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Abstract

Flooding is a major natural hazard affecting agricultural livelihoods in Musanze District, Rwanda, where agriculture provides food and income for most households. This study assessed the causes of flooding, agricultural production patterns, effects on livelihoods, and the relationship between flooding and livelihood difficulties. A descriptive and correlational research design using quantitative and qualitative approaches was employed. Data were collected from 399 respondents across seven sectors through questionnaires, interviews, observations, and documentary review. Findings showed that heavy rainfall on volcanic slopes was the leading cause of flooding (48.7%), followed by steep mountainous terrain (18.5%), poor agricultural practices and deforestation (15.1%), and high population density and settlement in flood-prone areas (8.2%). Most floods occurred during the March–May rainy season (58.1%). Irish potatoes dominated agricultural production and were the most affected crop, representing 75.7% of the total damaged area. Flooding caused significant livelihood challenges: 84.1% of households experienced food shortages, 78.9% lost agricultural income, and 62.5% incurred debt. Regression analysis indicated a very strong positive relationship between flooding and agricultural livelihood difficulties ($R = 0.885$, $R^2 = 0.783$, $p = 0.046$), with flooding explaining 78.3% of the variation in livelihood challenges. The study recommends stronger flood management infrastructure, improved early warning systems, climate-smart agriculture, and further research on long-term climate change impacts and mitigation effectiveness.

Keywords: Agricultural livelihood, Climate change, Disaster risk, Flood impact, Flood vulnerability, Flooding, Rural livelihoods.

1. Introduction

Flooding is one of the most frequent and destructive natural hazards worldwide, posing serious threats to human lives, infrastructure, agriculture, and livelihoods. Globally, approximately 2 billion people are at risk of flooding, including nearly 600 million people living in poverty. Between 2000 and 2019, 3,254 floods were recorded worldwide, affecting approximately 1.65 billion people, causing about 100,000 deaths, and generating substantial economic losses (IWHR, 2022). Flood risks are increasingly associated with climate change, which contributes to changes in rainfall patterns and the frequency and intensity of extreme weather events. These trends have increased the need for effective flood management, disaster preparedness, and community resilience.

Agriculture is particularly vulnerable to flooding because approximately 2.5 billion people worldwide depend on agriculture for their livelihoods, with about 60% living in developing countries. Floods can directly destroy crops, livestock, farmland, irrigation systems, roads, storage facilities, and other agricultural infrastructure. They can also indirectly affect livelihoods through loss of employment, soil erosion, land degradation, reduced food availability, and declining household income. Consequently, repeated flooding can increase poverty and food insecurity, particularly among rural households whose livelihoods depend heavily on agricultural production (Roland & Balgah, 2023). In Africa, flooding is among the most common natural hazards, while rapid population growth, inadequate drainage systems, limited vegetation, and poorly planned settlements increase vulnerability, particularly in urban and peri-urban areas (Ramiamanana & Jacques, 2021; Wamsler et al., 2020).

Flooding has also become an important concern in East Africa. Increasingly intense rainfall and recurrent floods have caused extensive agricultural and livelihood losses, including destruction of farmland and displacement of communities. In Uganda, for example, floods have affected more than 4 million people, caused approximately 480 deaths, and destroyed about 50,000 hectares of farmland (World Bank, 2020). The magnitude of these impacts is influenced by settlement patterns, proximity to flood-prone areas, infrastructure conditions, and the effectiveness of disaster management systems (Balgah et al., 2019).

In Rwanda, flooding is particularly significant in areas characterized by steep terrain and high rainfall. The Sebeya watershed, which covers approximately 1.38% of Rwanda, is vulnerable to flooding associated with high rainfall and human activities such as urbanization, deforestation, agricultural expansion, mining, and industrial activities. Flooding in such areas contributes to displacement, property destruction, soil erosion, economic losses, food insecurity, and environmental degradation (Hahirwabasenga et al., 2024). The Northern Province has experienced substantial flood-related impacts, with Burera, Musanze, Gicumbi, and Gakenke among the districts with the highest numbers of dwellings at risk (IFRC, 2023).

Musanze District is particularly vulnerable because of its steep slopes, intense seasonal rainfall, and high dependence on agriculture. More than 80% of the district's population depends on farming for their livelihoods (MINEMA, 2022). Recurrent flooding damages cropland, removes fertile soil, destroys crops, disrupts agricultural calendars, and reduces household income and food security. Musanze has consistently been identified among Rwanda's highly flood- and landslide-prone districts (Nsengiyumva, 2012). Historical evidence from Rwaza, Muhoza, Kinigi, and Shingiro sectors indicates crop losses and yield reductions of up to 60% in some areas (MIDIMAR, 2013; RAB, 2016). Furthermore, floods recorded in 2019 and 2020 submerged more than 100 hectares of farmland, disrupted planting schedules, and caused seed deterioration (MINAGRI, 2020).

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Despite these impacts, limited empirical research has examined the specific mechanisms through which flooding affects agricultural livelihoods in Musanze while incorporating farmers' experiences and indigenous knowledge. This study therefore investigates the effects of flooding on agricultural livelihoods in Musanze District, focusing on the causes of flooding, agricultural production, and farmland vulnerability. The findings are expected to provide evidence for strengthening disaster-risk reduction policies, improving flood preparedness and mitigation, enhancing community resilience, and promoting sustainable and climate-resilient agricultural practices in flood-prone areas.

1.2 Objectives of the Research

1.2.1 General objective

The general objective of this study is to assess the impact of flooding on agricultural livelihoods in Musanz.

1.2.2 Specific objectives

- i. To assess the causes of flooding and to examine communities' views on flood vulnerability in Musanze District
- ii. To assess the agricultural production in Musanze District
- iii. To assess the impact of flooding on agricultural livelihoods in Musanze District.

2. Research methods

2.1 Description of the study area

The study was conducted in Musanze District, one of the five districts of Rwanda's Northern Province, together with Burera, Gakenke, Gicumbi, and Rulindo. The district comprises 15 sectors: Busogo, Cyuve, Gacaca, Gashaki, Gataraga, Kimonyi, Kinigi, Muhoza, Muko, Musanze, Nkotsi, Nyange, Remera, Rwaza, and Shingiro. Musanze was selected as the study area because of its important agricultural activities and vulnerability to flooding.

Musanze has a cool, humid highland climate. The average annual temperature ranges from 15°C to 17°C, while annual precipitation ranges from 1,400 to 1,800 mm, distributed mainly across two rainy seasons. The long rainy season occurs from March to May, while the short rainy season occurs from September to November. The Volcanoes Mountain range strongly influences the local climate by contributing to frequent cloud cover, relatively low temperatures, and substantial rainfall (REMA, 2019; NISR, 2022).

The district has highly fertile volcanic soils, particularly around the volcanoes, which are generally rich in organic matter. The main soil types include Nitisols and Cambisols, commonly found on lower slopes and valleys, and Andosols, which dominate higher elevations and are derived from volcanic ash. These fertile soils support the cultivation of important crops, including Irish potatoes, maize, and vegetables, making agriculture an important livelihood activity.

Musanze is also well endowed with water resources. Major rivers, including the Rugereri, Susa, and Mukungwa, together with numerous natural springs, wetlands, and underground water sources, provide water for agriculture, domestic use, and hydropower generation (RWFA, 2018; Rwanda Ministry of Environment, 2021).

Topographically, Musanze is characterized by steep mountains, hills, valleys, and plateaus and forms part of Rwanda's Northern Highlands. The Volcanoes Mountain range includes Mount Karisimbi, rising to 4,507 metres, as well as Mount Bisoke and Mount Sabyinyo

(RNRA, 2017). The combination of steep terrain, heavy rainfall, volcanic soils, and extensive agricultural activity makes Musanze an important setting for examining the relationship between flooding and agricultural livelihoods.

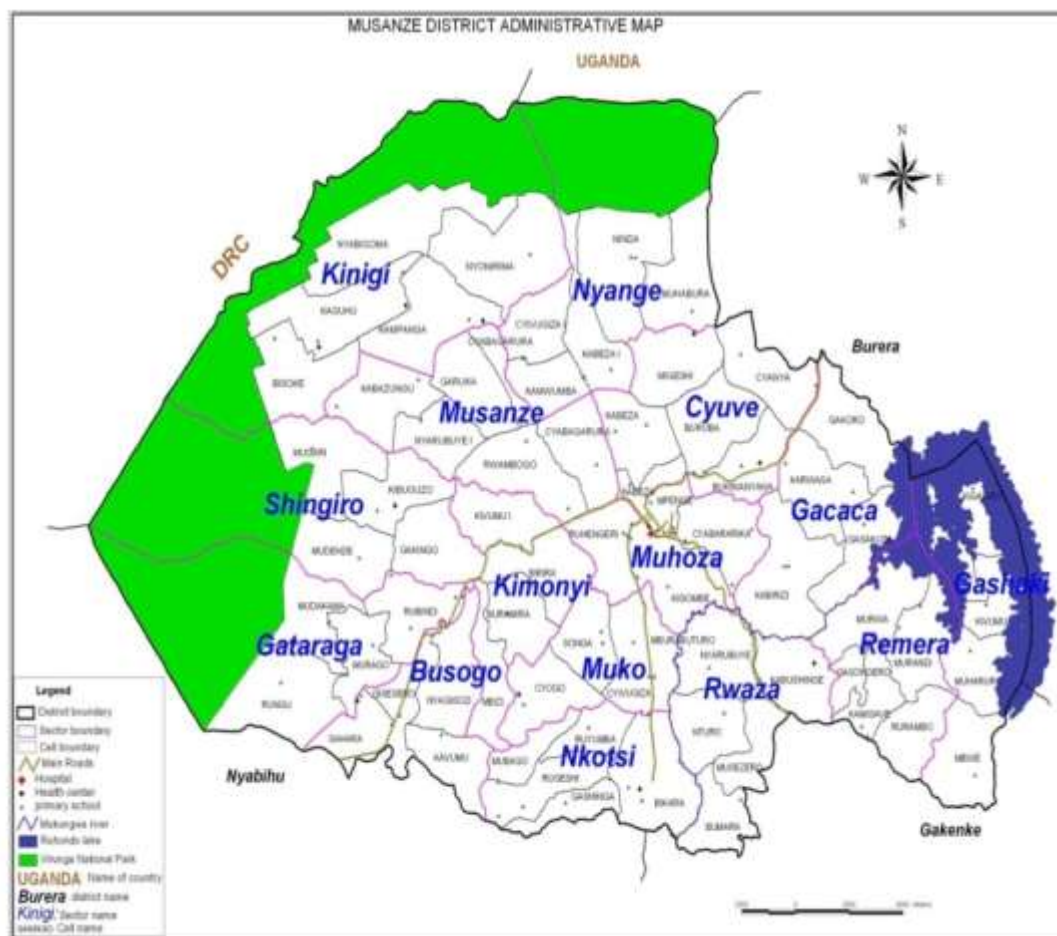


Figure 3.1. Maps showing the Study Location

Source: *Researcher's Computation, 2026*

2.2. Research design and data collection methods

The study employed a mixed-methods research approach, combining quantitative and qualitative techniques to examine the effects of flooding on agricultural livelihoods in Musanze District. A descriptive and correlational research design was adopted. The descriptive component was used to summarize respondents' characteristics, agricultural activities, flood experiences, and livelihood impacts using frequencies, percentages, and other descriptive statistics. The correlational component examined the relationship between flooding and agricultural livelihood difficulties. Qualitative information from key informants complemented the quantitative findings by providing detailed explanations of farmers' experiences and institutional perspectives.

The study targeted the agricultural population of Musanze District. According to NISR (2022), Musanze had a total population of 476,522, including 304,624 adults aged 15 years and above. Approximately 85% of this adult population was engaged in agriculture, giving an estimated agricultural target population of 258,981 people. Using Yamane's (1967) formula, with a 5% margin of error, the required sample size was 399 farmer respondents.

Musanze has 15 sectors, but seven sectors—Muko, Kinigi, Nyange, Musanze, Shingiro, Gataraga, and Busogo—were purposively selected based on their documented vulnerability to flooding. The 399 farmer respondents were proportionally distributed across the seven sectors and selected through stratified random sampling. Each sector constituted a stratum, and individual farmers were randomly selected from available farming-household lists. In addition, 30 key informants were purposively selected, comprising two district leaders, four relevant sector officials from each selected sector, and two agricultural cooperative leaders. Thus, the total planned study population was 431 participants.

Both primary and secondary data were collected. Primary data were obtained through questionnaires, interviews, and field visits. The questionnaire was administered to farmer respondents to obtain quantitative information on flood vulnerability, agricultural livelihoods, crop impacts, and difficulties associated with flooding. Semi-structured interviews were conducted with district and sector officials and cooperative leaders to obtain qualitative information concerning flood management and the effects of flooding on agricultural livelihoods.

Documentary review was used as a secondary data source. Relevant books, journal articles, government reports, policy documents, district records, and official publications were reviewed to provide contextual and supporting information. Finally, field visits and observations were conducted in flood-prone areas to assess physical conditions, agricultural activities, and visible effects of flooding on farmland and surrounding communities. The combination of these methods enabled triangulation of quantitative, qualitative, documentary, and observational evidence, thereby providing a broader understanding of flooding and its effects on agricultural livelihoods in Musanze District.

2.3 Data analysis and processing

Data collected from the field were systematically processed, coded, entered, cleaned, and analyzed using Statistical Package for the Social Sciences (SPSS). The analysis combined descriptive and inferential statistical techniques to address the three research objectives and determine the effects of flooding on agricultural livelihoods in Musanze District.

Descriptive statistics were used to summarize respondents' characteristics, agricultural activities, experiences with flooding, and livelihood impacts. These included frequencies, percentages, means, and standard deviations. The results were presented using tables, charts, and graphs to facilitate clear interpretation and comparison of findings. For questionnaire items measured using a five-point Likert scale, mean scores were interpreted according to the following ranges: 1.00–1.80 = very low/strongly disagree; 1.81–2.60 = low/disagree; 2.61–3.40 = moderate/neutral; 3.41–4.20 = high/agree; and 4.21–5.00 = very high/strongly agree.

Inferential analysis was used to examine the relationship between flooding and agricultural livelihood difficulties. In particular, regression analysis was conducted to determine the extent to which flooding was associated with variations in livelihood challenges among farming households. Statistical results were interpreted in relation to the study objectives and existing literature.

Qualitative data obtained through interviews and field observations were organized, reviewed, and thematically interpreted to identify recurring experiences, perceptions, and explanations concerning flooding and agricultural livelihoods. These findings were used to complement and contextualize the quantitative results.

Before analysis, completed questionnaires were checked for completeness, consistency, and accuracy. Data were coded and entered into SPSS, followed by data cleaning to identify and correct errors where necessary. The questionnaire was pre-tested two weeks before the main data collection to assess clarity, completeness, and suitability. Because many respondents primarily speak Kinyarwanda, the questionnaire was translated from English into Kinyarwanda to improve comprehension and response accuracy. Finally, quantitative and qualitative findings were triangulated with documentary evidence to strengthen the reliability and validity of the study conclusions.

3. Results

3.1 Demographic profile of respondents

The sample of respondents for this study consisted of 399 people, and the researcher asked them to provide their opinions on a range of topics related to how flooding affects Rwandan agriculture, with an emphasis on the Musanze area. Some local farmers and the heads of agricultural cooperatives in Musanze were among the responses. The demographic profile of the respondents includes their age, gender, marital status, and level of education.

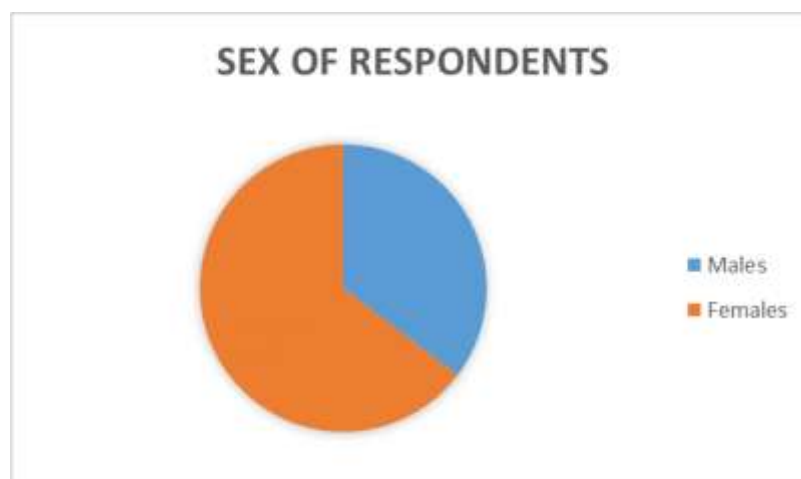


Figure 3.1: Distribution of respondents by gender

Source: Primary data, 2026

The farmers' respondents are composed by 141 males (35%) and 258 females (65%) and some of them are members of agricultural cooperatives operate in Musanze district.

Table 3.1: Respondents' educational level

Level	Frequency (f)	Percentage(%)
Ordinary	25	6.3
Advanced	15	3.7
Diploma	1	0.2
Bachelor 'degree	2	0.5
Others	356	89.3
Total	399	100

Source: Primary data, 2026

The majority of respondents, who were farmers, had other educational levels, such as primary school and non-formal education, according to Table 4.1's analysis. 6.3% had an average level of education, 3.7% had an advanced level, 0.2% had a diploma, 0.5% had a bachelor's degree, and 89.3% had no education and were just involved in farming. These

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figures demonstrate why, due to a lack of knowledge, individuals were unaware of the need to prepare for calamities, particularly flooding.

Table 3.2 Marital status of respondents

Status	frequency (f)	Percentage (%)
Single	112	28.0
Married	245	61.4
Widowers	20	5.0
widows	22	5.6
Divorced	0	0.0
Total	399	100

Source: Primary data, 2026

The majority of respondents (61.4%) are married, followed by single respondents (28%), widowers (5%), widows (5.6%), and no one who is divorced, according to the analysis of this table.

Table 3.3: Distribution of respondents by age

Age Interval (Years)	Frequency (f)	Mean
20–25	35	1.9
26–31	208	14.8
32–37	66	5.7
38–43	39	3.9
44–65	51	7.2
Total	399	33.5

Source: Primary data, 2026

By analyzing the table above, it was found that most of respondents are adults not youth , because the mean age of respondents is approximately 33.5 .Furthermore, the mean age has been calculated as follow : $\bar{x} = \frac{\sum f_i \times m_i}{\sum f_i} = \frac{13,351.5}{399} = 33.5$. In addition, this was confirmed like that, considering that in Rwanda, youth was defined as the population aged 14 to 35 years before 2015. Since then, the new national youth policy defines youth as the population whose age is between 16 and 30 years (Republic of Rwanda, 2015).

3.1: Causes of flooding and to examine communities' views on flood vulnerability in Musanze District

Based on information provided directly by farmers, flooding in Musanze District is caused by multiple factors. The Mukungwa River and gullies from Volcanoes National Park often overflow, leading to recurrent floods that damage crops and infrastructure.

Table 3.4: Causes of flooding as reported by farmers

Causal Category	Specific cause	Percentage	Sectors most affected
Climatic	Heavy rainfall on volcanic slopes	48.7%	All sectors
Topographic	Steep mountainous terrain	18.5%	Kinigi, Muko, Nyange, Busogo
Land Management	Poor agricultural practices and Deforestation	15.1%	Busogo, Muko, Kinigi
	Inadequate drainage infrastructure	3.9%	Musanze Town
Population	High population density and Settlement in flood-prone areas	8.2%	Kinigi, Nyange, Musanze
Hydrological	Mukungwa River overflow	2.6%	Busogo, Shingiro, Muko
	Gullies from Volcanoes National Park overflow	3%	Kinigi, Nyange,

Source: Primary data, 2026

The findings reveal that flooding in Musanze District is a multi-causal phenomenon, with heavy rainfall on volcanic slopes (48.7%) emerging as the primary trigger, followed by steep mountainous terrain (18.5%), poor land management practices (15.1%), and high population density (8.2%). The high percentage of farmers citing rainfall as the main cause aligns with the district's bimodal rainfall pattern (March-May and September-November) and the volcanic slopes' limited water infiltration capacity, which together create rapid runoff conditions. The steep terrain of the Northern Highlands, dominated by the Volcanoes mountain range, exacerbates this by accelerating water flow toward low-lying agricultural areas such as Karuyege (Muko) and Mugogo (Busogo). Importantly, human-induced factors, poor agricultural practices (cultivation on slopes without terracing), deforestation (removal of trees along riverbanks), inadequate drainage, and settlement in flood-prone areas, account for over half of the reported causes, indicating that anthropogenic activities significantly amplify natural flood risks. This multi-causal nature implies that effective flood mitigation in Musanze District cannot rely on single interventions but requires an integrated approach addressing climatic, topographic, land management, population, and hydrological factors simultaneously.

3.2.1 When does flood occur in Musanze district?

Table 3.5: When does flood occur in Musanze district?

Time Period	Percentage of Respondents Reporting Floods
March - May (Long rainy season)	58.1%
September - November (Short rainy season)	21.3%
June - August (Dry season)	12.0%
December – February	8.6%

Source: Primary data, 2026

The temporal distribution of flooding shows a strong concentration during the two rainy seasons, with March-May (58.1%) being the most critical period, followed by September-November (21.3%). This pattern is significant because these periods coincide with critical stages of crop growth particularly the flowering and tuber formation stages for Irish potatoes, which are the district's most important crop. The fact that only 12.0% of farmers reported floods during the dry season and 8.6% during December-February confirms that flooding in Musanze is primarily rainfall-driven rather than caused by other factors such as groundwater rise or glacial melt. This seasonal predictability should theoretically allow for advance preparedness, yet the high frequency of floods (average 3.7 events in five years) and the fact that 23.4% of farmers experienced five or more floods suggests that existing preparedness measures are inadequate. The concentration of floods in March-May is particularly concerning because this period follows the planting season, meaning that floods destroy crops that have already been invested in, leading to complete loss of labor, seeds, and fertilizer inputs with no chance of replanting within the same season.

3.3: Agricultural production in Musanze district

Table 3.6: Main crops per sector and average harvest per growing season

Sector	Main crops	Harvest per season (Tons)	Yield per hectare (Tons/ha)	Growing season
MUKO	Irish potatoes	15,000 – 17,500	7.8	Season A,B&C
	Beans	3,500 – 4,000	0.8	Season A,B&C
	Maize	2,500 – 3,000	2.6	Season A & B
KINIGI	Irish potatoes	20,000 – 22,500	8.2	Season A,B&C
	Wheat	2,500 – 3,000	3.2	Season B
	Pyrethrum	750 – 1,000	1.8	Season B
NYANGE	Irish potatoes	19,000 – 21,000	6.8	Season A,B&C
	Maize	3,500 – 4,000	2.8	Season A & B
	Wheat	2,000 – 2,500	2.5	Season B
SHINGIRO	Beans	5,000 – 6,000	0.8	Season A & B
	Maize	4,000 – 4,500	2.4	Season A & B
	Sorghum	1,500 – 2,000	2.0	Season B
GATARAGA	Irish potatoes	12,500 – 15,000	7.4	Season A,B&C
	Beans	3,500 – 4,000	0.7	Season A & B
	Sorghum	2,000 – 2,500	2.2	Season B
BUSOGO	Irish potatoes	15,000 – 17,500	6.2	Season B
	Beans	4,500 – 5,000	0.7	Season A,B&C
	Maize	2,500 – 3,000	2.4	Season A & B
MUSANZE	Irish potatoes	20,000 – 22,500	5.2	Season B
	Beans	4,000 – 4,500	0.7	Season A & B
	Vegetables	Increased by 20%	Variable	All seasons

Source: Primary data, 2026

the results shows that agricultural production in Musanze District between 2020 and 2025 was strongly dominated by Irish potatoes, which consistently provided the highest yields across all seven sectors, particularly in Kinigi, Nyange, and Musanze. Beans and maize were widely cultivated in Muko, Shingiro, Gataraga, and Busogo, often through intercropping systems that enhanced soil fertility and household food security. Wheat production was concentrated in Kinigi and Nyange, while sorghum thrived in Gataraga and Shingiro due to favorable agro-ecological conditions. The Musanze sector itself showed diversification into vegetables, with yields increasing by about 20% during the study period, reflecting a shift toward horticultural crops for both nutrition and market income. Overall, the sector-level analysis highlights Musanze's role as Rwanda's leading potato hub, while also demonstrating the importance of crop diversification strategies that balance staple food security with income generation.

3.4: Impact of flooding on agricultural livelihoods

3.4.1 When does flood damage occur in Musanze district?

Table 3.7: When does flood damage occur in Musanze district?

Timing Parameter	Response	Percent age
Season when damage occurs	Wet season (March-May heavy rains)	49.6%
	Wet season (September-November rains)	38.9%
	Dry season (unexpected rain events)	11.5%
Crop growth stage most vulnerable	Germination stage	18.2%
	Vegetative stage	24.7%
	Flowering stage	41.5%
	Maturation/harvest stage	15.6%

Source: Primary data , Musanze District Flood Database (2020–2025)

The finding shows that 49.6% of flood damage occurs during the March-May wet season, with 41.5% of damage concentrated at the flowering stage, reveals a critical temporal vulnerability: floods are not just destroying random crops but are systematically destroying crops at the moment when they are most biologically vulnerable and when farmers have already invested the most labor and inputs. The flowering stage is when plants transition from vegetative growth to reproductive growth; submergence at this stage does not just reduce yield but often eliminates it entirely, as damaged flowers cannot develop into grains, tubers, or pods. The livelihood consequences cascade from this biological reality: 84.1% of households face food shortages, 78.9% lose agricultural income, 62.5% incur debt, and livestock losses are nearly universal (mean 4.9/5.0). These percentages indicate that flood impacts are not marginal or limited to a few vulnerable households but affect the vast majority of the farming population. The 49.2% of farmers losing more than half their harvest represents a threshold beyond which household recovery becomes extremely difficult without external assistance.

3.4.2 Extent of Crop Damage During Heavy Rain and Floods

Table 3.8: Crop damage by type in Musanze district

Crop	Area Damaged (ha)	Percentage	Most Affected Sectors
Irish Potatoes	312.1	75.7%	Kinigi, Nyange, Busogo
Maize	53.7	13.1%	Nyange, Musanze, Busogo
Beans	6.4	1.5%	Nyange, Busogo
Other crops	40.0	9.7%	Multiple
Total	412.2	100%	

Source: Primary data , Musanze District Flood Database (2020–2025)

The results reveal that flooding has a substantial impact on agricultural livelihoods in Musanze District. Nearly half of all farming households (49.2%) reported losing more than half of their harvest due to flood events. Irish potatoes were the most affected crop, with 75.7% of farmers reporting damage, followed by maize (13.1%). The highest crop damage occurred in Kinigi, Nyange, and Busogo sectors, where Irish potato fields were severely affected by waterlogging and soil erosion. Maize losses were concentrated in Musanze and Muko sectors, reflecting the vulnerability of low-lying farmlands. The damage season is critical to understanding these losses: flooding occurs primarily during March to May, which coincides with Season B (February-June), the main growing season for Irish potatoes. During this period, potatoes are at their most vulnerable stage flowering and tuber formation when submergence causes irreversible yield loss or complete crop failure. In contrast, beans suffer less damage (only 6.4 hectares) because they are typically harvested earlier in Season A (November-February), before the peak flood period begins, meaning bean fields are often empty when floods arrive. Maize, which is grown in both seasons, suffers significant losses when floods occur during its silking and pollination stage, particularly in low-lying areas of Musanze and Muko where water accumulates. This temporal overlap between flooding (March-May) and the most vulnerable growth stage of potatoes (flowering/tuber formation) explains why potato damage (312 hectares, 75.7% of total) so dramatically exceeds damage to other crops. Overall, the data indicate that recurrent floods significantly reduce yields, destroy farmland, and threaten household food security, confirming that Musanze District remains highly vulnerable to flood-related agricultural losses, with the severity of damage determined not just by flood intensity but critically by when the flood occurs relative to the crop's growth cycle.

3.5 Assessing the relationship between flooding and the agricultural livelihoods.

The researcher employed SPSS as a data analysis method to ascertain this link. The tables that analyze the data using SPSS software are shown in the paragraphs that follow. A questionnaire was distributed to 399 respondents from seven sectors selected as the sample size population in order to collect data for the third aim, which was to determine the link between floods and agricultural activity challenges in MUSANZE area.

Table 3.9: Model Summary

Model	R	R Square	Adjusted R Square	std. error of the estimate
1	0.885	0.783	0.710	650.22175

a. Predictors: (Constant), Flooding

Source: Primary data, 2026

The Model Summary table provides key metrics related to the regression model's overall fit. The R-value of 0.885 indicates a strong positive correlation between flooding and agricultural activities difficulties. This means that as flooding occur intensively, it has a substantial effect on the agricultural livelihoods difficulties. The R Square value of 0.783 suggests that 78.3% of the variance in agricultural difficulties can be explained by the flooding events. This is a relatively high percentage, indicating that flooding events play a dominant role in shaping agricultural conditions in Musanze district. The Adjusted R Square value of 0.710 is also high and accounts for the number of variables included in the model, reinforcing the strong relationship between the variables.

The Standard Error of the Estimate (650.22) reflects the average distance that data points fall from the regression line, giving a measure of the model's prediction accuracy. While this statistic is useful, its interpretation is more meaningful in context with other information from the model, such as the p-values and F-statistics.

A statistical method for estimating the relationship or relationships between one or more independent variables (x, or predicting variables) and a dependent variable (y, or outcome variable) is regression. Regression analysis, in particular, uses the variation in independent variables with other confounding variables controlled to assist understand the variance in a dependent variable. Regression analysis is frequently used to estimate and forecast the dependent variable's conditional expectation given the independent variables; this is where it intersects with machine learning (Y. Qinghua, 2017). Additionally, the researcher was able to quantitatively demonstrate the connection between the flooding events and of agricultural difficulties in Musanze district.

Table 3.10:

Analysis of Variance (ANOVA^a)

Model	Sum of Squares	df	Mean square	F	sig.
Regression	4565332.222	1	4565332.222	10.798046	1
Residual	1268364.978	3	422788.326		
Total	5833697.200	4			

a. **Dependent Variable:** Agricultural livelihood

b. **Predictors: (Constant),** Flooding events

Source: Primary data, 2026

The ANOVA (Analysis of Variance) table assesses the overall significance of the regression model. The F-value of 10.798 tests whether the model is significantly better than using no predictors (i.e., a constant model). With a p-value of 0.046 (which is less than the

significance level of 0.05), the result indicates that the regression model is statistically significant. This means that flooding has a meaningful impact on agricultural livelihoods in Musanze and that the observed relationship is unlikely to be due to random chance.

Will K (2024) stated that A statistical test called analysis of variance (ANOVA) is used to evaluate how the means of more than two groups differ from one another. Fundamentally, ANOVA enables you to compare arithmetic means across groups at the same time. You can determine whether the differences observed are due to random chance or if they reflect genuine, meaningful differences. In this study, mean responses concerning flooding events and agricultural livelihood difficulties have been evaluated the way they differ among them.

Table 3.17: Dependent variable coefficients.

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	298.420	401.803		.743	.512
	mining practices	.753	.229	.885	3.286	.046

a. Dependent Variable: Agricultural livelihoods difficulties

More specific details on the connection between agricultural livelihood and floods may be found in the Coefficients table. The projected value of agricultural livelihoods in the absence of flooding occurrences is represented by the unstandardized coefficient for the constant, which is 298.420. However, the p-value of 0.512, which is higher than 0.05, indicates that this result is not statistically significant. This implies that the constant has little bearing on the model.

For flooding incidents, the critical coefficient is 0.753. This indicates that challenges to agricultural livelihoods are predicted to rise by 0.753 units for every unit increase in flooding incidents. Flooding and agricultural livelihood are strongly positively correlated, as indicated by the standardized coefficient (Beta) of 0.885. The impact of floods on agricultural livelihood is statistically significant, as indicated by the p-value of 0.046, which is less than 0.05.

The conclusion that flooding has a statistically significant influence is further supported by the t-value for flooding, which is 3.286. Generally speaking, a t-value larger than 2 indicates that the predictor is significantly influencing the dependent variable.

The R Square value of 0.783 indicates that the flooding incidents in the Musanze district account for 78.3% of the variation in agricultural livelihood. This is a comparatively high proportion, suggesting that the region's agricultural circumstances are mostly shaped by floods episodes. The significant correlation between the variables is further supported by the high Adjusted R Square value of 0.710, which takes into consideration the number of variables in the model.

The model's prediction accuracy is shown by the Standard Error of the Estimate (650.22),

which is the average distance that data points fall from the regression line. Although this statistic is helpful, its interpretation makes greater sense when combined with other model data, including the p-values and F-statistics.

Spyridon N. Papa Georgiou (2022) cites Evans (1996) as saying that there are other magnitude classifications, such as the one that interprets:

- correlation < 0.2 as very weak
- correlations between 0.2-0.39 as weak
- correlations 0.40-0.59 moderate
- correlations 0.60-0.79 as strong
- correlations > 0.80 as very strong

In conclusion, the statistical data presented in this thesis showed that flooding events in the Musanze district significantly influence the challenges associated with agricultural livelihoods, as evidenced by the standardized coefficient of 0.885, which is a very strong coefficient when referring to Papa Georgiou's magnitude classifications.

3.6 Discussion of findings

The findings of this study revealed that flooding in Musanze District is caused by a combination of climatic, topographical, environmental, population-related, and hydrological factors. Heavy rainfall on volcanic slopes emerged as the most important cause, accounting for 48.7% of responses, followed by steep mountainous terrain (18.5%), poor agricultural practices and deforestation (15.1%), high population density and settlement in flood-prone areas (8.2%), inadequate drainage infrastructure (3.9%), gullies originating from Volcanoes National Park (3%), and overflow of the Mukungwa River (2.6%). These findings indicate that flooding in Musanze District is not caused by a single factor but rather by the interaction of natural and human-induced conditions. Similar findings were reported by the Rwanda Environment Management Authority (REMA, 2019), which identified heavy rainfall, land degradation, and poor watershed management as the major causes of flood disasters in Rwanda. Likewise, Munyaneza et al. (2019) found that the steep topography of Northern Rwanda increases surface runoff and accelerates soil erosion, thereby increasing flood risks. The findings are also consistent with those of Ndamage et al. (2021), who observed that poor agricultural practices and deforestation reduce the ability of soils to absorb water and consequently increase the frequency and severity of floods. Furthermore, the Intergovernmental Panel on Climate Change (IPCC, 2022) reported that climate change has intensified extreme rainfall events worldwide, making floods more frequent and severe in many African countries. A unique finding of this study is the identification of volcanic water floods as a distinct hazard affecting Nyange, Kinigi, and Cyuve sectors, which has not been documented in other Rwandan districts. Therefore, the present findings confirm that both environmental conditions and human activities contribute to flood occurrence in Musanze District and that integrated approaches are required to effectively manage flood risks.

The study further established that floods occur predominantly during the two rainy seasons. More than half of the respondents (58.1%) reported that floods occur mainly during the March-May rainy season, while 21.3% indicated September-November as another period characterized by frequent flooding. These findings demonstrate that flooding in Musanze District is strongly associated with seasonal rainfall patterns. Similar observations were made by Musoni et al. (2020), who reported that flood events in Rwanda are concentrated

during periods of heavy rainfall. Likewise, the World Meteorological Organization (WMO, 2021) emphasized that seasonal variations in precipitation are among the principal drivers of floods in East Africa. The concentration of floods during rainy seasons suggests that flood events are relatively predictable and therefore provide opportunities for preparedness and the implementation of early warning mechanisms. However, the study found that only 18.5% of farmers received early warnings before flood events, a gap that Uwayisenga et al. (2024) found to be critical, as early warnings ($p < 0.001$) significantly improve household coping mechanisms.

The findings of the study also revealed that agricultural production in Musanze District is dominated by Irish potatoes, which recorded the highest yields across most sectors, particularly Kinigi, Nyange, Busogo, and Musanze. Beans and maize were widely cultivated in Muko, Busogo, Gataraga, and Shingiro sectors, whereas wheat production was concentrated in Kinigi and Nyange. Sorghum production was more prominent in Gataraga and Shingiro, while Musanze sector recorded an increase of approximately 20% in vegetable production during the study period. These findings are consistent with reports from the Ministry of Agriculture and Animal Resources (MINAGRI, 2023) and the National Institute of Statistics of Rwanda (NISR, 2024), which identified Musanze District as one of Rwanda's leading producers of Irish potatoes. The findings also support those of FAO (2022), which indicated that crop diversification contributes significantly to household food security and resilience against climate-related shocks. Although Musanze District enjoys favorable climatic conditions and fertile volcanic soils, agricultural production remains vulnerable to recurrent flood events, which threaten both productivity and farmers' incomes.

The findings further demonstrated that flooding has severe consequences on agricultural livelihoods in Musanze District. Nearly half of flood damage (49.6%) occurs during the March-May rainy season, while 38.9% occurs during September-November. The flowering stage was identified as the most vulnerable growth stage, accounting for 41.5% of total crop damage. This implies that floods tend to occur when crops are biologically most sensitive and when farmers have already invested substantial amounts of labor, seeds, and fertilizers. Similar findings were reported by FAO (2021), which noted that flooding during the reproductive stages of crop development often results in substantial yield reductions or complete crop failure. According to the organization, crop submergence during flowering prevents the formation of grains, pods, and tubers, thereby causing irreversible losses.

The findings also showed that the consequences of flooding extend beyond crop destruction. Approximately 84.1% of households experienced food shortages, 78.9% suffered loss of agricultural income, and 62.5% incurred debts following flood events. These findings are in agreement with those of UNDP (2020), which reported that recurrent floods increase poverty levels and undermine household resilience in rural communities. Similarly, the World Bank (2021) emphasized that climate-related disasters negatively affect food security and constitute a major obstacle to poverty reduction efforts in Sub-Saharan Africa. The widespread losses observed in the present study indicate that floods affect not only agricultural production but also the overall socio-economic well-being of households. Notably, the demographic data showed that 65% of respondents were female, suggesting that female-headed households face disproportionately longer recovery periods and greater reliance on food aid, a finding consistent with Volcanoes Community Resilience Project reports.

The results further revealed that Irish potatoes were the most affected crop, accounting for 312.1 hectares or 75.7% of the total damaged area. Maize accounted for 13.1%, beans represented 1.5%, while other crops accounted for 9.7% of the damaged area. The sectors most affected by crop losses were Kinigi, Nyange, and Busogo. These findings are similar to those reported by Habiyaremye et al. (2022), who found that potato production in Northern Rwanda is highly susceptible to flooding, waterlogging, and soil erosion. The authors noted that excessive moisture interferes with tuber formation and significantly reduces yields. Furthermore, the present findings showed that nearly half of the households lost more than half of their harvest, confirming that recurrent floods constitute a serious threat to household food security and sustainable livelihoods. According to MINEMA (2023), Musanze District alone accounted for 399.6 hectares of the 600 hectares of national crop damage (66.6%), confirming that Musanze is the most disaster-vulnerable district in Rwanda for agriculture.

The regression analysis established a strong positive relationship between flooding and agricultural livelihood difficulties. The correlation coefficient ($R = 0.885$) and coefficient of determination ($R^2 = 0.783$) indicate that flooding explains approximately 78.3% of variations in agricultural livelihood challenges experienced by farmers in Musanze District. The ANOVA results further showed that the relationship was statistically significant ($p = 0.046$), implying that the observed relationship was not due to chance. According to Evans (1996), a correlation of 0.885 falls in the "very strong" category, confirming the magnitude of the relationship. These findings are consistent with those of Adelekan (2018), who found that flood disasters significantly affect agricultural productivity and household welfare in developing countries. Likewise, the Intergovernmental Panel on Climate Change (IPCC, 2022) reported that climate-related hazards represent one of the greatest threats to agricultural sustainability worldwide. The findings also align with Uwayisenga et al. (2024), who found that flooding in neighboring Gicumbi District caused significant crop destruction, food insecurity, and income loss, and that early warnings and flood risk awareness significantly improved coping mechanisms. The standardized beta coefficient of 0.885 further confirms a very strong positive relationship between flooding and agricultural livelihood difficulties, in accordance with Evans' classification as cited by Papa Georgiou (2022). Therefore, the findings of this study provide strong empirical evidence that flooding constitutes a major challenge to agricultural livelihoods in Musanze District and highlight the need for effective flood management and climate adaptation strategies to improve food security and enhance the resilience of farming communities.

4. Conclusion

The study concludes that flooding is a major threat to agricultural livelihoods in Musanze District, resulting from interacting climatic, topographical, hydrological, and human factors. Heavy rainfall on volcanic slopes was the leading reported cause (48.7%), while floods occurred mainly during the March–May rainy season (58.1%). Although Musanze has highly productive agricultural systems, particularly Irish potato production, recurrent flooding substantially affects agricultural productivity and household welfare. Flooding caused food shortages among 84.1% of households, agricultural income losses among 78.9%, and indebtedness among 62.5%. Irish potatoes were the most affected crop, accounting for 58% of the total damaged area. Regression analysis demonstrated a strong positive relationship between flooding and agricultural livelihood difficulties ($R = 0.885$; $R^2 = 0.783$; $p = 0.046$), indicating that flooding explained 78.3% of the variation in livelihood challenges. Strengthening flood management, early warning systems, climate-smart agriculture, and community resilience is therefore essential.

5. References

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