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The relationship between climate variability and rice production in the Gisagara district, Rwanda

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Abstract

This research was to assess the impact of climate variability on rice production in Rwanda's Gisagara district for a period of 2012 up 2023. Primary numerical data had been collected from 5 cooperatives in two most rice productive sectors of Gikonko and Mamba, while secondary climate data were from Rwanda meteo stations of Gikonko, Cyili, Mukindo, Gakoma, Save, Kansi, Kigembe. All quantitative data have been entered, cumulated with excel sheets in two seasons A and B and their analysis and presentation were done with R programming and Excel tools for variation statistics, regression analysis. The author of the study examined historical patterns and variations of temperature, and rainfall level variations in Gisagara District from 2012 to 2023, along with agricultural rice production aspects; total production, yield, cultivated area, and chemical fertilizer use changes over a similar time frame from multiple organizations databases. The climate variability was revealed with high seasonal variation in rainfall where CV was 32.46089% in season A most varied than 24.41247% in season Band consistant (low variability) temperatures for both seasons A and B (1.534474% and 1.36846E-14%). The objective 2 has been verified showed remarkable variation in agricultural parameters' coefficients of variation: 21.01582039% high variation of chemical fertilizer use in season A than in B; 13.97895821%. The total production varied considerably during the seasons of the study with 31.9459166% in A29.04583% in B. The yield moderately varied at 13.92049% in A and 9.594967% in season B. The cultivated area varied at 17.51288% in season A and 14.81715% in B. Climate components were in relation with production components. Some models had been made to make predictions of dependant with independent variables. In order to reach sustainable rice production and improve food security, it is essential to enhance the adoption of climate-smart agriculture measures and strengthening early warning systems, diversifying crops, and implementing sustainable water management strategies will also enhance resilience.

Key words: Climate variability, rice production, Gisagara District and Rwanda

1. Introduction

Climate change is a worldwide concern that is disrupting businesses and negatively impacting the livelihood of the local population, and it is anticipated that the tendency will persist (Millar et al. 2007) and is primarily due to anthropogenic activities (IPCC, 2001 and 2007).It is already affecting agriculture, leading to lower agricultural yields and lower incomes in affected regions worldwide (FAO 2013a; Rian, 2008).Climate conditions affect human well-being in two ways: directly, through the physical effects of climate extremes, and indirectly, through their effects on air pollution levels and the freshwater, marine, and agricultural industries that supply food and water. Knowing that the average world surface has warmed by 0.80 degrees Celsius over the last century and 0.60 degrees Celsius during the last three decades, and the tendency is expected to continue (Millar et al. 2007), Climate change, currently the most pressing issue on the world is already having an effect, with average temperatures anticipated to increase by 1.4° to 5.8°C by 2100, with many implications and negative consequences for agriculture resulted to future water shortages and floods, changing soil moisture status, and pest and disease incidence (Chinvanno, 2010). Bazimenyera

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et al. (2013) and Gustave et al. (2020) predict that carbon dioxide, temperature, precipitation, glacial runoff, and the relationships between them, as well as the impact of agriculture on crops, food chains, and production cycles, will all be significantly impacted by global warming, leading to variations in productivity and growth operations.

Africa is especially susceptible to the consequences of climate change due to a number of stresses and weak adaptation abilities caused by widespread poverty, inadequate institutions, complex disasters, and linked conflicts (ISDR, 2008). Millions of people's livelihoods and access to food security are expected to be jeopardized as a result of the negative effects of such climate change in nearly every sector of the African economy (IPCC, 2007; Yanda et al., 2007). Sub-Saharan Africa (SSA) is primarily impacted by changes in weather and rainfall patterns endangering food production in several countries (Arndt et al. 2012).Sub-Saharan Africa (SSA) is primarily impacted, with changes in weather and rainfall patterns endangering food production in several countries.

Agriculture is one of the most susceptible areas of the economy to flood damage due to its direct dependency on climatic conditions (Izabela, 2020). It also has a negative impact on the socioeconomic system and the environment, such as destroying farms, reducing food output, and causing freshwater scarcity in the area (Mind'je et al. 2019). Guha-Sapir et al. (2012) go on to show that between 2001 and 2010, flood-related incidents caused an average annual damage of $21.39 billion. However, flood-related disasters were predicted to have cost $70.72 billion in global losses in 2011, making them the second most devastating disaster of that year.

Other climatic change and variability revelations, such as rainfall variation, soil humidity and temperature variation, rising sea water and river flow, resulting in farmland flooding, landslides, and soil erosion, are among the detrimental factors in crop production worldwide, particularly in Rwanda (Gustave et al., 2020).

Rwanda, small landlocked country in East-Central Africa with a population density of 503 inhabitants per square kilometer and a total population of 13246394 in 2022 (NISR, 2023), agriculture remains the backbone of Rwanda's ongoing economic growth, employing 62.3% of the population directly. Agriculture in Rwanda is also critical for food supply, exports, and livelihoods, all of which are required to transition the economy into a knowledge-based middle-income economy (MINAGRI, 2017). The country's rice production takes place primarily in marshlands grown twice a year: once during agricultural season A, which runs from July to December, and once during agricultural season B, which runs from January to June of the same calendar year (NISR, 2018a:1), although local production is insufficient to meet local demand and is mostly planted by smallholder farmers who participate in government-sponsored farmer cooperative schemes.In Rwanda, one of the most significant elements influencing annual crop productivity is climate unpredictability and extreme occurrences. Crop output has drastically decreased due to climate variability and the increased frequency of shocks connected to extreme events like drought and flooding (Catherine et al., 2020). Prolonged drought affects the Eastern and South Eastern regions the most, while strong rains in the Northern and Western regions cause catastrophic erosion, flooding, and landslides.

For instance, floods in the Western province usually cause major declines in crop production as well as damage to plantations, agro-ecosystems, and important infrastructure (Mikova et al. 2015). Rising landslides in the country's northwestern region are another evidence of climate change's harmful influence on Rwanda (RoR 2006).

2. Review of Literature

2.1. Rainfall

Climate is a major factor in agricultural production; variations in rainfall may also result in lower yields, yet they may at least in certain locations, result in higher yields (McCarl et al., 2001; Schmidhuber and Tubiello, 2007).

Sub-Saharan Africa's (SSA) economy depends heavily on rainfed agriculture. Some SSA nations lead the globe in rainfed agriculture for grain foods (CEREAL CROPS). Furthermore, in the majority of developing nations, it provides the impoverished communities with daily sustenance (Wani et al., 2009). However, many families in Africa and Asia, where rainfed agriculture is the primary farming operations, continue to experience poverty, hunger, food insecurity, and malnutrition regardless of all the recent advancements made in (attempts to) enhancing productivity and ecological circumstances in many developing countries (Wani et al., 2009).

Rwanda has a temperate climate with an average annual temperature of 19 degrees Celsius, making it one of the most densely inhabited countries in the world and the most populous in Africa (NISR, 2014). A high-altitude area, the central plateau, the plateau of the eastern lowlands, and the west are its three agroclimatic zones (FAO, 2005). There are two main rainy seasons in the region: a short one (mid-September to mid-December) called ``Umuhindo``, which is marked by heavy precipitation in November, and a long one (March to May) called ``Itumba``, which is marked by heavier precipitation in April than in November (Ntirenganya, 2018).

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The majority of people in Rwanda, a developing nation, rely on climate-sensitive rainfed agriculture, which affects roughly 61.8% of small-scale farmers and 9.9% of wage farms (NISR, 2011).One of the most dangerous and expensive natural disasters is flooding. It has detrimental social and environmental effects, including as ruining farms, lowering food yields, and resulting in a lack of freshwater in the region.These types of floods are caused by the frequency, severity, and length of rainfall events that produce excess stream flow that exceeds the capacity of man-made or natural motion systems found in cities, river basins, canals, drainage systems, culverts, and streams. They are additionally impacted by elements related to topography, geomorphology, drainage, and constructions (Mind'je et al., 2019). Only lowland areas and mountainous ecosystems can experience flooding. These types of floods are caused by the frequency, severity, and length of rainfall events that produce excess stream flow that exceeds the capacity of man-made or natural motion systems found in cities, river basins, canals, drainage systems, culverts, and streams through asphyxia and being prone to fungal diseases attack due to high humidity of soil and crops; with rice included, reduced food security, loss of energy, and loss of water used for production of the crop (Maziar et al., 2020; Izabela et al.,2020).
Flooding of farms along the shore can result in immediate and long-term crop losses. Salt deposition from sea water leaves the soil with a legacy of salinity that hinders the growth of many crops and has long-term consequences on the composition and structure of the soil, even after flood levels subside. Seasonality is important for assessing agricultural damage from floods and the consequences for post-flood management and crop restoration (Iain et al., 2020).

Flood-related catastrophes ranked second in terms of devastation in 2011 with estimated damages of $70.72 billion worldwide. According to Guha-Sapir et al. (2012), the average annual cost of damage from flood-related incidents between 2001 and 2010 was $21.39 billion. Furthermore, floods caused $21 billion in lost crops and animals in poor nations between 2008 and 2018, making them the second-highest agricultural calamity behind droughts, according to the United Nations Food and Agriculture Organization (FAO) (FAO 2021).

Rainfall patterns and the slow change in the rice fruiting and flowering season have a significant impact on the variability in rice output (Tripathi and Singh, 2013). Rahman et al. (2017) found that although the total amount of rainfall per year is rising, the number of days without rain is also rising. Therefore, according to Sarker (2012), extreme weather events including floods and droughts that have a detrimental impact on rice output and production are expected to decrease by 8–17% by 2050.

It has been demonstrated by science that crop productivity is becoming more and more vulnerable to frequent extreme weather events relating to rainfall intensity, density, and frequency distribution, which in turn cause drought, floods, and infestations of pests and diseases (Douglas, 2009 and Tao et al., 2000).

2.2. Temperature

According to the IPCC (2001), human activity is contributing to the rise in global temperatures, which has been 0.8°C over the last century and 0.6°C during the previous decades. The National Research Council of the National Academies (2006) affirmed this, emphasizing that the last few decades of the 20th century were actually the warmest in the previous 400 years and that, as predicted by the IPCC (2001) and UNFCC (2007), the mean global temperatures will rise by 1.4 to 5.8 degrees Celsius by the end of this century due to the ongoing rise in greenhouse gases.
Higher spikelet infertility in rice and decreased grain yield are the results of this high temperature increase (Wassmann and Dobermann, 2007). When rice crops were exposed to high temperatures for 1.0 or 2.0 hours during anthesis, the percentage of sterile grains grew, and the temperature decreased pollen sustainability, pollen germination on stigma, and abnormal anther dehiscence, resulting in sterility and productivity loss. High temperatures also caused high percentages of spikelet sterility, lower spikelet fertility, and decreased grain-filling, which led to less filled grains, a smaller grain weight per panicle, and a lower harvest index. Upon raising the average temperature from 35.0 to 45.0 ◦C, the proportion of sterile grains rose to 100%. In addition, excessive heat accelerated flag leaf senescence and decreased the rate of photosynthesis by 40.0–60.0% during the ripening period (Pranee et al., 2023).
High temperatures during the grain-filling phase have been shown to reduce starch production, increase enzymes that break down starch (such as amylase), impede assimilation of starch, and increase grain chalkiness. The assimilation of grain proteins and carbohydrates was further hampered by the effects of high temperatures. Grain quality has been found to be impacted by high temperatures. It was discovered that during the grain filling period, rising temperatures were correlated with higher percentages of chalky grain per unit area (Hategekimana and Kamuhanda, 2023). Germination can be impacted by elevated temperatures during seed development and maturation. In example, high temperatures at the

physiological stage might diminish the seed vitality and the ability to germinate. Rice seeds exposed to 39.0 ◦C for 24.0–72.0 h during initial seed growth resulted in seeds failing to develop. In addition to affecting germination, temperatures between 28.0 and 34.0ºC during seed development also impacted storability, resulting in a 55.0% lower shelf life than normal growth (Pranee et al., 2023). Rice is extremely sensitive to the effects of high temperatures during meiosis and panicle formation, which results in abnormal pollen maturity and complete sterility. According to Johkan (2011), high temperatures reduce the production of crops, livestock, and fisheries by 10.0–25.0%.Hunter et al. (2020) state that in Rwanda, significant temperature increases (1.7–2.1°C) during October–December will increase crop water demand and evapotranspiration losses of water from agricultural soils, which will coincide with the decreased precipitation anticipated for the same months. This impact is likely to improve the risk of crop failure due to insufficient or irregular rainfall during the formation of rainfed crops, especially for climate-sensitive or marginal crops like maize and horticultural/vegetable crops like tomatoes and peppers. The increased normal temperatures are also likely to include more frequent or severe heat waves and uncommonly hot days, which will further contribute to evapotranspirative transpiration of water and crop stress.

In many regions of the world, there is fear that climate change-induced warming may reduce crop yields and endanger food security because agriculture is weather-dependent and crops are known to lose yield when temperatures are excessive (Iftekhar, 2015).

2.3. Agricultural Productivity

The quantity of output produced with a specific quantity of inputs is known as productivity. Technological innovation and improvements in farmer production efficiency lead to long-term increases in productivity. By enabling farmers to produce more with a smaller amount of improving agricultural efficiency increases their viability and competitiveness (ABARES, 2022).

Over the past ten years, Rwanda has seen a 70% rise in rice output thanks to a 120% rise in production area; nevertheless, the extension to lands with slight potential for rice production has resulted in a 24% decrease in mean output. Given that Rwanda has low soil productivity as a result of soil erosion and lack of nutrients from overcultivation, it is essential to implement more prudent fertilizer use in order to accomplish agricultural intensification. The Abuja Declaration on Fertilizer for an Agricultural Green Revolution recommends 50 kg/ha of fertilizer (MINAGRI, 2014). In Rwanda, farmers acknowledge the need of fertilizer use; nonetheless, its application is contingent upon a number of factors, including dealer incentive and promotion, profit potential, availability, and tradition. Because most farmers have limited resources, which influences their decisions about fertilizer use, it is crucial to maximize the return on their fertilizer investment. In order to balance economic, agronomic, and environmental considerations, decisions about fertilizer use must be flexible. Fertilizer use can be extremely beneficial for Rwanda's rice production (Nsharwasi et al., 2019).

According to Nsharwasi et al. (2019), the application of N, P, K, and MgSZnB enhanced Rwanda's grasslands the production of rice grains by an average of 2.3, 1.5, 1.7, and 1.7 Mg ha−1, accordingly, with significant implications for food security and farm profitability. These findings suggest that rates for optimizing net returns to the use of fertilizers should be 34% higher for N, 20% higher for P, and 64% higher for K with intermediate concentrations fertilizer use expenditures.

Peng et al. (2004), found that a 1ºC increase in night time temperature reduced rice yields by 10%. This loss has been emphasized in Kumar et al. (2017), by use of panel data from India concluded that heat stress during flowering significantly increased grain sterility which leadstoyield loss of up to 15%. Climate change impacted negatively the rice production as analyzed from satellite imagery from South Asian rice fields in Lobell et al. (2012) and found that warming trends could reduce rice production by 4% per decade if adaptation measures are not implemented.

Concerning water stress; droughts and Flooding, Masutomi et al. (2021) using climate models to simulate future rice yields in Japan, predicted that the increased flooding events could lower rice production by 12% by 2050. In His accordance, Bashir et al. (2018) using regression models on African rice farms found that a 10% decrease in water availability during growth stages led to a 7% yield decline.

According to MINAGRI (2021), its NRDS2 calls for the development of at least 9,000 hectares of new marshlands and the rehabilitation of at least 3,000 hectares of currently cultivated marshland for rice cultivation by 2024, followed by the development of an additional 4,600 hectares of new wetlands for rice cultivation by 2030. Additionally, it has been noted that rice may produce extremely high yields of over 7 t/ha in Rwanda (Jagwe et al., 2003), with several studies showing that some high-yielding rice varieties have the ability to produce up to 10 t/ha on-farm and the maximum technical yield potential in experimental plots as 12.5 t/ha, which is higher than the revenue from any other kinds of cereals that can be planted in wetlands (MINAGRI, 2021).

Globally, it was estimated that flood-related yield losses would be 4% for soy, 3% for rice, 2% for wheat, and 1% for maize. According to Kim et al.

(2023), these losses resulted in a total revenue loss of 5.5 billion USD between 1982 and 2016. Of the $166 billion in damages resulting from the drought, this loss accounted for 3% (Kim et al. 2019).

Hategekiman and Kamuhanda (2023) discovered that the minimum and maximum annual temperatures fluctuated between 14°C and 17°C and 27°C and 28.3°C, respectively, from 2012 to 2021, with a 0.4°C increase in the maximum temperature over the past decade. On average, the temperatures ranged from 21.6°C to 22.5°C, and the annual precipitation peaked in 2020 at 1176.31 mm and fell to 628.77 mm in 2017, highlighting the problem of water stress. Over a 20-year period, it is predicted that precipitation will decrease by 18.76 mm, with the greatest annual evaporation rate being 3.83 mm in 2013, which resulted in more water being lost from water bodies (Hategekimana and Kamuhanda, 2023).

3. Materials and Methods

This study was carried out in the 678.9 square kilometer Gisagara District, which is in the Southern Province. It is separated into 524 villages, 59 cells, and 13 sectors: Gikonko, Gishubi, Kansi, Kibilizi, Kigembe, Mamba, Muganza, Mugombwa, Mukindo, Musha, Ndora, Nyanza, and Save. The Republic of Burundi borders it on the south and east, Nyanza District borders it on the north, and Huye and Nyaruguru Districts border it on the west

The non-experimental design had been used for sampling and collecting data. Quantitative secondary data were collected from Rwanda Meteorology Agency for meteorological data (rainfall, Temperature, study has covered five most rice cultivating cooperatives (Cyili,Nyiramageni and Gatare) of Gikonko and Mamba marshlands most rice cultivating sectors and in Migina, Kabogobogo and Mirayi marshland where rice production data were recorded from five rice cooperatives (COOPRORIZ: CYILI, NYIRAMAGENI, GATARE, KABOGOBOGO, and MIRAYI) management offices for primary data collection.

Concerning meteorological data, dataset has been made using secondary data collected from Rwanda Meteorology Agency (RMA) from nearby stations in Gisagara District (Gikonko, Cyili, Mukindo, Gakoma, Save, Kansi, and Kigembe) to check Rainfall, temperature and eleven recent previous years and data were cumulated according to rice production seasons in Gisagara wetlands.

About rice productivity and yield, data of eleven recent previous years of production (2012-2023) had been recorded from cooperatives and cumulated accordingly with cropping seasons. The probability sampling was used for getting sample on which accurate data had been recorded using a Proportionate stratified sampling from Cyili marshland of 320 Ha and Nyiramageni of 180 Ha and Mwura-Gatare of 110 Ha and Mirayi of 150 Ha, Migina of 200Ha and Kabogobogo 35of 35 Ha where equal number of sample had been taken from cooperative located in those marshlands (Cyili, Nyiramageni, Gatare, Kabogobogo, and Mirayi rice cooperatives).

4. Results and Discussion

4.1. Analysis of the historical trends and patterns of temperature, and rainfall variability in Gisagara District

This section displays the findings of previous trends and patterns of Gisagara District's temperature, and rainfall level fluctuation.

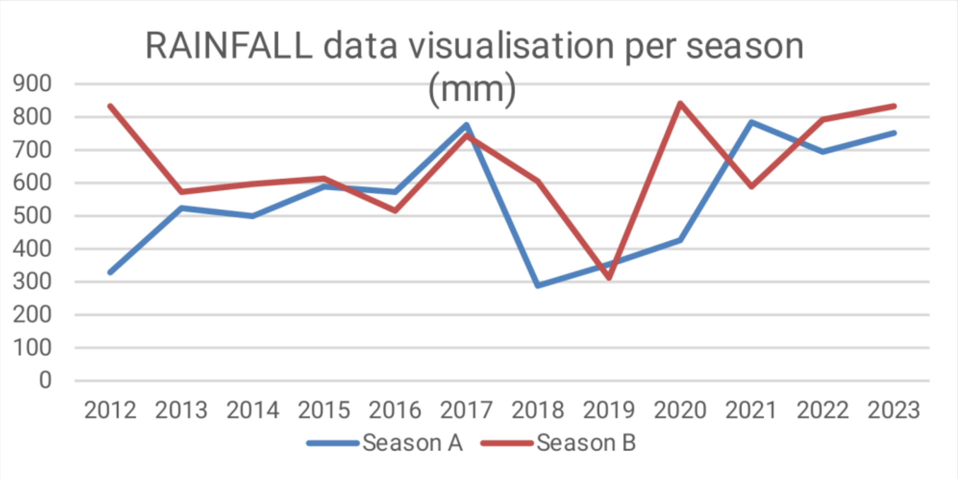

Fig1. Visualization of rainfall data per year from 2012-2023
Source: Meteo Rwanda, 2012-2023

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Table1. SEASON A RAINFALL STATISTICS	
Mean	543.7891
Standard Error	50.95658
Median	543.3571
Mode	#N/A
Standard Deviation	176.5188
Sample Variance	31158.88
Kurtosis	-1.37792
Skewness	-0.01888
Range	494.2857
Minimum	284.7143
Maximum	779
Sum	6525.469
Count	12
Confidence Level(95.0%)	112.1547
Coefficient of Variation(%)	**32.46089**

Source: meteo Rwanda ,2012-2023

Table2. SEASON B RAINFALL STATISTICS	
Mean	650.7949
Standard Error	45.86329
Median	607
Mode	#N/A
Standard Deviation	158.8751
Sample Variance	25241.3
Kurtosis	0.306244
Skewness	-0.59353
Range	529.5714
Minimum	310.5714
Maximum	840.1429
Sum	7809.539
Count	12
Confidence Level(95.0%)	100.9444
Coefficient of Variation(%)	**24.41247**

Source: meteo Rwanda ,2012-2023

Results in figure 1 with tables 1 and 2 indicated that there has been variation of rainfall since 2012 up to 2023.Accordingly, the rainfall was seen throughout two distinct seasons: A, which spans July through December, and B, which occurs within the same calendar year and lasts from January to June (NISR, 2018a:1). Comparing the coefficients of variation of the rainfall in the seasons of this research,season A presented higher variability with CV of 32.46089% compared with 24.41247% of season B with the coefficients ratio greater than 1

4.2. Variability of temperature

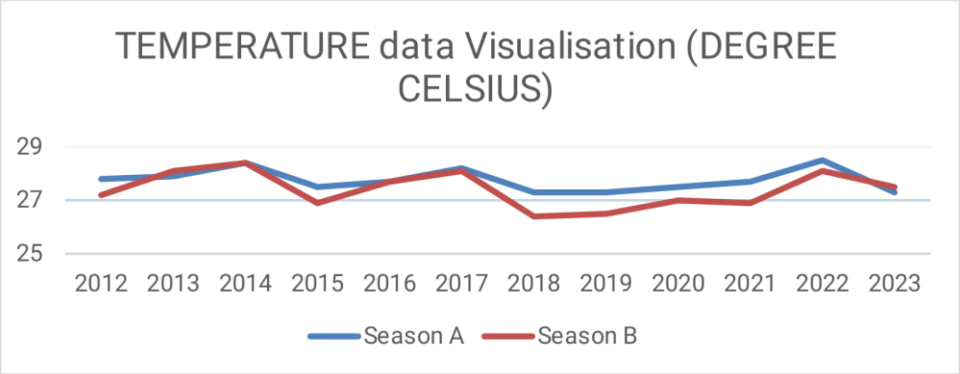

Fig 2. Temperature visualization (degree Celsius)

Source: Meteo Rwanda, 2012-2023

Table 3. SEASON A TEMPERATURE STATISTICS

Mean	27.70907
Standard Error	0.122741
Median	27.68983
Mode	#N/A
Standard Deviation	0.425188
Sample Variance	0.180785
Kurtosis	-0.98228
Skewness	0.532061
Range	1.224729
Minimum	27.20194
Maximum	28.42667
Sum	332.5088
Count	12
Confidence Level(95.0%)	0.270152
Coefficient of Variation(%)	**1.534474**

Source: meteo Rwanda ,2012-2023

Table 4. SEASON B TEMPERATURE STATISTICS

Mean	27.1157
Standard Error	1.07E-15
Median	27.1157
Mode	27.1157
Standard Deviation	3.71E-15
Sample Variance	1.38E-29
Kurtosis	-2.44444
Skewness	-1.14891
Range	0
Minimum	27.1157
Maximum	27.1157
Sum	325.3884
Count	12
Confidence Level(95.0%)	2.36E-15
Coefficient of variation(%)	**1.37E-14**

Source: meteo Rwanda ,2012-2023

By looking on this figure 2. and tables 3 with 4 Representing the temperature, records of season A presented in blue and season B in Red showed low variability (most conistant) of rainfall both seasons with their coefficients of variation which are less than 10%; 1.534474%in A and 1.36846E-14% in B. In A, the minimum record was 27.20194 degree Celsius measured in2018and the maximum of 28.42667 degree Celsius was recorded in 2022. These findings allow to say that this season is hotter than season B with minimum record of 26.30687 degree Celsius in 2018 and the maximum of 28.38888-degree Celsius in 2014.During the research time limit, the mean temperature recorded in season A was 27.70907 degree Celsius, hotter than 27.33728 degree Celsius recorded in B. The ratio of coefficients of variation was greater than 1; to mean the A was highly heterogenous than B.

4.3. Rice production in Gisagara

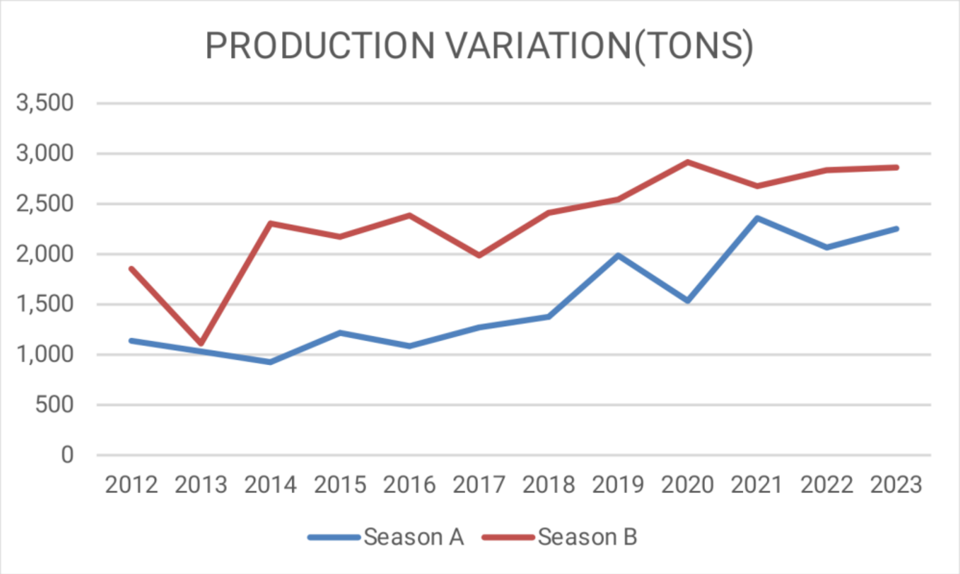

Fig3. Data visualization of Rice output per season

Source: Primary data 2025

Table 5. SEASON A TOTAL PRODUCTION STATISTICS

Mean	1625.333
Standard Error	149.8881
Median	1453
Mode	#N/A
Standard Deviation	519.2276
Sample Variance	269597.3
Kurtosis	-1.83246
Skewness	0.301743
Range	1322
Minimum	1021
Maximum	2343
Sum	19504
Count	12
Confidence Level(95.0%)	329.9015
Coefficient of variation (%)	**31.94592**

Source: Primary data, 2025

Table 6. SEASON B TOTAL PRODUCTION STATISTICS

Mean	2218.339
Standard Error	186.0035
Median	2382.5
Mode	#N/A
Standard Deviation	644.335
Sample Variance	415167.7
Kurtosis	0.189026
Skewness	-0.98773
Range	2010
Minimum	905
Maximum	2915
Sum	26620.07
Count	12
Confidence Level(95.0%)	409.391
Coefficient of variation(%)	**29.04583**

Source: Primary data, 2025

This figure 3. and tables 5 with 6 revealed that the total rice production has been highly varied according to seasons where A presented the higher variability in total production (31.9459166%) than that of season B (29.04583%) with peak produced was 2915 Tons in season B 2020 shown in red and the lowest produced was 905 Tons in season A 2014 shown blue color.

Table 7: t-Test: Paired Two Sample for Means

	Season A	Season B
Mean	1625.333	2218.339
Variance	269597.3	415167.7
Observations	12	12
Pearson Correlation	0.357366	
Hypothesized Mean Difference	0	
df	11	
t Stat	-3.07719	
P(T<=t) one-tail	0.005262	
t Critical one-tail	1.795885	
P(T<=t) two-tail	0.010524	
t Critical two-tail	2.200985	

This t-Test table 7 showed the accordance with coefficient of variation that there had been significance difference in total production for those two seasons A and B as proven with P(T<=t) two-tail equal to 0.010523957which was lesser than 0.05 and also with absolute value t Stat of 3.077190227 greater than t Critical two-tail of 2.20098516. The mean difference in total production of those two seasons was 593.005834 tons with season B more productive than A.

4.4. Yield variation

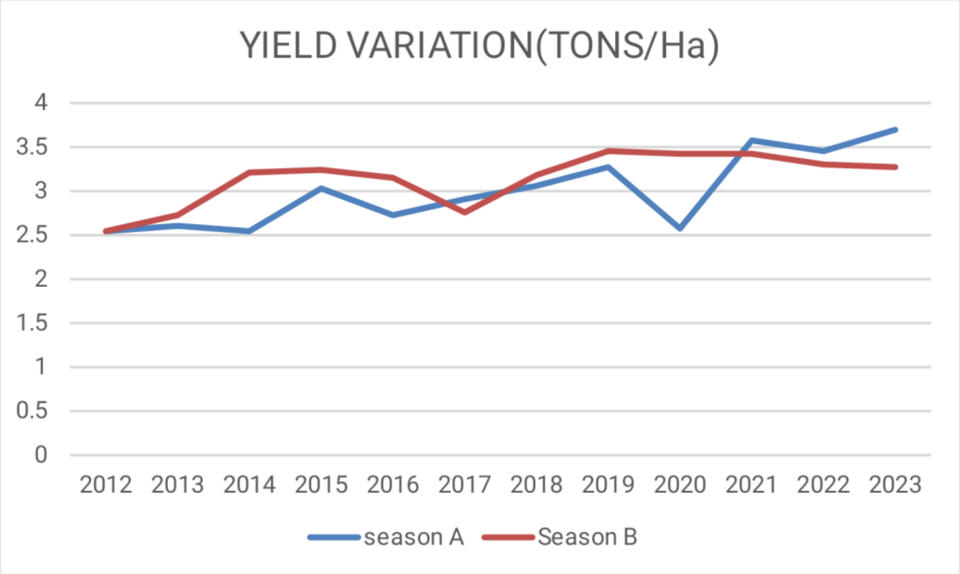

Fig.4. Data visualisation of rice yield per seasons

Source: Primary data, 2025

Table 8. RICE YIELD SEASON A STATISTICS	
Mean	2.983667
Standard Error	0.119899
Median	2.962
Mode	#N/A
Standard Deviation	0.415341
Sample Variance	0.172508
Kurtosis	-1.30663
Skewness	0.421105
Range	1.14
Minimum	2.528
Maximum	3.668
Sum	35.804
Count	12
Confidence Level(95.0%)	0.263895
Cofficient of variation(%)	**13.92049**

Source: Primary data, 2025

Table 9. RICE YIELD SEASON B STATISTICS	
Mean	3.126683
Standard Error	0.086604
Median	3.207
Mode	#N/A
Standard Deviation	0.300004
Sample Variance	0.090003
Kurtosis	-0.1633
Skewness	-1.03203
Range	0.903
Minimum	2.535
Maximum	3.438
Sum	37.5202
Count	12
Confidence Level(95.0%)	0.190614
Cofficient of variation(%)	**9.594967**

Source: Primary data, 2025

On this figure 4. and tables 8 and 9 showed the rice yield variation in Gisagara district during the research time scope revealed the low variability in yield; consistent data (9.594967%) in season B and moderate yield variability (13.92049%) in season A. The maximum yield in season A was 3.668 tons/Ha with 2.528 tons/Ha as minimum with mean of 2.983667 tons/Ha in the same season. In season B, the maximum yield was 3.438 tons/Ha and 2.535 tons/Ha the minimum with the mean of 3.126683 tons/Ha in that seanson.

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Table 10: t-Test: Paired Two Sample for Mean

	Season A	Season B
Mean	2.983667	3.126683
Variance	0.172508	0.090003
Observations	12	12
Pearson Correlation	0.532241	
Hypothesized Mean Difference	0	
df	11	
t Stat	-1.37474	
P(T<=t) one-tail	0.098285	
t Critical one-tail	1.795885	
P(T<=t) two-tail	0.196569	
t Critical two-tail	2.200985	

Source: Primary data, 2025

In table 10. With P(T<=t) two-tail 0.196569 greater than 0.05 and t Stat 1.37474 absolute value lesser than t Critical two-tail 2.200985, there was no significant difference in rice yield among seasons A and B of the study while the yield mean difference was 0.14 ton per hectare.

Relationship between rainfall, temperature, rice production, rice yield and cultivated area and fertilizer use

Correlation coefficients (r): is a statistical measure that quantifies the strength and direction of a relationship between two variables

Table 11: Matrix Correlation coefficients

	Year	**Temperature**	**Rainfall**	**Feltirizer**	**TotProd**	**Yield**	**Cultvarea**
Year	1	-0.2	0.3	0.46	0.66	0.75	0.6
Temperature	-0.2	1	0.18	-0.4	-0.4	-0.33	-0.42
Rainfall	0.3	0.18	1	0.25	0.37	0.27	0.34
Feltirizer	0.46	-0.4	0.25	1	0.56	0.62	0.78
TotProd	0.66	-0.4	0.37	0.56	1	0.64	0.75
Yield	0.75	-0.33	0.27	0.62	0.64	1	0.65
Cultvarea	0.6	-0.42	0.34	0.78	0.75	0.65	1

Source: Field data 2025

|r|≈0.00-0.19’nvery weak or no correlation
|r| ≈ 0.20-0.39’nweak correlation
|r| ≈ 0.40-0.59’nmoderate correlation
|r| ≈ 0.60-0.79’nstrong correlation
|r| ≈ 0.80-1.00’nvery strong correlation

The temperature as climate factor in table 11, is negatively correlated to agricultural factors (chemical fertilizer use, total rice production, yield and cultivated area of rice). There is a weak negative relationship (-0.33) between temperature and yield compared tonegative moderate relationship with fertilizer used, total production and cultivated area. So, the higher rise of the temperature the fewer use chemical fertilizer, smaller area cultivated and fewer rice produced in Gisagara district.

The rainfall in table, has a positive relationship with dependent variables (agricultural factors); chemical fertilizer use (0.25: weak), total rice production (0.37: weak correlation),yield (0.27: weak), and cultivated area (0.34: weak correlation). The higher the rain to th

e optimum, the higher increased those agricultural factors.
From those correlation strength and directions between dependant and independent variables it is important for regression analysis to get the regression lineal model useful in forecasting.

4.5. Regression Analysis

Dependent variable Total production

Table12: Regression analysis for Total Production

```
call:
lm(formula = TotProd ~ Year + Temper + Felti + Cultvarea, data =dat1)
Residuals:
Min                    1Q        Median     3Q         Max
-531.78                -257.15   13.96      131.84     1274.85
Coefficients:
                       Estimate  Std. Error  t Value   Pr (>|t|)
(Intercept)            -1.22E+05   6.21E+04   -1.966   0.0641.
Year                    6.27E+01   3.10E+01    2.021   0.0576.
Temperature            -1.36E+02   1.64E+02    -0.83     0.4171
Feltilizer             -2.46E+00   5.74E+00   -0.429     0.6728
Cultivated Area         2.37E+00   1.02E+00    2.334   0.0307*

Signif.codes:0 '***    0.001 '**'  0.01 '*'   0.05 '.'  0.1 "           1
Residual standard error:  418.8 on 19 degreesof freedom
Multiple R-squared:       0.6544,
Adjusted R-squared:            0.5817
F-statistic:              8.995 on 4 and 19 DF,
p-value:                    0.000298
```

Source: field data 2025

Multiple R-squared (R^2) of 0.6544 revealed that changes of the predictors (independents) of model have been explained at 65.44% with dependent variable where cultivated area was the only one factor with significant effect on the model.

Total Production (Tons) = Year +Temperature +rainfall+Fertilizer + cultivated area

Low variability (most conistant) of rainfall both seasons with their coefficients of variation which are less than 10%; 1.534474%in A and 1.36846E-14% in B. In A, the minimum record was 27.20194 degree Celsius measured in 2018 and the maximum of 28.42667 degree Celsius was recorded in 2022. These findings allow to say that this season is hotter than season B with minimum record of 26.30687 degree Celsius in 2018 and the maximum of 28.38888-degree Celsius in 2014.During the research time limit, the mean temperature recorded in season A was 27.70907 degree Celsius, hotter than 27.33728 degree Celsius recorded in B. The ratio of coefficients of variation was greater than 1; to mean the A was highly heterogenous than B.

These results are in accordance with Trenberth, 2011 who states that higher temperatures can cause drought by increasing evapotranspiration which reduce soil moisture, and leads to less precipitation. This climate change has intensified both heavy rainfall events and droughts, as rising global temperatures influence weather patterns (Pendergrass &Knutti, 2018). And Hategekimana and Kamuhanda (2023),the increase of temperature increased the evaporation which heightened water body depletion

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and exacerbating drought and water scarcity as seen in this research in Gisagara during the season A of rice cultivation using flood irrigation techniques.The figure 4.3 and tables 4.5 with 4.6 and 4.7of solid grain fertilizer uses in different rice cultivation seasons; A in blue and B in red, showed that season has a high variability in its utilization (21.01582039%) according to seasons of the research where fertilizer use was moderately variable in B with coefficient 13.97895821% . For the season A, the minimum range of fertilizer used and recorded at cooperative level was 73 tons in 2014 and 139 tons as the maximum used in 2019

The temperature as climate factor is negatively correlated to agricultural factors (chemical fertilizer use, total rice production, yield and cultivated area of rice). This finding is in accordance with Peng et al.,(2004) who stated that the high temperatures can reduce yields by accelerating crop development, reducing grain-filling duration, and increasing spikelet sterility as rice yield declines by 10% for every 1ºC rice above the optimal temperature(26-28ºC) during the growing season. It has also revealed in Bouman et al., (2007) that severe drought during reproductive stages (panicle initiation to flowering) can cause grain sterility.

Whereas rainfall is in a positive relationship with dependent variables (agricultural factors); chemical fertilizer use (0.25: weak), total rice production (0.37: weak correlation), yield (0.27: weak), and cultivated area (0.34: weak correlation). The higher the rain to the optimum, the higher increased those agricultural factors.

With this correlation analysis, it has been revealed that chemical fertilizer use is strongly correlated with yield and cultivated area. It is also moderately correlated with total rice quantity produced all with same positive trend: the increase of chemical fertilizer to the optimum will strongly affect the increase of in yield and cultivated area of rice and moderately increase the total quantity of produced rice in Gisagara district.

5. Conclusions

This research showed that the impact of climate variability on rice production in Rwanda**,** Gisagara district , is significant poses a serious challenge to food security and livelihoods as key findings showed that the rise in temperature is harming rice production components (total production; productivity, yield, cultivated area and fertilizer use) negatively correlated, while the higher increased the rainfall to the optimum, the higher increased rice production.

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