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PERCEIVED POTENTIAL OF AI-ENABLED CLIMATE SERVICES FOR ENHANCING RURAL WOMEN FARMERS' PARTICIPATION IN CLIMATE EMERGENCY MANAGEMENT IN GICUMBI DISTRICT, RWANDA

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Abstract

Climate-induced flooding continues to threaten agricultural livelihoods, food security, and rural development across Sub-Saharan Africa, with women farmers disproportionately affected due to limited access to resources, Artificial Intelligence (AI), climate information, and adaptive technologies. However, limited research has examined the gendered dimensions of AI adoption among rural women farmers in Africa, particularly in climate-vulnerable regions. This study addresses these gaps by examining how AI can enhance the participation of rural women farmers in climate emergency management in Gicumbi District, Rwanda. Adopting the Capability Approach and Community-Based Disaster Risk Management (CBDRM) frameworks, the study employed a mixed-methods approach involving key informant interviews and focus group discussions with GIS-based spatial analysis using high-resolution satellite imagery and Digital Elevation Models (DEM) to identify flood-prone areas. Data were collected from women farmers across selected sectors of Gicumbi District to assess flood experiences, access to climate information, perceptions of AI technologies, and barriers to climate adaptation. Spatial analysis was used to identify communities exposed to varying levels of flood risk. The findings reveal that women farmers in highly vulnerable communities, particularly Tidgiri, Gaseke, Rwafandi, Mugina, and Rusumo, experience recurrent crop losses, livelihood disruptions, and reduced food security due to seasonal flooding. Although participants recognized the potential of AI-enabled weather forecasting, flood prediction, and early warning systems to improve preparedness and decision-making, adoption remains constrained by low digital literacy, limited internet access, financial barriers, and inadequate technological infrastructure. The GIS results further demonstrate that flood vulnerability is closely associated with low-lying terrain and poor accessibility. The study concludes that integrating AI-driven climate services with community-based adaptation strategies can strengthen women's participation in climate emergency management. Targeted investments in digital inclusion, climate information services, and spatially informed disaster planning are essential for building resilient and gender-responsive agricultural systems in Rwanda.

Keywords: Artificial Intelligence; Climate Emergency Management; Digital Inclusion; Flood Vulnerability; GIS Mapping; Rwanda; Women Farmers

1.0 INTRODUCTION

Climate change has become one of the most significant environmental and developmental challenges of the twenty-first century, with far-reaching implications for human well-being, food security, livelihoods, and ecosystem sustainability. The Intergovernmental Panel on Climate Change (IPCC, 2023) defines climate change as long-term alterations in temperature, precipitation patterns, and climatic conditions resulting primarily from anthropogenic greenhouse gas emissions. Across the globe, climate change is increasing the frequency, intensity, and unpredictability of extreme weather events, including floods, droughts, heatwaves, storms, and landslides (UNEP, 2024). These impacts are particularly severe in developing countries, where limited adaptive capacity, poverty, and infrastructural deficits amplify vulnerability to climate-related hazards (World Bank, 2022).

Sub-Saharan Africa is among the regions most affected by climate variability and environmental disasters. Increasing incidences of flooding, prolonged droughts, and land degradation have disrupted agricultural production, threatened food security, and undermined rural livelihoods (FAO, 2023). Rwanda is especially vulnerable because of its mountainous topography, high population density, intense seasonal rainfall, and dependence on rain-fed agriculture (MINEMA, 2024). Gicumbi District in the Northern Province experiences recurrent floods and landslides that damage agricultural lands, destroy infrastructure, displace households, and exacerbate livelihood insecurity among smallholder farmers. These impacts are often more pronounced among rural women who depend heavily on natural resources and agricultural production for household survival (REMA, 2017; UN Women, 2024).

The concept of resilience has therefore become central to climate adaptation and disaster risk reduction. Resilience refers to the capacity of individuals, households, communities, and institutions to anticipate, withstand, adapt to, and recover from environmental shocks while maintaining essential functions and well-being (UNDRR, 2023). Building resilience requires access to timely information, adaptive technologies, social networks, and institutional support systems that enable vulnerable populations to respond effectively to climate-related risks (Okafor and Akanwa, 2025).

In recent years, Artificial Intelligence (AI) has emerged as a transformative innovation for strengthening climate resilience. AI refers to computer systems capable of performing tasks that normally require human intelligence, including learning, prediction, problem-solving, pattern recognition, and decision-making (United Nations Development Programme (UNDP, 2024). AI technologies are increasingly being applied in weather forecasting, flood prediction, climate modelling, early warning systems, precision agriculture, and disaster response planning (WMO, 2024). These applications provide opportunities for improving preparedness, reducing losses, and enhancing adaptive capacities among climate-vulnerable populations. However, the benefits of AI remain unevenly distributed. Rural women farmers often face barriers related to limited digital literacy, inadequate access to digital devices, poor internet connectivity, financial constraints, and socio-cultural norms that restrict their participation in technology-driven initiatives (FAO, 2023; UN Women, 2024).

This study is framed on the Capability Approach and Community-Based Disaster Risk Management (CBDRM) framework. The Capability Approach, developed by Sen (1999) and expanded by Nussbaum (2011), focuses on individuals' freedoms and opportunities to achieve valued ways of living. Within climate adaptation contexts, access to information, technology, education, and institutional support expands people's capabilities to make informed decisions and respond effectively to environmental risks.

Complementing this perspective, CBDRM emphasizes local participation, community ownership, indigenous knowledge, and collective action in disaster preparedness, response, and recovery processes (Shaw, 2012; UNDRR, 2023). Combining these frameworks provides a robust analytical lens for examining how AI can strengthen the capabilities of rural women farmers and enhance their participation in climate emergency management.

Although substantial studies have examined AI applications in agriculture and climate adaptation, limited attention has been given to how AI can empower rural women as active agents of climate resilience. While previous studies in Rwanda have advanced understanding of flood hazards through hydrological, topographic, and GIS-based vulnerability assessments, limited attention has been given to how flood risk intersects with gender inequalities, digital exclusion, and the capacity of rural women farmers to access emerging technologies such as artificial intelligence for climate adaptation and disaster preparedness (World Bank, 2022; FAO, 2024). Existing research has therefore overlooked the socio-spatial dimensions of vulnerability that shape women's participation in climate emergency management

Furthermore, few studies have integrated GIS-based flood vulnerability mapping with capability-oriented and participatory disaster management frameworks to assess women's engagement in climate emergency management in Gicumbi District.

The uniqueness of this study, therefore, lies in its integration of Artificial Intelligence, GIS-based flood vulnerability assessment, the Capability Approach, and Community-Based Disaster Risk Management to examine women's participation in climate emergency management. Specifically, the study sought to: (1) identify flood-prone zones within Gicumbi District using GIS-based flood vulnerability mapping; (2) assess the role of AI technologies in improving climate information access among rural women farmers; (3) examine barriers limiting women's participation in AI-enabled climate emergency management; (4) evaluate the relationship between flood vulnerability, digital inclusion, and community resilience; and (5) propose policy interventions that promote gender-inclusive AI adoption for climate adaptation.

Therefore, the central objective of this study is to examine how Artificial Intelligence can enhance the participation of rural women farmers in climate emergency management within flood-prone communities of Gicumbi District, Rwanda. By linking technological innovation with gender-responsive resilience building, the study advances understanding of how rural women can transition from being viewed solely as climate-vulnerable populations to becoming active agents of adaptation, disaster preparedness, and sustainable community resilience.

2.0 LITERATURE REVIEW

2.1 Conceptual Framework: Capability Approach and Community-Based Disaster Risk Management (CBDRM)

This study is anchored on the Capability Approach (CA) and the Community-Based Disaster Risk Management (CBDRM) framework to examine how Artificial Intelligence (AI) can enhance the participation of rural women farmers in climate emergency management in Gicumbi District, Rwanda. The integration of these frameworks provides a comprehensive understanding of the relationship between technological access, individual empowerment, community participation, and climate resilience.

The Capability Approach, developed by Sen (1999) and further advanced by Nussbaum (2011), emphasizes people's substantive freedoms and opportunities to achieve outcomes they value. Rather than focusing solely on the availability of resources, the approach examines individuals' capabilities to convert resources into meaningful actions and achievements. In the context of climate change, capabilities include access to

climate information, digital literacy, technological resources, agricultural knowledge, and decision-making opportunities that enable individuals to anticipate, respond to, and recover from environmental shocks (Robeyns, 2017). For rural women farmers, AI technologies such as flood forecasting systems, mobile-based weather advisories, and digital agricultural platforms can expand their capabilities by improving access to timely information, enhancing adaptive decision-making, and strengthening livelihood security.

Community-Based Disaster Risk Management (CBDRM) complements the Capability Approach by emphasizing local participation, collective action, indigenous knowledge, and community ownership in disaster preparedness and response (Shaw, 2012). CBDRM recognizes that communities are not passive victims of disasters but active agents capable of identifying risks, mobilizing local resources, and implementing context-specific adaptation strategies. The framework advocates for inclusive participation of vulnerable groups, particularly women, in disaster planning, implementation, monitoring, and evaluation processes (Maskrey, 2011).

The integration of these frameworks suggests that access to AI-enabled climate information alone may not guarantee resilience unless women possess the capabilities required to understand, utilize, and apply such information within supportive community structures. Consequently, women's participation in climate emergency management is influenced by both individual capabilities (digital literacy, education, access to technology, knowledge, and agency) and collective capacities (community networks, local institutions, disaster preparedness systems, and participatory governance).

Within this study, recurrent flooding and climate-related hazards constitute the primary environmental stressors. AI technologies function as enabling resources that provide weather forecasts, flood alerts, climate information services, and agricultural advisories. These resources enhance women's capabilities by improving knowledge acquisition, risk awareness, preparedness, and adaptive decision-making. Through CBDRM processes such as community participation, local planning, knowledge sharing, and collective action, these enhanced capabilities contribute to improved disaster preparedness, reduced vulnerability, and increased climate resilience.

The conceptual framework, therefore, positions AI access and utilization as key enabling factors that strengthen women's capabilities, which in turn promote active participation in community-based disaster risk management and ultimately enhance climate resilience among rural women farmers in Gicumbi District, Rwanda.

2.2 Artificial Intelligence and Climate Adaptation

Climate change has emerged as one of the most pressing global challenges of the twenty-first century, intensifying the frequency and severity of floods, droughts, heatwaves, and other extreme weather events. These hazards threaten agricultural productivity, food security, livelihoods, and sustainable development, particularly in developing countries where adaptive capacities remain limited (IPCC, 2023). In response, Artificial Intelligence (AI) has gained increasing attention as a transformative technology capable of supporting climate adaptation and disaster risk reduction. AI refers to computer systems designed to perform tasks that normally require human intelligence, including learning, reasoning, prediction, pattern recognition, and decision-making (UNDP, 2024).

Recent advancements in AI have enabled the development of sophisticated climate services, including weather forecasting, flood prediction models, crop monitoring systems, precision agriculture applications, and early warning mechanisms. Through machine learning algorithms and big-data analytics, AI can process large volumes of meteorological and environmental data to predict climate risks with greater accuracy and speed than traditional methods (Rolnick et al., 2022). AI-driven climate information systems have been shown to improve preparedness, reduce disaster losses, and support evidence-based decision-

making among farmers and emergency management agencies (Vinuesa et al., 2023). Consequently, AI is increasingly recognized as a critical component of climate resilience strategies worldwide.

2.3 Climate Resilience and Climate-Induced Flooding

Climate resilience refers to the capacity of individuals, communities, institutions, and ecosystems to anticipate, absorb, adapt to, and recover from climate-related shocks and stresses while maintaining essential functions and livelihoods (UNEP, 2024). Resilience extends beyond physical infrastructure and encompasses social, economic, institutional, and environmental dimensions that enable communities to cope with uncertainty and change (Kim & Lim, 2016).

Among climate-induced hazards, flooding remains one of the most devastating disasters globally. According to the IPCC (2023), increased rainfall variability, changing precipitation patterns, and extreme weather events are contributing to more frequent and intense floods across Africa. In Rwanda, recurrent flooding and landslides have become major environmental concerns, particularly in mountainous regions characterized by steep slopes, fragile ecosystems, and high population densities (MINEMA, 2024). Floods damage agricultural lands, destroy infrastructure, contaminate water sources, and disrupt livelihoods, thereby increasing poverty and food insecurity among rural households.

Geographic Information Systems (GIS) and remote sensing technologies have become valuable tools for identifying flood-prone zones and assessing vulnerability. Spatial vulnerability mapping enables decision-makers to identify high-risk areas, prioritize interventions, and allocate resources more effectively (Sultana, 2021). Geospatial analysis has also increasingly been used to connect environmental degradation, socio-ecological vulnerability, and adaptation planning in African contexts (Akanwa et al., 2026). However, many flood vulnerability studies continue to focus primarily on biophysical indicators such as elevation, rainfall intensity, drainage density, and land-use patterns, often neglecting the social dimensions of vulnerability that influence exposure and adaptive capacity.

2.4 Women in Agriculture and Climate Vulnerability

Women play a central role in agricultural production across Sub-Saharan Africa, contributing substantially to food production, processing, and household food security. The Food and Agriculture Organization (FAO, 2023) estimates that women constitute approximately 48 per cent of the agricultural labour force in Africa. Despite their significant contributions, women frequently face systemic barriers that limit access to land ownership, agricultural inputs, credit facilities, extension services, technology, and climate information.

Climate change amplifies these existing inequalities. Studies indicate that women are often disproportionately affected by climate-related disasters due to gendered divisions of labour, caregiving responsibilities, limited mobility, and restricted access to resources needed for adaptation (UN Women, 2024). During flood events, women frequently experience greater livelihood losses, reduced access to markets, food insecurity, and increased burdens associated with household recovery and care work (FAO, 2023). These challenges are particularly severe for rural women farmers whose livelihoods depend directly on climate-sensitive agricultural activities.

The concept of gender-responsive climate resilience emphasizes the importance of recognizing women's knowledge, capacities, and leadership roles in adaptation planning and disaster management. Rather than viewing women solely as vulnerable populations, contemporary climate scholarship increasingly highlights their potential as active agents of resilience and community transformation (Sultana, 2022).

2.5 Digital Inclusion, Artificial Intelligence, and Women's Climate Resilience

The growing application of digital technologies presents new opportunities for strengthening women's participation in climate adaptation and emergency management. Mobile applications, digital advisory platforms, AI-enabled weather forecasting systems, and early warning technologies can improve access to climate information and support informed decision-making among rural farmers (Klerkx & Rose, 2023). These technologies can help women anticipate extreme weather events, adopt climate-smart agricultural practices, reduce crop losses, and participate more effectively in disaster preparedness initiatives.

However, the benefits of AI are not equally distributed. Significant digital divides persist across many African countries, particularly between urban and rural populations and between men and women. Limited digital literacy, inadequate internet connectivity, affordability constraints, and socio-cultural norms continue to restrict women's access to emerging technologies (FAO, 2023). As a result, many rural women remain excluded from technology-driven climate adaptation initiatives despite being among the populations most vulnerable to climate impacts.

Emerging scholarship argues that inclusive AI deployment requires targeted investments in digital literacy, gender-responsive technology design, community engagement, and policy frameworks that address structural inequalities (UNDP, 2024). Integrating AI with participatory disaster risk management approaches can strengthen local capacities while ensuring that technological innovations respond to community needs and priorities

3.0 METHODOLOGY

This study adopted a mixed-methods research design that integrated qualitative methods such as photographic documentation, Key Informant Interviews (KIIs), and Focus Group Discussions (FGDs). Also, spatial analysis was used to investigate climate-related vulnerabilities and the role of Artificial Intelligence (AI) in enhancing the participation of rural women farmers in climate emergency management in Gicumbi District, Rwanda. The mixed-method approach was considered appropriate because climate vulnerability is both a physical and social phenomenon, requiring an understanding of environmental exposure alongside the lived experiences of affected populations. Secondary sources include institutional and governmental reports and journals.

3.1 Qualitative Data

The qualitative data were collected through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs) to examine community experiences of climate hazards, women's participation in climate emergency management, perceptions of Artificial Intelligence (AI), and barriers to climate adaptation in Gicumbi District, Rwanda. Photographic documentation was employed to capture visible evidence of flood-prone landscapes, agricultural impacts, damaged infrastructure, and community adaptation practices. The photographs served as visual validation of field observations and enriched the interpretation of qualitative findings.

The study involved 12 participants: six key informants and six women farmers who participated in two focus group discussions, with three participants in each FGD. Participants were purposively selected based on their knowledge, experience, and involvement in climate adaptation, agriculture, disaster risk management, and community development from different sectors in Gicumbi district. Participants included a representative from the local government authority, a disaster management agency, an agricultural extension officer, a women's cooperative, a community leader, an environmental officer, and a technology or digital expert operating within the district. Purposive sampling was considered appropriate because it enabled the selection of participants with specialized knowledge relevant to the study objectives.

Semi-structured interviews were conducted between June and July 2025. Each interview lasted approximately 45–60 minutes, allowing participants sufficient time to discuss their experiences, perceptions, and recommendations regarding climate risks, flood management, AI adoption, and women's involvement in decision-making processes. The interviews were conducted primarily in Kinyarwanda, the local language widely spoken by participants, while some interviews with government officials and technical experts were conducted in English. This bilingual approach enhanced participant comfort and facilitated richer discussions.

With participants' informed consent, all interviews were audio-recorded and supplemented with detailed field notes. The recordings were subsequently transcribed verbatim. Interviews conducted in Kinyarwanda were translated into English by the research team to ensure consistency in analysis. To enhance reliability, translated transcripts were reviewed and cross-checked against the original recordings to minimize translation bias and preserve participants' intended meanings.

3.2 Data Analysis

Qualitative data were analyzed using thematic analysis following the procedures outlined by Braun and Clarke (2021). The transcripts were read repeatedly to achieve familiarity with the data. Initial codes were generated and organized into broader themes related to climate vulnerability, flood impacts, gendered experiences, digital inclusion, AI-enabled adaptation, barriers to participation, and community resilience. Emerging themes were further refined and interpreted within the Capability Approach and Community-Based Disaster Risk Management (CBDRM) framework. The qualitative findings were subsequently integrated with GIS-based spatial analysis and photographic evidence to identify micro-vulnerability hotspots and provide a deeper understanding of the relationship between environmental exposure, social vulnerability, and women's adaptive capacities.

3.3 Spatial Vulnerability Mapping

Spatial Vulnerability Mapping was conducted using Geographic Information System (GIS) techniques to identify flood-prone zones and visualize areas most susceptible to recurrent flooding within Gicumbi District, Rwanda. The analysis integrated both biophysical and socio-demographic vulnerability indicators to provide a spatially explicit assessment of climate-induced flood exposure.

The primary spatial dataset was a 30 m × 30 m Digital Elevation Model (DEM) obtained from the Shuttle Radar Topography Mission (SRTM) archive. The DEM was used to derive elevation and slope characteristics, which are critical determinants of flood susceptibility in low-lying coastal environments. Additional spatial layers included drainage networks, land-use characteristics, settlement distribution, and community infrastructure. All datasets were projected into a common coordinate reference system and processed using ArcGIS 10.8.

Flood-risk zones were identified through a weighted overlay analysis that combined elevation, proximity to drainage channels, surface characteristics, and flood exposure indicators. Rainfall intensity thresholds were informed by historical precipitation patterns for Bayelsa State, where annual rainfall exceeds 2,500 mm, and extreme rainfall events frequently occur during the peak rainy season between June and October. Areas located below 10 m above sea level, characterized by poor drainage, swampy terrain, and frequent inundation records, were classified as “Very High Flood Vulnerability Zones.” Moderate-risk zones comprised areas between 10–20 m elevations with seasonal flooding records, while areas above 20 m elevation and with better drainage conditions were classified as low-risk zones.

The GIS outputs were subsequently integrated with interview and focus group findings to identify micro-vulnerability hotspots. This mixed-method spatial approach enabled the validation of community

experiences and provided locational evidence of climate-related risks affecting rural women farmers. By combining spatial data with community narratives, the study generated a more comprehensive understanding of how environmental exposure, social vulnerability, and technological access interact to influence women's participation in climate emergency management and resilience-building efforts in Gicumbi District.

3.4 Ethical Considerations

Ethical approval was obtained, and participation was voluntary and restricted to adults only. Verbal informed consent was adopted, and participants were informed of their right to withdraw without consequences. No personal identifiers were recorded, and data were anonymised and securely stored to protect confidentiality.

4.0 RESULTS

This data from interviews with key informants, photographs, discussions, and spatial analysis, including elevation and flood vulnerability maps, is presented and discussed. The findings from the 6 Key Informant Interviews (KIIs) and 6 women participants in the Focus Group Discussions (FGDs) are presented in thematic headings.

Table 1 shows the demographic characteristics of the participants involved in the study. The qualitative study involved twelve participants, comprising six key informants and six women farmers who participated in two Focus Group Discussions. Females constituted 75% of the participants, reflecting the study's focus on women's participation in climate emergency management. Most participants were within the economically active age categories of 31–50 years, while half had lived or worked in the study area for more than ten years, providing substantial knowledge of local environmental conditions and disaster experiences. Educational attainment varied from primary education to university level, ensuring a diversity of perspectives.

Table 1: Socio-Economic Characteristics of Study Participants.

NO	Category	Description	Frequency(n)	Percentage (%)
1	Participant Type	Key Informants	6	50.0
		FGD Participants (Women Farmers)	6	50.0
2	Gender	Female	9	75.0
		Male	3	25.0
3	Age Group (Years)	18–30	2	16.7
		31–40	4	33.3
		41–50	3	25.0
		Above 50	3	25.0
4	Educational level	Primary Education	2	16.7
		Secondary Education	4	33.3
		Diploma/Technical Training	3	25.0
		University Degree and Above	3	25.0
5	Occupation/Role	Women Farmers	6	50.0
		Local Government Official	1	8.3
		Disaster Management Officer	1	8.3
		Agricultural Extension Officer	1	8.3
		Women's Cooperative Representative	1	8.3
		Community Leader	1	8.3
		Environmental/Technology Expert	1	8.3

6	Years of	Less than 5 Years	2	16.7
	Experience/	5–10 Years	4	33.3
	Residence	Above 10 Years	6	50.0

Source: Compiled by authors (2026).

Table 2 indicates the profile of the participants represented, which includes a local government representative, a disaster management institution, an agricultural extension officer, a women's cooperative stakeholder, a community leadership representative, an environmental management technology expert, and rural women farmers. This diversity enabled the study to capture both institutional and community-level perspectives on climate vulnerability, AI adoption, disaster preparedness, and resilience-building in Gicumbi District.

Table 2: Profile of Study Participants

Participant Category	Number	Description
Local Government Official	1	Responsible for local development planning
Disaster Risk Management Officer	1	District disaster preparedness and response officer
Agricultural Extension Officer	1	Supports farmers with agricultural innovations
Women's Cooperative Leader	1	Coordinates women's farming groups
Environmental Office	1	Oversees environmental management activities
ICT/AI Expert	1	Works on digital technologies and climate information dissemination
Women Farmers (FGD 1)	3	Smallholder farmers from flood-prone communities
Women Farmers (FGD 2)	3	Smallholder farmers from flood-prone communities
Total Participants	12	6 KIIs and 6 FGD participants

Source: Compiled by authors (2026).

4.1 Findings from Key Informant Interviews and Focus Group Discussions

Theme 1: Recurrent Flooding as a Major Threat to Livelihoods

Participants consistently acknowledged flooding as the most frequent climate-related hazard affecting farming activities, food production, and household welfare, as shown in Plate 1. Women farmers explained that heavy rainfall often destroys crops, washes away fertile soil, damages roads, and restricts access to markets. One participant stated:

"When floods come, our beans and maize are destroyed. Sometimes we lose almost everything we planted for the season." (KII 1).

The Disaster Risk Management Officer confirmed that several sectors within Gicumbi experience recurrent flooding due to steep slopes, poor drainage systems, and increasing rainfall variability. These findings correspond with recent studies showing that climate change has intensified hydrological hazards across East Africa, increasing livelihood vulnerability among rural farming households (IPCC, 2023).

Findings from participants' interviews and discussions reveal that farming clearly remains the dominant livelihood activity, particularly for the rural women (See Plates 2, 3 &4). A woman farmer explained,

"Rural women are mostly involved in farming staple crops as a source of daily income and livelihood." (KII 2).

Gicumbi women cultivate staple crops such as sweet potatoes, beans, sorghum, maize, cassava, Irish potatoes, vegetables, and bananas. They also rear livestock, such as goats, pigs, and chickens. This result reflects the need for AI-enabled technologies for these rural women farmers to protect their farms and sources of income from climate risks such as floods, crop pests and diseases, among others.



Plate 1: Showing farmland damaged by flood events in Gicumbi District

Source: Compiled by authors, 2025

4.2 Theme 2: Limited Access to Climate Information among Women Farmers

Most women reported relying on traditional weather observations, community announcements, and radio broadcasts for climate information. Participants indicated that access to real-time weather forecasts remains limited. A Women's Cooperative Leader noted:

"Many women farmers still depend on experience and local signs to predict rainfall because they do not have access to digital tools." (KII 3).

The Agricultural Extension Officer explained that although climate information services exist, many rural women lack smartphones, internet connectivity, and digital literacy skills needed to utilize available technologies effectively. This finding highlights a digital divide that limits adaptive capacity among rural women.



Plate 2: Women farmers weeding in Gicumbi District

Source: Compiled by authors, 2025



Plate 3: Women farmers harvesting potatoes in Gicumbi District

Source: Compiled by authors, 2025



Plate 4: Some women farmers working in Gicumbi District

Source: Compiled by authors, 2025

4.3 Theme 3: Perceived Benefits of Artificial Intelligence in Climate Emergency Management

Participants expressed a strong interest in AI-enabled climate services. The ICT Expert explained that AI systems can predict rainfall patterns, generate flood warnings, support crop monitoring, improve agricultural decision-making, and disseminate climate advisories. According to the ICT Expert:

"Artificial Intelligence can help communities move from reacting to disasters to preparing before disasters occur."(KII 4).

While women farmers indicated that receiving timely information could help them adjust planting dates, harvest early, protect livestock, and reduce crop losses. Participants generally perceived AI as a useful tool capable of strengthening resilience and reducing disaster impacts

4.4 Theme 4: Barriers to AI Adoption among Rural Women

Table 3 captures several constraints identified by participants to the use of AI despite recognizing its potential benefits. These barriers reduce women's ability to benefit from emerging digital climate solutions. One participant remarked:

"Even if the information exists, many women do not know how to access it."(KII 5).

Table 3 indicates that limited training opportunities (91.7%) emerged as the most significant barrier to AI adoption among rural women farmers in Gicumbi District. This was followed by low digital literacy (83.3%) and limited awareness of AI applications (83.3%), suggesting that knowledge and skills deficits remain major constraints to digital inclusion. The high cost of digital devices (75.0%) further restricts women's ability to access AI-enabled climate information services.

Similarly, poor internet connectivity (66.7%) and gender inequalities in technology access (66.7%) continue to hinder effective participation in climate emergency management. More than half of the participants (58.3%) identified language barriers, emphasizing the need for AI applications and climate information services to be localized in Kinyarwanda. Additionally, 50.0% of participants cited inadequate electricity supply as a challenge to sustained use of digital technologies.

These findings suggest that while AI has significant potential to strengthen climate resilience, successful implementation requires investments in digital literacy training, affordable technology access, rural connectivity infrastructure, localized information platforms, and gender-responsive capacity-building programmes. Such interventions would enhance women's capabilities and participation in climate emergency management, consistent with the principles of the Capability Approach and Community-Based Disaster Risk Management (CBDRM).

Table 3: Perceived Barriers to AI Adoption among Study Participants

Barrier to AI Adoption	No of Participants	Percentage (%)	Illustrative Evidence
Low digital literacy	10	83.3	Participants reported difficulties using smartphones, mobile applications, and digital climate information platforms.
High cost of digital devices	9	75.0	Many women indicated that purchasing smartphones and maintaining internet subscriptions were financially challenging.
Poor internet connectivity	8	66.7	Participants highlighted unstable network coverage in some farming communities, limiting access to real-time climate information.
Limited AI and digital training opportunities	11	91.7	Most respondents reported little or no formal training on AI-enabled climate information systems and digital tools.
Language barriers	7	58.3	Participants noted that many digital applications and climate information platforms are presented in English rather than Kinyarwanda.
Gender inequalities in technology access	8	66.7	Women reported lower access to digital devices, financial resources, and decision-making opportunities compared to men.
Inadequate electricity supply	6	50.0	Some rural communities experience difficulties charging devices due to unreliable electricity access.
Limited awareness of AI application	10	83.3	Participants were generally unfamiliar with how AI could support farming and climate emergency management.

Source: Compiled by author, 2026

4.5 Theme 5: Community-Based Approaches Strengthen Climate Resilience

Participants emphasized the importance of local knowledge and collective action in managing climate risks. Women reported engaging in community savings groups, cooperative farming, mutual support networks, and informal flood monitoring. The Community Leader observed:

"People trust information more when it comes through local groups and community leaders."(KII 6).

This finding supports Community-Based Disaster Risk Management (CBDRM) principles, which emphasize local participation, ownership, and indigenous knowledge in disaster preparedness.

4.6 Theme 6: AI as a Capability Enhancement Tool for Women

Findings strongly support the Capability Approach. Participants suggested that access to AI technologies would expand their ability to make informed farming decisions, access climate information, protect livelihoods, participate in disaster planning, and improve household resilience. The Women's Cooperative Leader stated:

"Knowledge is power. When women receive information early, they can protect their farms and families."(KII 3).

This demonstrates that AI is not merely a technological innovation but also a mechanism for expanding women's capabilities, agency, and participation in climate emergency management.

The study reveals that recurrent flooding remains a major challenge in Gicumbi District. While AI presents significant opportunities for improving early warning systems, climate information access, and disaster preparedness, women face substantial barriers related to digital literacy, affordability, infrastructure, and gender inequality. The findings further show that integrating AI with community-based disaster management approaches can strengthen resilience by enhancing women's capabilities, participation, and adaptive capacity in climate emergency management. These results provide empirical support for combining the Capability Approach and CBDRM as frameworks for promoting gender-responsive climate resilience in rural Rwanda.

4.7 Spatial Analysis Mapping

Figures 1 and 2 present spatial analysis maps showing elevation patterns and flood vulnerability across the Gicumbi District. Elevation data derived from the Digital Elevation Model (DEM) enabled the identification of low-lying and high-altitude areas susceptible to runoff accumulation and flood occurrence. The flood vulnerability map integrated topographic characteristics and hydrological conditions to classify areas into varying risk categories. These spatial outputs provided empirical evidence of flood-prone locations, supporting the identification of vulnerable communities and informing targeted climate adaptation and disaster risk management interventions.

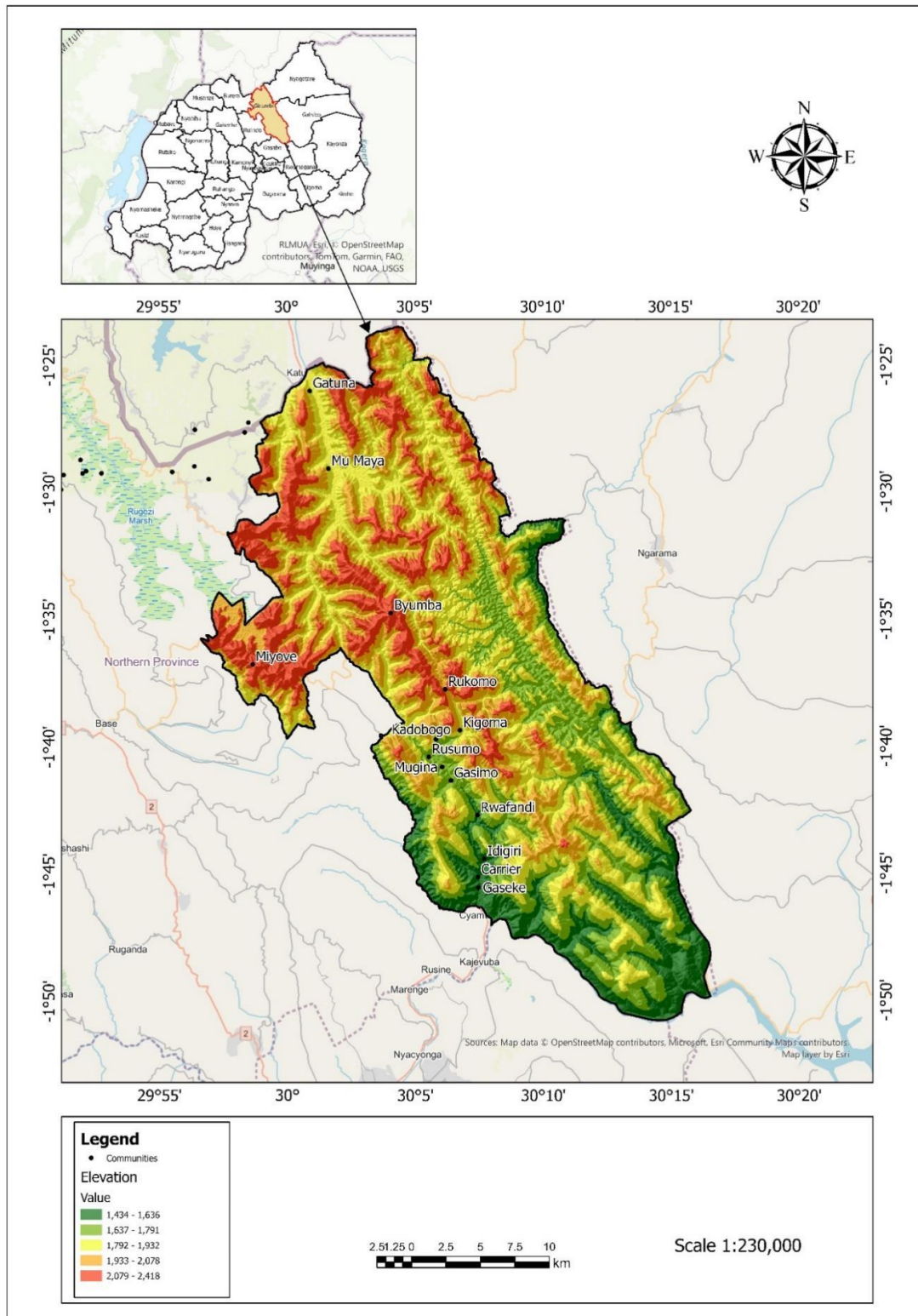


Figure 1: Elevation map of the study area

Source: Compiled by authors (2025)

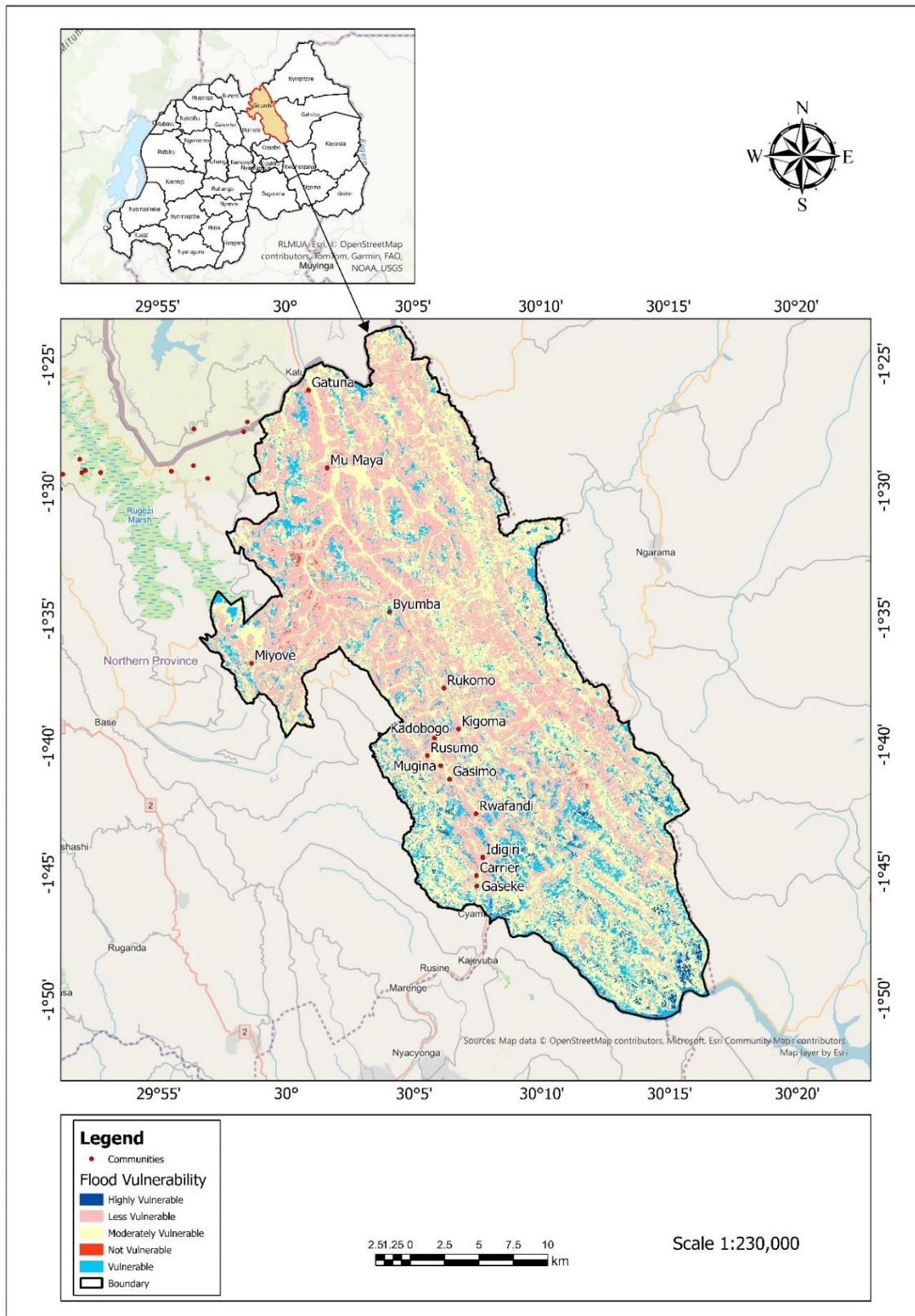


Figure 2: Flood Vulnerability of the study area

Source: Compiled by authors (2025)

5.0 DISCUSSION

The findings of this study demonstrate that climate vulnerability among rural women farmers in Gicumbi District is defined by both environmental exposure and unequal access to information, technology, and adaptive resources. By integrating qualitative findings with GIS-based elevation and flood vulnerability mapping, the study provides a more comprehensive understanding of how physical geography influences women's participation in climate emergency management.

The GIS analysis revealed significant spatial variations in flood vulnerability across Gicumbi District. Table 4 shows that communities such as Carrier, Tidgiri, Gaseke, Rwafandi, Mugina, and Rusumo were identified as highly vulnerable due to their location within low-lying floodplains and river corridors. These areas correspond closely with lower elevations ranging from approximately 1,434 to 1,791 metres above sea level. In contrast, Gatuna, Mu Maya, Byumba, and parts of Miyove occur predominantly within less vulnerable zones because of their relatively higher elevations. These findings confirm that topography remains a key determinant of flood exposure and environmental risk, consistent with previous studies on flood vulnerability in Rwanda and other mountainous regions of Sub-Saharan Africa (IPCC, 2023; World Bank, 2022).

Table 4: Shows Vulnerable Communities and Major Impacts

Flood Vulnerability Class	Colour on Map	Major Communities	Major Impacts
Highly Vulnerable	Dark Blue	Parts of Carrier, Tidgiri, Gaseke, Rwafandi, Mugina, Miyove, and the river valley sections surrounding these communities	Severe flooding, crop destruction, soil erosion, displacement, damage to roads and rural infrastructure
Vulnerable	Light Blue/Cyan	Carrier, Tidgiri, Gaseke, Rwafandi, Mugina, Rusumo, and portions of Miyove	Seasonal flooding, waterlogging, reduced agricultural productivity, transport disruptions, contamination of water sources
Moderately Vulnerable	Cream/Yellow	Kadobogo, Kigoma, Gasimo, Rusumo, Rukomo, and parts of Mu Maya	Localized flooding, moderate soil erosion, occasional crop losses, infrastructure deterioration during intense rainfall
Less Vulnerable	Pink	Byumba, Mu Maya, Gatuna, and portions of Rukomo	Relatively low flood exposure, but vulnerable to runoff concentration and drainage challenges
Not Vulnerable	Red/Orange	Isolated upland ridges around Gatuna, Mu Maya, Byumba, and Miyove	Minimal flood risk; however, steep slopes may experience erosion, landslides, and sediment transport

Source: Compiled by authors, 2026

The spatial patterns identified through GIS strongly corroborate the experiences reported by women farmers during interviews and focus group discussions. Participants from highly vulnerable communities consistently described recurrent crop destruction, declining soil fertility, loss of farm income, and disruptions to food production caused by seasonal flooding. Women cultivating beans, maize, Irish potatoes, bananas, and vegetables explained that floods frequently wash away seedlings, damage farmland, and delay planting and harvesting activities. These experiences support findings by the Food and Agriculture Organization (FAO, 2024), which emphasizes that climate-induced disasters disproportionately affect rural

women because of their dependence on climate-sensitive livelihoods and limited access to productive resources.

The integration of qualitative and spatial findings further reveals how physical marginalization reinforces social and economic vulnerability. Communities located in highly vulnerable flood zones often experience poor road connectivity, damaged infrastructure, and limited access to markets, agricultural inputs, and extension services. As a result, women farmers face greater challenges in recovering from climate shocks. This observation aligns with the Capability Approach, which argues that vulnerability is not solely determined by exposure to hazards but also by people's ability to access resources and opportunities needed to achieve desired outcomes (Sen, 1999). The flood vulnerability map, therefore, illustrates not only where climate risks occur but also where women's capabilities are most constrained.

A major finding of the study concerns the role of climate information and digital technologies in strengthening resilience. Most participants reported relying on indigenous knowledge, personal observations, community experiences, and radio broadcasts to anticipate rainfall and flood events. While these traditional systems remain valuable, they often provide limited forecasting accuracy and insufficient lead time for effective preparedness. Women from highly vulnerable communities reported difficulties making timely decisions regarding planting, harvesting, livestock management, and emergency response. Similar challenges have been documented across rural Africa, where inadequate access to digital technologies and climate information services limits adaptation capacity (Abdulai et al., 2023; REMA, 2017).

Participants generally perceived Artificial Intelligence (AI) as a promising tool for improving climate emergency management. They believed that AI-enabled weather forecasting systems, flood prediction models, mobile advisory platforms, and early warning systems could help farmers anticipate hazards, reduce crop losses, and improve decision-making. Recent studies indicate that AI applications can enhance disaster preparedness through predictive analytics, real-time monitoring, and risk forecasting, particularly when integrated with geospatial technologies such as GIS and remote sensing (World Bank, 2022). The flood vulnerability map demonstrates where such interventions would be most beneficial, particularly within Tidgiri, Gaseke, Rwafandi, Mugina, and Rusumo, where exposure to flood risks is greatest.

However, the study also identified significant barriers to AI adoption. Women reported low digital literacy, limited ownership of smartphones, poor internet connectivity, language constraints, and financial limitations that restrict access to digital services. These barriers create a digital divide that prevents many women from benefiting from emerging climate technologies. Consequently, spatial vulnerability is compounded by technological exclusion. Women living in highly vulnerable locations are often the same individuals with the least access to AI-based climate information and decision-support tools, creating a cycle of environmental and socioeconomic disadvantage.

From a Community-Based Disaster Risk Management (CBDRM) perspective, the findings highlight the importance of combining local knowledge with technological innovation. Women's cooperatives, social networks, community leaders, and local institutions already play important roles in disseminating information and coordinating responses during climate emergencies. Integrating AI-driven climate services into these existing community structures could enhance preparedness while ensuring that technology remains accessible and locally relevant (Shaw, 2012). Such an approach would strengthen women's participation in climate emergency management and improve collective resilience.

Overall, the combined qualitative and GIS findings demonstrate that flood vulnerability in Gicumbi District is both spatial and social. AI has the potential to bridge existing information gaps and enhance women's adaptive capacity, but its effectiveness will depend on addressing underlying inequalities in access,

affordability, digital literacy, and infrastructure. Targeted investments in AI-enabled early warning systems, digital training, climate information services, and community-based adaptation programmes are therefore essential for building resilient and inclusive climate emergency management systems in Gicumbi District.

6.0 POLICY IMPLICATIONS AND RECOMMENDATIONS

The findings demonstrate that flood vulnerability in Gicumbi District is not only a function of physical exposure but also of unequal access to climate information, digital technologies, and adaptive resources. The concentration of highly vulnerable communities in Tidgiri, Gaseke, Rwafandi, Mugina, and Rusumo suggests that climate interventions should be geographically targeted rather than uniformly implemented across the district.

First, local and national authorities should integrate GIS-based flood vulnerability mapping into climate emergency planning and resource allocation, particularly in highly vulnerable communities. Such spatially targeted approaches have been identified as effective mechanisms for reinforcing climate adaptation and disaster preparedness (IPCC, 2023; UNDRR, 2023).

Second, there is a need to strengthen women's access to AI-enabled early warning systems, and digital climate advisory services should be expanded to support women's participation in climate emergency management. Improving access to climate information has been shown to enhance adaptive capacity and resilience among smallholder farmers (FAO, 2024; World Bank, 2024).

Third, targeted digital literacy programmes should be developed for rural women farmers to enhance their capacity to use emerging technologies effectively. These initiatives should be delivered through women's cooperatives, farmer associations, and community-based organizations to ensure accessibility and sustainability. Fourth, climate adaptation policies should promote affordable internet access, rural digital infrastructure, and local-language climate information services to reduce technological exclusion.

Finally, Community-Based Disaster Risk Management (CBDRM) structures should be strengthened through the integration of local knowledge and AI-driven climate information systems. This would improve preparedness, participation, and resilience while ensuring that women farmers are recognized as active stakeholders in climate emergency management rather than passive recipients of assistance.

7.0 CONCLUSION

This study examined how Artificial Intelligence can enhance the participation of rural women farmers in climate emergency management in Gicumbi District, Rwanda. By integrating qualitative evidence with GIS-based flood vulnerability mapping, the study demonstrated that climate risks are shaped by the interaction between environmental exposure, social inequalities, and access to information. The findings show that women farmers living in highly vulnerable flood-prone communities face multiple challenges that limit their adaptive capacity, including livelihood insecurity, inadequate climate information, and restricted access to digital technologies.

The study contributes to knowledge by illustrating how spatial vulnerability and digital exclusion reinforce one another. While GIS mapping identified communities at greatest risk of flooding, qualitative findings revealed how limited access to AI-enabled climate services constrains preparedness and decision-making among women farmers. This highlights the importance of combining geospatial technologies with locally grounded knowledge to support more inclusive climate governance.

More broadly, the study demonstrates that the effectiveness of AI in climate emergency management depends not only on technological innovation but also on equitable access, digital literacy, and community participation. Strengthening these enabling conditions can transform AI from a technical tool into a mechanism for empowerment and resilience. The findings, therefore, underscore the need for gender-responsive, technology-inclusive, and place-based adaptation strategies that enhance women's agency and support sustainable climate resilience in vulnerable rural communities.

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