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Effects Climate Variability on Household Income Stability Among Smallholder Farmers in Rutsiro District of Western Province, Rwanda

Benjamin Ndayishimiye

realben.ndayishimiye@gmail.com

University of Lay Adventists of Kigali(UNILAK)

Jerome Ihuma

Bingham University

Delphine Mujawamariya

University of Lay Adventists of Kigali(UNILAK)

Jacques Nsengiyumva

Atlantic International University (AIU)

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Abstract

This study examined the effects of climate variability on household income stability among smallholder farmers in Rwanda as its main objective. The research was conducted in Ruhango and Murunda Sectors of Rutsiro District, Western Province, Rwanda, between 2024 and 2026. It focused on rainfall variability, floods, temperature changes, landslides, and extreme weather events and household income instability as well. A mixed-method research design was used, combining descriptive and explanatory approaches. Quantitative data were collected from 297 smallholder farmers using structured questionnaires. Qualitative data were obtained through key informant interviews with local leaders, agricultural extension officers and community representatives. Field observations, document review, and Meteo Rwanda climate data supported the study. Data were analyzed using descriptive statistics, correlation and regression analysis in SPSS version 28 and Excel. The findings showed that climate variability severely affects smallholder farmers. Rainfall had the highest mean score, followed by drought and temperature changes. Of the respondents, 60.3% were male and 39.7% female, with crop farming as the main income source. Household income was largely unstable, especially during droughts and extreme weather events. Statistical results showed a strong significant relationship between climate variability and income instability **($R = 0.822$, $R^2 = 0.675$, $p < 0.001$)**, meaning climate variability explains 67.5% of income instability. Farmers use different coping strategies such as adjusting planting dates, growing drought-resistant crops, and crop diversification, but these remain limited. The study concludes that climate variability has a strong negative effect on household income stability among smallholder farmers in study area. It recommends strengthening climate-smart agriculture, improving irrigation systems, soil conservation, and enhancing climate information services. Future research should examine the long-term impact of climate variability on agricultural productivity in other districts.

1.0 Introduction

Climate variability poses an escalating challenge to rain-fed agricultural systems across sub-Saharan Africa, where millions of smallholder farming households depend primarily on seasonal rainfall for their livelihoods and food security [1]. According to the Intergovernmental Panel on Climate Change (IPCC), climate-related events including extreme heat, heavy rainfall, prolonged droughts, and flooding have become more frequent and more severe, significantly disrupting food production systems and reducing rural income [2].

In Rwanda, agriculture contributes approximately 25–30% of Gross Domestic Product and employs over 60% of the population [3]. However, the majority of farming activities depend on rainfall rather than irrigation, exposing households to considerable vulnerability. The Western Province, including Rutsiro District, is particularly susceptible to climate variability due to its steep mountainous terrain, elevations ranging from 1,300–2,600 metres above sea level, and high annual rainfall concentrations. These geographic features amplify risks of soil erosion, landslides, and flooding during intense rainfall events [4].

Ruhango and Murunda Sectors in Rutsiro District exemplify this vulnerability. Most households cultivate beans, maize, Irish potatoes, bananas, and cassava on small plots under rain-fed conditions. When climate variability disrupts planting seasons, reduces yields, or destroys crops, household income becomes unstable and families struggle to meet basic needs[5]. Despite national-level evidence on climate-agriculture linkages, there is a scarcity of sector-specific, household-level data from Rutsiro District, limiting the capacity of policymakers to design targeted interventions [6].

The study sought to identify the major climate variability elements experienced by smallholder farmers in the study area; assess the level of household income stability among these farmers; determine the relationship between climate variability and household income instability; and identifying the coping and adaptation strategies employed by farmers to manage climate-induced income instability.

2.0 Material and Methods

2.1 Study area

As shown in Fig. 1, the study was conducted in Ruhango and Murunda Sectors of Rutsiro District, Western Province, Rwanda (approximately 1°50’S, 29°22’E). Rutsiro District has a population of approximately 369,180, with over 84% of households engaged in agricultural activities [7]. The landscape is mountainous and steep, with highly acidic, erosion-prone soils. The climate is classified as temperate tropical highland, characterised by consistent bimodal rainfall patterns.

2.3 Research design

A cross-sectional, mixed-methods research design was adopted, integrating quantitative survey data with qualitative information from key informant interviews and field observations. This design is well-suited to capturing both the statistical patterns and the contextual distinctions of climate variability impacts on rural livelihoods.

2.4 Sampling and Sample size

A mixed-methods research design was used, integrating descriptive and explanatory approaches. This design enabled both quantitative measurement of relationships and qualitative contextualization of farmer experiences. The target population comprised 1,149 smallholder farming households in the two sectors.

The sample size was calculated using Yamane's formula at a 95% confidence level and 5% margin of error:

$n = N / [1 + N(e)^2] = 1149 / [1 + 1149(0.05)^2] \approx 297$ households

Proportional allocation yielded 165 respondents from Ruhango and 132 from Murunda. Households were selected using systematic random sampling. Additionally, 24 key informants were purposively

selected (12 local leaders, 6 agricultural extension officers, 6 community representatives).

2.5 Data collection techniques

Primary data were collected using four complementary techniques: (i) structured questionnaires with five-point likert scales administered to 297 households; (ii) semi-structured key informant interviews; (iii) direct field observation of farm conditions; and (iv) documentary review of government reports. Secondary data were obtained from [3, 5, 7, 10]

Content validity was established through expert review, yielding a Content Validity Index (CVI) of 0.80 (24 relevant items out of 30), exceeding the 0.70 acceptable threshold.[8] Internal reliability was confirmed via Cronbach's Alpha ($\alpha \geq 0.70$), tested in a pilot study with 10% of the sample outside the study area.

2.6 Method of data analysis

Quantitative data were analyzed using descriptive statistics (means, standard deviations, and frequencies), Pearson correlation analysis, and simple linear regression, processed in SPSS. Qualitative data from interviews and observations were analyzed thematically. Instrument reliability was assessed using Cronbach's alpha, and construct validity was confirmed through expert review and pilot testing. The study adhered to ethical standards including informed consent, confidentiality, and voluntary participation.

3.0 Results

3.1 Socioeconomic and Demographic characteristics of respondents

As shown in Fig. 2 above, the respondents were almost equally distributed between Ruhango Sector (50.8%) and Murunda Sector (49.2%). Of the 297 respondents, 60.3% were male and 39.7% female. The majority (46.8%) were aged between 18 and 55 years, but more than 60% of them ranging between 25 and 45 of years old. Most respondents (53.2%) had between 11 and 20 years of farming experience, and 69.4% relied solely on farming as their primary source of household income. Crop farming was the predominant activity, practiced by 56.6% of respondents followed by mixed farming (crops and livestock) practiced by 30.3% and livestock farming (13.1%). These characteristics reflect a predominantly experienced, farm-dependent population with limited income diversification.

3.2 Climate variability elements

Table 1
Climate Variability Elements Experienced by Smallholder Farmers

Climate Variable	Frequency	Percent (%)	Mean	Std. Dev.
Rainfall variability (irregular rain)	275	92.6	4.21	0.78
Drought	264	88.9	4.11	0.85
Temperature changes (heat stress)	249	83.8	4.02	0.88
Other extreme weather events	217	73.1	3.89	0.94
Landslides	183	61.6	3.64	1.03
Floods	102	34.3	3.12	1.20
Source: Primary Data, 2026. n = 297, *Scale: 1 = Strongly Disagree; 5 = Strongly Agree*				

As shown in Table 1 above, rainfall variability was the most widely reported climate challenge, experienced by 92.6% of respondents (mean = 4.21, SD = 0.78), followed by drought (88.9%, mean = 4.11) and temperature changes (83.8%, mean = 4.02). Landslides affected 61.6% of respondents (mean = 3.64), while floods were the least reported (34.3%, mean = 3.12). The lower flood prevalence is consistent with findings from the Ministry in Charge of Emergency Management (MINEMA), which notes that steep mountainous terrain in Rutsiro makes landslides more dominant than riverine flooding [9].

3.3 Validation with Meteo-Rwanda Climate Data

Meteo-Rwanda records for Ruhango and Murunda Sectors over 2016–2025 corroborated farmer perceptions as shown in (Table 2 and Fig. 3). Average annual temperature increased steadily from 18.9°C (2016) to 19.9°C (2025), representing a 1.0°C rise over the decade. Annual rainfall declined from 1,592.6 (2016) mm to 1233.5 mm (2025) reflecting intensification of extreme weather events and confirming drier ambient conditions as mentioned by Farmers.

Table 2
Meteo-Rwanda climate data for Ruhango and Murunda sectors (2016–2025)

Year	Total rainfall (mm/year)	Avg temp (°C)
2016	1592.6	18.9
2017	1480.8	19.5
2018	1485.4	19.4
2019	1284.7	19.56
2020	1595.6	19.63
2021	1420.1	19.9
2022	1485.1	19.4
2023	985.9	20.1
2024	1406	20.53
2025	1233.5	19.9

Source:[10]

3.4 Household Income stability

Table 3
Level of Household Income Stability Among Smallholder Farmers

Statement	Freq. (SA + A)	Percent (%)	Mean	Std. Dev.
Income is sufficient to meet basic needs	191	64.3	3.82	1.02
Income fluctuates significantly between seasons	227	76.4	4.05	0.91
Income allows investment in farm inputs	178	59.9	3.70	1.08
Income affected by unexpected shocks (crop failure, floods)	241	81.1	4.12	0.87
Can save part of income regularly	132	44.4	3.22	1.15
Source: Primary Data, 2026 (n = 297)				

The results (Table 3) indicated a widespread income instability. A high proportion (81.1%) reported that unexpected shocks such as crop failure or floods affect income (mean = 4.12). Seasonal income fluctuations were noted by 76.4% of respondents (mean = 4.05). Only 44.4% could save regularly (mean = 3.22), reflecting limited financial resilience. Qualitative interviews confirmed that households manage

adequately after favorable harvests but fall into vulnerability during drought or landslides and flood events. One farmer said: "When rainfall fails, we have nothing to sell; we cannot buy food, pay school fees, or even prepare for the next season."

3.5 Relationship between Climate Variability and Household Income Instability

Pearson correlation analysis (Table 4) revealed a strong, positive, and statistically significant relationship between climate variability and household income instability ($r = 0.822$, $p < 0.001$, $n = 297$). This indicates that higher levels of climate variability are strongly associated with greater instability in household income. The relationship is not attributable to chance, as confirmed by the significance level well below the 0.05 threshold.

Table 4
Pearson Correlation between Climate Variability and Household Income Instability

Variable	Climate Variability	HH Income Instability
Climate Variability	1	0.822**
HH Income Instability	0.822**	1
p-value (2-tailed)	—	0.000
N	297	297
Source: Author, 2026		

3.6 Regression Analysis

Simple linear regression (Table 5) was conducted to assess the predictive power of climate variability on household income instability. The model yielded $R = 0.822$, $R^2 = 0.676$, and an Adjusted R^2 of 0.675, indicating that climate variability explains approximately 67.6% of the variance in household income instability. The ANOVA F-statistic was 614.557 ($p < 0.001$), confirming the overall significance of the model. The regression equation is expressed as:

$$HH\ Income\ Instability = 0.274 + 0.914 \times (Climate\ Variability) + \varepsilon$$

The coefficient for household income stability ($B = 0.914$, Beta = 0.822, $t = 24.790$, $p < 0.001$) indicates that for every one-unit increase in climate variability, Households income instability increases by 0.914 units, reflecting the strong bidirectional linkage between these variables.

Table 5
Regression Coefficients — Dependent Variable: HH Income Instability

Variable	B	Std. Error	Beta	t / Sig.
Constant	0.274	0.158	—	t = 1.741, p=.083
Climate Variability	0.914	0.037	0.822	t = 24.790, p=.000
Source: Author, 2026				

3.7 Coping and Adaptation Strategies

Farmers actively employ a range of strategies to manage climate-related income instability. As shown in Table 6, the most common strategy is adjusting planting dates to align with rainfall patterns (73.4%), followed by use of drought-resistant crop varieties (66.0%) and crop and livestock diversification (62.9%). Less commonly utilized strategies include surplus produce storage (47.8%), off-farm income seeking (46.5%), soil and water conservation techniques (44.1%), and access to government or NGO support programs (31.6%).

Table 6
Coping and adaptation strategies used by Farmers

Strategy	Freq.	Percent (%)	Mean	Std. Dev
Changing planting dates to match rainfall patterns	218	73.4	3.67	0.92
Using drought-resistant crop varieties	196	66.0	3.52	0.95
Diversifying crops and livestock	187	62.9	3.46	0.97
Storing surplus produce for future use	142	47.8	3.01	1.02
Seeking off-farm income opportunities	138	46.5	2.98	1.05
Using soil and water conservation techniques	131	44.1	2.92	1.08
Accessing government or NGO support programs	94	31.6	2.57	1.11
Source: Primary Data, 2026				

The relatively low uptake of institutional support programs (31.6%) suggests limited coverage and accessibility, pointing to an important gap in adaptive capacity among farming households.

4.0 Discussion

4.1 Climate Variability Patterns

The dominance of rainfall variability as the most prevalent climate challenge (92.6%) aligns with FAO findings that irregular precipitation is the primary driver of agricultural instability in sub-Saharan

Africa[11]. The strong agreement among respondents (mean = 4.21) and low standard deviation (0.78) confirm that this is a pervasive, not localized challenge. Meteo-Rwanda records corroborate these perceptions with a measurable 359.1 mm decline in annual rainfall over a decade and a near-doubling of storm days (12 to 29). This alignment between farmer perceptions and meteorological data strengthens the credibility of both data sources and reflects findings from comparable East African studies [12].

The distinction of landslides (61.6%) over floods (34.3%) is consistent with MINEMA's contingency planning reports, which attribute Rutsiro District's dominant hazard profile to steep terrain and high-intensity rainfall rather than riverine flooding [9].

The one of interviewed local leader said that, “Due to irregular rainfall occurrence in our area it results to high damages of infrastructures and land, caused by landslides and floods. And sometimes those hazards may result to loss of not only farmer’s properties but also their lives”. This statement aligns with literature showing that such events exist strongly in geographical area characterized by steep slopes, soil conditions, and high rainfall intensity [11]. This explains why landslides were mainly reported in areas with steep terrain, while floods were more common in low-lying locations. This contextual specificity underscores the importance of local-level evidence; a point reinforced by Ndayambaje and colleagues, who similarly found landslide risks to be disproportionately high in Western Rwanda's highland districts [13].

4.2 Level of Household Income Stability

The finding that 81.1% of households experience income shocks from unexpected climate events (mean = 4.12) reflects the systemic income vulnerability of rain-dependent smallholders. These results are consistent with the World Bank's assessment that over 90% of Rutsiro District households depend on agriculture as their primary livelihood, rendering income highly susceptible to seasonal and climate fluctuations [14]. However, the current study records a lower share of households relying exclusively on agriculture (69.4% versus 90% reported in 2018), suggesting that income diversification programs have had some impact. That nearly 70% still rely solely on agriculture highlights persistent vulnerability and the urgency of accelerating diversification efforts.

The low savings rate (44.4% saving regularly, mean = 3.22) indicates severely constrained financial resilience. This limits households' capacity to recover from shocks, invest in improved inputs, or adopt climate-smart technologies creating a well-documented poverty trap in which climate shocks perpetuate low productivity and reduced adaptive capacity [15].

4.3 Relationship between Climate variability and Income Instability

The strong Pearson correlation ($r = 0.822$, $p < 0.001$) and regression coefficient ($R^2 = 0.675$) establish climate variability as a dominant determinant of income instability, explaining 67.5% of variance. This finding surpasses previous estimates from comparable East African contexts: Mutunga and colleagues recorded moderate correlations ($r \approx 0.60$) in Kenya [16], while Deressa and colleagues found somewhat

lower explanatory power ($R^2 \approx 0.52$) in Ethiopian smallholder systems [17]. The higher values in the present study may reflect the particularly acute climate exposures in Rutsiro District's mountainous terrain and the high proportion of households relying exclusively on rain-fed agriculture.

The regression coefficient (B = 0.914) indicates that a unit increase in climate variability produces a near-equivalent unit increase in income instability; a relationship of particular policy significance. It demonstrates that without substantive climate adaptation measures, incremental climatic deterioration will produce nearly proportional income losses. This is consistent with global modelling by the IPCC, which projects that unmitigated warming will substantially increase poverty among rain-dependent smallholders in Africa [2].

4.4 Coping and Adaptation Strategies

The finding that adjusting planting dates (73.4%) is the most prevalent adaptation strategy reflects a widespread, low-cost behavioral response that requires no external inputs. This aligns with FAO climate-smart agriculture guidance, which identifies calendar adjustment as an accessible first-line adaptation for rain-fed systems [11]. However, its effectiveness is constrained when rainfall onset becomes increasingly erratic and unpredictable, as the Meteo-Rwanda data confirm. Drought-resistant varieties (66.0%) represent a technology-based adaptation that multiple studies identify as effective in reducing yield losses under water-deficit conditions[18]. The comparatively lower adoption of soil-water conservation techniques (44.1%) and government/NGO support programs (31.6%) indicates significant gaps in institutional outreach and access to capital-intensive adaptations. According to IFAD, households with diversified income sources are demonstrably more resilient to agricultural shocks [19], reinforcing the need to extend off-farm income support beyond the 30.6% currently accessing it.

5.0 Conclusions and recommendations

5.1 Conclusions

This study provides robust, sector-specific evidence that climate variability exerts a strong and statistically significant negative effect on household income stability among smallholder farmers in Ruhango and Murunda Sectors, Rutsiro District, Rwanda. Rainfall variability, drought, temperature change, landslides, and extreme weather events collectively undermine agricultural productivity and threaten household livelihoods. The strong relationship ($r = 0.822$, $R^2 = 0.675$, $p < 0.001$) demonstrates that climate variability is the primary driver of income instability in this system, accounting for over two-thirds of observed income variation. While farmers are actively implementing short-term coping strategies particularly calendar adjustments and drought-resistant varieties; these measures remain insufficient to fully counter the scale of climate-related income losses. Institutional support through government and NGO programs remains limited in reach, with less than one-third of households accessing such programs.

5.2 Recommendations

Based on the findings, the following policy and programmatic recommendations are made.

1. Local government authorities and MINAGRI should scale up climate-smart agriculture training, with specific focus on soil conservation, agroforestry, and improved water management. Irrigation development should be prioritized in sectors where topography permits, to reduce dependence on increasingly unreliable seasonal rainfall.
2. Income diversification must be actively promoted through support for livestock enterprises, small and medium enterprises, and cooperative savings schemes. Soil conservation and slope stabilization programs need strengthening, particularly in landslide-prone hillside areas.
3. Finally, Meteo-Rwanda and MINEMA should enhance the reach and accessibility of climate information and early warning systems to ensure that smallholder farmers receive actionable, location-specific forecasts at cell and village level. Future research should examine the long-term effects of climate variability on agricultural productivity across all districts of Rwanda. Additional studies should assess the cost-effectiveness of specific adaptation interventions, including irrigation scheme viability and the economic returns to climate-smart agriculture adoption at household scale. Research on gender-differentiated climate vulnerability would also strengthen the evidence base for targeted policy responses.

Declarations

6.1 Ethics approval and consent to participate

This study was reviewed and accepted by the Institutional Review Board of the University of Lay Adventists of Kigali (UNILAK). Ethical approval was also granted prior to data collection by Administrative Authorization of Rutsiro District, and all procedures were conducted in accordance with the ethical standards. The authorization letter of District has been provided as supplementary file 2.

All experiments and data collection procedures involving human participants were performed in accordance with the relevant guidelines and regulations, including the Declaration of Helsinki. Informed consent was obtained from all participants prior to their inclusion in the study.

6.2 Consent for publication

Not applicable, this research didn’t include an individual personal data or providing participant’s information

6.3 Availability of data and materials

The datasets used and analyzed during the current study are not publicly available.

6.3 Competing interests

The authors declare no competing interests

6.4 Funding Declaration

This research did not received specific grant from any funding.

6.5 Authors' contributions

NB Organized the study, collected data, analyzed data and drafted manuscript. JI critically reviewed the manuscript, DM and JN contributed to data interpretation and manuscript revision. All authors reviewed the final manuscript..

6.6 Questionnaire

The questionnaire used in this study was developed by the authors for this research and is provided as Supplementary File 1

References

1. Food and Agriculture Organization of the United Nations. (2022). *Climate variability and smallholder farmers' livelihoods in developing countries*. Rome: FAO.
2. Intergovernmental Panel on Climate Change. Climate change. (2022). *Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report.* Cambridge: Cambridge University Press.
3. National Institute of Statistics of Rwanda. (2023). *Statistical yearbook 2023*. Kigali: NISR.
4. Rutsiro District. (2025). *Environmental and Social Management Plan (ESMP) report for Rutsiro District.* Rutsiro District Local Government
5. MINAGRI. (2022). *Climate variability and agricultural performance in Rwanda*. Kigali: Ministry of Agriculture and Animal Resources
6. Ndayambaje J, Mugabo J, Habiyaremye G. (2020). *Effects of climate variability on smallholder farmers' livelihoods in Western Rwanda.* Journal of Social Sciences 4(2):77–91.
7. National Institute of Statistics of Rwanda. (2025). *Agricultural sector statistics report.* Kigali: NISR.
8. Polit DF, Beck CT. (2017). *Generating and assessing evidence for nursing practice. 10th ed*: Nursing research. Philadelphia: Lippincott Williams & Wilkins.
9. Ministry in Charge of Emergency Management. (2025). *Contingency plan for floods and landslides in Rwanda.* Kigali: MINEMA.
10. Meteo Rwanda. (2026). *Climate data for Rutsiro District (2016–2025*). Kigali
11. Food and Agriculture Organization of the United Nations. (2022). *Climate-smart agriculture sourcebook*. 2nd ed. Rome: FAO
12. Manson Incoom AB, Adjei KA, Odai SN, Siabi EK, Donkor P, Frimpong K. (2025). *Adaptation strategies by smallholder farmers to climate change and variability: The case of the savannah zone of Ghana*. Climate Risk Management 48:100723.

13. Ndayambaje JD, Wonkam C, Mugiraneza T, Munyanziza E. (2013). *Land-use change in the buffer zone of the Gishwati Forest Reserve, Rwanda*. Environmental and Natural resources Research 3(1):1–14.
14. World Bank. (2018). *Environmental and social impact assessment of Rutsiro District.* Washington DC: World Bank
15. World Bank. (2021). *Climate shocks, agriculture, and household income stability*. Washington DC: World Bank.
16. Mutunga E, Waithaka M, Kirimi L. (2019). *Climate variability and livelihood vulnerability of smallholder farmers in Kenya.* International Journal of Environmental and Rural Development (IJERD) 11 (4):112–126.
17. Deressa T, Hassan R, Ringler C. (2018). *Impact of climate variability on household income and food security among smallholder farmers in Ethiopia.* African Journal of Agricultural Research. 13(6):301–312.
18. United Nations Environment Programme. (2023). Adaptation gap report 2023: Underfinanced, underprepared. Nairobi: UNEP
19. IFAD. (2021). Rural development report: *Transforming food systems for rural prosperity.* Rome: International Fund for Agricultural Development

Figures

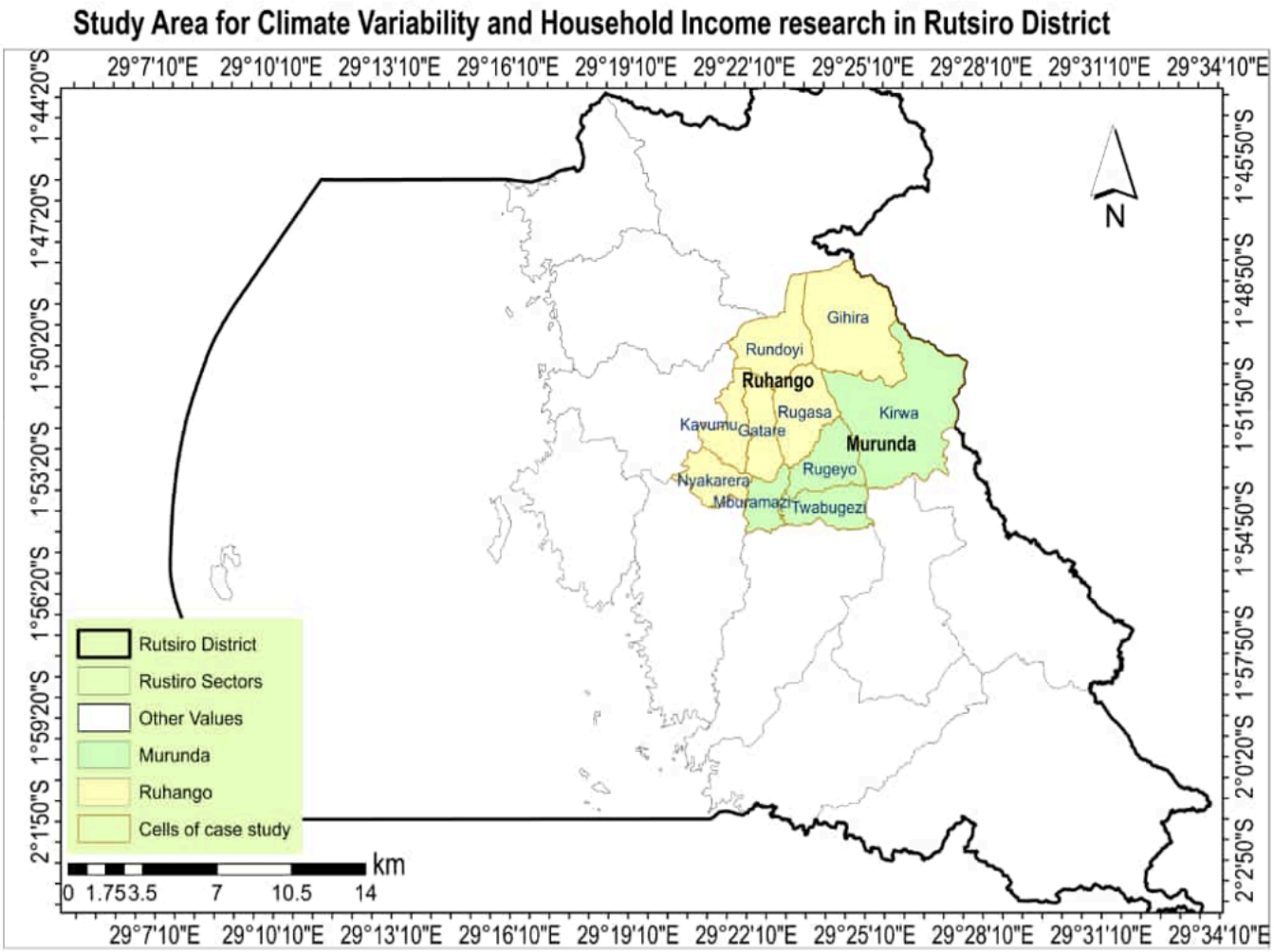


Figure 1

Map of study area showing Ruhango and Murunda sectors, Rutsiro District, western province of Rwanda
Source: Author, 2026

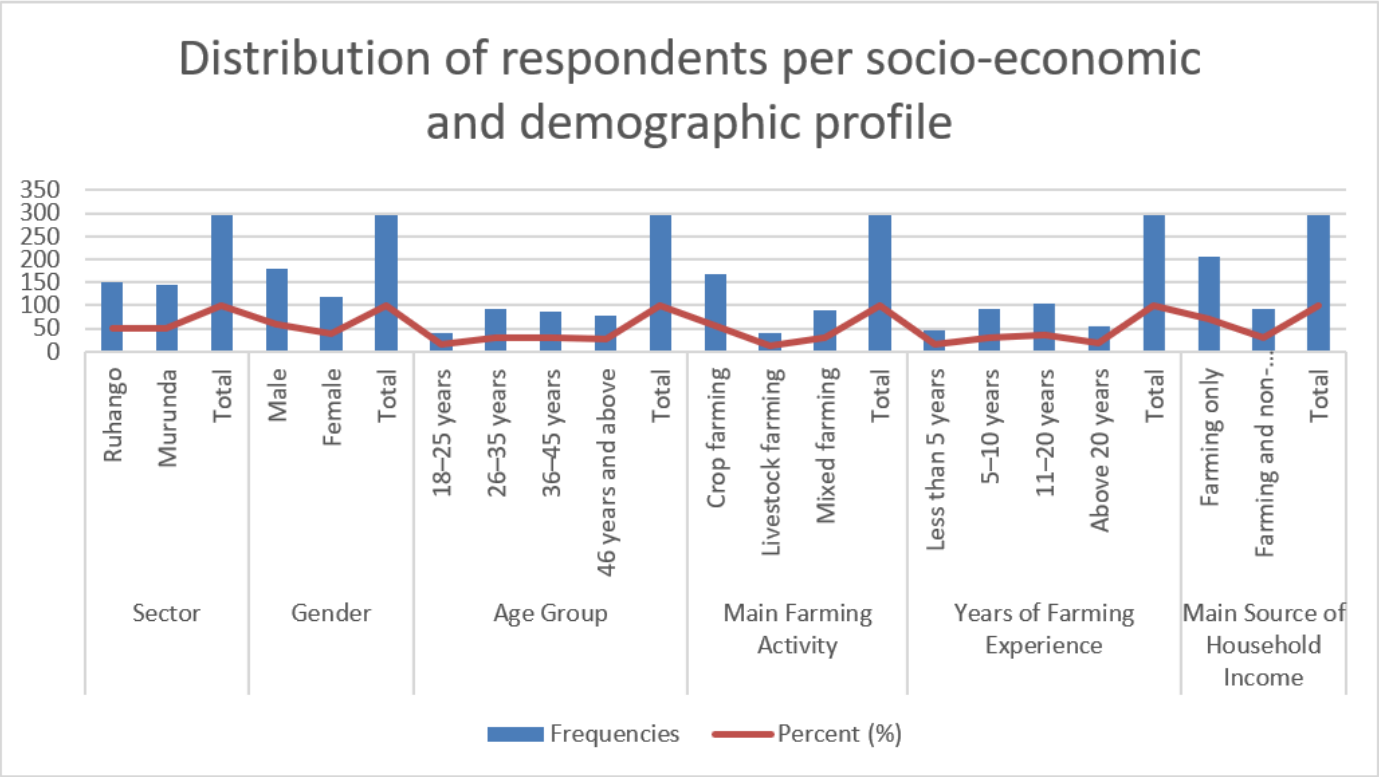


Figure 2

Socioeconomic and demographic characteristics of Respondants of study area (Source: Author, 2026)

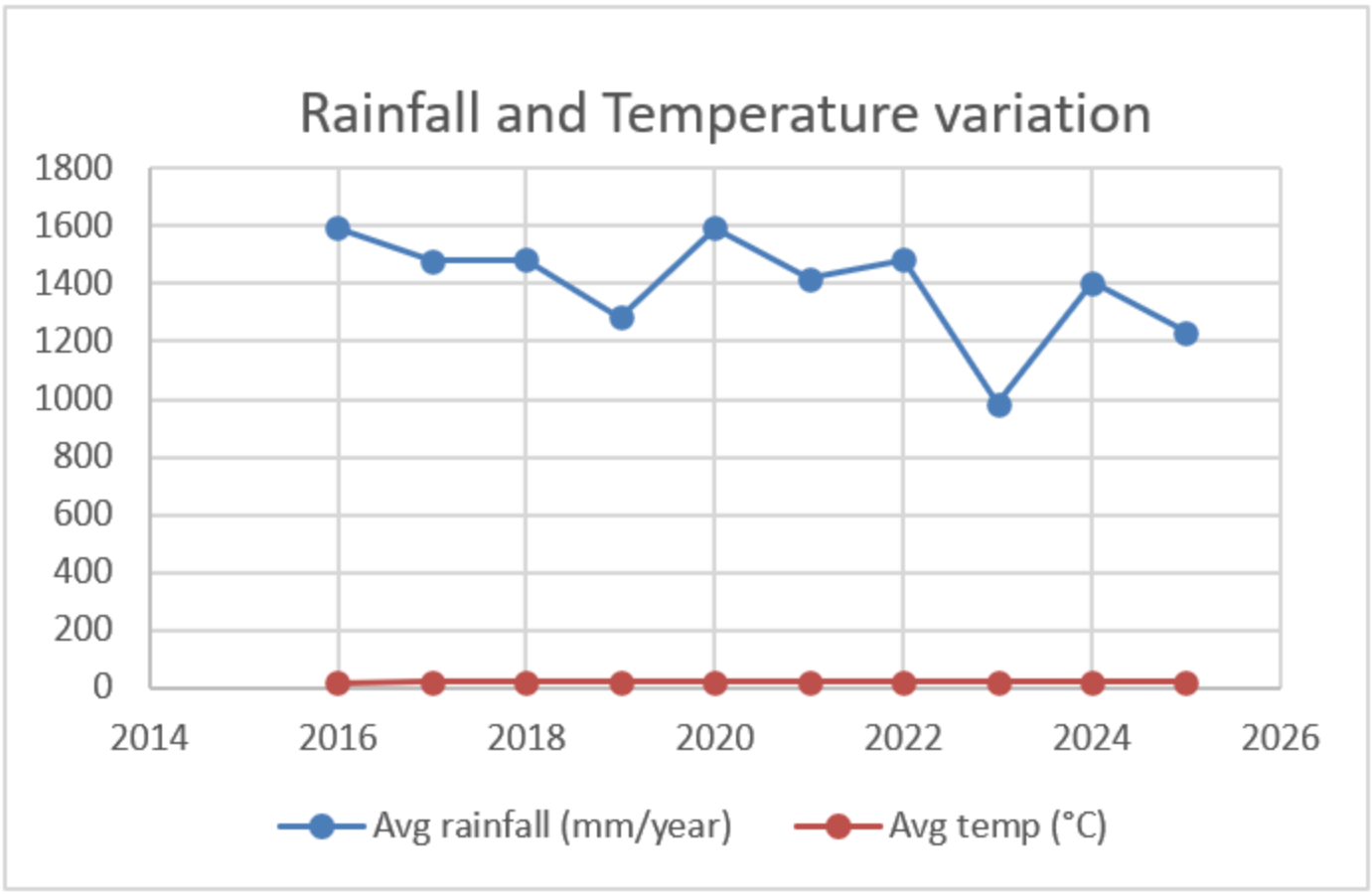


Figure 3

Variation trends of Rainfall and temperature in Murunda and Ruhango sectors within 2016-2025 period

Supplementary Files

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