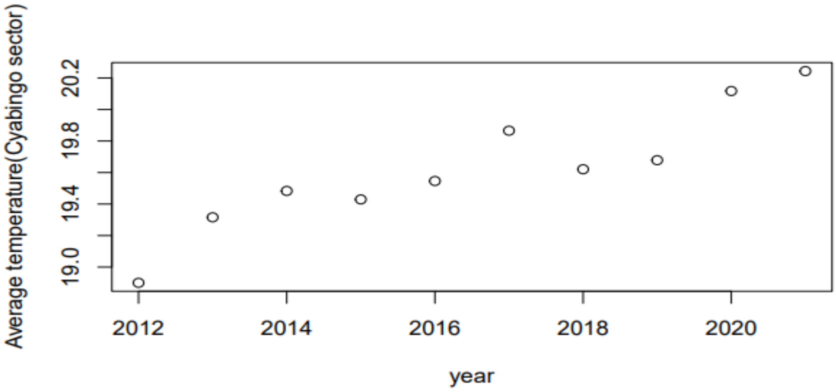

FIGURE 2: Trend of temperature for Cyabingo wetland between 2012 and 2021 (Source: RMA, 2024).

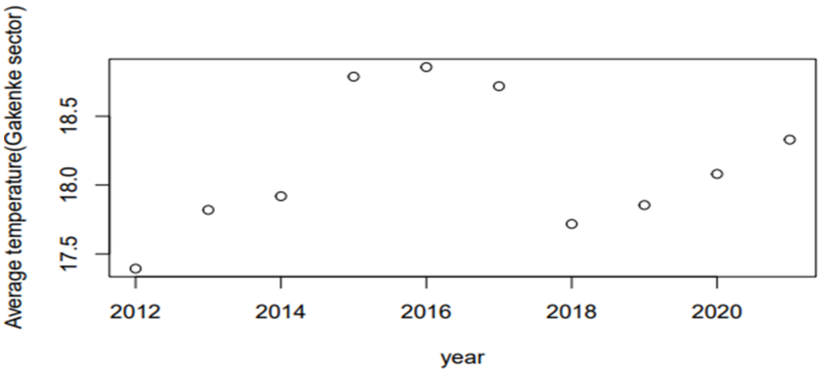

FIGURE 3: Trend of temperature for Gakenke wetland between 2012 and 2021 (Source: RMA, 2024).

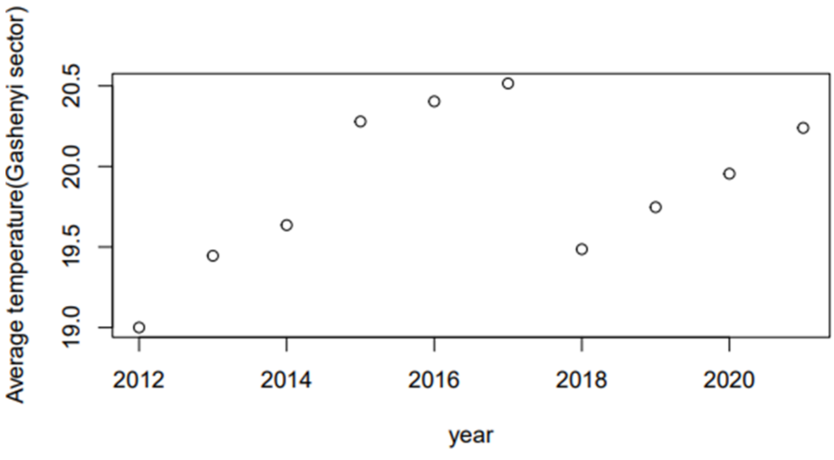

FIGURE 4: Trend of temperature for Gashenyi wetland between 2012 and 2021 (Source: RMA, 2024).

The results of this study show that the mean temperature has increased by +1.34ºC in Cyabingo, +1.47ºC in Gakenke, and by +1.52ºC in Gashenyi, These mean temperature increases are much greater compared to 1.09 ºC reported as the increase in global temperature in 2011-2020 above the reference period (1850-1900) [10]. Recent prediction shows that global temperature increase will be at 1.8 to 4.0ºC in the next few decades given that the earth's temperature is likely to rise about 0.1 to 0.2ºC per decade [2], [11]. However, Global warming reaching 1.5ºC is expected to cause unavoidable increases in multiple climate hazards and risks to ecosystems and humans [10].

3.1.2 Trend of Rainfall Patterns:

The of this study show that there is variation in rainfall patterns since 2012 to 2021 (Fig.5, Fig. 6, and Fig.7) with abnormal rainfall fluctuations, where a little increase is observed in Cyabingo and Gakenke wetlands while a high increase was noted in Gashenyi wetland. In Cyabingo the maximum precipitation was3.915mm whereas the minimum was 2.175mm. In Gakenke, the maximum precipitation was 4.556 mm whereas the minimum was 2.559 mm. In Gashenyi, the maximum precipitation was 5.019 mm whereas the minimum was 1.630 mm since 2012 to 2021.

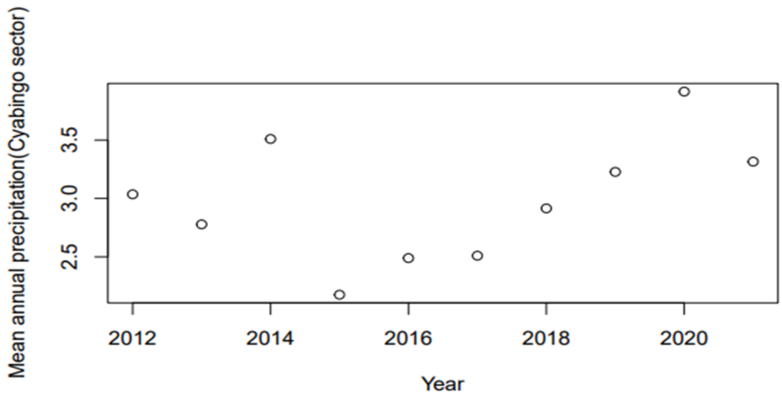

FIGURE 5: Trend of rainfall for Cyabingo wetland between 2012 and 2021 (Source: RMA, 2024).

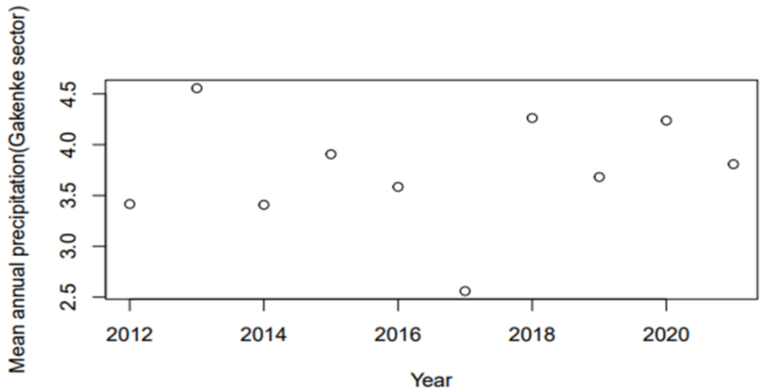

FIGURE 6: Trend of rainfall for Gakenke wetland between 2012 and 2021 (Source: RMA, 2024).

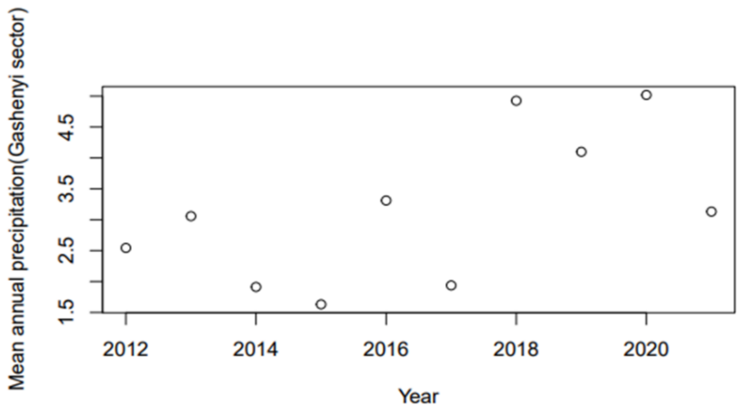

FIGURE 7: Trend of rainfall for Gashenyi wetland between 2012 and 2021 (Source: RMA, 2024).

The analysis of rainfall and temperature data recorded from weather stations indicated significant increase in temperature over the past 10 years and show the variability in rainfall. This is in accordance with the recent findings of rainfall and temperature in all regions of the country including the study areas (Uwiragiye A. , 2016).

3.2 Status of variation of maize yields over the past 10 years in Gakenke, Gashenyi and Cyabingo sector:

The results for the analysis of collected data (Fig.8, Fig.9, and Fig.10) indicate the variation of maize yield during the study period. In Cyabingo the maximum yield was 1.477 tons/ha whereas the minimum was 1.364 tons/ha since 2012 to 2021 with mean 1.421tons/ha. In Gakenke the maximum maize yield was 1.505 tons/ha whereas the minimum was 1.452 tons/ha since 2012 to 2021 with mean 1.472 tons/ha. In Gashenyi the maximum yield was 1.473 tons/ha whereas the minimum was 1.344 tons/ha since 2012 to 2021 with mean 1.414 tons/ha.

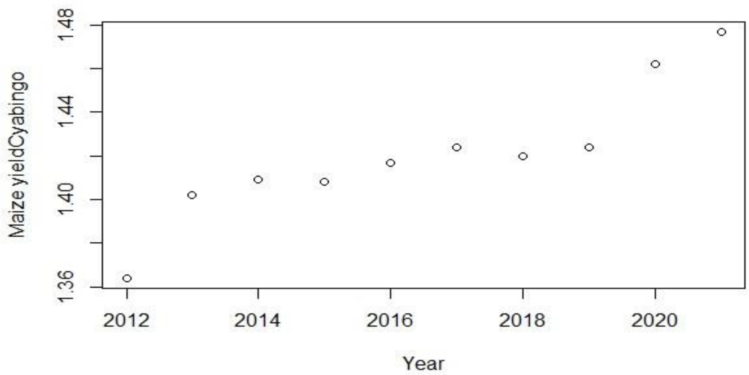

FIGURE 8: Variation of maize yields over the past 10 years in Cyabingo

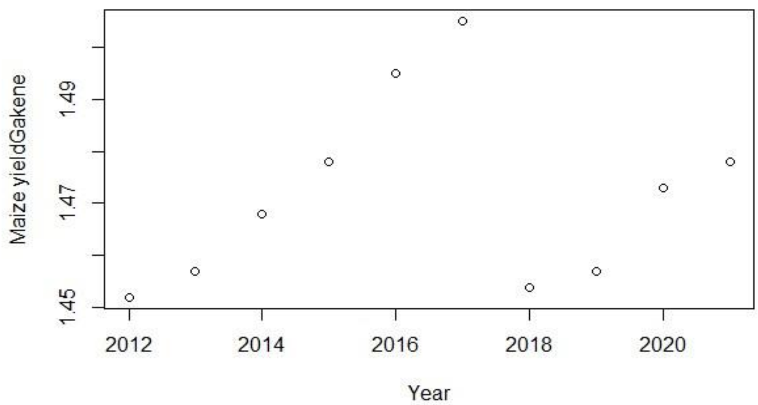

FIGURE 9: Variation of maize yields over the past 10 years in Gakenke

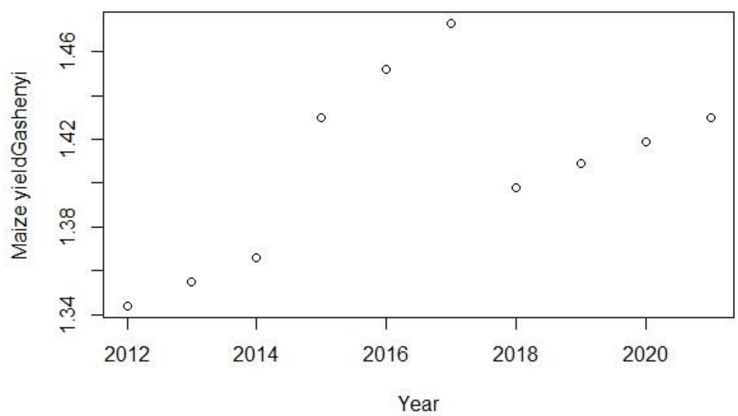

FIGURE 10: Variation of maize yields in the past 10 years in Gashenyi

3.3 Correlation between climate variability and maize yield:

3.3.1 Correlation between temperature, precipitation and maize yield in Cyabingo Sector:

TABLE 2
CORRELATION MATRIX OF TEMPERATURE, PRECIPITATION AND MAIZE YIELD IN CYABINGO SECTOR

Variable	*M*	*SD*	1	2
1. Temperature	19.62	0.39		
2. Precipitation	2.99	0.53	0.39 [-.32, .82]	
3. Maize_Yield	1.42	0.03	.98** [.91, 1.00]	0.43 [-.28, .83]

Note: M and SD are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation. * indicates p< .05. ** indicates p< .01.

The table 2 above shows the means, standard deviations, and correlations with confidence intervals. It highlights a strong correlation (r value =0.98) between temperature and maize yield during the past ten years. A mild correlation is also noticed between precipitation and maize yield and between temperature and precipitation with correlation coefficients (r) of 0.43 and 0.39, respectively.

3.3.2 Correlation between temperature, precipitation and maize yield Gakenke sector:

TABLE 3
CORRELATION MATRIX OF TEMPERATURE, PRECIPITATION AND MAIZE YIELD IN GAKENKE SECTOR

Variable	*M*	*SD*	1	2
1. Temperature	18.15	0.5		
2. Precipitation	3.74	0.56	-0.39 [-.80, .37]	
3. Maize_Yield	1.47	0.02	.90** [.63, .98]	-0.59 [-.89, .06]

Note.M and SD are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation. * indicates p< .05. ** indicates p< .01.

The table 3 above presents the means, standard deviations, and correlations with confidence intervals. The results of this study, in Gakenke sector, show a strong correlation (r value = 0.90) between temperature and maize yields during the past 10 years. On the other side, the results also show moderate negative correlation (r value = -0.59) between precipitation and maize yield in Gakenke sector and a mild negative correlation (r value = -0.33) between temperature and precipitation.

3.3.3 Correlation between temperature, precipitation and maize yield Gashenyi sector:

TABLE 4
CORRELATION MATRIX OF TEMPERATURE, PRECIPITATION AND MAIZE YIELD IN GASHENYI SECTOR

Variable	*M*	*SD*	1	2
1. Temperature	19.87	0.49		
2. Precipitation	3.16	1.21	-0.21 [-.74, .49]	
3. Maize_Yield	1.41	0.04	.94** [.76, .99]	-0.01 [-.64, .62]

Note. M and SD are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation. * indicates p< .05. ** indicates p< .01.

The table 4 above presents the means, standard deviations, and correlations with confidence intervals. It highlights a strong positive correlation (r value = 0.94) temperature and maize yield and a mild negative correlation between (r value = -0.21) between precipitation and temperature in Gashenyi sector. However, in this sector, the results obtained present a weak negative correlation (r value = -0.01) between precipitation and maize yield.

3.4 Effect of temperature and precipitation on maize production in Gakenke district:

3.4.1 The regression analysis of temperature and maize yields in Cyabingo sector:

The estimated model for maize yield highlights a linear relationship between the temperature and maize yields in this sector, and the regression analysis indicates that the yield of maize obtained by farmers was significantly influenced (at 96.0%) by temperature change during the past 10 years (R-squared = 0.960, with p-value = 0.000). Therefore, based on this study, the temperature can be considered as an important factor for maize production in Cyabingo sector and its change could potentially affect maize yields as highlighted by the regression model (expression/equation) presented in the Fig. 11 below.

TABLE 5
REGRESSION MODEL SUMMARY

Model	R	R-Square	P-value	Confidence interval
1	0.98	0.96	0	95%

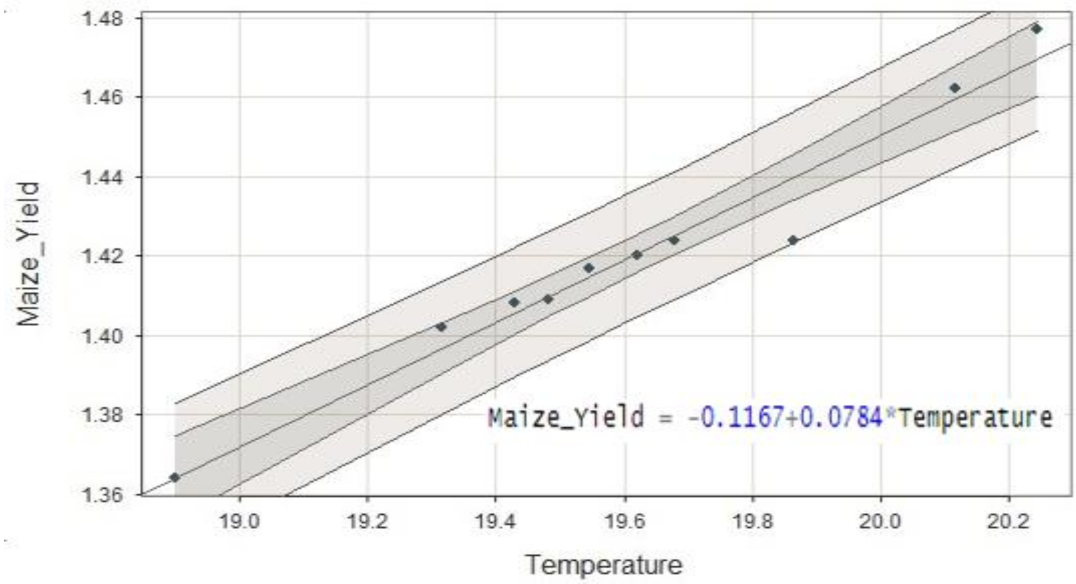

FIGURE 11: Simple linear regression model for maize yield in Cyabingo sector

3.4.2 The regression analysis of precipitation and maize yields in Cyabingo sector:

Although the estimated model for maize yield highlights a linear relationship between the precipitation and maize yields in this sector, the regression analysis (Fig. 12) indicates that the yield of maize obtained by farmers was not significantly influenced by precipitation change during the past 10 years (R-squared = 0.184, with p-value = 0.217). The change in maize yield observed can only be explained at 18.4% by precipitation change. As highlighted by the regression model presented in the Fig.12, the change in precipitation could not significantly affect the expected yields of maize in Cyabingo sector.

TABLE 6
REGRESSION MODEL SUMMARY

Model	R	R-Square	P-value	Confidence interval
1	0.428	0.183	0.217	95%

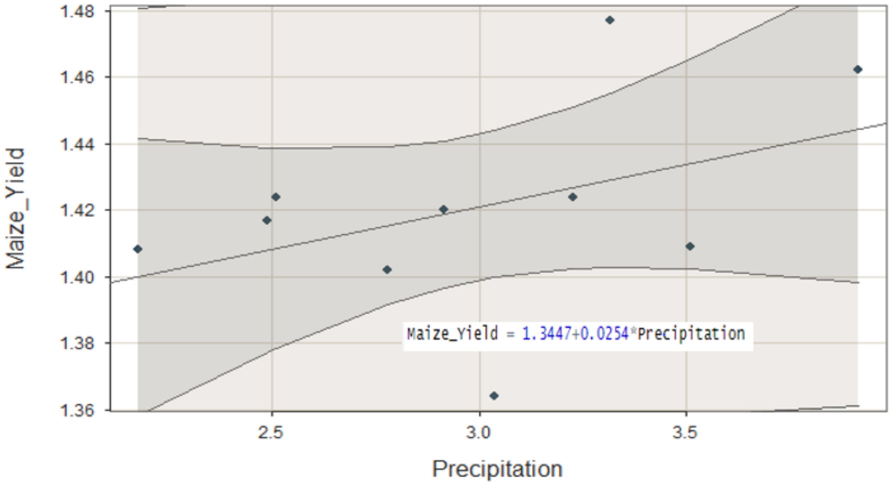

FIGURE 12: Simple linear regression model for maize yield in Cyabingo sector

3.4.3 The regression analysis of temperature and maize yields in Gakenke sector:

The estimated model for maize yield highlights a linear relationship between the temperature and maize yields in this sector, and the regression analysis (Fig.13) indicates that the yield of maize obtained by farmers was significantly influenced (at 81.5%) by temperature change during the past 10 years (R-squared = 0.815, with p-value = 0.000). Therefore, based on this study, the temperature can be considered as an important factor for maize production in Gakenke sector and its change could potentially affect maize yields as highlighted by the regression model presented in the Fig. 13 below.

TABLE 7
REGRESSION MODEL SUMMARY

Model	R	R-Square	P-value	Confidence interval
1	0.903	0.815	0	95%

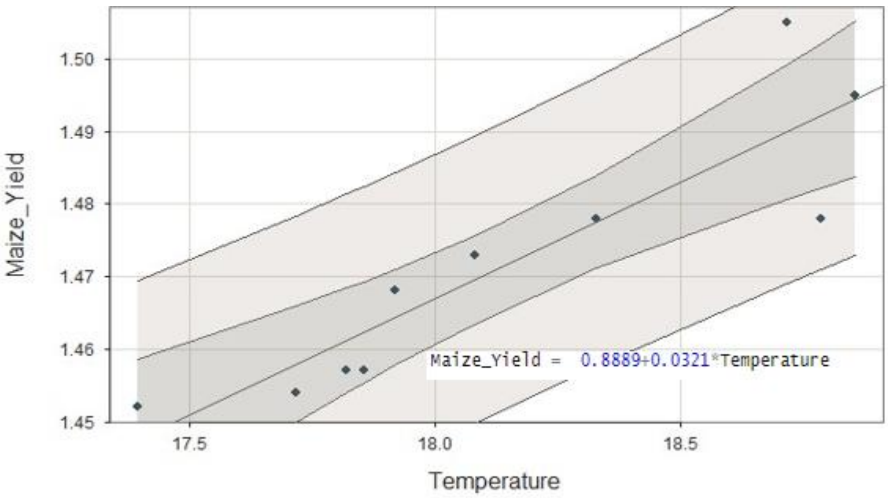

FIGURE 13: Simple linear regression model for maize yield in Gakenke sector

3.4.4 The regression analysis of precipitation and maize yields in Gakenke sector:

Although the estimated model for maize yield highlights a linear relationship between the precipitation and maize yields in this sector, the regression analysis (Fig. 14) indicates that the yield of maize obtained by farmers was not significantly influenced by precipitation change during the past 10 years (R-squared = 0.349, with p-value = 0.072). The change in maize yield observed can only be explained at 34.9% by precipitation change. As highlighted by the regression model presented in the Fig. 14, the change in precipitation could not significantly affect the expected yields of maize in Gakenke sector.

TABLE 8
REGRESSION MODEL SUMMARY

Model	R	R-Square	P-value	Confidence interval
1	-0.59	.349	.072	95%

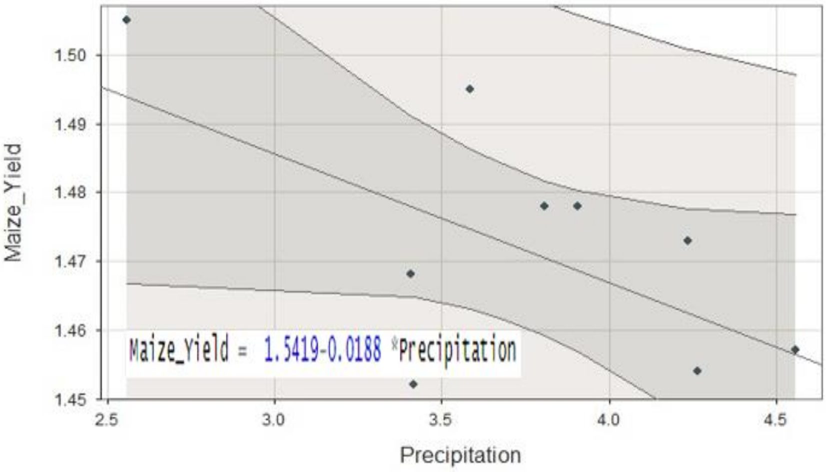

FIGURE 14: Simple linear regression model for maize yield in Gakenke sector

3.4.5 The regression analysis of temperature and maize yields in Gashenyi sector:

The estimated model for maize yield in Gashenyi sector highlights a linear relationship between the temperature and maize yields in this sector, and the regression analysis (Fig.15) indicates that the yield of maize obtained by farmers was significantly influenced (at 88.5%) by temperature change during the past 10 years (R-squared = 0.885, with p-value = 0.000). Therefore, based on this study, the temperature can be considered as an important factor for maize production in Gashenyi sector and its change could potentially affect maize yields as highlighted by the regression model presented in the Fig. 15 below.

TABLE 9
REGRESSION MODEL SUMMARY

Model	R	R-Square	P-value	Confidence interval
1	.941	.885	.000	95%

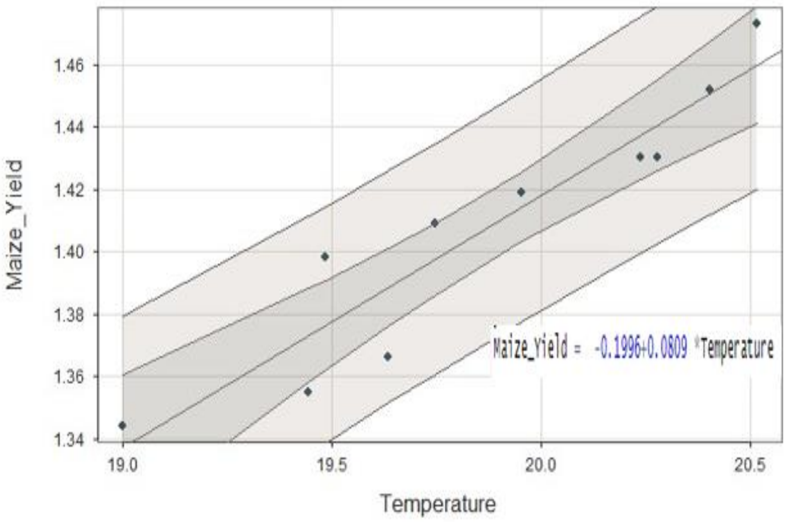

FIGURE 15: Simple linear regression model for maize yield in Gashenyi sector

3.4.6 The regression analysis of precipitation and maize yields in Gashenyi sector:

Although the estimated model for maize yield highlights a linear relationship between the precipitation and maize yields in this sector, the regression analysis (Fig. 16) indicates that the yield of maize obtained by farmers was not significantly influenced by precipitation change during the past 10 years (R-squared = 0.00016, with p-value = 0.971). The change in maize yield observed can only be explained at 0.016% by precipitation change. As highlighted by the regression model presented in the Fig.16 the change in precipitation could not significantly affect the expected yields of maize in Gashenyi sector.

TABLE 10
REGRESSION MODEL SUMMARY

Model	R	R-Square	P-value	Confidence interval
1	-0.013	.00016	.971	95%

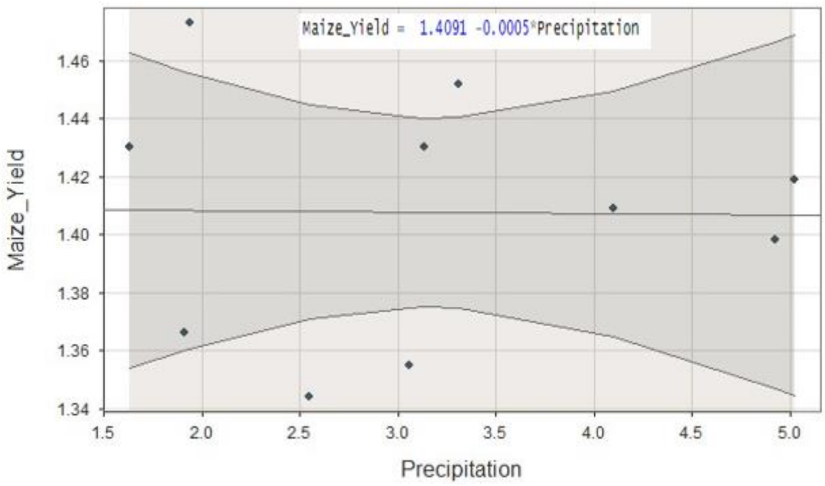

FIGURE 16: Simple linear regression model for maize yield in Gashenyi sector

IV. CONCLUSION

In conclusion, the results of this study reveals that, during the period dating from 2012 to 2021, there has been a remarkable variability in annual rainfall and annual mean temperature in the areas of study. This study provides evidence on the impacts of climate variability on maize production in Gakenke district, particularly through the variation of temperature. Thus, based on this study, the temperature can be considered as an important factor for maize production in Gakenke district, strongly positively correlated with maize yield, and its change has potentially affected maize yields as highlighted by the regression models presented above. The study does not show strong correlation between precipitation and maize yield, and the influence of precipitation was not statistically significant. However, the continuing rise in temperature observed in the study area could result in heavy rains and unexpected strong weather events, with ultimate disastrous effects on maize yields in the future. Yet, as the global temperature is continuingly increasing, climate change is expected to potentially affect the regions much depending on rain-fed agriculture [5], such as Rwanda. In this concern, regression models of maize yields were drawn for selected sectors, and could be a useful tool for future prediction.

V. RECOMMENDATIONS

This study shows an evidence regarding the variability in climatic parameters (precipitation and temperature) observed during the past 10 years and their potential impacts as highlighted by the regression models elaborated for maize yields in Gakenke district. Therefore, in this study area, adaptation strategies on climatic variability should be adopted and enhanced at farm level in order to minimize the disastrous effects of climate change on maize production. The perceptions of local farmers on the impacts of temperature and precipitation changes on maize production in Gakenke district could serve as a key asset for future research in order to investigate, in details, the way each climatic parameter is influencing the production of maize. Similar research should be conducted in other different agro-ecological zones in order to obtain sufficient data and a meaningful understanding on the effects of climate change on maize production, thereby contributing to the resilience and sustainability of agriculture in Rwanda.

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