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The Assessment of the Socioeconomic Impacts of Seasonal Flood on Livelihood in Bugarama Valley, Rusizi District, Rwanda

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Abstract

Flooding remains a major natural hazard undermining livelihoods and socioeconomic development in Rwanda, especially in low-lying agricultural valleys. This study assessed the socioeconomic impacts of floods in Bugarama Valley, Rusizi District, Rwanda (2015–2025). It identified flood-prone areas, analysed environmental drivers of flooding, and evaluated household-level losses using a mixed-methods design integrating quantitative, qualitative, and geospatial approaches. Primary data were collected from 252 households via structured questionnaires, supplemented by key informant interviews, focus group discussions, field observations, and secondary data. Geographic Information Systems (GIS) and remote sensing techniques—Digital Elevation Model (DEM), Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Topographic Wetness Index (TWI), flow accumulation analysis, and Inverse Distance Weighting (IDW) rainfall interpolation—were applied to map flood susceptibility.The findings recorded 20 flood events across five sectors of the valley (2015–2025), causing 7 deaths, 10 injuries, damage to 76 houses, destruction of 44.6 ha of crops, and damage to 4 bridges. Flood Impact Index (FII) analysis ranked Muganza sector as the most affected (FII = 75), followed by Bugarama sector (FII = 59.6). Geospatial analysis revealed that low elevation, poor drainage, high flow accumulation, sparse vegetation cover, and proximity to river systems increased flood susceptibility. Household surveys confirmed that major socioeconomic impacts included crop destruction, housing damage, displacement, disease outbreaks, and disruptions to transport, education, and health services. The study concludes that flooding presents a multidimensional threat to livelihoods, infrastructure, public health, and sustainable development in Bugarama Valley. Reducing flood vulnerability and building community resilience require strengthening drainage infrastructure, enforcing land-use regulations, promoting climate-smart agriculture, and improving early warning systems.

1. INTRODUCTION

Flooding is one of the most frequent and destructive natural hazards worldwide, causing substantial social, economic, environmental, and public health impacts. According to the United Nations Office for Disaster Risk Reduction (UNDRR), floods account for approximately 43% of all recorded natural disasters globally and affect millions of people each year [1]. Between 2000 and 2023, flood disasters affected more than 1.6 billion people worldwide and generated hundreds of billions of dollars in economic losses [2]. Climate change, population growth, environmental degradation, and unsustainable land-use practices have further increased the frequency and severity of flood events. The Intergovernmental Panel on Climate Change (IPCC) reports that human-induced climate change has intensified extreme precipitation events in many regions, increasing flood risks and threatening sustainable development, particularly in developing countries with limited adaptive capacity [3]. Consequently, floods continue to contribute to loss of life, displacement of populations, destruction of infrastructure, reduced agricultural productivity, and increased vulnerability among already disadvantaged communities [4].

In Sub-Saharan Africa, flood hazards have become increasingly severe due to climate variability, changing rainfall patterns, deforestation, rapid population growth, and expansion of settlements into

flood-prone areas. The World Meteorological Organization (WMO) reported that floods remain among the most damaging climate-related disasters across Africa, affecting millions of people annually and causing significant losses in agriculture, infrastructure, and livelihoods [5]. Because agriculture supports the livelihoods of a large proportion of the region's population, recurrent flood events frequently undermine food security, increase poverty levels, and disrupt local economies [6].

Rwanda is highly vulnerable to climate-related disasters because of its mountainous topography, intense rainfall, high population density, and dependence on rain-fed agriculture. Floods and landslides are among the most recurrent natural hazards affecting the country [7]. The Ministry in Charge of Emergency Management (MINEMA) has identified more than 522 disaster-prone hotspots across Rwanda, exposing thousands of households to recurrent flood and landslide risks [8]. The severe floods and landslides that occurred in May 2023 particularly affected the Western, Northern, and Southern Provinces, resulting in at least 135 deaths, more than 27,000 affected people, destruction of over 6,000 houses, and extensive damage to roads, bridges, schools, health facilities, and agricultural land [9, 10]. These losses highlighted the increasing influence of extreme weather events and the urgent need for improved disaster risk reduction and climate adaptation measures.

The Western Province is among the most flood-prone regions of Rwanda due to its high annual rainfall, steep terrain, dense river networks, and susceptibility to runoff-related hazards. Within this province, Bugarama Valley in Rusizi District experiences recurrent flooding because of its location within the lower Rusizi River Basin, low elevation, and proximity to wetlands and tributaries. The valley is one of Rwanda's major rice-producing areas and contributes significantly to national agricultural production and household livelihoods [11]. However, recurrent flooding frequently damages cropland, irrigation infrastructure, transportation networks, and water supply systems. These impacts not only threaten agricultural productivity and food security but also undermine local socioeconomic development and community resilience. Therefore, understanding flood vulnerability and its associated impacts is essential for informing effective mitigation and adaptation strategies in Bugarama Valley.

Although Rwanda has made notable progress in strengthening disaster risk reduction and climate adaptation through various policy and institutional frameworks, recurrent flooding continues to adversely affect livelihoods, infrastructure, and socioeconomic development in Bugarama Valley. To address this challenge, the present study employs both geospatial and socioeconomic approaches to assess flood dynamics and their impacts on local communities. By integrating Geographic Information Systems (GIS), remote sensing techniques, and socioeconomic analysis, the study generates empirical evidence to support effective flood risk management, resilience-building strategies, and sustainable development planning in the study area.

The specific objectives of this study are to identify the primary causes of floods in Bugarama Valley, map flood prone zones in Bugarama valley with GIS and remote sensing, identify Social economic loss of floods in Bugarama valley, and to analyse Social economic impacts of floods in Bugarama valley

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Bugarama Valley located in Rusizi District, Western Province, Rwanda (Fig. 1). The valley lies within the Rusizi River basin and is bordered by several tributaries including Rubyiro, Katabuvuga, and Cyarukara rivers. The study covered five sectors namely Bugarama, Gikundamvura, Gitambi, Muganza, and Nyakabuye. The area experiences two rainy seasons annually, from March to May and from September to November, which contribute to frequent flooding events. Agriculture is the dominant economic activity and most households depend on small-scale farming for their livelihoods.

2.2 Research Design

The study adopted an explanatory mixed-methods research design integrating quantitative, qualitative, and geospatial approaches. This design enabled comprehensive analysis of flood causes, spatial patterns, and socioeconomic consequences. Quantitative methods provided statistical evidence of flood impacts, while qualitative methods generated deeper insights into community experiences and coping mechanisms.

2.3 Sampling and Data Collection

A total of 252 respondents were selected using stratified random sampling across the five sectors. The sample size was determined using Yamane's (1967) formula with a 95% confidence level and a margin of error of ± 5%. Primary data were collected using structured questionnaires. In addition, 15 key informant interviews were conducted with local authorities, disaster management officers, health workers, and representatives of non-governmental organizations. Three focus group discussions involving farmers and community members were also organized.

Secondary data on flood frequency, casualties, infrastructure damage, and crop losses covering the period 2015–2025 were obtained from MINEMA and Meteo Rwanda. Field observations and Participatory Rural Appraisal (PRA) techniques were used to validate information collected from respondents.

2.4 Geospatial Analysis

Flood-prone areas were identified and mapped using GIS and remote sensing techniques in ArcGIS 10.8. Several geospatial indicators were generated from Landsat 8/9 satellite imagery and Digital Elevation Model (DEM) data. These included:

1. Digital Elevation Model (DEM) and slope analysis;
2. Normalized Difference Vegetation Index (NDVI);

3. Normalized Difference Water Index (NDWI);
4. Topographic Wetness Index (TWI);
5. Flow accumulation analysis; and
6. Inverse Distance Weighting (IDW) rainfall interpolation.

A composite flood risk map was produced through weighted overlay analysis integrating all flood-related factors.

2.5 Flood Impact Index (FII)

The Flood Impact Index (FII) was used to compare flood severity among sectors. The index integrated human, physical, and economic losses using the following formula:

FII=(Deaths+Injured) + (Houses\ Damaged+Bridges+Water\ Supply) +Crop\ Damage\ (Ha)

The FII enabled comparative assessment of cumulative flood impacts across sectors.

2.6 Data Analysis

Quantitative data were analyzed using Microsoft Excel to generate descriptive statistics, including frequencies, percentages, means, and tables for summarizing respondents' characteristics and flood-related impacts. Qualitative data obtained from key informant interviews and focus group discussions were analyzed using thematic analysis to identify recurring patterns, perceptions, and experiences related to flooding and its socioeconomic effects. Spatial data were processed, analyzed, and visualized using ArcGIS 10.8 to produce flood susceptibility maps and examine the spatial distribution of flood prone areas within Bugarama Valley.

3. RESULTS

3.1 Geospatial Analysis and Flood Risk Mapping

The results of the geospatial analysis revealed that the Bugarama Valley is predominantly characterized by low-lying terrain with gentle slopes of less than 5°, rendering the area highly susceptible to flooding. Zones with slopes below 2° exhibited particular vulnerabilities to prolonged water stagnation and inundation. The Fig. 2 illustrates Normalized Difference Water Index (NDWI) analysis further indicated significant moisture accumulation and surface water concentration within the valley floor, while the Fig. 3 shown Normalized Difference Vegetation Index (NDVI) revealed sparse vegetation cover in frequently flooded areas. Figure 4 represents Topographic Wetness Index (TWI) values, ranging from 8 to 14, confirmed a high potential for water accumulation in valley bottom zones. Flow accumulation modeling identified major drainage corridors along the Rusizi and Rubyiro rivers, where floodwaters tend to converge. Additionally, Fig. 5 displays the Inverse Distance Weighting (IDW) rainfall interpolation captured spatial variation in rainfall distribution across the valley.

3.2 Socioeconomic Characteristics of Respondents

Among the 252 respondents surveyed, 52% were male while 48% were female. The majority of respondents (61%) were aged between 25 and 44 years. Approximately 74% of households depended primarily on agriculture for their livelihoods. Furthermore, 82% of respondents reported experiencing floods multiple times during the study period, while 68% indicated that floods occurred several times annually.

3.3 Flood Events and Human Impacts

MINEMA data recorded 20 flood events in the study area between 2015 and 2025. Bugarama and Muganza sectors each accounted for 30% of all flood events. Flood-related deaths totaled 7, while 10 injuries were recorded, mainly in Bugarama sector.

3.4 Physical and Agricultural Impacts

A total of 76 houses were damaged during the study period. Muganza sector accounted for the highest number of damaged houses with 59 cases, followed by Bugarama sector with 17 cases. Four bridges were damaged across the valley, particularly in Nyakabuye, Gikundamvura, and Muganza sectors.

Figure 7 illustrates how rubyiro river overflowed and destroyed farm land where Crop losses reached 44.6 hectares, mainly affecting rice and maize fields in Bugarama and Muganza sectors. These losses significantly reduced household food security and agricultural productivity.

3.5 Flood Impact Index Analysis

The Flood Impact Index analysis (Table 1) showed substantial variation in flood severity across sectors. Muganza sector recorded the highest FII value of 75, followed by Bugarama sector with 59.6. The overall FII for the study area was 143.6, indicating significant cumulative flood impacts.

Table 1
Flood Impact Index Analysis by Sector.

Source: Computed from MINEMA secondary data (2015–2025).

Sector	Human Impacts	Physical Impacts	Crop Damage (Ha)	FII
Bugarama	12	17	30.6	59.6
Gikundamvura	1	1	2	4
Gitambi	2	0	0	2
Muganza	1	62	12	75
Nyakabuye	1	2	0	3
Total	**17**	**82**	**44.6**	**143.6**

3.6 Household-Level Socioeconomic Impacts

The survey findings revealed that crop destruction was the most severe impact reported by respondents (59%), followed by housing damage (20%), displacement (12%), and disruption of local business (2%). Floods also disrupted transportation, market access, education, and health services.

Public health impacts were significant, with 78% of respondents reporting disease outbreaks following floods. Common diseases included diarrhea, malaria, and skin infections. Educational disruptions were also widespread, with 71% of households indicating temporary school closures during flood periods.

3.7 Causes of Floods

The Fig. 8 indicates that the majority of respondents, 164 (65%), identified heavy rainfall as the primary cause of floods. This was followed by 40 respondents (16%) who reported overflow of rivers (Rusizi River and its tributaries), while 21 respondents (8%) indicated poor drainage systems. Additionally, 18 respondents (7%) attributed floods to settlement in flood-prone areas, and 9 respondents (4%) identified weak or lack of embankments (buffer zones).

3.8 Flood Management and Institutional Response

Local government institutions, District Disaster Management Committee (DIDIMAC), Sector Disaster Management Committee (SEDIMAC), and humanitarian organizations were identified as the principal actors involved in flood management and disaster response. The Rwanda Red Cross played a key role in providing relief assistance to affected households. In 2018, the Kibangira IDP Model Village was established to relocate households from high-risk flood zones.

4. DISCUSSION

The findings of this study indicate that flooding remains a major environmental, socioeconomic, and public health challenge in Bugarama Valley. Recurrent flood events have caused substantial losses to agriculture, infrastructure, household assets, and livelihoods. Crop destruction emerged as the most significant impact reported by respondents, reflecting the heavy dependence of local households on agriculture for both income generation and food security. This observation is consistent with studies conducted across Sub-Saharan Africa, where flood events have been associated with agricultural production losses ranging from 20% to 60% depending on flood severity and duration [12, 13]. Given that agriculture employs approximately 65% of Rwanda’s workforce and contributes significantly to rural livelihoods, repeated crop losses can have far-reaching implications for household welfare and food security [14].

The concentration of severe flood impacts in Muganza and Bugarama sectors can largely be attributed to their low elevation, proximity to the Rusizi River and associated wetlands, and the presence of settlements and agricultural activities within flood-prone areas. Similar findings have been reported in

flood-risk studies demonstrating that flood exposure is strongly influenced by topography, river proximity, drainage characteristics, and land-use patterns [15]. Continued expansion of agricultural and residential activities into floodplain environments may further increase exposure and vulnerability if appropriate land-use planning measures are not implemented.

The GIS and remote sensing analyses revealed that areas characterized by low slopes, high flow accumulation, sparse vegetation cover, and inadequate drainage systems exhibited the highest flood susceptibility. These findings corresponded closely with locations reporting severe socioeconomic losses during surveys. The results suggest that flood vulnerability in Bugarama Valley is shaped by both natural and anthropogenic factors. Previous studies have shown that deforestation, wetland degradation, and poor watershed management reduce the capacity of ecosystems to regulate runoff and increase the likelihood of flooding [16, 17]. Consequently, ecosystem restoration measures such as reforestation and wetland conservation may play a critical role in reducing future flood risks.

The study further demonstrated that flooding has important public health implications. Respondents reported increased incidences of malaria, diarrheal diseases, skin infections, and intestinal worm infestations following flood events. Similar observations have been documented globally, where floods are recognized as major drivers of waterborne and vector-borne disease outbreaks [18]. Floodwaters often contaminate drinking water sources and sanitation facilities, exposing communities to pathogens that cause diarrheal diseases and parasitic infections. Furthermore, stagnant water remaining after floods provides ideal breeding habitats for mosquitoes, increasing malaria transmission risks. According to the World Health Organization, climate sensitive diseases are expected to become increasingly important public health concerns as the frequency of extreme weather events continues to rise [19].

Beyond direct impacts on agriculture and health, flooding disrupted access to essential services and public infrastructure. Damage to roads, bridges, schools, and healthcare facilities reduced mobility and limited access to markets, healthcare services, and educational opportunities. The widespread destruction of infrastructure observed during Rwanda's 2023 flood disaster demonstrates how such impacts can impose substantial economic burdens on affected communities and government institutions [10]. Similar studies have shown that infrastructure damage often represents one of the largest components of flood-related economic losses in developing countries [20].

Although Rwanda has made considerable progress in disaster risk reduction through early warning systems, watershed restoration programs, climate adaptation initiatives, and emergency response mechanisms, important challenges remain. Many households reported inadequate preparedness, limited financial resources, and insufficient access to insurance or alternative livelihood opportunities. These constraints often delay recovery and increase dependence on external assistance following disaster events. Similar challenges have been documented across climate-vulnerable regions where limited access to financial protection mechanisms increases household vulnerability to recurrent disasters [21]. Strengthening community preparedness, promoting climate-resilient agriculture, expanding access to insurance and financial protection schemes, improving ecosystem management, and enhancing local

disaster response capacities are therefore essential for reducing future flood impacts and strengthening resilience in Bugarama Valley.

Overall, the results demonstrate that flood vulnerability in Bugarama Valley is the result of complex interactions among environmental conditions, socioeconomic factors, and institutional capacities. The findings underscore the importance of adopting integrated flood management strategies that combine geospatial planning, sustainable watershed management, environmental conservation, public health protection, and community based disaster risk reduction. Such approaches are essential for enhancing resilience, reducing flood-related losses, and supporting sustainable socioeconomic development in Bugarama Valley and other flood-prone areas of Rwanda.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study provides a comprehensive assessment of the socioeconomic impacts of floods in Bugarama Valley, Rusizi District, Rwanda. The findings demonstrate that flooding is a persistent hazard causing severe impacts on agriculture, infrastructure, health, education, and livelihoods. Between 2015 and 2025, flood events resulted in human casualties, destruction of houses and crops, infrastructure damage, and widespread socioeconomic disruption.

Geospatial analysis confirmed that flood susceptibility in Bugarama Valley is strongly associated with low-lying terrain, high water accumulation, inadequate drainage, and environmental degradation. Human activities including settlement in flood-prone areas and wetland encroachment further increase vulnerability.

The study concludes that sustainable flood risk reduction in Bugarama Valley requires integrated approaches combining infrastructure development, environmental management, land-use planning, climate adaptation, and community resilience building.

5.2 Recommendations

1. Reduce socioeconomic vulnerability through integrated flood risk management

Local and national authorities should implement integrated flood risk management strategies combining structural measures (such as embankments and drainage systems) and non-structural approaches (such as land-use planning and zoning). Restricting settlement and economic activities in high-risk flood zones is essential to reduce repeated household displacement, loss of livelihoods, and infrastructure destruction.

2. Strengthen protection of livelihoods and agricultural production

Agricultural policies should focus on reducing flood-induced crop losses through improved drainage in farmlands, promotion of flood-resistant crop varieties, and adoption of climate-smart agricultural practices. Extension services should be strengthened to ensure farmers receive timely information and technical support to adapt to changing flood patterns.

3.Enhance disaster preparedness and reduce human and infrastructure losses

Early warning systems should be strengthened and linked to community disaster response structures to ensure timely evacuation and preparedness. Public infrastructure such as schools, roads, and health facilities should be constructed or upgraded using flood-resilient designs to minimize damage and service disruption.

4. Enhance flood risk assessment and planning through Geographic Information Systems (GIS)

Geographic Information Systems (GIS) and remote sensing technologies should be fully integrated into flood monitoring, mapping, and risk assessment in Bugarama Valley. GIS can be used to identify flood-prone zones, analyze historical flood patterns, and support evidence based land use planning. It also enables real-time monitoring of rainfall, river levels, and spatial distribution of flood impacts, which improves decision-making for disaster preparedness and response.

Declarations

6.1 Ethics Approval and Consent to Participate

Ethics approval and consent to participate

Ethical clearance for this study was granted by the University of Lay Adventists of Kigali (UNILAK) through its established institutional review procedures. In addition, formal authorization to conduct the study in the research area was obtained from the Office of the Mayor of Rusizi District. The research was conducted in accordance with the ethical principles of the Declaration of Helsinki for studies involving human participants. Prior to data collection, participants were provided with comprehensive information regarding the purpose and procedures of the study and voluntarily agreed to participate by providing informed consent. The privacy, anonymity, and confidentiality of all respondents were strictly maintained throughout the research process. Participation was entirely voluntary, and respondents were informed of their right to decline participation or withdraw from the study at any stage without any adverse consequences. All data collected were securely managed and used solely for academic and research purposes.

6.2 Consent for Publication

Not applicable. The study did not involve the collection, use, or publication of identifiable personal information from participants.

6.3 Data availability

The data generated and analyzed during the current study are available from the corresponding author upon reasonable request.

6.4 Competing Interests

The authors declare that they have no financial, professional, or personal conflicts of interest that could have influenced the conduct or reporting of this research.

6.5 Funding Declaration

This research was conducted without financial support from any public, commercial, or non-profit funding agency.

6.6 Authors' Contributions

MN conceived and designed the study, conducted data collection, performed data analysis, and prepared the initial draft of the manuscript. IJ and NJ critically reviewed the manuscript for important intellectual content. MF contributed to the interpretation of results, revised the manuscript, and approved the final version for publication. CN assisted in the distribution of questionnaires, and the collection of primary data from respondents. All authors reviewed the manuscript

6.7 Questionnaire

The questionnaire employed in this study was specifically designed and developed by the authors to address the research objectives. A copy of the instrument is provided as Supplementary File 1.

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Figures

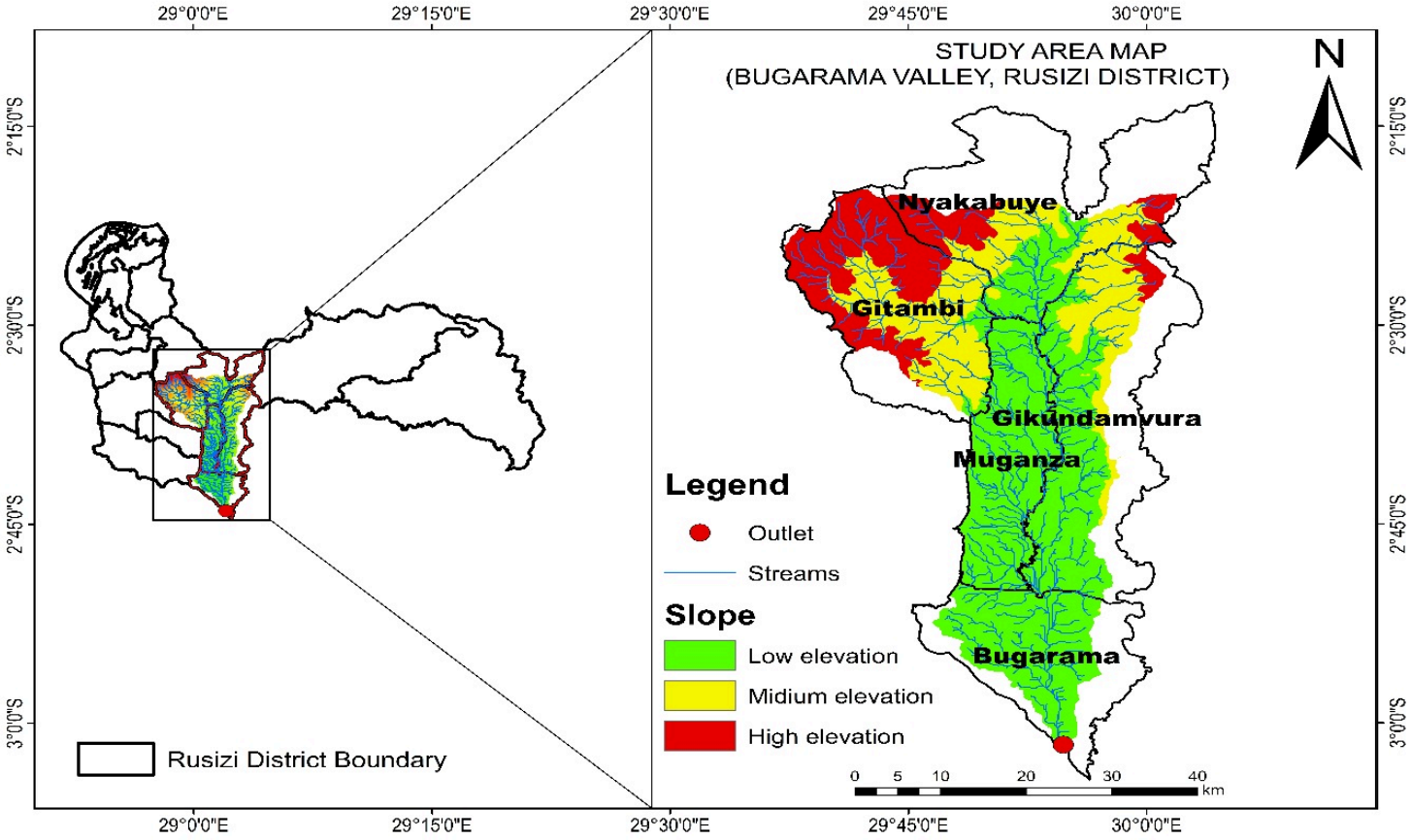


Figure 1

Location of Bugarama Valley in Rusizi District, Rwanda. **Source**: Author's GIS Analysis (2025).

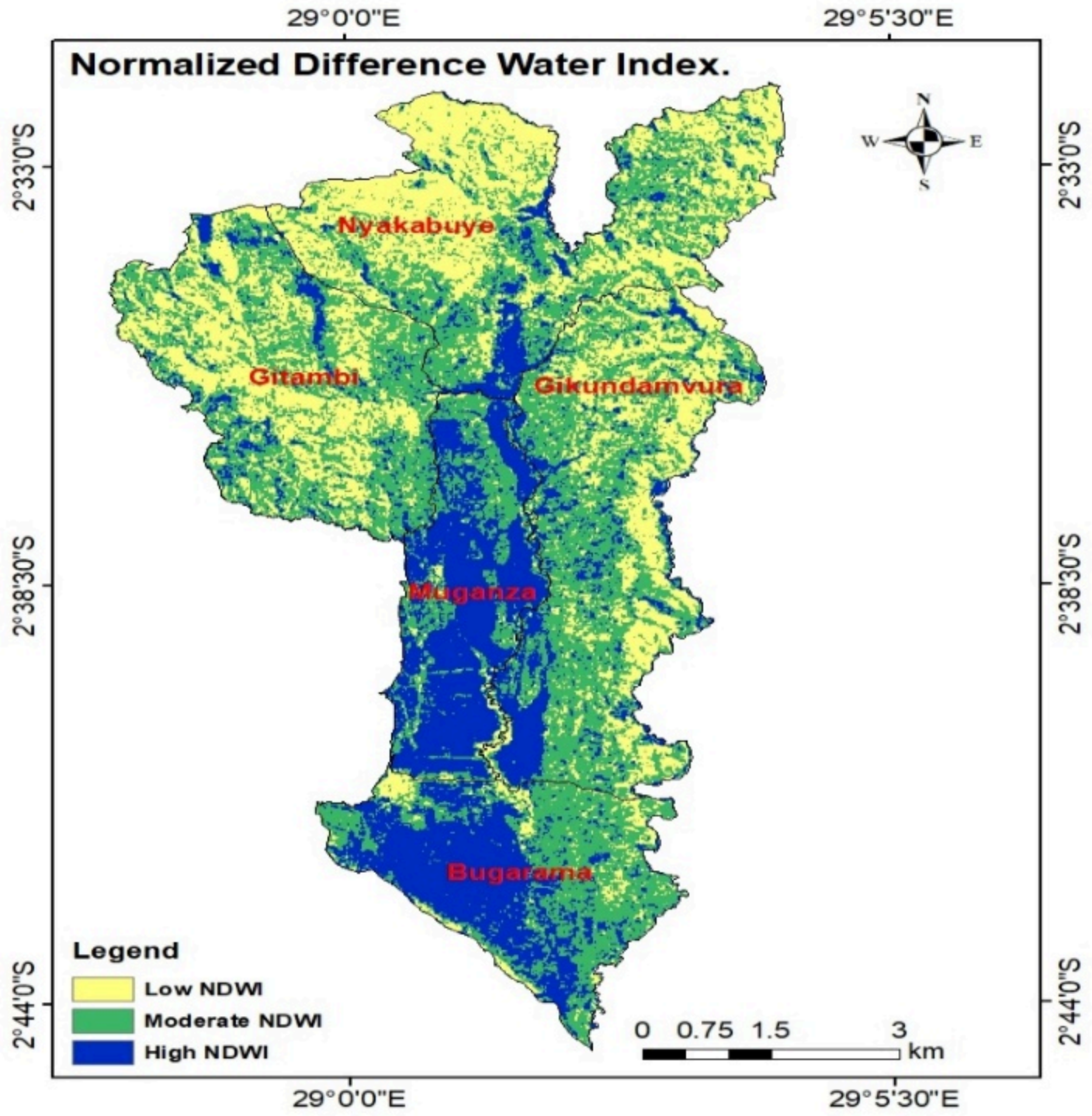


Figure 2

Normalized Different Water Index Map

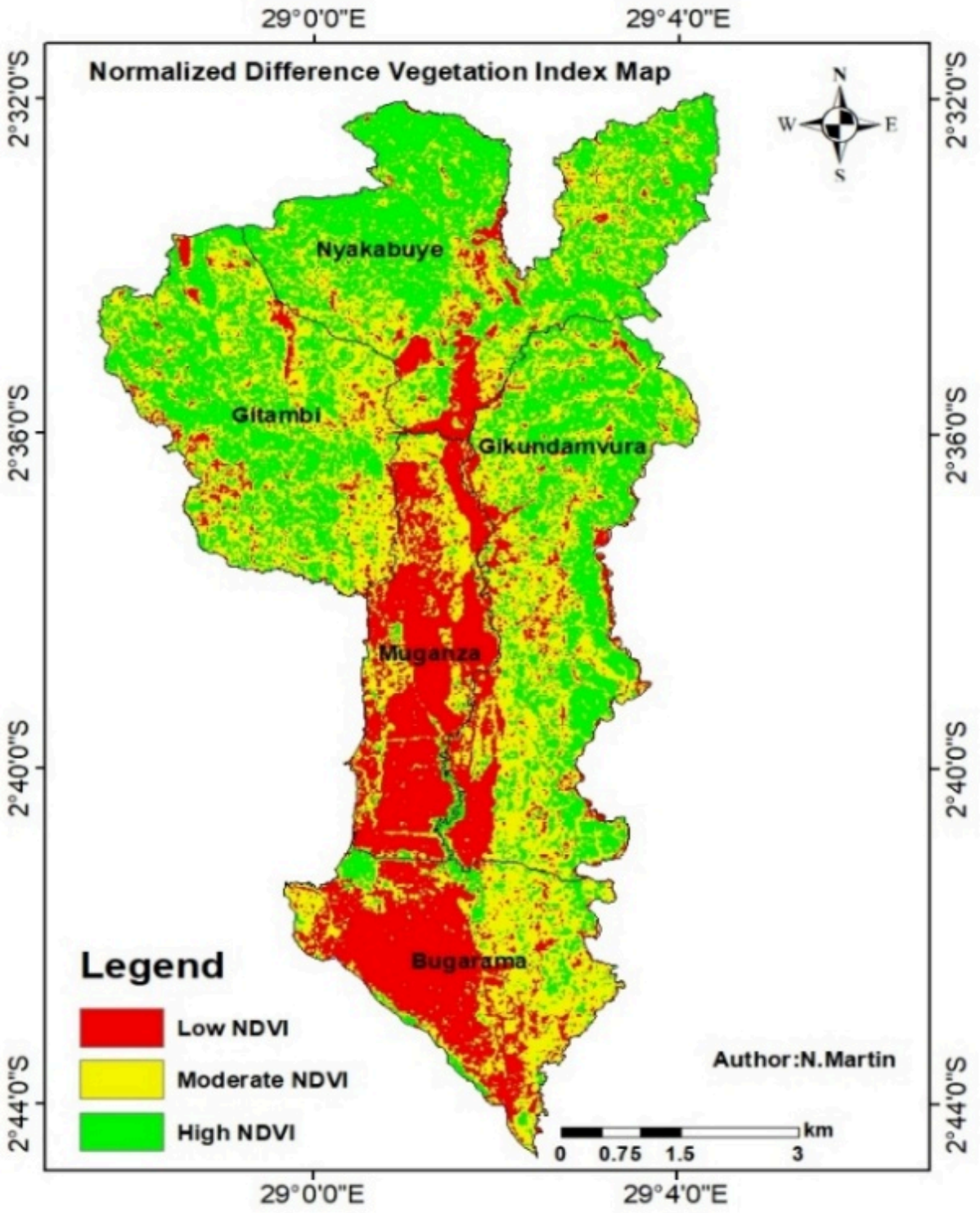


Figure 3

Normalized Different Vegetation Index Map

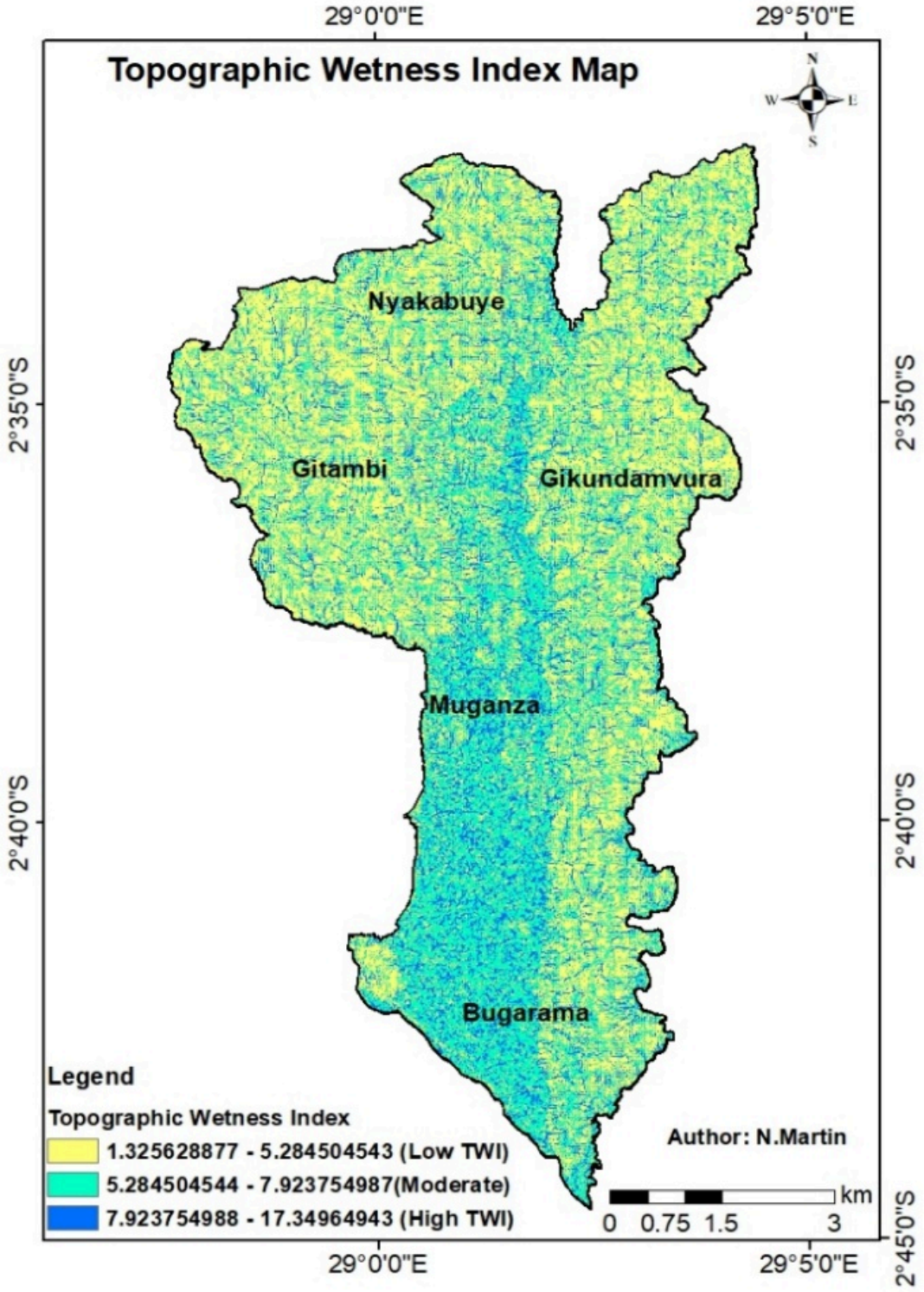


Figure 4

Topographic Wetness Index Map

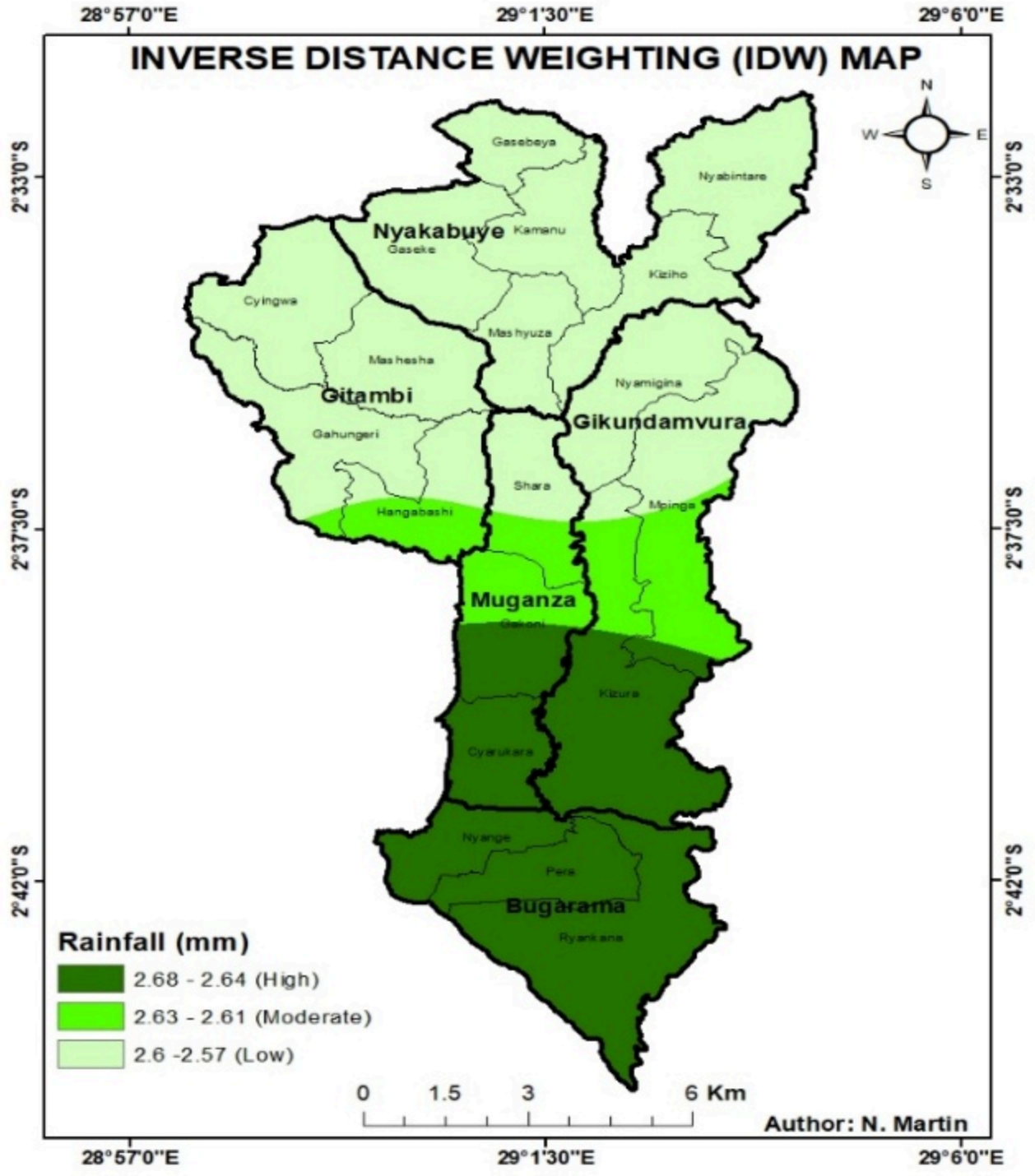


Figure 5

IDW Rainfall Map (Daily Data from Bugarama and Nyakabuye Stations)

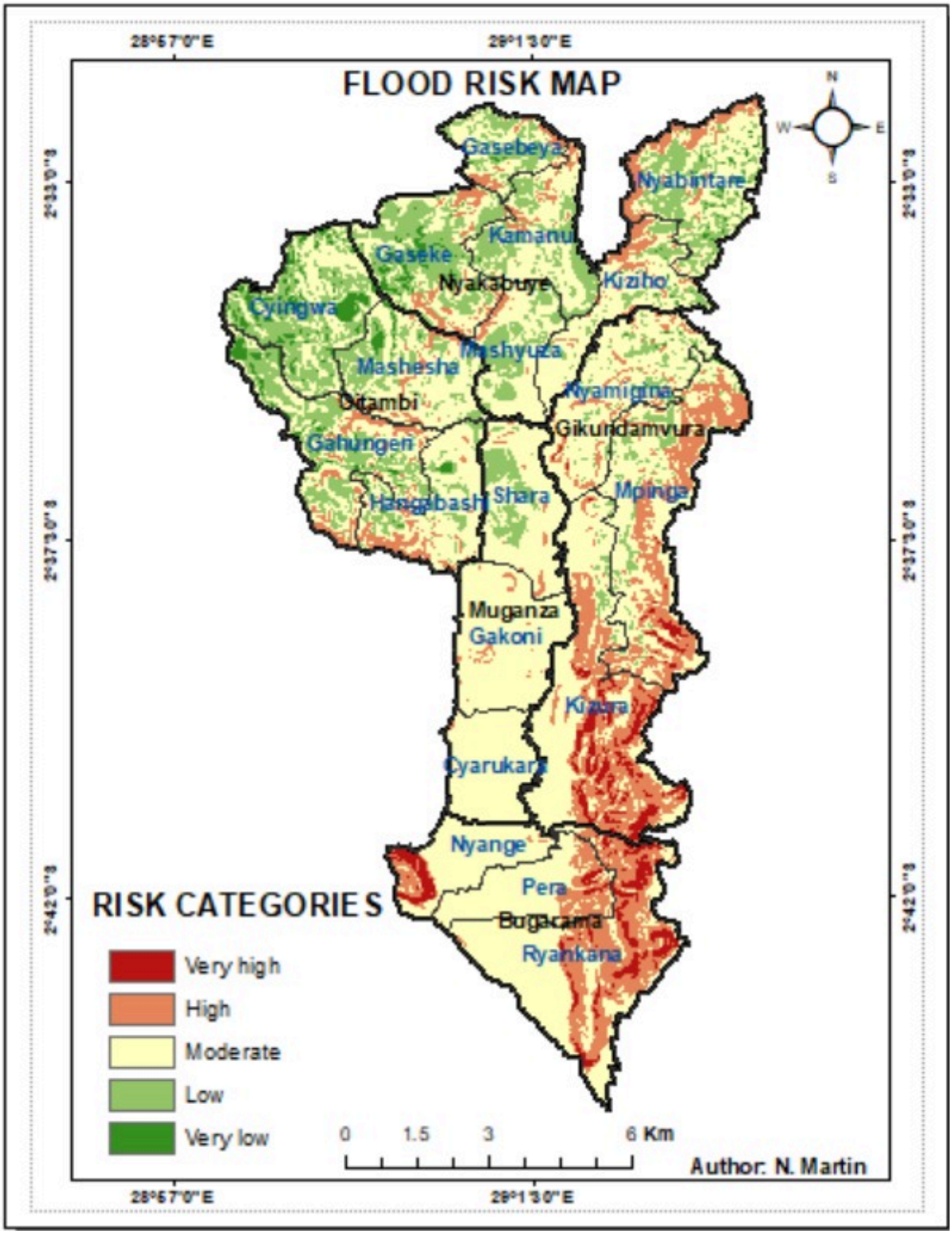


Figure 6

Composite Flood Risk Map



Figure 7

Rubyiro river overflowed and destroyed rice farm land at Bugarama Valley at Bugarama Sector [07.11.2023]. **Source** :Rusizi District, Archives.

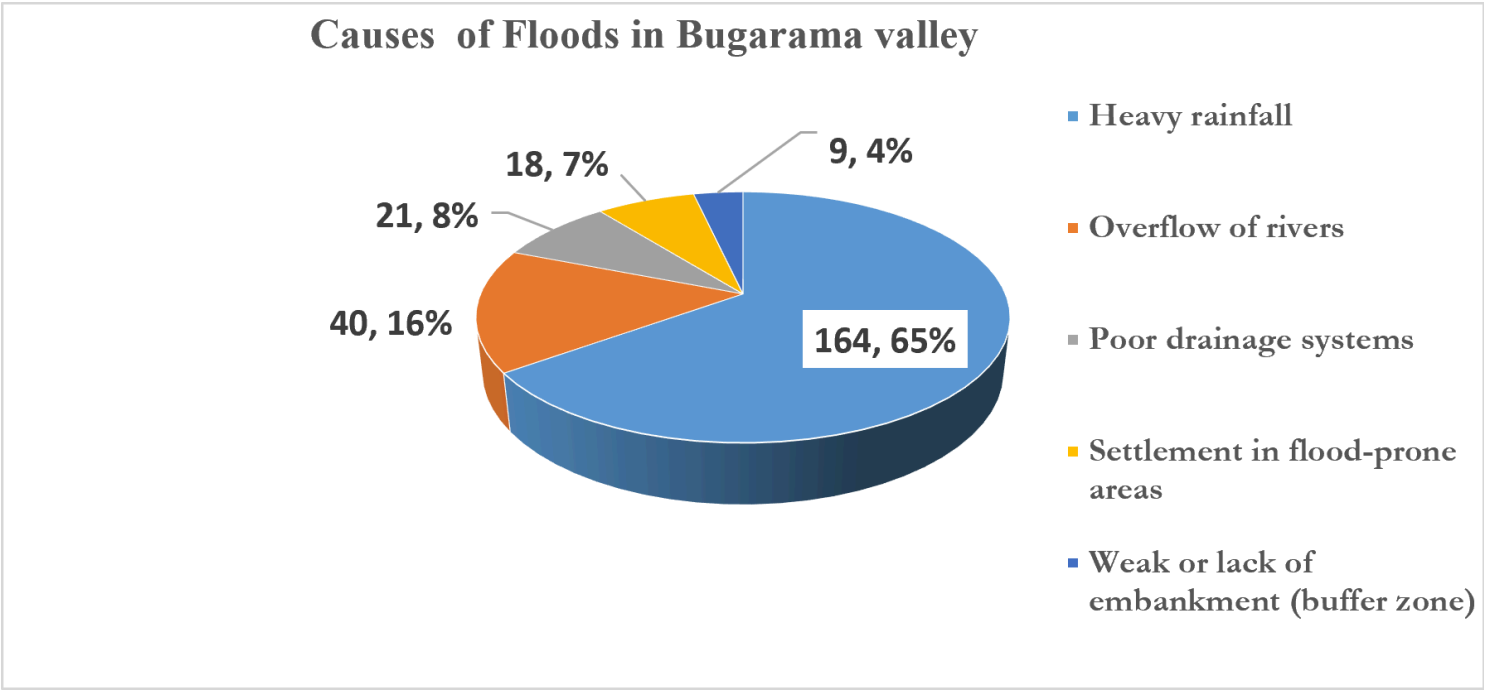


Figure 8

Causes of Floods in Bugarama valley

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- InterviewQuestionnaire.pdf

- ResearchAuthorizationandRequestLetters.docx