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(RESEARCH ARTICLE)



THE IMPACT OF CLIMATE VARIABILITY ON MILK PRODUCTION AMONG DAIRY FARMERS IN RWANDA, CASE STUDY ON SELECTED COOPERATIVES IN GICUMBI DISTRICT

MUKAMANA Sandrine * and Ndakize Joseph SEBAZIGA

Faculty of Environmental Studies, University of Lay Adventists Kigali, Rwanda.

* Corresponding Author: Email: smukamana@gmail.com.

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ABSTRACT

In Rwanda, smallholder dairy farmers are increasingly experiencing the effects of changing weather patterns, which influence pasture availability, water resources, and milk production. Gicumbi District, known for its dairy farming potential, has experienced noticeable fluctuations in rainfall and temperature, yet limited empirical evidence existed on how these climatic changes affect milk production among dairy farmers. This study assessed the impact of climate variability on milk production among dairy farmers in selected cooperatives in Gicumbi District, Rwanda. The study employed a cross-sectional research design using both quantitative and qualitative approaches. Data were collected from 313 dairy farmers selected from a population of 1,442 cooperative members through structured questionnaires, key informant interviews, meteorological data and documentary review. Quantitative data were analyzed using descriptive statistics, correlation, and regression analysis with the help of SPSS, while qualitative data were analyzed thematically. The findings revealed that Gicumbi District is experiencing significant climate variability characterized by irregular rainfall patterns, delayed rainfall onset, early cessation, uneven rainfall distribution, and increasing temperatures. About 86.6% of respondents observed changes in rainfall patterns, while 81.8% reported changes in temperature, with 63.3% specifically indicating increasing heat levels. Milk production among dairy farmers was found to be moderate and highly seasonal, with most farmers producing between 5 and 10 liters of milk per cow per day. Production levels increased during rainy seasons due to improved pasture and water availability and declined sharply during dry seasons because of feed scarcity and water shortages. Regression analysis established a statistically significant relationship between climate variability and milk production ($R = 0.589$, $R^2 = 0.347$). Rainfall variability ($B = -0.421$, $p < 0.001$) and temperature variability ($B = -0.318$, $p < 0.001$) were found to have significant negative effects on milk production. The study concludes that climate variability significantly affects dairy productivity in Gicumbi District and threatens the sustainability of smallholder dairy farming systems. The study recommends the promotion of climate-smart dairy farming practices, improved pasture and water management, access to drought-resistant fodder and improved dairy breeds, strengthened extension services, and enhanced institutional support and climate information systems.

Keywords: Adaptation Strategies, Climate Variability, Dairy Farmers, Gicumbi District, Milk Production, Rwanda

1 INTRODUCTION

Climate variability has become an important issue affecting agriculture around the world (Hansen, 2020). It refers to changes in weather conditions such as temperature, rainfall patterns, and the frequency of extreme events like droughts and heavy rains (Amamou, 2020). These changes influence many farming activities. Dairy farming is particularly sensitive to climate conditions because cows depend on good weather for feed, water, and overall health. As noted by the Food and Agriculture Organization (FAO, 2023), the global dairy sector produces more than 930 million tonnes of milk every year and plays a major role in food security and rural livelihoods. However, according to the Intergovernmental Panel on Climate Change (IPCC, 2022), rising temperatures and irregular rainfall are increasingly affecting livestock productivity, including milk production.

According to Thornton (2021), climate variability affects dairy production mainly through heat stress, reduced feed availability, and declining forage quality. When temperatures become too high, cows experience stress that reduces their appetite and productivity. As noted by Jennifer Polsky and Marina von Keyserlingk (2017), heat stress alone can reduce milk production by about 10–25 percent per cow. In addition, irregular rainfall and drought reduce pasture growth, which limits the feed available for dairy cattle. According to James W. West (2022), poor feed quality and water shortages further reduce milk yield and affect animal health.

Climate variability also affects other aspects of dairy production. As noted by Carolina Rojas-Downing (2018), changes in climate can influence milk quality, reproductive performance, and disease occurrence among dairy cattle. These effects are expected to increase as climate change continues. According to the Intergovernmental Panel on Climate Change (IPCC, 2022), many regions of the world are already experiencing stronger climate impacts on agriculture, particularly in areas where farmers have limited resources to adapt.

In developed countries, dairy farmers have more technologies to reduce the effects of climate variability. According to Alessandro Bernabucci (2019), technologies such as cooling systems, improved cattle breeds, and advanced feeding methods help farmers maintain milk production even during hot periods. However, climate variability still affects dairy farms in these countries. As noted by Peter J. Hansen (2020), high temperature and humidity levels can still reduce milk yield, even in farms that use modern technologies. Research in the United States also shows that heat stress causes economic losses in the dairy sector. According to Normand St-Pierre (2021), heat stress costs the U.S. dairy industry more than 1.5 billion US dollars every year due to reduced milk production and increased veterinary costs.

The situation is more challenging in low- and middle-income countries where most dairy farmers are smallholders. According to International Fund for Agricultural Development (IFAD, 2021), smallholder farmers often rely on rain-fed pasture and have limited access to improved feeds or climate-resilient technologies. As noted by Philip K. Thornton and Mario Herrero (2018), irregular rainfall and prolonged dry seasons can reduce milk production by 15–40 percent in many parts of Africa and Asia. According to Hatem Amamou (2020), these climate changes affect feed availability, water access, and animal health, which ultimately lowers dairy productivity and farmer income.

Across Africa, climate variability has become a major threat to livestock production. According to the Intergovernmental Panel on Climate Change (2022), average temperatures in Africa have increased by about 0.3°C per decade since the 1980s. This change has been accompanied by irregular rainfall and more frequent droughts. As noted by Klaus Descheemaeker (2018), climate-related feed shortages and heat stress reduce milk production and increase livestock diseases in many African countries. Similarly, according to Armel Montcho (2022), droughts in several African regions have led to significant declines in dairy productivity. Studies in Kenya and Ethiopia also show that milk production among smallholder farmers can drop by up to 50 percent during severe drought periods (Ngigi et al., 2019; Bekele et al., 2021). As noted by AdeyemiAreo (2023), such impacts threaten food security and the livelihoods of many rural households.

Rwanda's dairy sector has experienced substantial growth over the past two decades, contributing significantly to household nutrition, income generation, and national economic development (NISR, 2022). According to the Ministry of Agriculture and Animal Resources (2021), national milk production increased from approximately 142,000 tonnes in 2005 to over 890,000 tonnes in 2020. Despite this growth in total production, milk productivity per cow remains relatively low. The National Institute of Statistics of Rwanda (2022) reports an average yield of 6 to 8 litres per cow per day, which is far below the potential productivity of 18 to 22 litres under improved feeding and management systems. This persistent productivity gap continues to constrain farmer incomes and limits the full economic potential of the dairy sector.

Previous studies have identified multiple constraints affecting dairy productivity in Rwanda, including inadequate quality feeds, limited access to improved breeds, and suboptimal animal husbandry practices (Mpakaniye and Uwimpuhwe, 2025). However, an increasing body of evidence highlights climate variability as a critical and growing

factor influencing livestock production systems. For instance, Rurangwa (2020) found that irregular rainfall patterns and rising temperatures reduce pasture availability and negatively affect cattle health, thereby lowering milk yields. Similarly, Manishimwe (2023) reported that prolonged dry seasons contribute to severe feed shortages, increased production costs, and reduced milk output among smallholder dairy farmers.

Climate variability has been widely recognized in global and regional studies as a key driver of agricultural vulnerability, particularly in rain-fed livestock systems (Bekele et al., 2021). However, most existing research in Rwanda has focused on general agricultural production or broad climate impacts, with limited attention given to the specific relationship between climate variability and dairy productivity outcomes such as milk yield.

This gap is particularly important in Gicumbi District, where a large proportion of households depend on dairy farming for both income and nutrition. The district experiences noticeable variations in rainfall distribution and increasing dry spell frequency, which directly affect pasture regeneration and feed availability. Despite ongoing national efforts to promote climate-smart agriculture, there remains limited localized empirical evidence quantifying how climate variability specifically influences milk production among dairy farmers in this area.

Therefore, this study seeks to assess the impact of climate variability on milk production among dairy farmers in selected cooperatives in Gicumbi District, Rwanda, in order to generate evidence that can inform targeted adaptation strategies, improve dairy productivity, and strengthen climate-resilient livestock systems.

2 RESEARCH METHODOLOGY

2.1 Description of the Study Area

Gicumbi District is located in the Northern Province of Rwanda and covers approximately 956.5 km². The district is characterized by hilly and mountainous terrain with elevations ranging from 1,400 to 2,800 meters above sea level, which greatly influence local climatic conditions and agricultural activities. Gicumbi experiences a cool tropical highland climate with two rainy and two dry seasons. Annual rainfall ranges between 1,200 mm and 1,500 mm, while average temperatures range from 16°C to 20°C, creating generally favorable conditions for dairy farming (NISR, 2023).

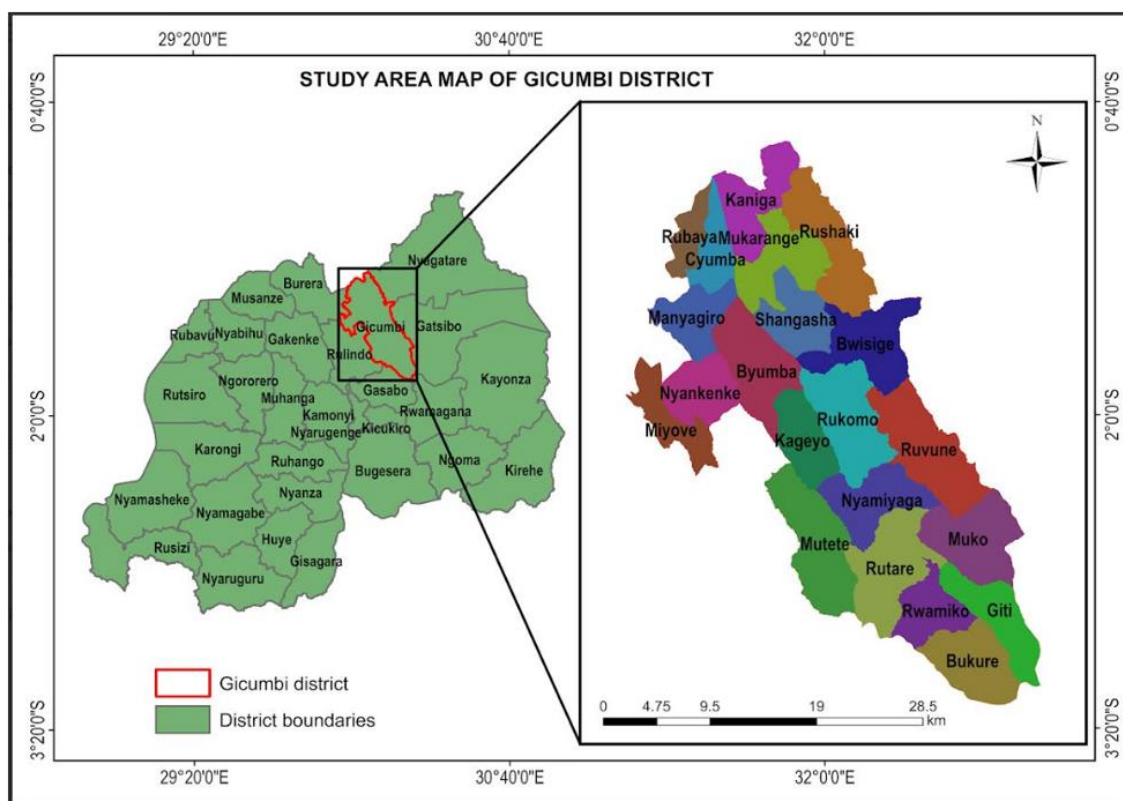


Figure 1: Study Area map

The district falls mainly within the Congo-Nile Divide and Buberuka Highlands agro-climatic zones, which are known for high rainfall, fertile soils, and suitability for livestock keeping. Agriculture is the main economic activity, with dairy farming playing an important role in household income and nutrition. However, climate variability, including irregular

rainfall, prolonged dry spells, and temperature fluctuations, increasingly affects pasture growth and milk production. Gicumbi District was selected for this study because of its strong dairy farming potential, varied topography, and observable climate variability, making it suitable for examining the relationship between climate variability and milk production among smallholder dairy farmers (RAB, 2021).

2.2 Research Design

This study used a cross-sectional descriptive research design combined with retrospective data analysis to examine the impact of climate variability on milk production among dairy farmers in Gicumbi District.

2.3 Sources of Data

Primary data were collected from dairy farmers in Gicumbi District using structured questionnaires and interviews. The data included information on milk production levels, herd characteristics, farm management practices, farmers' perceptions of climate variability, and socio-economic characteristics. In addition, Key Informant Interviews were conducted with milk collection center managers, agricultural extension officers, cooperative leaders, and officials from RAB and MINAGRI to gather insights on climate trends, milk production patterns, adaptation strategies, and institutional support programs. The combination of farmer surveys and stakeholder interviews enhanced the reliability and comprehensiveness of the study findings.

Secondary data were obtained from the Rwanda Meteorology Agency and cooperative milk collection centers. Meteorological records on rainfall and temperature covering the period 2010–2025 were used to analyze climate variability trends, while agricultural records provided information on milk production trends, herd composition, and livestock population dynamics. These secondary data complemented the primary data and strengthened the analysis of the relationship between climate variability and milk production in Gicumbi District.

2.4 Sampling Method and Sample Size

2.4.1 Sample Size Determination

The total population of the study, as presented in Table 1, is 1,442 respondents, comprising dairy farmers from cooperatives as well as milk collectors and transporters involved in the dairy value chain in Gicumbi District. To determine the appropriate sample size for the study, Yamane's (1967) formula was used. This formula is widely applied in social science research to calculate sample size from a finite population. The calculated sample size was 313 respondents. Table 1 below displays the sample size for both qualitative and quantitative data.

Table 1: Combined Sample Size for Quantitative and Qualitative Data by Population Category

Population Category	Total Population (N)	Proportion (N/1510)	Quantitative Sample (n)	Qualitative Sample (n)
IAKIB	704	0.466	153	0
COOPEMOBU	360	0.238	78	0
Jyambere Mworoz Ruvune	378	0.25	82	0
Milk collectors	-	-	0	8
Milk transporters	-	-	0	8
Agricultural extension officers	-	-	0	4
Leaders of dairy cooperatives	-	-	0	6
District-level officials (RAB)	-	-	0	2
Total	1442	1	313	28

Source: Calculated by the Researcher based on reports from Gicumbi District (2025) and field design (2026)

2.4.2 Sampling Techniques

The study employed a multi-stage sampling technique that combined probability and non-probability sampling methods to ensure representativeness and capture diverse perspectives. The quantitative sample of 313 respondents was proportionately distributed among different study categories, including IAKIB, COOPEMOBU, Jyambere Mworozu Ruvune, milk collectors, and milk transporters, according to their population sizes.

Stratified random sampling was used to select respondents within each category based on characteristics such as herd size and farming experience, while random number generation helped minimize selection bias. For qualitative data, purposive sampling was applied to select knowledgeable key informants, including cooperative leaders, milk collection center managers, agricultural extension officers, and officials from RAB and MINAGRI. This approach ensured both statistical representativeness and detailed qualitative insights, strengthening the reliability and comprehensiveness of the study.

2.5 Data Analysis

2.5.1 Quantitative Data Analysis

Quantitative data from questionnaires and secondary sources were coded, cleaned, and analyzed using SPSS version 28. To assess historical climate variability trends, rainfall and temperature data from 2010–2025 obtained from Meteo Rwanda were analyzed using the Mann–Kendall test to detect trends and graphical trend analysis to visualize climate variations over time.

To evaluate milk production status and trends, descriptive statistics such as means, standard deviations, frequencies, and percentages were used to summarize milk yields, herd characteristics, and farm management practices. Seasonal differences in milk production between rainy and dry seasons were analyzed using comparative statistical tests, while trend graphs and cross-tabulations were used to examine production patterns across seasons and farming categories.

To examine the relationship between climate variability and milk production, correlation and regression analyses were conducted. Climate variables such as rainfall and temperature were matched with milk production data to determine their influence on milk yield while controlling for farm-level factors. Statistical significance was tested at the 95% confidence level ($p < 0.05$). Trend analysis, line graphs, and scatter plots were also used to visualize relationships and seasonal fluctuations in milk production.

2.5.2 Qualitative Data Analysis

Qualitative data from key informant interviews and observations were analyzed using thematic content analysis. Data were transcribed, coded, and grouped into themes related to climate variability, milk production challenges, and adaptation strategies. The qualitative findings were triangulated with quantitative results to improve validity and provide deeper explanations of the study findings. Results were presented using tables, charts, graphs, descriptive narratives, and selected respondent quotations.

2.5.3 Ethical Considerations

Before data collection, ethical clearance was obtained from the relevant authorities at UNILAK, and permission to conduct the study was sought from local authorities in Gicumbi District and the selected dairy cooperatives. The study complied with institutional ethical guidelines governing research involving human participants. All respondents were informed about the purpose, objectives, and procedures of the study prior to their participation. Participation was voluntary, and informed consent was obtained from all participants before administering questionnaires and conducting interviews. Participants were assured that the information they provided would be treated with strict confidentiality and used solely for academic purposes. To protect respondents' privacy, no personal identifiers were included in the analysis or reporting of findings.

3 FINDINGS

The findings in Table 2 show that the majority of respondents were male (64.2%), while females accounted for 35.8%, indicating that dairy farming activities are predominantly managed by men in the study area. This gender distribution reflects the labor-intensive nature of livestock farming, which often requires substantial physical input.

Regarding age distribution, most respondents (46.6%) were in the 31–45 age group, followed by 24.9% aged 46–60 years. This suggests that dairy farming in Gicumbi District is mainly undertaken by economically active and middle-aged individuals who are likely to have both experience and physical capacity to manage livestock. In terms of education, the majority of respondents had primary education (45.0%), followed by secondary education (31.0%), while 13.4%

had no formal education. Only 10.5% had attained tertiary education. This indicates a moderate level of literacy among dairy farmers, which may influence their ability to adopt improved farming practices and respond to climate variability information.

Table 2: Demographic Characteristics of Respondents (n = 313)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	201	64.2
	Female	112	35.8
Age	18–30 years	58	18.5
	31–45 years	146	46.6
	46–60 years	78	24.9
	Above 60 years	31	9.9
Education level	No formal education	42	13.4
	Primary	141	45
	Secondary	97	31
	Tertiary	33	10.5
Marital status	Single	39	12.5
	Married	236	75.4
	Widowed	26	8.3
	Divorced/Separated	12	3.8
Main occupation	Farming	271	86.6
	Business	22	7
	Formal employment	12	3.8
	Other	8	2.6
Farm size	<1 ha	89	28.4
	1–2 ha	142	45.4
	2–5 ha	63	20.1
	>5 ha	19	6.1
Length of residence	Less than 5 years	28	8.9
	5–10 years	67	21.4
	11–20 years	104	33.2
	Above 20 years	114	36.4

Source: Primary data

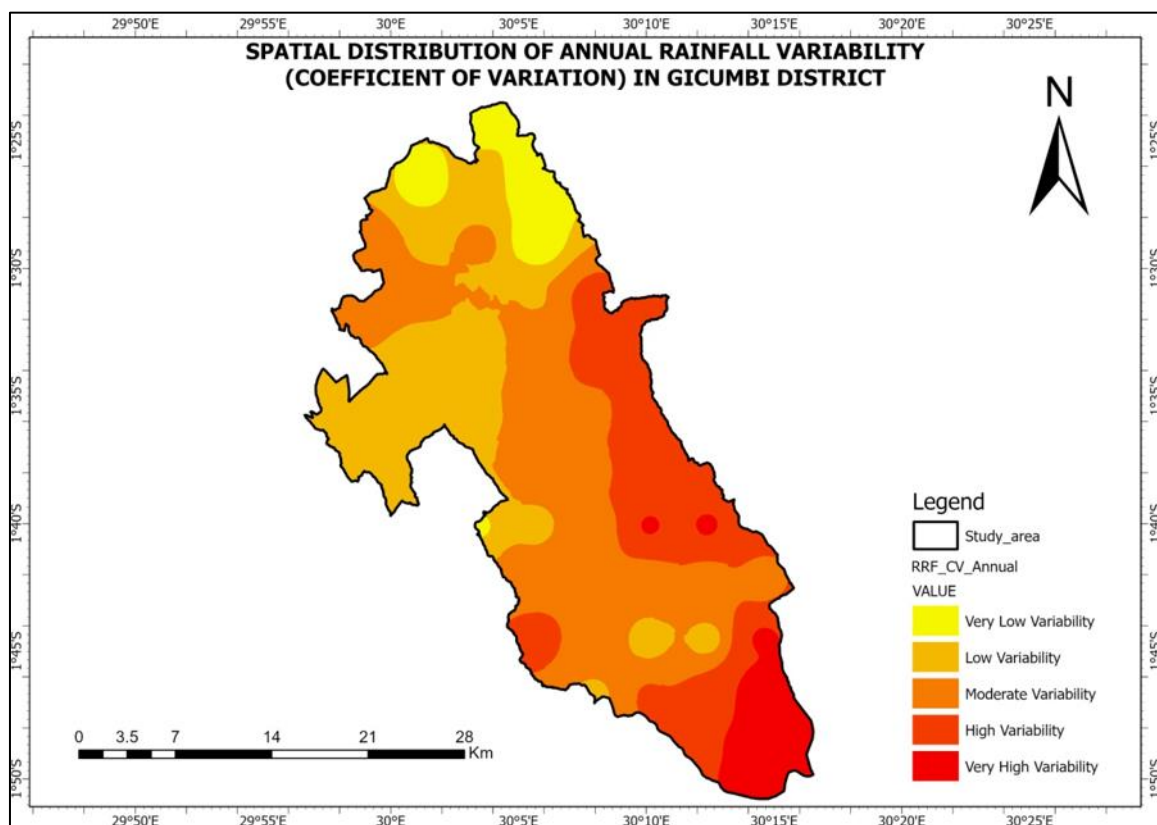
The marital status results show that most respondents (75.4%) were married, suggesting that dairy farming is largely a household-based economic activity supporting family livelihoods. Widowed, single, and divorced respondents represented smaller proportions. With respect to occupation, a large majority (86.6%) were primarily engaged in farming, confirming that dairy production is the main source of livelihood in the study area. Only a small proportion engaged in business (7.0%), formal employment (3.8%), or other activities (2.6%). Finally, farm size distribution indicates that most respondents (45.4%) owned between 1–2 hectares of land, followed by 28.4% with less than 1 hectare. Only a small proportion (6.1%) had more than 5 hectares, suggesting that dairy farming is largely practiced on small to medium-scale farms. Finally, the findings indicate that the majority of respondents, 114 (36.4%), had lived in the study area for more than 20 years, followed by 104 (33.2%) who had resided there for 11–20 years, while only 28 (8.9%) had lived in the area for less than 5 years.

3.1 Climate Variability Trends

This section presents the findings related to the first research objective, which is to assess historical climate variability trends (temperature and rainfall fluctuations) in selected cooperatives in Gicumbi District between 2010 and 2025. The analysis focuses on key indicators such as perceived rainfall changes, temperature changes, and observed climate variability patterns among dairy farmers.

Using Mann–Kendall and Sen’s slope tests to assess trend significance and magnitude, Figure 4.1 presents the monthly rainfall climatology of Gicumbi District for the period 2010–2025, showing the seasonal distribution and variability of rainfall over time. The analysis indicates noticeable fluctuations in rainfall patterns across the study period, with some years recording above-average precipitation while others experienced prolonged dry conditions. The rainfall regime generally follows the bimodal pattern characteristic of Rwanda, with the long rainy season occurring between March and May and the short rainy season extending from September to December. However, variations in the onset, intensity, and duration of rainfall seasons were observed, reflecting increasing climate variability in the district.

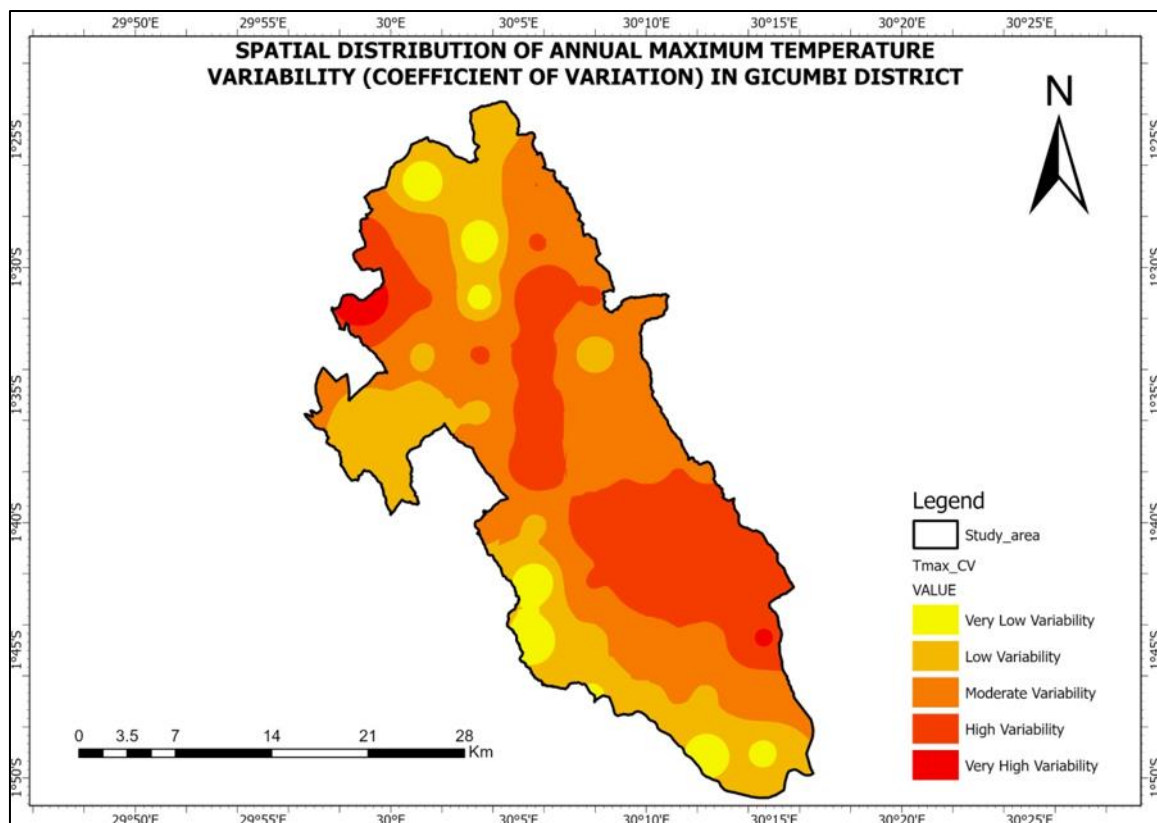
The Mann–Kendall trend test revealed a weak negative rainfall trend over the study period ($\tau = -0.133$), although the trend was not statistically significant at the 5% significance level ($p > 0.05$). This suggests that while rainfall variability exists, there is insufficient evidence to confirm a strong long-term decline in total rainfall amounts. Nevertheless, the Sen’s slope estimator showed a slight negative slope of approximately -4.74 mm per year, indicating a gradual reduction in annual rainfall totals over time.



Source: Rwanda Meteorology Agency (Meteo Rwanda), 2010-2025

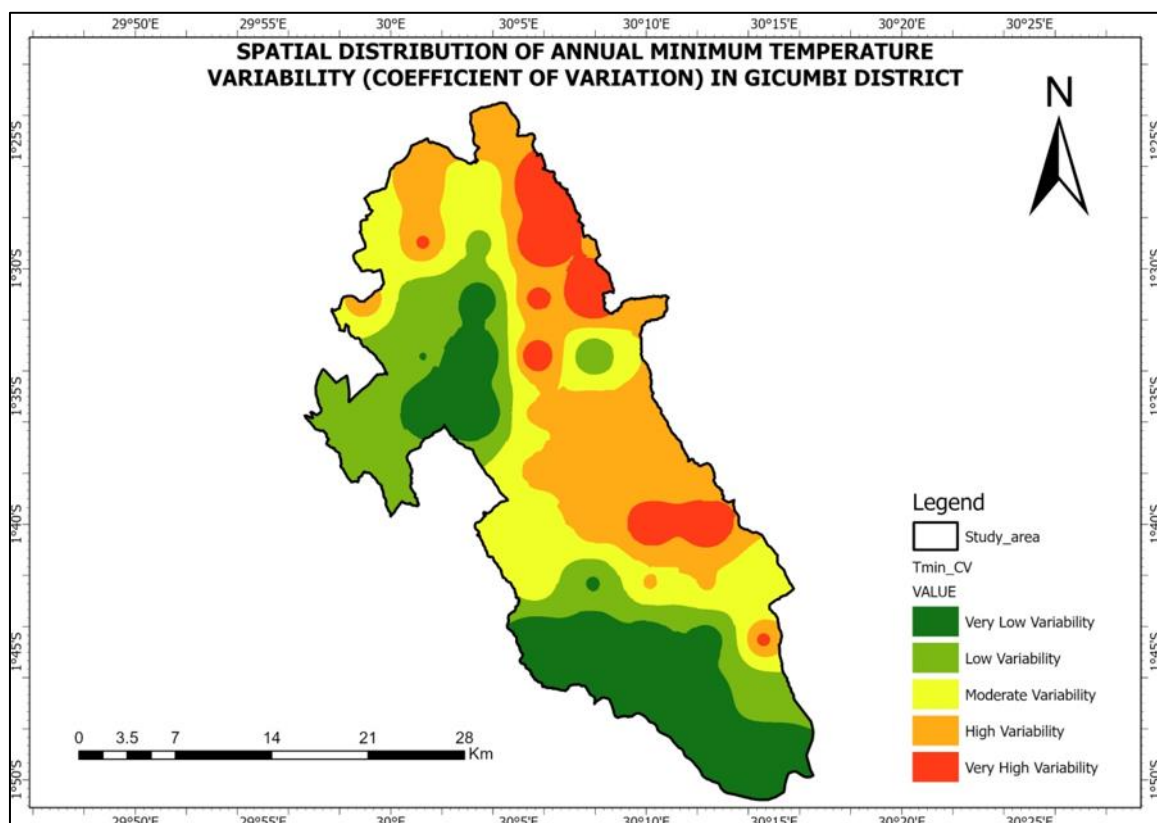
Figure 2: Spatial Distribution of Annual Rainfall Variability (Coefficient of Variation) in Gicumbi District (2010-2025)

Figure 2 presents the spatial distribution of annual rainfall variability in Gicumbi District for the period 2010-2025, using the coefficient of variation (CV) to measure the degree of inter-annual rainfall fluctuation across different areas. The map shows clear spatial heterogeneity in rainfall stability, with some locations exhibiting high CV values, indicating strong year-to-year variability in rainfall amounts, while other areas show relatively lower CV values, reflecting more stable and consistent rainfall patterns. The zones with higher rainfall variability are more exposed to climate-related risks such as drought episodes, unpredictable growing seasons, and reduced agricultural reliability, which may negatively affect crop and livestock production systems. In contrast, areas with lower variability tend to benefit from more predictable rainfall conditions, supporting better agricultural planning and water resource management. Overall, the spatial pattern highlights that rainfall variability in Gicumbi District is unevenly distributed, emphasizing the need for location-specific climate adaptation and resilience strategies.



Source: Rwanda Meteorology Agency (Meteo Rwanda), 2010-2025

Figure 3: Spatial Distribution of Annual Maximum Temperature Variability (Coefficient of Variation) in Gicumbi District (2010-2025)



Source: Rwanda Meteorology Agency (Meteo Rwanda), 2010-2025

Figure 4: Spatial Distribution of Annual Minimum Temperature Variability (Coefficient of Variation) in Gicumbi District (2015-2025)

Figure 3 presents the spatial distribution of annual maximum temperature variability in Gicumbi District for the period 2010-2025 using the coefficient of variation (CV), showing clear spatial differences in how maximum temperatures fluctuate across the district. The map indicates that some areas experience higher variability, reflected by higher CV values, meaning that maximum temperatures in these zones vary significantly from year to year and are therefore more unstable and less predictable. In contrast, other areas show lower CV values, indicating relatively stable and consistent maximum temperature conditions over time. This spatial pattern suggests uneven exposure to thermal climate risks within the district, where high-variability zones are more likely to experience heat stress impacts on agriculture, livestock, and human activities, while low-variability zones benefit from more stable climatic conditions that support better planning and adaptation.

Figure 4 presents the spatial distribution of annual minimum temperature variability in Gicumbi District for the period 2010-2025 using the coefficient of variation (CV), illustrating how consistently or inconsistently minimum temperatures fluctuate across different areas of the district. The map shows clear spatial heterogeneity, with some locations exhibiting higher CV values, indicating greater inter-annual variability and less stable minimum temperature conditions, while other areas show lower CV values, reflecting more stable and consistent nighttime temperature patterns over time. Areas with higher variability are more exposed to thermal instability, which can affect crop growth cycles, livestock health, and human comfort, particularly due to fluctuating cold stress conditions. Overall, the figure demonstrates that minimum temperature variability is unevenly distributed across Gicumbi District, highlighting spatial differences in climate stability and associated vulnerability to temperature-related risks.

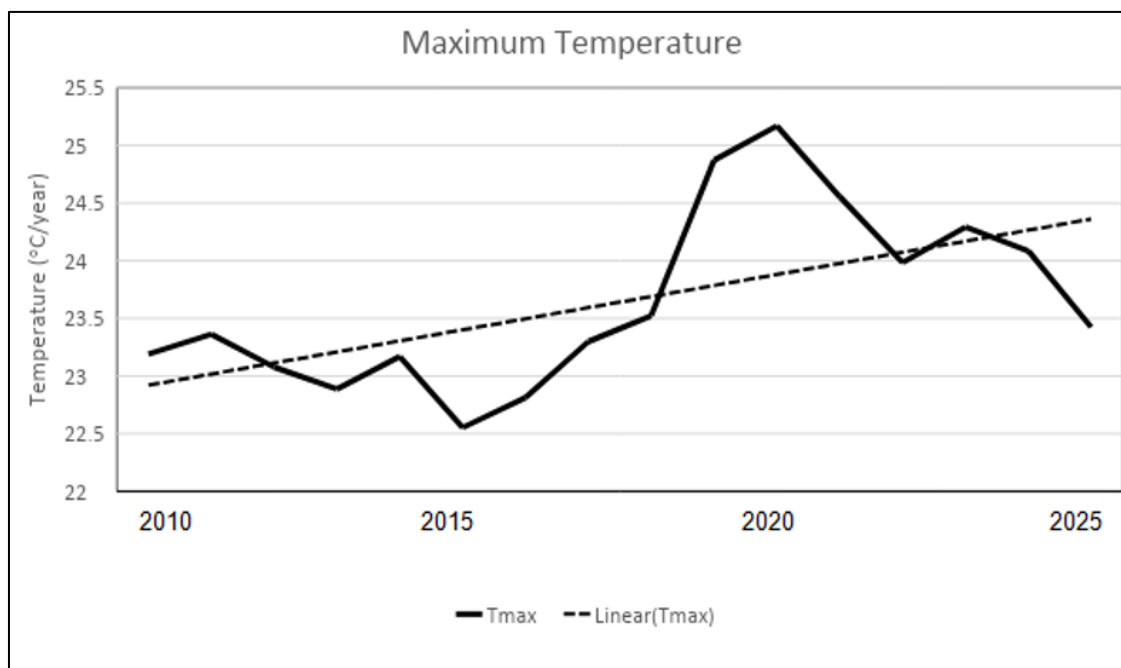


Figure 5: Maximum Temperature in Gicumbi District (2010-2025)

Figure 5 presents the trend of maximum temperature in Gicumbi District over the period 2010-2025, showing how daily or annual peak temperatures have changed over time. The graph indicates a general upward trend in maximum temperatures, with noticeable inter-annual fluctuations where some years record relatively lower peaks while others show higher temperature extremes. Despite these variations, the overall pattern suggests a gradual increase in maximum temperature levels across the study period, reflecting a warming climate signal in the district. This rising trend implies increasing exposure to heat stress conditions, which may affect agricultural productivity, livestock performance, and water demand. Overall, the figure highlights a consistent but fluctuating increase in maximum temperatures in Gicumbi District between 2010 and 2025.

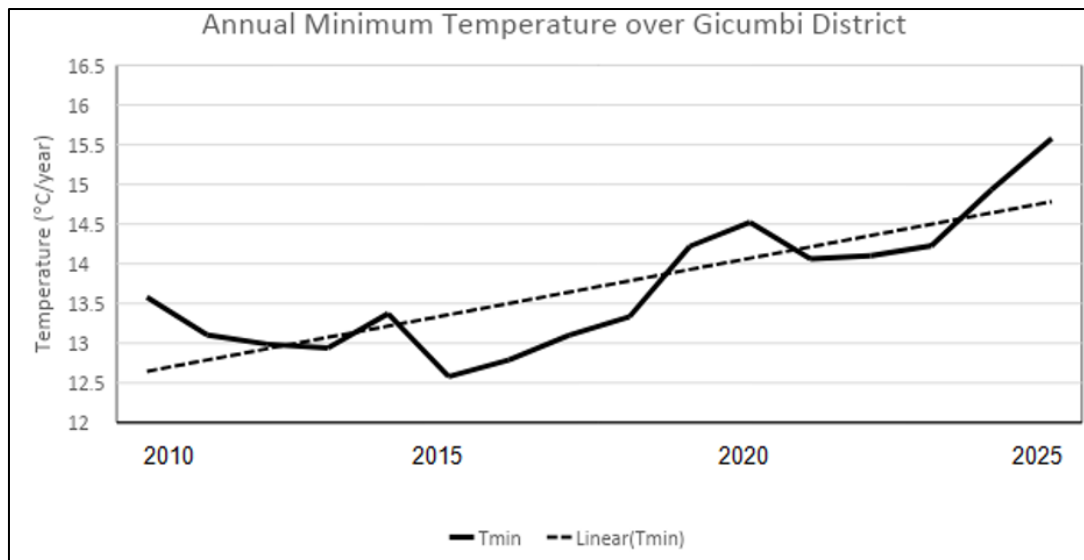


Figure 6: Annual Minimum Temperature in Gicumbi District (2010-2025)

Figure 6 presents the annual minimum temperature trends in Gicumbi District for the period 2010-2025, showing year-to-year variations in nighttime or lowest temperature conditions over time. The graph indicates noticeable fluctuations across the study period, with some years experiencing relatively cooler minimum temperatures while others record higher values, reflecting inter-annual climate variability. Despite these fluctuations, the overall trend shows a gradual increase in minimum temperatures, suggesting a progressive reduction in nighttime cooling and a general warming of the district over time. This upward trend in minimum temperatures is important because it can influence crop development cycles, increase pest and disease survival rates, and affect livestock and human thermal comfort. Overall, the figure highlights both variability and a consistent warming tendency in annual minimum temperatures in Gicumbi District between 2010 and 2025.

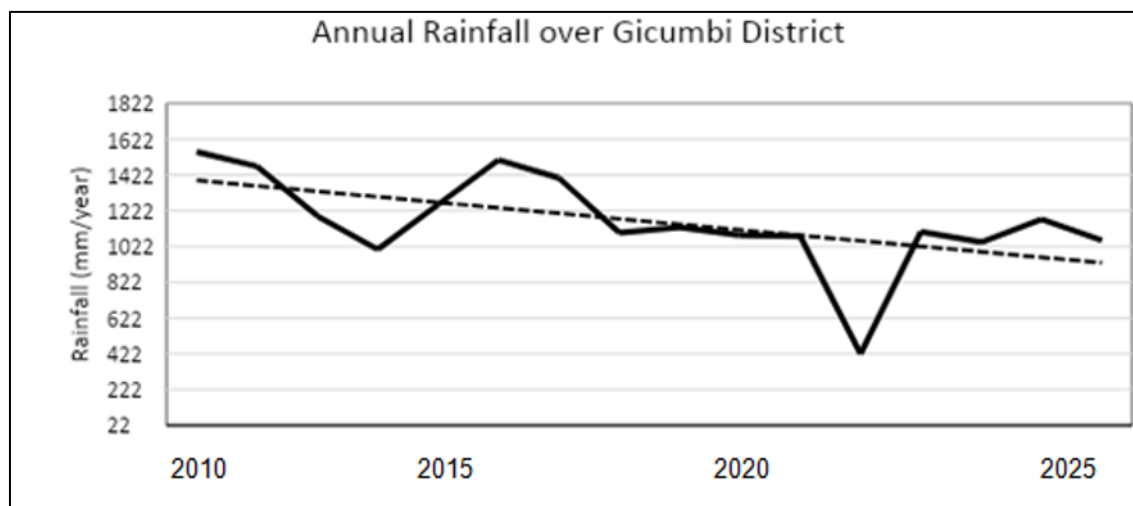


Figure 7: Annual Rainfall in Gicumbi District (2010-2025)

Figure 7 presents the annual rainfall trends in Gicumbi District for the period 2010–2025, illustrating the inter-annual variability in total rainfall received over time. The graph shows noticeable fluctuations from year to year, with some years recording relatively high rainfall amounts while others experience lower totals, reflecting strong rainfall variability within the study period. Despite these fluctuations, the overall pattern suggests a slight declining tendency in annual rainfall, although not strictly uniform across all years. This variability indicates increasing instability in rainfall distribution, which may affect agricultural planning, crop yields, and water availability in the district. Overall, the figure highlights both high inter-annual variability and a weak downward trend in annual rainfall in Gicumbi District between 2010 and 2025.

3.2 Milk Production Status and Trends

This section presents the findings related to the second research objective, which is to evaluate the status and trends of milk production (total yield and seasonal availability) among dairy farmers in selected cooperatives in Gicumbi District. The analysis focuses on key indicators such as milk yield per cow, total herd production, seasonal variation, and production trends over time.

Table 2: Milk Production Characteristics of Dairy Farmers (n = 313)

Variable	Category	Frequency (n)	Percentage (%)
Milk yield per cow/day (liters)	<5 liters	74	23.6
	5–10 liters	161	51.4
	>10 liters	78	24.9
Total herd milk production/day	<20 liters	69	22
	20–50 liters	173	55.3
	>50 liters	71	22.7
Seasonal variation in milk production	Yes	258	82.4
	No	55	17.6
Season of highest production	Rainy season	237	75.7
	Dry season	58	18.5
	No difference	18	5.8
Season of lowest production	Dry season	244	77.9
	Rainy season	52	16.6
	No difference	17	5.5
Milk production trend (past years)	Increasing	68	21.7
	Decreasing	189	60.4
	Stable	56	17.9

The findings in Table 2 indicate that most dairy farmers produce between 5 and 10 liters of milk per cow per day (51.4%), while only 24.9% achieve production above 10 liters. This suggests that milk productivity in the study area is generally moderate and below optimal commercial dairy standards. In terms of total herd production, more than half of the respondents (55.3%) produce between 20 and 50 liters per day, while 22.0% produce less than 20 liters and 22.7% produce above 50 liters. These results reflect variations in herd size, breed type, and farm management practices among dairy farmers in Gicumbi District. The majority of respondents (82.4%) reported that milk production varies with seasons, confirming strong seasonal dependency. The rainy season was identified as the period of highest production by 75.7% of farmers, while 77.9% reported the dry season as the period of lowest production. This clearly indicates that milk production is highly sensitive to climatic conditions, particularly feed and water availability. Finally, analysis of production trends shows that 60.4% of respondents reported a decreasing trend in milk production over recent years, while only 21.7% reported an increase. This suggests that milk production is generally declining, which may be associated with climate variability and related stressors such as reduced pasture availability and heat stress.

Table 3: Seasonal Milk Production Estimates in Highland Dairy Systems (Metric Tons per Season)

Season	Estimated Milk Production (Metric Tons)	Interpretation
March – May	12,500 MT	Peak production due to abundant pasture
September – December	10,800 MT	High but slightly reduced production
January – February	6,200 MT	Reduced production due to feed scarcity
June – August	4,900 MT	Lowest production period

Source: Compiled from RAB Gicumbi district dairy production monitoring reports (2015–2025)

The findings in Table 3 indicate clear seasonal variation in milk production in highland dairy systems, with output closely linked to climatic conditions. The highest milk production is recorded during the long rainy season (March–May), reaching approximately 12,500 metric tons, attributed to abundant pasture and improved water availability. This is followed by the short rainy season (September–December), with production estimated at 10,800 metric tons, reflecting sustained but slightly reduced feed resources. In contrast, milk production declines significantly during the dry seasons, with the short dry season (January–February) recording about 6,200 metric tons due to limited pasture availability, while the long dry season (June–August) registers the lowest output at 4,900 metric tons. Overall, these results demonstrate strong seasonal dependency of milk production on rainfall-driven feed availability, consistent with monitoring reports from the Rwanda Agriculture and Animal Resources Development Board.

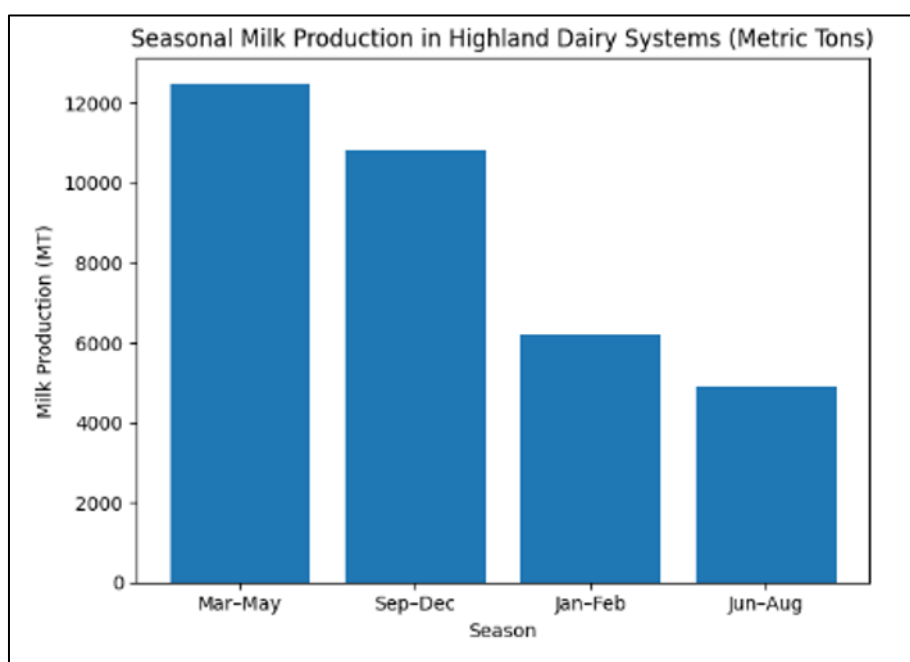


Figure 8: Seasonal Variation of Milk Production (Metric Tons) in Highland Dairy Systems (2010–2025)

The figure illustrates seasonal fluctuations in milk production expressed in metric tons, showing a clear cyclical pattern across the year. Production peaks during the rainy seasons, particularly March–May, where output reaches approximately 12,500 metric tons, supported by abundant pasture and water availability. The short rainy season (September–December) maintains relatively high production at around 10,800 metric tons, although slightly lower than the peak season.

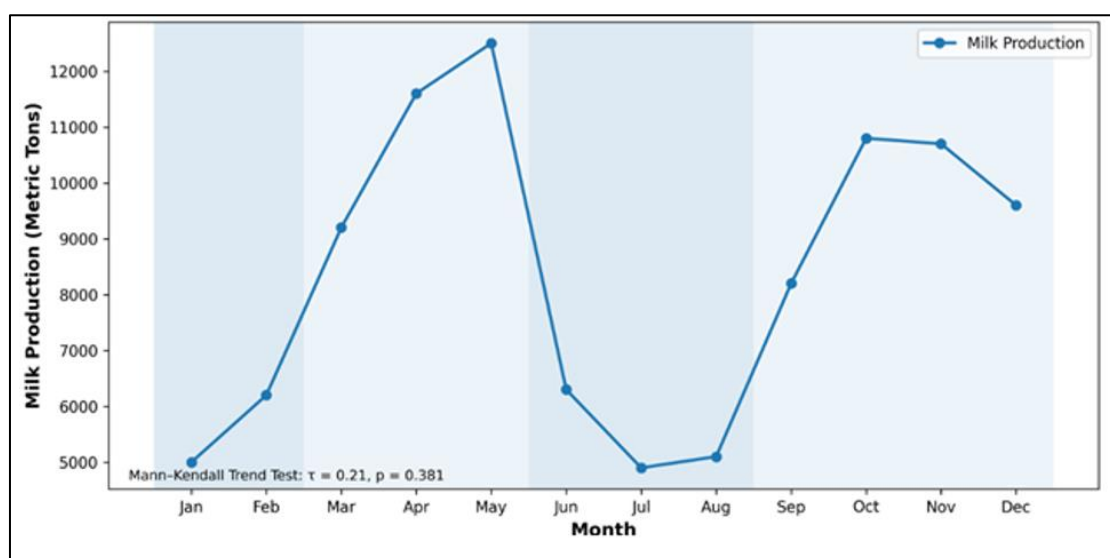


Figure 9: Intra-Annual Variability of Milk Production in Gicumbi District (2010–2025)

In contrast, milk production declines sharply during dry seasons. The short dry season (January–February) records approximately 6,200 metric tons, while the long dry season (June–August) shows the lowest production level at about 4,900 metric tons, mainly due to feed and water shortages. In sum, this pattern confirms strong seasonal dependency of milk production on climatic conditions, particularly rainfall-driven pasture availability, consistent with the findings from Gicumbi District. These findings are displayed also on Figure 4.8 showing monthly milk production in Gicumbi District. Figure 9 presents the variability of milk production in Gicumbi District from 2010 to 2025, demonstrating a clear seasonal pattern strongly linked to climatic conditions. The figure indicates that milk production increases significantly during rainy seasons when pasture availability and water supply are abundant, reaching peak production during March–May and maintaining relatively high levels during September–December. In contrast, milk production declines sharply during dry seasons, particularly between June and August, when feed scarcity and water shortages become more severe. The figure therefore highlights a strong dependency of dairy production on climatic conditions, suggesting that fluctuations in rainfall and temperature directly influence fodder availability, cattle nutrition, and ultimately milk productivity among dairy farmers in the selected cooperatives. In sum, the findings from Objective Two revealed that milk production among dairy farmers in Gicumbi District is generally moderate, with most farmers producing between 5 and 10 liters per cow per day and relatively few exceeding 10 liters.

3.3 Relationship Between Climate Variability and Milk Production

This section presents the findings related to the third research objective, which is to examine the relationship between climate variability and milk production among dairy farmers in selected cooperatives in Gicumbi District. The analysis focuses on key indicators such as climate variability variables (rainfall and temperature), milk production levels, and the statistical relationship between these variables using regression analysis.

Table 4: Model Summary of Climate Variability and Milk Production (n = 313)

Model	R	R Square	Adjusted R Square	Std. Error of Estimate
1	0.589	0.347	0.343	0.621

a. Predictors: (Constant), Rainfall variability, Temperature variability; b. Dependent Variable: Milk production (liters per cow/day); Source: Author's compilation (2026)

The findings in Table 4 indicate a moderate positive relationship between climate variability and milk production, with an R value of 0.589. The R Square value of 0.347 shows that 34.7% of the variation in milk production is explained by rainfall and temperature variability, while the adjusted R Square (0.343) confirms the reliability of the model. This suggests that climate variability is a significant factor influencing milk production, although other factors also contribute.

Table 5: ANOVA Results for Climate Variability and Milk Production

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	62.418	2	31.209	79.52	0.000
Residual	117.566	310	0.379		
Total	179.984	312			

Source: Author's compilation (2026)

The ANOVA results in Table 5 show that the regression model is statistically significant ($F = 79.52$, $p < 0.001$). This indicates that climate variability variables (rainfall and temperature) significantly predict milk production among dairy farmers. The significance level confirms that the relationship is not due to chance, and therefore the model provides a good fit for the data.

Table 6: Regression Coefficients for Climate Variability and Milk Production

Variable	B	Std. Error	Beta	t	Sig.
Constant	2.184	0.312	—	7	0
Rainfall variability	-0.421	0.081	-0.356	-5.2	0
Temperature variability	-0.318	0.074	-0.291	-4.3	0

Source: Author's compilation (2026)

The coefficients results show that both rainfall variability and temperature variability have a statistically significant negative effect on milk production. Rainfall variability ($B = -0.421$, $p < 0.001$) indicates that irregular rainfall patterns significantly reduce milk production. Similarly, temperature variability ($B = -0.318$, $p < 0.001$) shows that increasing temperatures negatively affect milk yield. The standardized beta values further confirm that rainfall variability (-0.356) has a stronger effect on milk production compared to temperature variability (-0.291). This suggests that changes in rainfall patterns are the most influential climate factor affecting dairy productivity in the study area.

Findings from KIIs supported the regression results showing a significant relationship between climate variability and milk production in Gicumbi District. Informants, including extension officers, cooperative leaders, and officials from the Rwanda Agriculture and Animal Resources Development Board, emphasized that both rainfall and temperature changes directly affect dairy productivity, with rainfall variability having a more pronounced impact. One informant explained that “when rainfall is irregular, pasture does not grow well, and this immediately reduces milk production,” while another noted that “increased temperatures cause heat stress in cows, lowering their milk yield.” Several informants further highlighted that “rainfall patterns are the most critical factor because they determine feed and water availability,” reinforcing the stronger negative effect of rainfall variability observed in the quantitative findings. Overall, these qualitative insights confirm that climate variability, particularly erratic rainfall and rising temperatures, plays a significant and negative role in shaping milk production trends among dairy farmers in the district.

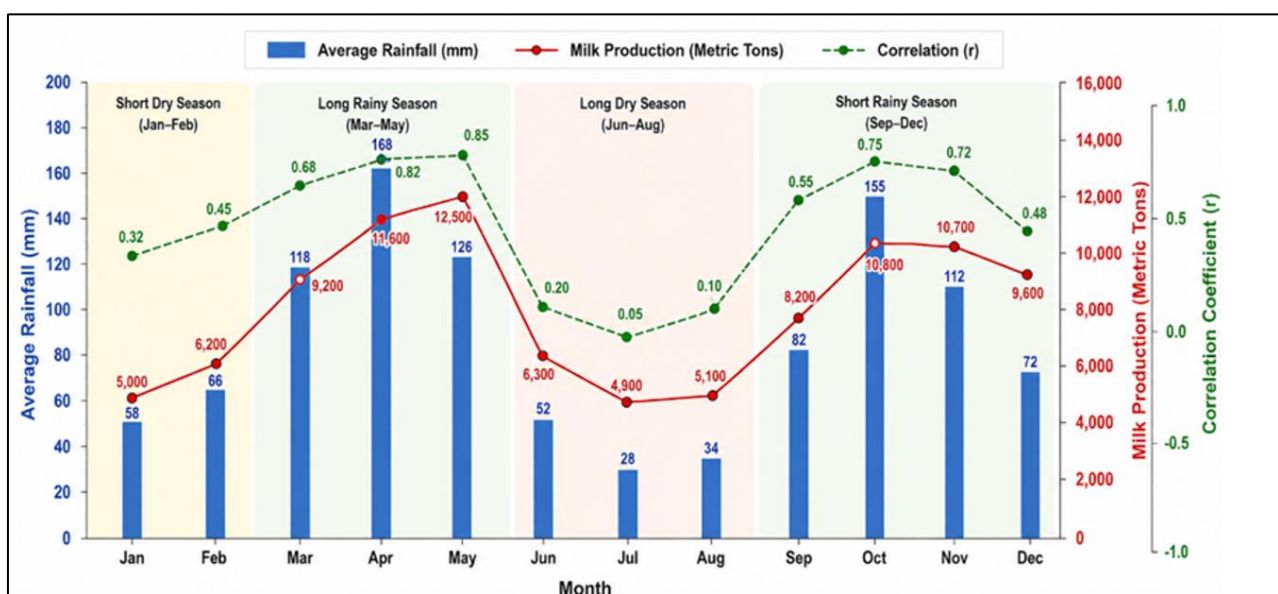


Figure 10: Correlation between Intra-Annual Climate Variability and Milk Production in Gicumbi District (2010–2025)

The findings presented in Figure 10 demonstrate a strong positive relationship between intra-annual climate variability, particularly rainfall patterns, and milk production in Gicumbi District between 2010 and 2025. The figure shows that milk production increases during the rainy seasons, especially between March and May, when rainfall levels are highest and pasture availability improves. During this period, milk production reaches peak levels of approximately 12,500 metric tons. Similarly, relatively high production is maintained during the short rainy season from September to November due to favorable moisture conditions and improved fodder availability.

In contrast, milk production declines considerably during the dry seasons, particularly between June and August, when rainfall amounts are lowest. The long dry season records the lowest milk output, mainly because reduced pasture growth and water scarcity negatively affect livestock feeding conditions and productivity. The correlation trend illustrated in the figure confirms that fluctuations in rainfall are closely associated with changes in milk production levels. Overall, the findings indicate that climate variability significantly influences dairy production in Gicumbi District, with favorable rainfall conditions supporting higher milk yields while prolonged dry periods contribute to reduced production among dairy farmers in the selected cooperatives.

4 DISCUSSION OF FINDINGS

The findings from Objective One showed that Gicumbi District is experiencing noticeable rainfall variability characterized by seasonal fluctuations, irregular rainfall distribution, and alternating wet and dry periods over the period 2010–2025. The monthly rainfall climatology revealed two major rainfall peaks occurring during March–May and September–November, while the dry season was particularly evident between June and August. The Mann–Kendall

trend analysis indicated a weak negative rainfall trend, and the Sen's slope estimator showed a slight annual decline in rainfall amounts, confirming the presence of climate variability in the district. These findings are consistent with Nyongesa et al. (2023) in Kenya, who reported that rainfall variability between 2010 and 2020 became increasingly unpredictable, with prolonged dry spells reducing pasture availability and milk production. In their study, over 70% of farmers reported difficulties in planning grazing activities due to shifting rainfall patterns, which corresponds with the findings of the present study where a large proportion of respondents reported noticeable changes in rainfall patterns and seasonal unpredictability affecting dairy farming activities.

The findings further indicate that changing rainfall conditions in Gicumbi District have important implications for dairy production because pasture growth, fodder availability, and water accessibility largely depend on seasonal rainfall performance. The prolonged dry conditions observed during the June–August period may contribute to reduced pasture regeneration and limited feed availability, which negatively affects milk productivity among dairy farmers. These results are in agreement with studies by Vroege et al. (2023) and Palandri et al. (2025), which demonstrated that climate variability significantly reduces livestock productivity through feed shortages, heat stress, and reduced animal performance. Although those studies focused strongly on temperature effects and technologically advanced dairy systems, the current study emphasizes the vulnerability of smallholder dairy farmers in Gicumbi who rely heavily on natural rainfall cycles and rain-fed fodder systems.

Furthermore, the seasonal rainfall variability observed in Gicumbi District corresponds with findings from Zhu et al. (2024), who highlighted the importance of climate regulation and adaptive management in sustaining dairy productivity. In the present study, milk production was reported to be higher during rainy seasons when pasture and water resources are more available, while production declines during dry periods due to fodder shortages and water stress. Overall, the findings suggest that climate variability remains a major challenge to dairy farming in Gicumbi District, particularly because of the strong dependence on rainfall-dependent production systems and limited adaptive capacity among smallholder dairy farmers.

The findings for Objective Two revealed that milk production among dairy farmers in Gicumbi District is generally moderate, with most farmers producing between 5 and 10 liters per cow per day and relatively few exceeding 10 liters. This pattern is consistent with findings by Ribeiro da Rosa et al. (2024), who reported that local breeds produce about 7.13 kg/day compared to 11.49 kg/day for crossbred cattle under similar climatic conditions. The results suggest that the dominance of local or low-performing crossbreeds, combined with limited feeding and management practices, contributes to moderate productivity levels in Gicumbi. However, while Ribeiro da Rosa et al. (2024) emphasized the role of breed type, the current study further highlights the combined influence of management practices and environmental constraints, particularly in smallholder systems where access to improved breeds and inputs is limited.

The study also found strong seasonal variation in milk production, with peak production occurring during the rainy seasons and significant declines during dry periods. This aligns with Nyongesa et al. (2023), who reported that rainfall variability directly affects pasture availability, leading to fluctuations in livestock productivity. Similarly, secondary data in the present study showed that milk production can reach about 12,500 metric tons during the long rainy season but drops to approximately 4,900 metric tons during the long dry season. These findings confirm that dairy production in Gicumbi is highly dependent on rainfall-driven feed availability. In contrast, studies such as Zhu et al. (2024) demonstrated that improved housing and controlled feeding systems can increase milk yield by up to 33%, reducing seasonal variability. This highlights a key difference, as dairy farmers in Gicumbi largely rely on natural pasture, making them more vulnerable to climatic fluctuations.

Furthermore, the declining trend in milk production observed in this study, with 60.4% of respondents reporting reduced output over time, is consistent with global evidence on the impacts of climate variability on dairy systems. For example, the University of Illinois (2025) found that extreme weather events led to a 1% annual reduction in milk production across approximately 18,000 dairy herds, equivalent to a loss of 1.4 billion pounds over five years. Similarly, Vroege et al. (2023) reported substantial reductions in milk output due to temperature increases. While the magnitude of decline in developed systems appears smaller due to technological adaptation, the current study suggests a more pronounced decline in Gicumbi, likely due to limited adaptive capacity and dependence on climate-sensitive resources. Overall, the findings confirm that milk production trends in the study area are shaped by a combination of climatic, biological, and management factors, with climate variability playing a central role in

The findings for Objective Three demonstrated a statistically significant relationship between climate variability and milk production in Gicumbi District, with rainfall and temperature jointly explaining 34.7% of the variation in milk yield ($R^2 = 0.347$). Both variables exhibited a negative effect, with rainfall variability ($B = -0.421$) having a stronger influence than temperature variability ($B = -0.318$). These results are consistent with Nyongesa et al. (2023), who found that unpredictable rainfall patterns, including delayed onset and prolonged dry spells, significantly reduced pasture availability and livestock productivity among smallholder dairy farmers in Kenya. While Nyongesa et al. (2023)

primarily provided qualitative evidence, the current study strengthens this relationship through quantitative analysis, clearly demonstrating the magnitude of climate influence on milk production.

The negative impact of temperature variability observed in this study also aligns with findings from Vroege et al. (2023) and Gisbert-Queral et al. (2021), who reported that a one standard deviation increase in temperature resulted in a reduction of approximately 20 metric tons of milk per farm annually in the United States. Similarly, Palandri et al. (2025) found that heat stress could reduce milk production by up to 10%, with effects persisting even after temperatures normalize. In comparison, the present study confirms a significant negative relationship between rising temperatures and milk yield in a smallholder context, where adaptive mechanisms such as cooling systems are largely absent. This suggests that the impact of temperature variability may be more severe in Gicumbi due to limited technological and management interventions.

Furthermore, the stronger effect of rainfall variability compared to temperature in this study is supported by Zhu et al. (2024), who demonstrated that improved environmental and feeding conditions can increase milk yield by 33%, emphasizing the critical role of feed availability in dairy productivity. In Gicumbi District, where feeding systems depend heavily on natural pasture, rainfall variability directly determines feed and water availability, thereby exerting a greater influence on milk production. Additionally, findings from the University of Illinois (2025) showed that extreme weather events caused a 1% annual decline in milk production across 18,000 herds, indicating that even in advanced systems, climate variability significantly affects productivity. Overall, while global studies confirm the negative effects of climate variability, the present study highlights that in rain-fed, smallholder systems like Gicumbi, rainfall variability plays a more dominant role than temperature, making dairy production highly vulnerable to changing climatic conditions.

The findings of this study have important implications for policy, practice, and research in Rwanda's dairy sector. The strong evidence that climate variability, particularly rainfall irregularity and rising temperatures, significantly reduces milk production highlights the urgent need for climate-resilient dairy farming strategies in districts like Gicumbi. Interventions should prioritize improving feed availability through pasture development, fodder conservation (e.g., silage and hay), and irrigation where feasible, alongside promoting climate-adapted and higher-yielding dairy breeds. Strengthening extension services and scaling up farmer training on adaptive management practices is also critical, with support from institutions such as the Rwanda Agriculture and Animal Resources Development Board. Additionally, investments in water infrastructure and early warning systems can help farmers better cope with seasonal variability. Overall, these measures are essential to stabilize milk production, enhance farmer resilience, and support sustainable dairy development under changing climatic conditions.

5 CONCLUSION

The study concludes that climate variability has a significant negative impact on milk production among dairy farmers in Gicumbi District, with increasing temperatures and irregular rainfall patterns disrupting pasture availability, water resources, and overall dairy farm management. The findings revealed that milk production is highly dependent on seasonal climatic conditions, with higher production during rainy seasons and reduced output during prolonged dry periods, confirming the vulnerability of dairy farming systems to climate variability. Rainfall variability emerged as the most influential climatic factor affecting milk production because of its direct effect on fodder availability and water supply, while rising temperatures contributed to heat stress and declining milk yields. Overall, the study demonstrates that dairy farming in Gicumbi District is highly climate-sensitive and constrained by limited adaptive capacity among smallholder farmers. Without effective adaptation measures, climate variability is likely to continue reducing dairy productivity and threatening farmer livelihoods. The study therefore emphasizes the need for climate-smart agricultural practices, improved pasture and water management, farmer training, and stronger institutional support from stakeholders such as the Rwanda Agriculture and Animal Resources Development Board to strengthen resilience and promote sustainable dairy production in the district.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Author Contributions

- Conceptualization: MUKAMANA Sandrine
- Data curation: MUKAMANA Sandrine
- Formal analysis: MUKAMANA Sandrine
- Methodology: MUKAMANA Sandrine
- Writing – original draft: MUKAMANA Sandrine
- Writing – review & editing: Ndakize Joseph SEBAZIGA

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