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Effect of Climate Variability on Productivity of Crop in Gicumbi District of Rwanda, (2007-2022)

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ABSTRACT: Climate change has been raising concerns about potential changes to crop yields and production systems. The focus of the present study is to assess the impact of climate variability on food crop yield in the Gicumbi district of Rwanda. Independent Climate variables like rainfall and temperature, and dependent beans and Irish potatoes production data over the past fifteen years i.e. a period from 2007 to 2022 have been used to investigate the evidence of climate variability in Gicumbi, changes in mentioned food crop production, and the likelihood of relationship between crop production of food crops and these climatic variables. Therefore, this research analyzed the effect of climate variability on the productivity of food crops (beans and Irish potatoes) in the Gicumbi district.

The specific objectives are to analyze the climate variability in the Gicumbi district from 2007 up to 2022, to assess the productivity of beans and Irish potatoes in the same period, and to determine the extent to which climate variability influences the production of beans and Irish potatoes. The researcher used a descriptive research design.

The total population of this study is from 3 selected sectors of Gicumbi totaling 91,054 residents and the sample size is 204 respondents selected using a convenient sampling technique. The primary data was collected using a questionnaire and key informant interviews. The regression analysis was used to analyze the relationship between climate variability and the changes in food crop production in study areas. Specifically, regression analysis was used to determine the relationship between temperature and rainfall variability and food crops (beans & Irish potatoes) production in the focus District.

Key Words: Beans and Irish production, Climate change, Rainfall Variability, Temperature Variability, Gicumbi district, Rwanda

I. INTRODUCTION

Many studies have identified climate change as one of the most serious risks facing global society (Fischer et al, 2014). The effects of climate change, associated with natural disasters such as severe floods, prolonged droughts, landslides, melting ice, storms, and hurricanes, typically result in significant loss of human life, agricultural and livestock losses, land degradation, and other problems that negatively impact their lives (Rugema 2013).

According to the IPCC (2019), global warming and rainfall patterns are gradually reducing crop yields and creating food insecurity among the world's growing population. Unfortunately, the world's average annual temperature continues to rise due to large emissions of greenhouse gases (GHGs) into the atmosphere (World Bank 2010).

In this situation, climate change and agriculture appear to be intertwined, with climate change having a direct positive or negative impact on agriculture through variations in temperature and precipitation, while agriculture also impacts climate through greenhouse gas emissions (Rosegrant et al. 2008).

It has been highlighted that emissions from agriculture account for up to 30% of total global emissions (Garnett 2020). Theyare directly or indirectlydependent on rain-fed agriculture (Nyanga et al. 2018), and the factthattheagricultural sector is one of the most vulnerable and sensitive sectors to climate change and weather conditions has made them vulnerable to climate change. The impact of change on their live lihoodsissevere. It is expected to be particularly high in developing countries where the majority of people live in rural areas (Nelson et al. 2009). Various studies have confirmed that the population of developing countries is increasingrapidly. As a result, climate change is having alasting and significant negative impact on agriculture, on which the majority of

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people depend for food and employment (USAID 2014).

Additionally,themajority of farmers in developing countries are smallholders, meaning they own insufficient land relative to their household size. This is due to significant population growth associatedwith intensive land use in developing countries (Rosegrant et al. 2008).

Regarding adaptation to climate change, our understanding of theimpactof climate change on crop yields and farmers' adaptability (technical and financial) isstill incomplete. Comprehensive research and information on theimpactof climate change on crop yieldsisrareor non-existent, especially in developing countries duetolackoffunding (UNFCCC 2007). Most developing countries need international financial assistance to combat the effects of climate change.

Rwanda's economy is mostly based on rain-fed agriculture, and the country's environment ranges from humid tropical to arid, with a wide range of meteorological conditions (rainfall and temperature). As a result, the country is more vulnerable to extreme climatic occurrences and their consequences (GoR and SSEE 2018). Several programs, policies, and strategies in all sectors of the economy have been put in place to make the Middle Income Country status by 2035 (GDP per capita of over USD 4,036)and High-Income Country status by 2050 (GDP per capita of over USD 12,476) through a series of seven-year National Strategies for Transformation (NST), underpinned by sectoral strategies focused on meeting the UN’s Sustainable Development Goals (SDGs).

Climate change is a cross-cutting problem that has been incorporated into all of the programs (MINECOFIN 2000). (MINECOFIN 2013). According to the EDPRS, the economic repercussions of climate change have intensified as a result of more frequent droughts, floods, and soil erosion, which have caused significant damage, particularly in the agriculture sector. The frequency and intensity of natural hazard-induced disasters, particularly floods and droughts, have increased the economic and environmental damages, according to the Ministry in Charge of Emergency Management (MINEMA) former Ministry of Disaster Management and Refugee Affairs (MIDIMAR 2019). As a result, for a fifteen-year study period, this research will examine the effect of climate variability on the productivity of crops in Rwanda's Gicumbi district, with a case study of beans and Irish potatoes.

II. METHODS AND MATERIALS

2.1 Description of study area

Gicumbi district is located in Rwanda's Northern province and shares borders with Uganda to the north, Kigali to the south, Nyagatare and Gatsibo Districts to the east, and Rulindo and Burera Districts to the west. Gicumbi District has a population of 448,824people, with 232,435women and 216,389men, including 420,693 rural populations, and 28,131 urban populations (Census 2022). It has an area of 829 km2 and a population density of 541.5/km². The district is divided into 21 sectors, 109 cells, and 199 planned settlements (MINAGRI, 2013).

Figure 1. Gicumbi map (Source: designed by the researcher using GIS Software (Arc MAP, March 2021)

Gicumbi district is characterized by Mountains with an altitude of 1,200-1,500 and an average temperature which is between 15 and 16 degrees Celsius. Because of its topography, the district is especially subject to landslides and soil erosion (REMA, 2013). As a result, the government of Rwanda and other development partners have set up programs to assist farmers in preventing landslides and soil erosion. The district's total land protected especially by radical terraces from soil erosion amounts to 89.8% of the total land, while irrigated land accounts for 1% of the entire land (NISR, 2012a).

2.2 Data collection and analysis

Different types of data were used in this study. Over the last 15 years (207-2022), time series data (secondary data) on beans and Irishpotato yield were collected as stipulated by the National Institute of Statistics in Rwanda (NISR), climate variables (rainfall and temperatures) were collected from the Rwanda Meteorological Center. Statistical Package for the Social Sciences (SPSS) version 21 was used to process and analyze data, which influenced how the results, analysis, and interpretation were presented. The Spearman Test was used to analyze the relationship or correlation between climate variability and crop production. Parametric and non-parametric tests were also conducted.

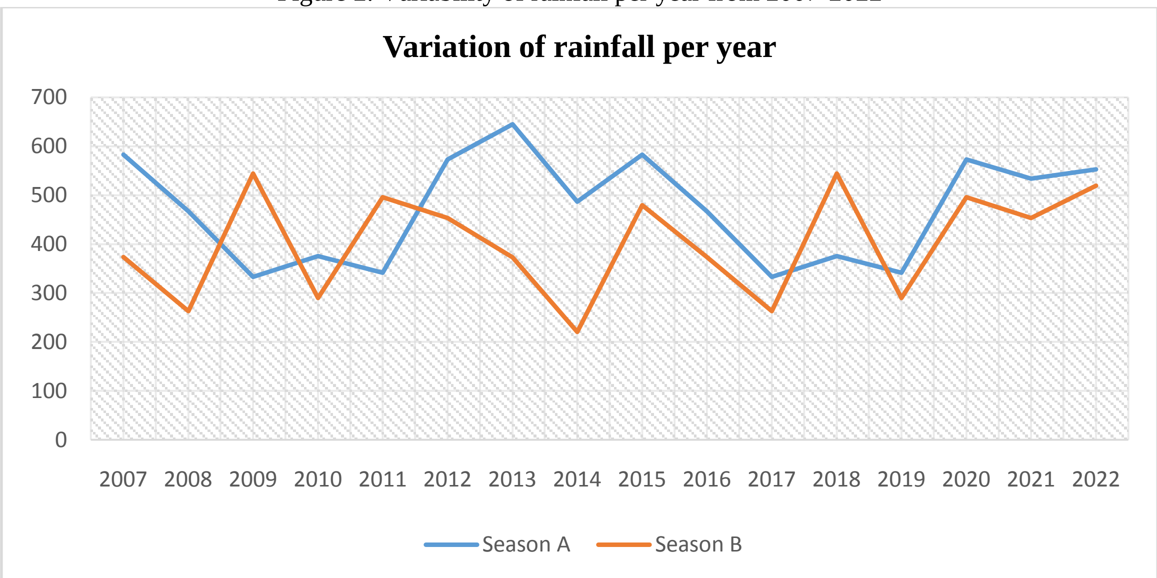
III. RESULTS

The results were presented based on specific objectives which were to analyze the historical trends and patterns of temperature and rainfall variability in the Gicumbi District of Rwanda from 2007 to 2022, to analyze crop production variation in the same period, and to find out the relationship between climate variability and agriculture production. Charts and map were used as quantitative statistics to determine the relationship between the variables of the research. The findings are presented in a way that is understandable and relevant to policymakers, farmers, and other stakeholders.

3.1 Analysis of the historical trends and patterns of temperature and rainfall variability in Gicumbi District

The section presents the result of the historical trends and patterns of temperature and rainfall variability in the Gicumbi District.

Figure 2. Variability of rainfall per year from 2007-2022

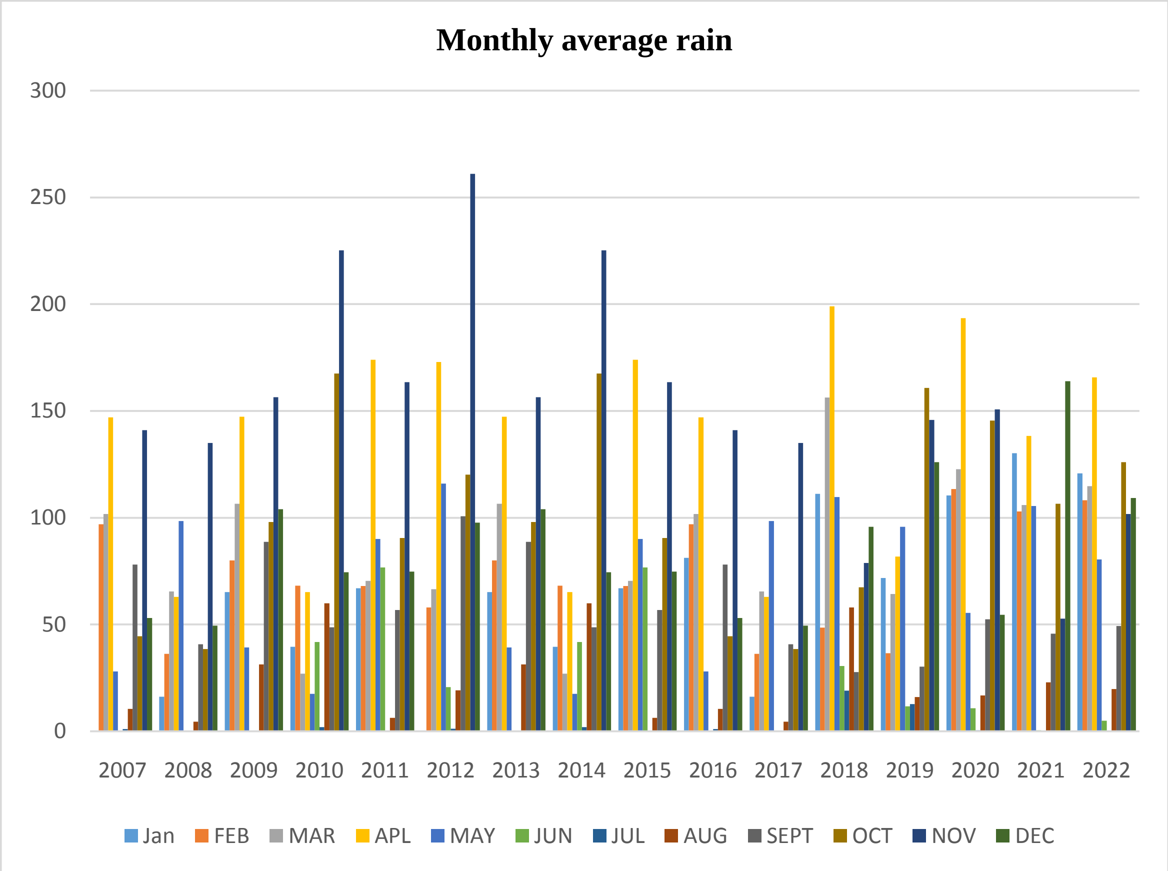


Source: Meteo Rwanda, 2007-2022

Results in figure 2. Indicates that there has been variability in rainfall from 2007 up to 2022. In this regard, the rainfall was presented in two seasons which are A and B seasons. A season in blue pattern indicates the timewhenGicumbi had too much rain measured in the range between 332.78mm in 2017 which is the minimum and the maximum was 645mm in 2013. However, when you look at the pattern it is clear that the rainfall reduced since 2013, increased in 2019, and reduced again in 2020 up to 2022.

For season B, the rainfall indicated by an orange pattern, it is clear that the Gicumbi has experienced a variation of rainfall ranging from 220.75mm in 2014 to 524mm in 2018.

Figure 3. Monthly average rainfall from 2007-2022



Source: Meteo Rwanda, 2007-2022

The figure 3 indicates the pattern changes inthe monthly average of rainfall in the Gicumbi district, in 2007 the minimum average rainfall was 1.25 in July 2007 whilethe maximum rainfall monthly average is 216mm in 2007. Based on the patterns of rainfall it is clear that there is a remarkable monthly rainfall in the Gicumbi district and this affects agricultural activities. The problem with rainfall data is to choose an optimal threshold level needed for the threshold method for measuring rainfall. The precipitation, which is less than 0.85 mm, was not considered as a rainy day. We choose a slightly higher threshold than 0.85 mm to avoid any complications for the recording of very small values of rainfall data. It is also important to note that the value of 0.85mm is used operationally in the determination of rain as a rainy day.

The results are in line with Rugema (2019) who stated that the extent of rainfall is one of the critical that influence the crop production of farmers. In rain-fed agriculture, the percolated rainfall in the roots is the source of moisture and water consumption for the crops. The erratic nature of rainfall makes rain-fed agriculture unreliable for farmers and it is for this reason that the agricultural productivity of rain-fed areas is lower than irrigated.

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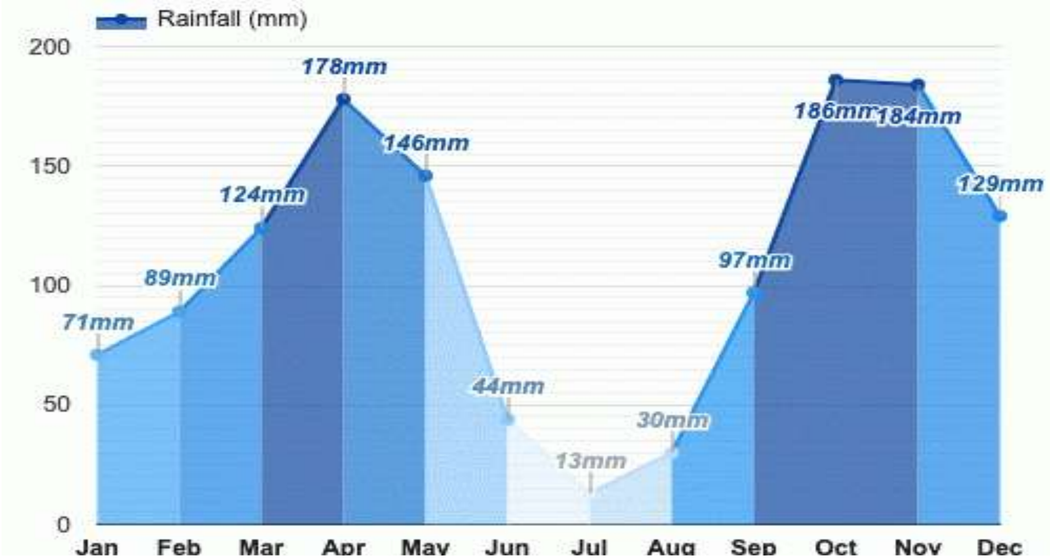
Figure 4. Average monthly rainfall in Gicumbi



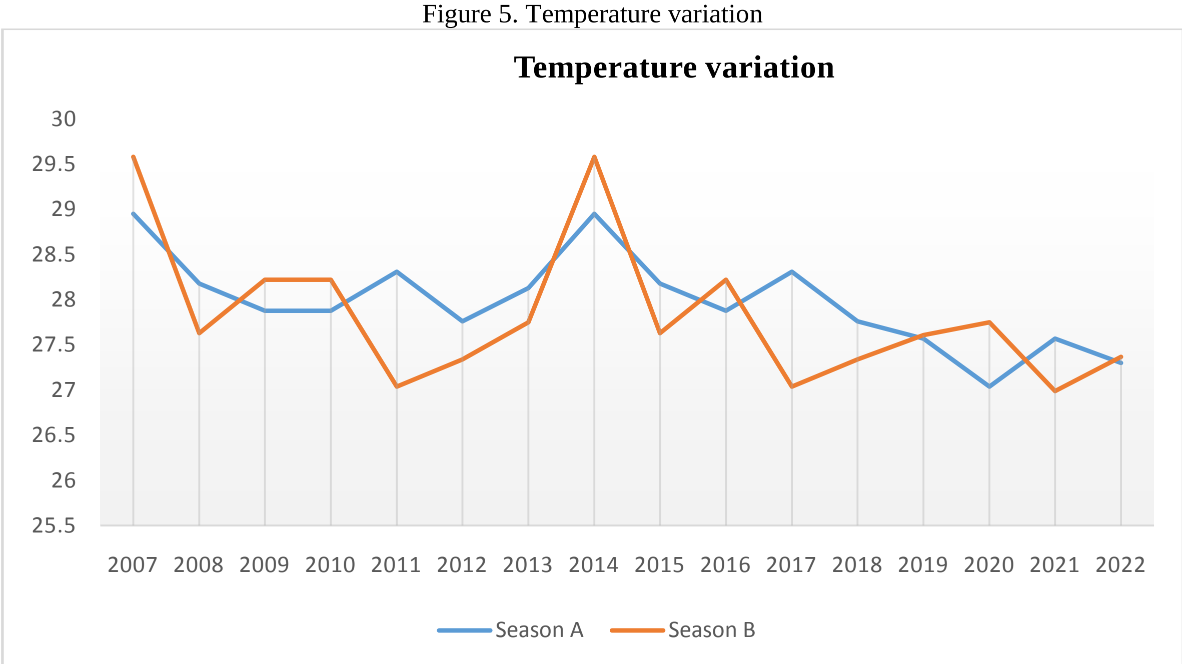
Source: Meteo Rwanda, 2007-2022

Figure 3, indicates thatthe average monthly rainfall in March is 124mm and the wettest month (with the highest rainfall) is October (186mm). The driest month (with the least rainfall) is July (13mm).

3.2 Variability of temperature

Climate change is altering climate extremes and variability of environmental conditions, yet much of the focus on the impacts of climate change on wild populations remains on how shifts in average conditions will affect dynamics and distributions. Yet as average temperatures shift, both temperature variability and the frequency of extreme events, such as marine heatwaves, are changing. Changes in temperature variation and extremes can have profound impacts on individuals and populations, as temperature affects their rates of metabolism, consumption, somatic growth, reproduction, and survival.

Figure 5. Temperature variation



Source: Meteo Rwanda, 2007-2022

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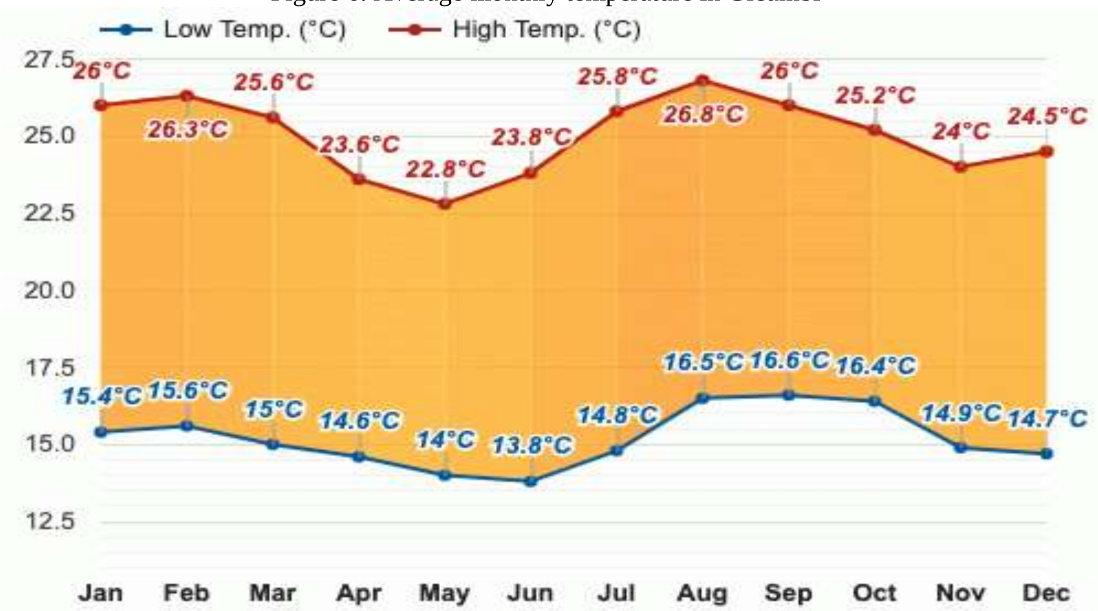
Figure 5 Indicates the variability of the temperature throughout 2007-2022 based on annual season basis.

Figure 6. Average monthly temperature in Gicumbi

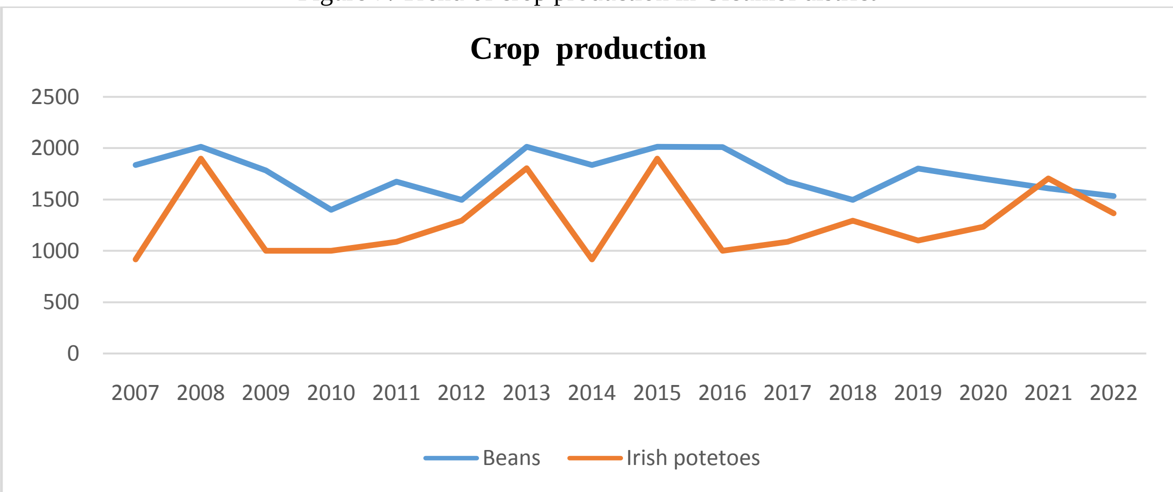


From figure 6, the average high temperature is 25.6°Cin March. The warmest month (with the highest average high temperature) is August (26.8°C). The month with the lowest average high temperature is May (22.8°C). The average low temperature is 15°C in March and the month with the highest average low temperature is September (16.6°C). The coldest month (with the lowest average low temperature) is June (13.8°C).

3.2. Crop production in Gicumbi District

The section presents the findings on crop production in Gicumbi district based on the seasons of A and B. They are presented in Figure 7.

Figure 7. Trend of crop production in Gicumbi district



Source of data: NISR (2007-2022)

Figure7, indicates that in season A indicated by the blue pattern, the crop production in Gicumbi was 2007 Kg/Ha in 2013, in 2014 reduced to 1835.6 Kg/Ha, in 2015 the production increased to 2007.3 Kg/Ha, in 2016 production declined to 500 Kg/Ha, in 2017 the production increased to 1,673 Kg/Ha, in 2018 the production of decreased again to 1,496 Kg/Ha, in 2019, the production increased a little bit to 1,801.4 Kg/Ha, in 2020 the production decreased again to 1,700 Kg/Ha, in

2021 the production decreased also 1,608.8 Kg/Ha and finally in 2022 the production reached to 1,533 Kg/Ha. The variation of Crop production had a mixed slope but mostly there has been a decrease in Crop production in the Gicumbi district from 2013 up to 2022.

Concerning season B indicated by orange pattern, the production of Beans and Irish potatoes in Gicumbi was 805Kg/Ha in 2013, 915.3 Kg/Ha in 2014, 897 Kg/Ha in 2015, 1001Kg/Ha in 2016, 1,087Kg/Ha in 2017, 1,292 Kg/Ha in 2018, 1,100.14 Kg/Ha in 2019, 1,234 Kg/Ha in 2020, 1,704.3 Kg/Ha in 2021 and 1,363 Kg/Ha in 2022. By looking at the variation of Crop production in season B in the Gicumbi district, the figure indicates that there is an increase in slope throughout 2013 up to 2022. However, the production in season B was less than the production in season A.

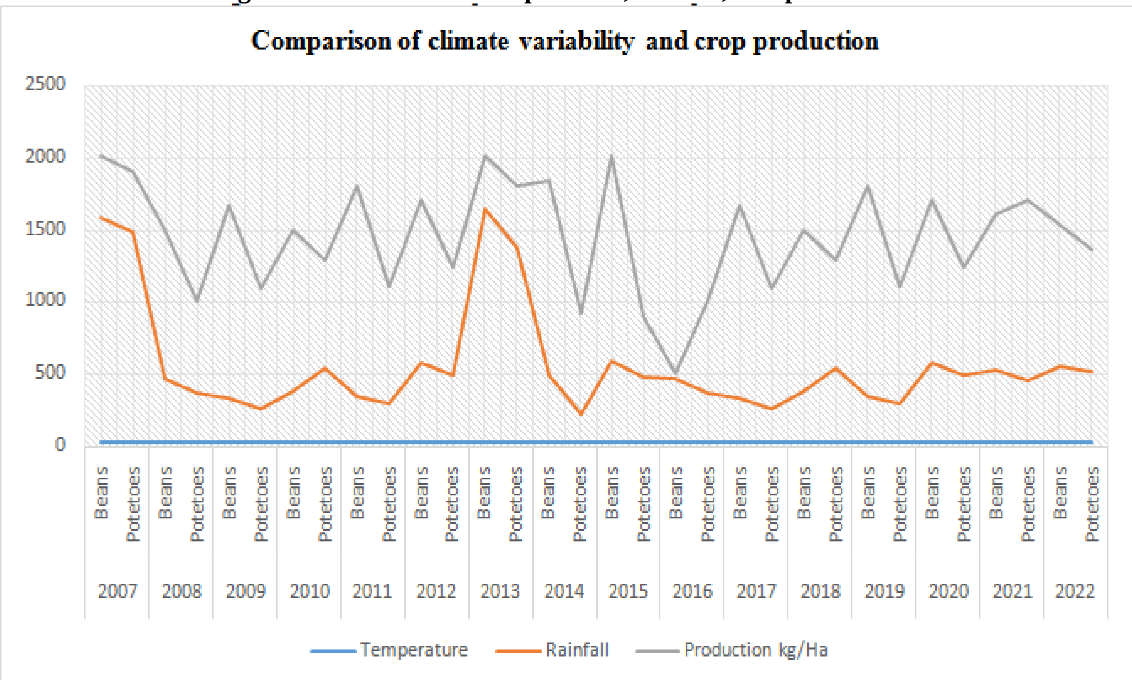
3.3. Relationship between rainfall, temperature, and crop production

As indicated by Nabahungu&Visser (2021), an increase in dry spells during the rainy season contributes to poor performance of crops and therefore, agricultural productivity due to the late set of rainfall and/or early rainfall cessation. The section presents the relationship between temperature, rainfall, and production of beans and Irish potatoes in Gicumbi district.

3.3.1. Variation of temperature, rainfall and crop production in Gicumbi district

The section presents the variability of temperature, and rainfall as indicators of climate variability and crop production in Gicumbi district as factors of crop production.

Figure 4.8 Variation of temperature, rainfall, and production



Source: NISR and Meteo Rwanda (2007-2022)

By looking at figure 4.8, it is clear that the variability of temperature, rainfall, and production of beans and Irish potatoes in Gicumbi is proportional to one another which shows the relationship between climate variability and crop production.

3.3.2. Regression analysis

In regression, the researcher analyzed the coefficient of variables, model summary, and ANOVA.

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Table 4.1: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	.324	.863		.292	.774
	Rainfall variation	.415	.255	.212	1.844	.021
	Temperature variation	.316	.482	.237	0.655	.012
a. Dependent Variable: Crop production						

Table 4.1, revealed that holding Rainfall variability, temperature variability to a constant zero, crop production would be 0.324. Indeed, this constant called y-intercept is not realistic but it is a needed parameter in the model.

A unit increase in Rainfall variability, would lead to increase in Crop production by a factor of 0.212 which reject the first hypothesis of the research said that there is no significance relationship climate variability and crop production because the t test [t=1.844] was greater than p= 0.05. The $H_0 2$ said that there is no significance effect of Temperature variability on crop production in Gicumbi district was also rejected because the t test [t=0.655] was greater than p= 0.05 and in this research it has been revealed that a unit change in temperature variability, lead to change in Crop production by a factor of 0.237.

Table 4.2: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.716[a]	.512	.676	.16732

Source: Field data, 2023

a. Predictors: (Constant), Rainfall variability, temperature variability)

From the table 4.2; regression analysis revealed a positive relationship (R = 716). The R coefficient of 0.716 indicates that the predictors of the model which are rainfall variability and temperature variability, have a correlation of 71.6% with the dependent variable (Crop production in Gicumbi district). The study also revealed that a combination of rainfall variability and temperature variability together contributed to 51.2% (R^2= 0.512) of the Crop production in Gicumbi district.

Table 4.3: ANOVA

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	.991	3	.248	10.747	.034[a]
	Residual	.369	12	.023		
	Total	1.360	15			

Source: Field data, 2023

a. Dependent Variable: Crop production

b. Predictors: (Constant), rainfall variability and temperature variability.

The table 4.3 shows the Analysis of Variance means that are established to show if there is significance difference between the means of the variable and under study and also to examine the overall significance of the model. Overall significance of the model is important in establishing whether the model is fit to giving true estimate of the variables. In this study, ANOVA was used to establish whether there exists a significance relationship between the Independent variable and Dependent variable.

Table 4.12. shows that variations in Crop production in Gicumbi district can be explained by the model to the extent of 0.991 out of 1.360 or 72.8 % while other variables not captured by this model can explain 27.1 % (0.369 out of 1.361) of the variations in Crop production in Gicumbi district. F value of the model produces a p-value of 0.015 which is significantly different from zero. A p-value of 0.015 is less than the set level of significance of 0.05 (0.015<0.05) for a normally distributed data. This means that the model is

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significant in explaining Crop production in Gicumbi district.

3.4. Results discussion

Results in figure 4.1. Indicates that there has been variability of rain fall since 2007 up to 2022. In this regard, the rainfall was presented in two seasons which are A and B seasons. A season which is shown by blue pattern, indicate that it is the time where Gicumbi had too much rain measured in range between 332.78mm in 2017 which is the minimum and maximum was 645mm in 2013. However, when you look at the pattern it is clear that the rainfall reduced since 2013, and increased in 2019 and reduced again in 2020 up to 2022. For the season B, the rainfall indicated by orange pattern, from the graph, it is clear that Gicumbi has experienced a variation of rainfall ranging from 220.75mm in 2014 to 524mm in 2018.

In conformity with RMA (2016) and Rwanyiziri & Rugema (2019), the fluctuation characterized by an overall decrease in the country's rainfall has resulted in poor performance of agriculture and therefore, food insecurity in Rwanda. In addition, the fact that rain shortage is associated with seasonal irregularities, heavy rains, and associated extreme events such as floods and landslides, are also among the big challenges that affect the production of beans and Irish potatoes in the Gicumbi district, the country, and the whole region, have been facing (Ballantine et al. 2017).

The table 4.2; revealed a positive relationship (R =0. 716) between climate variability and crop production. The R coefficient of 0.716 indicates that the predictors of the model which are rainfall variability and temperature variability, have a correlation of 71.6% with the dependent variable (Crop production in Gicumbi district). The study also revealed that a combination of rainfall variability and temperature variability together contributed to 51.2% (R^2= 0.512) of the Crop production in Gicumbi district.

The findings of this study reflected RAB (2020) which suggested a decrease of crop yield in various areas of Rwanda due to seasonal irregularities. In fact, seasonal irregularities are associated with extreme events which have direct and indirect impacts on crop yield (Nahayoet al. 2017). The situation could be aggravated and lead to poor performance of agriculture and therefore, food insecurity not only among local farmers but also in the whole country (Webber et al. 2022).