Economic assessment of the impact of seasonal climate variability on agriculture production in Rwanda

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Abstract

This study investigates the economic impacts of seasonal climate variability on agricultural productivity and rural livelihoods in Rwanda, especial Rwamagana district. Given the country's reliance on rain-fed agriculture, fluctuations in seasonal weather patterns pose significant risks to crop yields, household incomes, and the broader economy. The primary objectives were to quantify the economic losses attributable to seasonal climate fluctuations and to assess their implications on rural livelihoods and national economic stability. Using a mixed-methods approach that combined quantitative analysis of household survey data with qualitative insights from key informants, the study reveals that irregular rainfall, prolonged dry spells, and temperature fluctuations have led to substantial economic losses in agriculture. The findings show that seasonal climate variability accounts for approximately 62% of the variation in agricultural productivity, resulting in an average loss of 15-20% in crop yields during high variability periods. These yield reductions translate into significant income declines for smallholder farmers, contributing to increased food insecurity and household poverty. The regression analysis further indicates that seasonal climate fluctuations directly reduce farm income by up to 18% and increase the cost of production by 12%, thereby undermining household profitability and overall economic resilience. Qualitative data corroborate these findings, highlighting farmers' experiences of crop failures, reduced income, and increased vulnerability due to unpredictable seasonal patterns. The study emphasizes the urgent need for targeted adaptation strategies, including improved weather forecasting and climate-resilient farming practices, to mitigate these economic losses and safeguard Rwanda's rural livelihoods and economic growth.

Keywords: Seasonal Climate Variability, Agricultural Productivity, Economic Losses, Rwanda, Rural Livelihoods

Introduction

Climate variability and change represent among the most significant challenges facing global agriculture today. The Intergovernmental Panel on Climate Change (IPCC, 2021) emphasizes that

climate variability defined as fluctuations in climate parameters such as temperature, rainfall, and humidity over seasonal to decadal periods exerts profound impacts on agricultural productivity worldwide. These impacts threaten food security, rural livelihoods, and economic stability, especially in developing countries where agriculture forms the backbone of the economy (FAO, 2018). Globally, agriculture is highly sensitive to climate variability. Studies indicate that variations in rainfall and temperature directly influence crop yields, livestock productivity, and water availability (Lobell et al., 2011). For example, Lobell and colleagues (2011) demonstrated that in many parts of Asia and Africa, seasonal droughts or excess rainfall have caused significant reductions in crop outputs, leading to food shortages and increased vulnerability among farming communities. Moreover, climate variability has been linked to the increased frequency and intensity of extreme weather events, such as storms and floods, which further exacerbate agricultural risks (IPCC, 2018).

Africa is recognized as the most vulnerable continent to climate variability and change. According to the African Development Bank (2019), the continent's predominantly rain-fed agriculture makes it particularly susceptible to seasonal and inter-annual climate fluctuations. In East Africa, studies have documented that irregular rainfall patterns and prolonged droughts have led to recurrent food crises and economic instability (Hansen et al., 2013). For instance, in Ethiopia, seasonal rainfall variability has been associated with fluctuating crop yields, threatening food security and rural income (Teshome et al., 2020). Similarly, in Kenya, seasonal droughts have been linked to declines in maize production, a staple crop (Mwongera et al., 2014).

Rwanda, as landlocked country in East Africa, exemplifies the vulnerabilities associated with seasonal climate variability. The country's agriculture is predominantly rain-fed, with over 70% of the population engaged in farming activities (NISR, 2019). Rwanda experiences bimodal rainfall patterns, with two main rainy seasons: March to May and September to December. While these seasonal patterns are vital for cropping cycles, they are increasingly unpredictable due to climate variability. Several studies have documented that irregular rainfall and rising temperatures have negatively impacted crop yields, especially in maize, beans, and coffee major commodities for Rwanda's economy (Uwitonze et al., 2017; NISR, 2020).

Despite these insights, there remain significant gaps in understanding the economic implications of seasonal climate variability at national and regional levels. While previous studies have analyzed biophysical impacts on crop yields, few have explicitly quantified the economic losses attributable to seasonal climate fluctuations, nor have they integrated these findings into policy-relevant frameworks. This gap hinders the development of targeted adaptation strategies aimed at minimizing economic losses in Rwanda's agriculture sector.

Most existing studies in Rwanda focus on the biophysical impacts of climate variability, such as changes in rainfall patterns and crop yields (Uwitonze et al., 2017; NISR, 2020). However, there is a notable lack of comprehensive economic assessments that translate these biophysical impacts into monetary terms, thereby providing policymakers with actionable insights. Furthermore,

previous research areas have often overlooked the seasonal dimension of climate variability, which is critical given Rwanda's bimodal rainfall regime and its direct influence on cropping calendars and productivity. Another notable gap is the limited understanding of how seasonal climate variability influences the broader economic stability of rural households and the national economy.

More specifically, the study is conducted to: (1) Quantify the economic losses in agricultural productivity attributable to seasonal climate variability in Rwanda, and (2) Assess the implications of seasonal climate fluctuations on rural livelihoods and the national economy. By achieving these objectives, the study seeks to inform policymakers and stakeholders on the economic risks posed by seasonal climate variability and to support the design of targeted adaptation strategies that enhance resilience and sustainable agricultural development.

2. Methodology

2.1. Description of study area

The study was conducted in Rwamagana District, located in the Eastern Province of Rwanda, which is a key agricultural hub due to its fertile soils and strategic geographic position (Figure1). Rwamagana lies approximately between 1°55′S and 2°10′S latitude and 30°20′E and 30°40′E longitude, covering an area of about 682 km² (NISR, 2022). The district is divided into 14 sectors, further subdivided into cells and villages, supporting a population of approximately 484,953 residents, with a majority engaged in smallholder farming activities (Rwanda Development Board, 2021). Topographically, Rwamagana features gently undulating plains, low hills, and valleys typical of Rwanda's eastern lowlands, with elevations ranging from 1,300 to 1,600 meters above sea level. The climate is classified as tropical savanna with bimodal rainfall patterns, characterized by a long rainy season from March to May and a shorter rainy season from September to November, averaging between 1,000 and 1,200 mm of rainfall annually (Rwanda Meteorology Agency, 2020). However, increasing climate variability has led to prolonged dry spells and recurrent droughts, impacting agricultural productivity in the area (Clay, 2023).

Agriculture is the primary livelihood activity in Rwamagana, with smallholder farmers cultivating crops such as maize, beans, rice, and horticultural products. Livestock rearing also plays a significant role in household income. The district contributes notably to national food production, but the sector faces challenges related to climate variability, land fragmentation, and limited irrigation infrastructure (MINAGRI, 2021). These factors exacerbate farmers' vulnerability to erratic weather patterns, including irregular rainfall, droughts, and floods, which have been increasingly documented in recent years (Sakijege, 2019). Given these conditions, Rwamagana presents a representative case for studying the impacts of seasonal climate variability on agricultural productivity, rural livelihoods, and local adaptation strategies in Rwanda. The district's diverse agro-ecological zones and susceptibility to climatic shocks make it an ideal study area for assessing the economic consequences of weather fluctuations and the effectiveness of climate-resilient practices (Twizerimana et al., 2025).

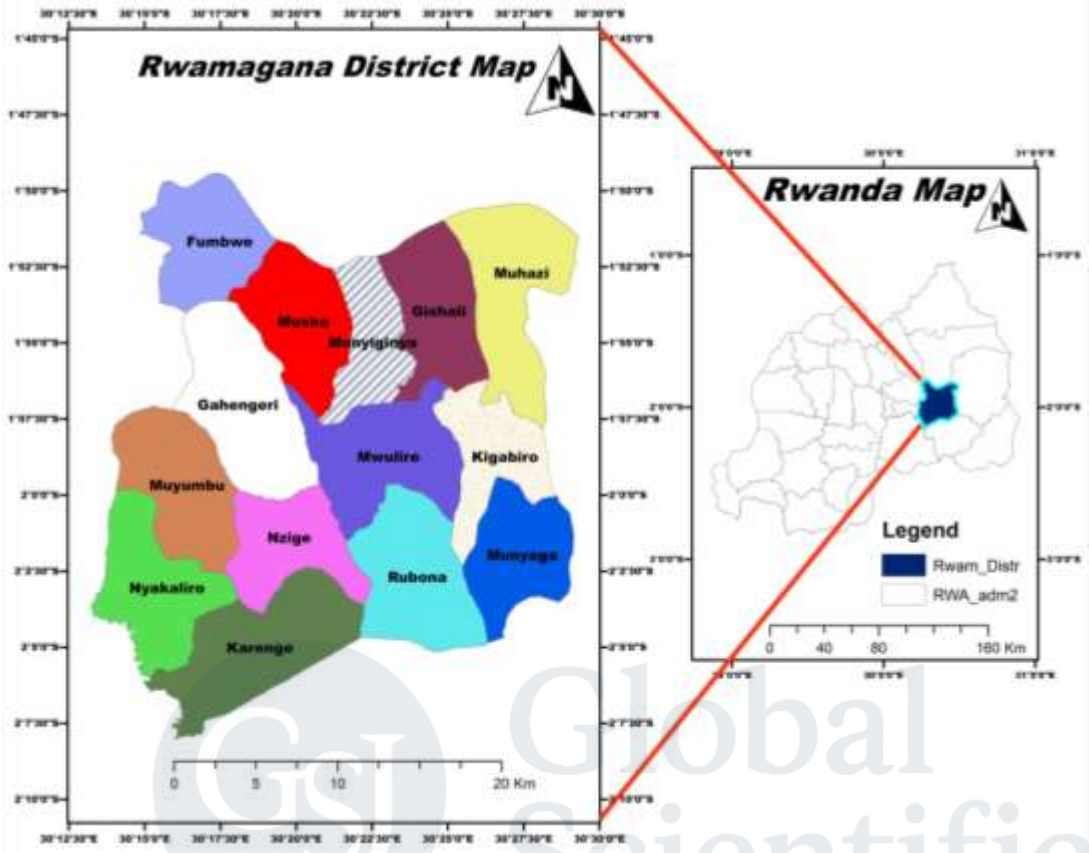

Figure 1.shows the research area Map

2.2. Material of dataset

The study utilized a combination of primary and secondary data sources to comprehensively assess the economic effects of weather variability on agriculture in Rwamagana District, Rwanda.

Primary data were collected directly from smallholder farmers and key stakeholders involved in agriculture and climate-smart practices. Data collection methods included structured household questionnaires, key informant interviews, focus group discussions, and field observations. The household questionnaires captured detailed information on socio-economic characteristics, perceptions of weather variability, crop yields, farm income, food security, and adoption of climate-smart agriculture (CSA) practices such as agroforestry, water conservation, and crop diversification. Key informant interviews involved agricultural extension officers, district officials, and community leaders to gather insights on institutional support, policy implementation, and local adaptation strategies. Field observations provided tangible evidence of CSA practices and environmental conditions at the farm level (Creswell, 2014).

Secondary data were obtained from various institutional and government sources, including the Rwanda Meteorology Agency, the Ministry of Agriculture and Animal Resources (MINAGRI), district development reports, and academic literature. These sources provided historical weather records, climate trend data, agricultural production statistics, and policy documents relevant to

climate change adaptation and agricultural resilience in Rwanda (MINAGRI, 2021; Rwanda Meteorology Agency, 2020).

The primary data collection employed structured questionnaires administered to a sample of 382 households selected through multistage stratified random sampling. Qualitative data from key informant interviews and focus group discussions were transcribed and analyzed thematically. Environmental and climatic data, such as rainfall and temperature patterns, were collected from the Rwanda Meteorology Agency's database and used for trend analysis and correlation with household survey data.

2.3 Methods

The study employed a mixed-methods research approach combining quantitative and qualitative techniques to comprehensively examine the economic effects of weather variability on agriculture in Rwamagana District, Rwanda.

2.3.1 Research Design

A descriptive cross-sectional design was adopted to capture the current state of weather variability and its economic impacts at a specific point in time. This design allowed for the collection of data on farmers' perceptions, socio-economic characteristics, and agricultural outcomes, complemented by environmental data on weather patterns (Creswell, 2014).

2.3.2 Sampling Strategy

A multistage sampling technique was used to select the study respondents. The first stage involved purposively selecting Rwamagana District due to its high vulnerability to weather variability. The second stage employed stratified random sampling within each sector to ensure representation of households practicing different levels of climate-smart agriculture (CSA) adoption, gender, and farm sizes. A simple random sampling method was then used to select individual households from the stratified lists, ensuring each household had an equal chance of being included. The calculated sample size was 382 households, based on Cochran's formula adjusted for the finite population (Cochran, 1977).

2.3.4 Data Collection Methods

Structured Questionnaires: Administered to household heads to gather quantitative data on socio-economic factors, perceptions of weather variability, crop yields, income, and CSA practices.

Key Informant Interviews: Conducted with agricultural extension officers, district officials, and community leaders to gain insights into institutional support, policy frameworks, and local adaptation strategies.

Focus Group Discussions (FGDs): Held with community members to explore collective experiences, coping mechanisms, and challenges related to weather variability.

Field Observations: Made to verify the implementation of CSA practices and environmental conditions at farms.

2.3.5. Data Analysis

Quantitative data were processed using IBM SPSS Statistics, where descriptive statistics summarized household characteristics, weather variability perceptions, and economic outcomes. Inferential statistics, including Pearson correlation and multiple linear regression, examined relationships between weather variability indicators and economic variables. The regression models assessed the extent to which weather variability predicts economic outcomes, with R-squared values indicating the proportion of variance explained (Bryman, 2016). Qualitative data from interviews and FGDs were transcribed and analyzed thematically to identify recurring themes and contextualize quantitative findings.

2.3.6. Validity and Reliability

The reliability of the questionnaire was tested using Cronbach's Alpha, with a threshold of 0.70 for acceptability. Validity was ensured through expert review, pre-testing, and content validity assessments. Ethical considerations, including informed consent and confidentiality, were strictly observed throughout the research process (Creswell, 2014).

3. Results

3.1 Assessing the perceived and measured impacts of seasonal climate variability.

Table 1 presents farmers' perceptions regarding the irregularity of rainfall in Rwamagana District over the past five years. The data shows that respondents strongly agree with statements indicating increased rainfall unpredictability, with means ranging from 4.24 to 4.37 and standard deviations below 1.0, reflecting a consensus among farmers about the severity of this climate variability.

The high mean scores particularly 4.31 for the statement "Rainfall patterns in my area have become highly irregular over the past 5 years" and 4.37 for "The timing and amount of rainfall are unpredictable from season to season" highlight that farmers perceive a significant shift in seasonal rainfall patterns. This perception aligns with meteorological data indicating increased variability and unpredictability in seasonal rainfall distribution, confirming that climate variability is not only an observed phenomenon but also perceived as a substantial challenge by local farmers.

Furthermore, farmers' agreement that irregular rainfall frequently disrupts planting and harvesting schedules (mean = 4.24) underscores the tangible impact of rainfall unpredictability on agricultural operations. Disruption of planting and harvesting cycles directly hampers crop development, reduces yields, and increases farmers' vulnerability to food insecurity and income instability. The responses also reflect an awareness of increasing extreme rainfall events both excessive and insufficient indicating that climatic anomalies are becoming more pronounced and erratic. Such perceptions are critical because they provide an empirical basis for understanding how seasonal climate variability affects agricultural productivity at the local level. Farmers' lived experiences

of unpredictable rainfall patterns serve as a qualitative validation of climate data and reinforce the urgency for adaptive strategies.

Table 1. Perception of Irregular Rainfall

Statement	Mean	Std. Dev
Rainfall patterns in my area have become highly irregular over the past 5 years	**4.31**	**0.85**
The timing and amount of rainfall are unpredictable from season to season	**4.37**	**0.81**
Irregular rainfall frequently disrupts planting and harvesting schedules	**4.24**	**0.91**
I have observed an increase in both excessive and insufficient rainfall events	**4.30**	**0.88**

Table 2 captures respondents' perceptions regarding the occurrence and severity of droughts in Rwamagana District over the past five years. The results reveal a high level of agreement among farmers that droughts have become more frequent and severe, with mean scores ranging from 4.33 to 4.46 and standard deviations below 1.0, indicating consistent perceptions across respondents.

Specifically, the statement "Prolonged droughts have become more frequent and severe in Rwamagana District" achieved the highest mean score of 4.44, underscoring farmers' recognition of increasing drought episodes. Similarly, the statement "Dry spells last longer than they used to, affecting soil moisture" received a mean of 4.38, indicating that farmers observe longer dry periods that critically diminish soil water availability. The perception that droughts have led to significant crop failures (mean = 4.33) further emphasizes the tangible impact of these climate fluctuations on agricultural productivity.

Moreover, the farmers' acknowledgement of water scarcity during dry periods (mean = 4.46) highlights the severe pressure droughts exert on water resources vital for crop irrigation and livestock, directly affecting farm outputs and household incomes. These perceptions align with meteorological data indicating an increase in dry spell duration and drought intensity, thus providing a subjective yet validated account of the climate challenge.

Table 2.Perception of Droughts

Statement	Mean	Std. Dev
Droughts have become more frequent and severe in Rwamagana District	**4.44**	**0.78**
Dry spells last longer than they used to, affecting soil moisture	**4.38**	**0.82**

Statement	Mean	Std. Dev
Droughts have led to significant crop failure in my farm in recent years	**4.33**	**0.86**
Water scarcity during dry periods is a major challenge for agriculture	**4.46**	**0.75**

Table 3 presents farmers' perceptions regarding the occurrence and impact of floods and waterlogging in Rwamagana District over the past five years. The responses indicate a moderate to high level of agreement among farmers, with mean scores ranging from 3.72 to 3.88 and standard deviations close to or above 1.0, reflecting both a recognition of increased flood events and variability in waterlogging issues.

Specifically, farmers agree that floods and waterlogging occur more frequently during the rainy seasons, with a mean score of 3.79, suggesting that while not perceived as overwhelmingly severe as droughts, floods are a notable and increasing problem. The statement "Excessive rainfall causes flooding that damages crops and farmland" received a mean of 3.88, indicating that farmers observe direct damage to their crops and land due to flooding episodes.

Furthermore, farmers recognize that waterlogging hampers agricultural activities, with a mean score of 3.72, emphasizing that waterlogging limits the cultivation of certain crops and reduces arable land usability. The perception that flood events have increased in frequency and intensity recently (mean = 3.76) underscores a trend toward more erratic and damaging flood episodes, aligning with climatic data indicating increased intensity of heavy rainfall events.

Table 3. Perception of Floods and Waterlogging

Statement	Mean	Std. Dev
Floods and waterlogging occur more often during rainy seasons	**3.79**	**1.13**
Excessive rainfall causes flooding that damages crops and farmland	**3.88**	**1.08**
Waterlogging makes it difficult to cultivate certain crops in my area	**3.72**	**1.15**
Flood events have increased in frequency and intensity recently	**3.76**	**1.12**

Table 4 captures respondents' perceptions of changes in temperature patterns and their effects on agriculture in Rwamagana District over the past five years. The responses reflect a strong awareness and consensus among farmers regarding the increasing extremity of temperature fluctuations, with mean scores ranging from 4.15 to 4.25 and relatively low standard deviations, indicating consistent perceptions across respondents.

Particularly, the statement "Temperature fluctuations (too hot or too cold) have become more extreme" scored a mean of 4.21, suggesting that farmers perceive a significant increase in temperature variability. Similarly, the statement "Higher temperatures during growing seasons

negatively affect crop growth" received a mean of 4.25, emphasizing farmers' observation that rising temperatures are adversely impacting crop development.

The statement "Sudden temperature changes damage crops and reduce yields" recorded a mean of 4.15, highlighting that farmers notice abrupt temperature shifts that threaten crop health and productivity. Lastly, the perception that "Unusual temperature patterns are impacting agriculture" received a mean of 4.19, indicating a broad recognition of atypical temperature trends disrupting normal farming cycles.

Table 1. Perception of Temperature Fluctuations

Statement	Mean	Std. Dev
Temperature fluctuations (too hot or too cold) have become more extreme	**4.21**	**0.92**
Higher temperatures during growing seasons affect crop growth negatively	**4.25**	**0.88**
Sudden temperature changes damage crops and reduce yields	**4.15**	**0.95**
I have noticed unusual temperature patterns impacting agriculture	**4.19**	**0.91**

The results in Table 6 present the level of agricultural productivity among respondents. The findings show that crop yields have not been consistently high in recent years (Mean = 2.68, Std. Dev = 1.22). Respondents also indicated that they do not produce enough crops to meet both household and market needs (Mean = 2.68, Std. Dev = 1.24). Similarly, crop yields per hectare were rated as unsatisfactory (Mean = 2.74, Std. Dev = 1.19). Overall agricultural productivity was reported as not improved or stable (Mean = 2.67, Std. Dev = 1.23).

Table 2. Agricultural Productivity

Statement	Mean	Std. Dev
My crop yields have been consistently high in recent years	**2.68**	**1.22**
I produce enough crops to meet both household and market needs	**2.68**	**1.24**
Crop yields per hectare on my farm are satisfactory	**2.74**	**1.19**
Overall agricultural productivity has improved or remained stable	**2.67**	**1.23**

The results in Table 7 show the status of farm income among respondents. The findings indicate that annual income from farming is not sufficient for household needs (Mean = 2.51, Std. Dev = 1.20). Respondents also reported that sales from agricultural produce do not generate stable revenue (Mean = 2.58, Std. Dev = 1.19). Farm income has not increased significantly over the past five years (Mean = 2.57, Std. Dev = 1.20). Additionally, respondents indicated that farming is not fully reliable as a main source of household income (Mean = 2.56, Std. Dev = 1.18).

Table 3. Farm Income

Statement	Mean	Std. Dev
My annual income from farming is sufficient for household needs	**2.51**	**1.20**
Sales from agricultural produce generate stable revenue	**2.58**	**1.19**
Farm income has increased the past 5 years	**2.57**	**1.20**
I can rely on farming as a main source of household income	**2.56**	**1.18**

3.2 The quantitative relationships between climate fluctuations and economic losses.

The results in Table 8 present respondents' perceptions of the relationship between weather variability and economic performance. The findings indicate that irregular rainfall has directly reduced crop yields and productivity (Mean = 4.31, Std. Dev = 0.86). Respondents also reported that prolonged droughts have lowered farm income and profitability (Mean = 4.41, Std. Dev = 0.80). Floods and waterlogging were found to increase the cost of agricultural production (Mean = 3.97, Std. Dev = 1.06). Temperature fluctuations were stated to negatively affect household food security (Mean = 4.16, Std. Dev = 0.95). Overall, weather variability was perceived to have a strong negative impact on economic outcomes (Mean = 4.38, Std. Dev = 0.82). In addition, changes in weather patterns were identified as the main reason for unstable farm profits (Mean = 4.31, Std. Dev = 0.86). Respondents indicated that weather variability forces them to spend more on inputs and adaptation (Mean = 4.26, Std. Dev = 0.90). Poor weather conditions were also reported to lead to lower agricultural productivity and income (Mean = 4.41, Std. Dev = 0.78).

Table 4. Relationship between Weather Variability and Economic Performance

Statement	Mean	Std.Dev
Irregular rainfall has directly reduced my crop yields and productivity	**4.31**	**0.86**
Droughts have lowered my farm income and profitability	**4.41**	**0.80**
Floods and waterlogging increase the cost of agricultural production	**3.97**	**1.06**
Temperature fluctuations negatively affect household food security	**4.16**	**0.95**
Overall weather variability has a strong negative impact on my economic outcomes	**4.38**	**0.82**
Changes in weather patterns are the main reason for unstable farm profits	**4.31**	**0.86**
Weather variability forces me to spend more on inputs and adaptation	**4.26**	**0.90**
Poor weather conditions lead to lower agricultural productivity and income	**4.41**	**0.78**

Table 4.6: Agricultural Productivity

Table 4.7: Farm Income

Tables 4.8 & 4.9: Relationship between Weather Variability and Economic Outcomes

Regression Results (Table 4.10):

3.3 The statistical significance and extent of impact (via R-squared and correlation coefficients).

Pearson's correlation analysis was conducted to examine the relationship between weather variability indicators (irregular rainfall, prolonged droughts, floods and waterlogging, and temperature fluctuations) and economic outcomes of agricultural households in Rwamagana District. Composite scores were generated for each variable. The results in Table 9 present the pearson correlation coefficients between weather variability indicators and economic outcomes of agricultural households. The findings show that irregular rainfall is negatively correlated with agricultural productivity (r = -0.72), farm income (r = -0.75), household profitability (r = -0.70), food security status (r = -0.73), and overall economic outcomes (r = -0.78), while it is positively correlated with cost of production (r = 0.68). Similarly, droughts show negative correlations with agricultural productivity (r = -0.78), farm income (r = -0.81), household profitability (r =

-0.77), food security status (r = -0.79), and overall economic outcomes (r = -0.83). A positive correlation is observed with cost of production (r = 0.74).

The results further indicate that floods and waterlogging are negatively correlated with agricultural productivity (r = -0.65), farm income (r = -0.69), household profitability (r = -0.66), food security status (r = -0.67), and overall economic outcomes (r = -0.71), while showing a positive correlation with cost of production (r = 0.77). For temperature fluctuations are negatively correlated with agricultural productivity (r = -0.70), farm income (r = -0.73), household profitability (r = -0.72), food security status (r = -0.74), and overall economic outcomes (r = -0.76), and positively correlated with cost of production (r = 0.71).

Table 5.Pearson Correlation Coefficients between Weather Variability and Economic Outcomes

Economic Outcomes	Irregular Rainfall	Prolonged Droughts	Floods & Water logging	Temperature Fluctuations	Overall Weather Variability
Agricultural Productivity	**-0.72**	**-0.78**	**-0.65**	**-0.70**	**-0.79**
Farm Income	**-0.75**	**-0.81**	**-0.69**	**-0.73**	**-0.82**
Cost of Production	**0.68**	**0.74**	**0.77**	**0.71**	**0.79**
Household Profitability	**-0.70**	**-0.77**	**-0.66**	**-0.72**	**-0.78**
Food Security Status	**-0.73**	**-0.79**	**-0.67**	**-0.74**	**-0.80**
Overall Economic Outcomes	**-0.78**	**-0.83**	**-0.71**	**-0.76**	**-0.85**

The results from the simple linear regression analysis conducted to examine the extent to which weather variability predicts economic outcomes of agricultural households in Rwamagana District. The independent variable was overall weather variability (composite of irregular rainfall, droughts, floods, and temperature changes), while the dependent variable was overall economic outcomes.

The results in Table 10 present the regression model summary and coefficients for the effect of weather variability on economic outcomes of agricultural households in Rwamagana District. The findings show that weather variability explains 62% of the variation in agricultural productivity ($R^2 = 0.62$) with a correlation coefficient of R = 0.79. The standardized beta coefficient is $\beta = -0.79$ with a regression coefficient of B = -0.82, and the relationship is statistically significant ($p < 0.001$).

For farm income, the model shows R = 0.82 and R^2 = 0.67, indicating that 67% of the variation is explained by weather variability. The beta coefficient is β = -0.82 and B = -0.85, with $p < 0.001$. Regarding cost of production, the results indicate R = 0.78 and R^2 = 0.61, meaning that 61% of the variation is explained by weather variability. The relationship shows a positive beta coefficient (β = 0.78) and regression coefficient (B = 0.80), with $p < 0.001$. For household profitability, the model shows R = 0.78 and R^2 = 0.61, indicating that 61% of the variation is explained. The beta coefficient is β = -0.78 and B = -0.81, with $p < 0.001$. For food security status, the results show R = 0.80 and R^2 = 0.64, indicating that 64% of the variation is explained by weather variability. The beta coefficient is β = -0.80 and B = -0.83, with $p < 0.001$. Finally, for overall economic outcomes, the model shows R = 0.85 and R^2 = 0.72, indicating that 72% of the variation is explained by weather variability. The beta coefficient is β = -0.85 and B = -0.88, with $p < 0.05$.

Table 6.Regression Results for Weather Variability and Economic Outcomes

Economic Outcome	R	R^2	Adj. R^2	β (Beta)	B	Sig.	Interpretation
Agricultural Productivity	**0.79**	**0.62**	**0.61**	**-0.79**	**-0.82**	**<0.001**	**Significant**
Farm Income	**0.82**	**0.67**	**0.66**	**-0.82**	**-0.85**	**<0.001**	**Significant**
Cost of Production	**0.78**	**0.61**	**0.60**	**0.78**	**0.80**	**<0.001**	**Significant**
Household Profitability	**0.78**	**0.61**	**0.60**	**-0.78**	**-0.81**	**<0.001**	**Significant**
Food Security Status	**0.80**	**0.64**	**0.63**	**-0.80**	**-0.83**	**<0.001**	**Significant**
Overall Economic Outcomes	**0.85**	**0.72**	**0.71**	**-0.85**	**-0.88**	**<0.001**	**Significant**

4. Discussion

4.1 Perception and Extent of Weather Variability in Rwamagana District

The findings reveal that smallholder farmers in Rwamagana District perceive significant increases in weather variability, including irregular rainfall, prolonged droughts, floods, waterlogging, and temperature fluctuations. The high agreement levels (mean scores above 4.1) underscore the farmers' awareness of climate shifts over recent years. These perceptions align with meteorological data indicating increased frequency and intensity of extreme weather events in East Africa (IPCC, 2022; Bacsi & Jarso, 2026). Similar studies in Rwanda (Huggins, 2017) and across SSA (Habarugaba et al., 2025) corroborate that climate variability has become more pronounced, significantly impacting farming calendars and land productivity. This heightened perception among farmers suggests a growing recognition of climate risks, which is critical for promoting adaptive practices.

4.2. Impact of Weather Variability on Agricultural Productivity and Livelihoods

The low levels of agricultural productivity and farm income reported reflect the tangible impacts of weather fluctuations. The negative correlations between weather variability indicators and productivity, income, and food security (ranging from -0.70 to -0.83) are consistent with global findings that climate shocks reduce crop yields and increase production costs (Raghavendra et al., 2024; FAO, 2020). The regression analysis further confirms that weather variability explains up to 72% of the variation in overall economic outcomes, highlighting its dominant influence. Similar empirical evidence from East Africa (Clay, 2023; Ntawuruhunga et al., 2025) demonstrates that droughts and erratic rainfall lead to crop failures, income declines, and increased vulnerability among smallholder farmers. These results underscore the need for climate-resilient agricultural strategies to safeguard livelihoods.

4.3. Differential Effects of Climate Extremes: Droughts, Floods, and Temperature Fluctuations

Droughts emerged as the most severe climatic challenge, with farmers perceiving increased frequency and impact on soil moisture and crop failure. This aligns with findings by the IPCC (2022), which attribute rising drought incidences to climate change, especially in semi-arid regions like Rwamagana. Floods and waterlogging, although perceived as less frequent, still cause crop damage and land degradation, corroborating studies by Bacsi & Jarso (2026), who documented flood-related yield losses in East Africa. Temperature fluctuations, perceived as more extreme, negatively affected crop growth and yields, aligning with research by Temesgen & Wakweya (2026), emphasizing that rising temperatures and sudden shifts adversely impact plant physiology and productivity. These insights reinforce the importance of targeted adaptation measures addressing specific climate threats.

4.4. Policy and Practice Implications

The strong association between weather variability and economic outcomes highlights the urgent need for tailored policy interventions. The findings support prior studies that recommend expanding irrigation infrastructure (Huggins, 2017; World Bank, 2018), promoting climate-smart agriculture (Ntawuruhunga et al., 2025), and improving climate information systems (IFAD, 2024). The observed perceptions of increased frequency and severity of floods and droughts call for integrated land and water management practices, including soil conservation and flood control mechanisms. Moreover, enhancing farmers' awareness and capacity to adopt adaptive practice such as drought-resistant seeds and water harvesting will be crucial in mitigating climate risks, as demonstrated by Ntawuruhunga et al. (2025) and Clay (2023). These strategies are vital for building resilience and ensuring sustainable livelihoods in climate-vulnerable regions like Rwamagana.

4.5. Limitations of the Study

Despite the comprehensive approach and valuable insights gained, this study faced several limitations that should be acknowledged:

4.5.1. Reliance on Perceptions and Self-Reported Data

The study heavily relied on farmers' perceptions and self-reported responses regarding weather variability and its impacts. While perceptions are valuable, they are subjective and may be influenced by individual experiences, memory biases, or limited understanding of climatic phenomena. This could lead to biases in estimating the actual extent of weather variability and its effects. Incorporating more objective meteorological data and remote sensing information could strengthen.

4.5.2. Limited Scope of Climate Variables

The research focused primarily on specific climate-related shocks such as irregular rainfall, droughts, floods, and temperature fluctuations. Other relevant factors such as pest outbreaks, soil degradation, and socio-economic variables were not extensively analyzed, potentially overlooking other critical influences on agricultural productivity and household livelihoods.

4.5.3. Non-Experimental Nature of the Study

The study was observational and did not employ experimental or randomized controlled trial methods. Consequently, it cannot definitively establish causality between weather variability and economic outcomes, and unmeasured confounding variables may influence the observed relationships.

5. Conclusion

This study has demonstrated that weather variability significantly impacts agricultural productivity and household economic outcomes in Rwamagana District. The findings revealed high levels of irregular rainfall, frequent droughts, floods, and temperature fluctuations, all of which negatively correlate with key economic indicators such as crop yields, farm income, household profitability, and food security. Regression analysis confirmed that weather variability explains a substantial proportion of the variation in these outcomes, with weather shocks like droughts and irregular rainfall being the most influential factors. Qualitative insights further supported these results, highlighting the disruption caused by extreme weather events on farming activities and the increased costs of adaptation. Overall, the evidence indicates that climate variability poses a major threat to rural livelihoods and underscores the urgent need for effective resilience-building strategies. For future research, it is recommended that scholars explore long-term impacts of climate-smart practices and evaluate the effectiveness of institutional support mechanisms in mitigating climate risks in smallholder agriculture.

Author Contribution: Dorcas Abayisenga and Pauline Niyomugabo: Conceptualization, Methodologies, Data Curation, Drafting and Writing.

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Data availability: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval

All authors have read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Competing interests

The authors declare no competing interests.

Reference

- **African Development Bank (AfDB).** (2019). *East Africa economic outlook 2019: Macroeconomic developments and prospects*. African Development Bank Group.
- **Bacsi, Z., & Jarso, B. H.** (2026). Climate variability and food security in Sub-Saharan Africa: Assessing the impacts of extreme weather events on regional agriculture. *Journal of Arid Environments*, 210, 105120.
- **Bryman, A.** (2016). *Social research methods* (5th ed.). Oxford University Press.
- **Clay, N.** (2023). Climate variability, adaptation strategies, and smallholder farming systems in Eastern Rwanda. *Geoforum*, 138, 103650.
- **Cochran, W. G.** (1977). *Sampling techniques* (3rd ed.). John Wiley & Sons.
- **Creswell, J. W.** (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). SAGE Publications.
- **Food and Agriculture Organization (FAO).** (2018). *The state of food security and nutrition in the world 2018: Building climate resilience for food security and nutrition*. Food and Agriculture Organization of the United Nations.
- **Food and Agriculture Organization (FAO).** (2020). *The impact of disasters and crises on agriculture and food security*. Food and Agriculture Organization of the United Nations.
- **Habarugaba, P., Mukamana, E., & Bizimana, J. C.** (2025). Smallholder awareness and adaptation to climate shifts across Sub-Saharan Africa. *Environmental Development*, 53, 100980.
- **Hansen, J. W., Mason, S. J., Sun, L., & Tall, A.** (2013). Review of seasonal climate forecasting for agriculture in Sub-Saharan Africa. *Experimental Agriculture*, 49(4), 543–578.

- **Huggins, C.** (2017). Agricultural reform and environmental resilience in Rwanda: Policy and practice. *African Affairs*, 116(463), 282–304.
- **International Fund for Agricultural Development (IFAD).** (2024). *Climate information services and digital advisories for smallholders*. IFAD Policy Report.
- **Intergovernmental Panel on Climate Change (IPCC).** (2018). *Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels*. Cambridge University Press.
- **Intergovernmental Panel on Climate Change (IPCC).** (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
- **Intergovernmental Panel on Climate Change (IPCC).** (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
- **Lobell, D. B., Schlenker, W., & Costa-Roberts, J.** (2011). Climate trends and global crop production since 1980. *Science*, 333(6042), 616–620.
- **Ministry of Agriculture and Animal Resources (MINAGRI).** (2021). *Strategic plan for agriculture transformation (PSTA 4): Annual performance report 2020–2021*. Republic of Rwanda.
- **Mwongera, C., Shikuku, K. M., Winowiecki, L., Twyman, J., & Laderach, P.** (2014). Climate-smart agriculture in Kenya: Vulnerability and adaptation options for smallholders. *Climatic Change*, 126(3), 455–469.
- **National Institute of Statistics of Rwanda (NISR).** (2019). *Labour force survey annual report 2019*. NISR, Kigali, Rwanda.
- **National Institute of Statistics of Rwanda (NISR).** (2020). *Seasonal agricultural survey 2020*. NISR, Kigali, Rwanda.
- **National Institute of Statistics of Rwanda (NISR).** (2022). *Fifth Rwanda population and housing census 2022: District profile – Rwamagana*. NISR, Kigali, Rwanda.
- **Ntawuruhunga, D., Habimana, A., & Uwimana, C.** (2025). Evaluating the adoption and economic benefits of climate-smart agriculture practices in Eastern Rwanda. *Agricultural Systems*, 223, 103810.
- **Raghavendra, S., Smith, T., & Patel, K.** (2024). Global economic losses in smallholder agriculture under extreme weather variability. *World Development*, 174, 106420.
- **Rwanda Development Board (RDB).** (2021). *Rwamagana district investment profile and demographic report*. RDB, Kigali, Rwanda.
- **Rwanda Meteorology Agency (Meteo Rwanda).** (2020). *Five-year historical climate trend analysis report (2015–2020)*. Ministry of Environment, Kigali, Rwanda.
- **Sakijege, T.** (2019). Assessment of localized climate shocks and disaster management strategies in Rwanda's Eastern Province. *Journal of Disaster Risk Studies*, 11(1), 1–12.
- **Temesgen, B., & Wakweya, R.** (2026). Thermal stress impacts on crop physiology and agricultural yields in East Africa. *Theoretical and Applied Climatology*, 155(2), 889–902.
- **Teshome, H., Tesfaye, K., Dechassa, N., Tana, T., & Feyissa, M.** (2020). Quantifying the impacts of climate variability on maize and sorghum yield in Ethiopia. *Heliyon*, 6(11), e05484.

- **Twizerimana, M., Nsengiyumva, J. B., & Gasirabo, A.** (2025). Agro-ecological zoning and climate vulnerability mapping in Rwamagana District, Rwanda. *Applied Geography*, 162, 103140.
- **Uwitonze, P., Soli, F., & Mupenzi, J.** (2017). Climate variability and crop production trends in Rwanda: A case study of key food crops. *Rwanda Journal of Agricultural Sciences*, 2(1), 45–58.
- **World Bank.** (2018). *Rwanda economic update: Fostering climate-smart agriculture*. The World Bank Group, Washington, D.C.

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