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Geospatial Analysis of Effects of Flooding in Gasabo District; A Case of Bumbogo Sector

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Abstract

This study conducted a geospatial analysis of flooding effects in Bumbogo Sector, Gasabo District, using data from a sample of 99 respondents selected from a population of 7,066 individuals aged 21 and above through both probability and non-probability sampling. Data were gathered through GIS, remote sensing, and surveys and analyzed using SPSS version 23.0. In mapping flood-prone areas, findings revealed that key contributors to flooding include rainfall (mean = 3.33), topography/elevation (3.24), land/soil cover (3.36), proximity to water bodies (3.33), and human activities (3.12). The study highlighted that intense rainfall, steep slopes, and unregulated urbanization significantly heighten flood risks, emphasizing the critical role of geospatial tools in continuous flood risk assessment. When evaluating environmental effects, respondents strongly agreed that flooding leads to pollution (mean = 3.06), soil erosion (3.07), habitat destruction (3.09), landslides (3.11), and biodiversity loss (3.07). Economically, property damage (3.98), infrastructure destruction (3.96), crop losses (3.11), and livestock losses (3.94) were major concerns. Human and social impacts included loss of life (3.54), health risks (3.44), disruption of education (3.53), and displacement or homelessness (3.44). Statistical analysis revealed a strong and significant relationship between causes and flood effects. The Pearson correlation coefficient between causes and environmental effects was 0.715 ($p < 0.01$), suggesting a significant positive relationship. For economic effects, the coefficient was 0.883 ($p < 0.01$), indicating a very strong correlation. The relationship between causes and human/social effects also showed a strong positive correlation at 0.704 ($p < 0.05$). These findings indicate that increases in the underlying flood causes result in proportional increases in environmental, economic, and social impacts. Spatial elements such as topography and land use further mediate these effects. The study confirms existing literature and calls for targeted, location-specific flood mitigation strategies. It recommends the use of geospatial analysis in planning and proactive risk management in flood-prone zones like Bumbogo Sector.

Keywords: *Geospatial Analysis, Flooding, Flood Prone Area*

1. Introduction

The Floods are the most common occurring natural disasters that affect human and its surrounding environment (Hewitt, 1997). It is more vulnerable to different regions of the World. It affects social and economic stability of various countries. In Europe, recent years have witnessed an increase in the frequency and intensity of flooding events. The 2002 Central European floods and the 2013 Central European floods highlight the devastating consequences of flooding, including infrastructure damage, loss of life, and economic disruption (Hoyois, 2016). Similarly, the United States has also experienced severe flooding, such as the 2019 Midwest floods, which affected multiple states, leading to extensive property damage and agricultural losses (FEMA, 2020).

Africa, particularly the sub-Saharan region, is highly vulnerable to the impacts of climate change and extreme weather events. Flooding in Africa has been associated with the El Niño Southern Oscillation (ENSO) phenomenon, resulting in increased rainfall and subsequent river overflow (Abbot, 2017). In the EAC, which comprises Burundi, Kenya, Rwanda, South Sudan, Tanzania, and Uganda, flooding events have been frequent, causing displacement, food insecurity, and disease outbreaks (Ondieki et al., 2019).

Rwanda, located in East Africa, experiences recurrent flooding, primarily due to its topography, climate, and land use patterns. The country's hilly terrain and heavy rainfall during the rainy season contribute to runoff and subsequent flooding. Furthermore, rapid urbanization and insufficient drainage infrastructure exacerbate the vulnerability of densely populated areas, like Gasabo District (Mukabayire et al., 2020).

Flooding events in Rwanda have been documented for many years, with some of the most notable events occurring in 2007, 2010, and 2018. These events have caused significant damage to infrastructure, including roads, bridges, and buildings, as well as to agriculture and natural resources (Mukabayire et al., 2020). Additionally, flooding can have significant impacts on human populations, including loss of life, displacement, and economic hardship. Vulnerable populations, such as those living in low-lying areas or in informal settlements, are particularly at risk.

In order to better understand the effects of flooding in Rwanda, researchers have conducted studies on various aspects of the problem. These include investigations into the environmental impacts of flooding, such as soil erosion and damage to ecosystems, as well as studies on the economic and social impacts of flooding, including its effects on agriculture, infrastructure, and public health.

Gasabo District is one of the four districts in Rwanda's capital city, Kigali. It is located in the central part of the country and experiences the impacts of flooding, with Bumbogo Sector being one of the most affected areas. Bumbogo is situated in the northeastern part of Gasabo District, and its vulnerability to flooding is influenced by factors such as its topography, land cover, and proximity to water bodies.

In order to assess the effects of flooding in Bumbogo Sector, a geospatial analysis will be conducted. This analysis will involve the collection and integration of various datasets, including digital elevation models (DEM), rainfall data, land use/land cover maps, and population density information. By overlaying and analyzing these datasets using Geographic Information Systems (GIS) techniques, the study aims to identify flood-prone areas, assess the impacts on infrastructure, agriculture, and livelihoods, and propose potential mitigation measures.

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Geospatial analysis plays a crucial role in understanding and mitigating the effects of flooding (Hoyois, 2016). The results of the geospatial analysis helps in identifying vulnerable locations and understanding the factors contributing to their susceptibility to flooding. Such insights are essential for developing effective disaster risk reduction strategies, urban planning, and emergency response measures (Ondieki et al., 2019). Furthermore, the geospatial analysis assists in evaluating the potential impacts of flooding on infrastructure, agriculture, livelihoods, and the environment within a such area (Abbot, 2017).

By employing Geographic Information Systems (GIS) and integrating various spatial datasets, this study seeks to identify and map flood-prone areas within the Bumbogo Sector. The integration of elevation data with hydrological information allows the delineation of floodplains and low-lying areas that are susceptible to inundation during heavy rainfall events.

Through this geospatial analysis, the study aims to assess the spatial distribution and characteristics of flood-prone areas in Bumbogo Sector. In addition, this geospatial analysis will contribute to the existing knowledge on flooding in Gasabo District, specifically in Bumbogo Sector, providing valuable insights for policymakers, urban planners, and other stakeholders.

1.1 Research Objectives

1.1.1 General objective

The general objective of this study is to conduct a comprehensive geospatial analysis of the effects of flooding in Gasabo District's Bumbogo Sector, Rwanda.

1.1.2 Specific objectives

The specific objectives of this study are the followings:

(i) To identify and map flood-prone areas within Gasabo District's Bumbogo Sector using geospatial techniques, including GIS and remote sensing, and to analyze the key factors contributing to flooding in the area;
(ii) To evaluate the different effects of flooding on environment of Bumbogo Sector;
(iii) To establish correlations between flood-prone areas and effects of flooding in the Bumbogo Sector.

2. Materials and methods

2.1 Profile of Bumbogo Sector

Bumbogo Sector is a sector in the Gasabo district of Kigali Province in Rwanda. It is located in the northern part of Kigali city and covers an area of about 60.60 km² Area square. The sector is composed of 7 cells, namely Nkuzuzu, Kinyaga, Musave, Mvuzo, Ngara, Nyabikenke, and 343 Villages. Nyagasozi. Bumbogo Sector has 112,899 Population (with 56,361=49.4% of males and 56,538=50.1% of females) and it has 1,863/km² Population Density (Census15 August, 2022) dispatching in the above 7 Cells.

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Bumbogo Sector is home to various amenities, including schools, health centers, and markets, which serve the residents of the sector and the neighboring areas.

The flooding happened in Ngara Cell, in Uwaruraza na Gisasa Villages. In this Cell, there are 14,128 inhabitants whose 7066 are above 21 years old (they are mature to respond to the questions and give needed information).

Map 3.1: Study area description- Bumbogo sector.

2.2 Research design and data collection methods

The study employed a descriptive research design, integrating both qualitative and quantitative methods to comprehensively explore the impacts of flooding. This mixed-methods approach allowed the researcher to gain a deeper understanding of complex environmental and social issues by combining statistical data with descriptive insights. The design facilitated triangulation, enhancing the validity of findings and addressing limitations associated with relying solely on one data type. Through this approach, the research effectively investigated flood-prone areas, assessed environmental impacts, and explored community experiences with flooding.

The integration of geospatial techniques such as Geographic Information Systems (GIS) and remote sensing played a central role in the research. These tools enabled the identification and mapping of flood-prone areas in Bumbogo Sector by analyzing satellite imagery, digital elevation models (DEMs), land use patterns, topography, and hydrological features. These technologies supported objective one by producing visual representations of vulnerable zones based on physical and environmental parameters.

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Field surveys, particularly structured questionnaires, were used to gather primary data from residents who experienced the effects of flooding. These surveys targeted two specific villages—Uwaruraza and Gisasa in Ngara Cell—where significant flood incidents were reported. The questionnaires collected data on causes of flooding, frequency, severity, and community-level impacts. Respondents were selected based on their age (21 years and above), ensuring they had the maturity and experience to provide relevant information.

For objective two—evaluating the effects of flooding on the environment—field surveys were again employed, this time focusing on environmental, economic, and social dimensions. The questionnaire addressed issues such as infrastructure damage, loss of property, disruption of livelihoods, and public health concerns. The data collected provided measurable indicators that were later analyzed to establish correlations between flood-prone zones and observed consequences.

Table 3.1.Sample size distribution by Cell and gender

Cell	Village	Population	Sample size
Ngara	Uwaruraza	3482	$n = \frac{3482*99}{7066} = 49$
	Gisasa	3584	$n = \frac{3584*99}{7066} = 50$
Total		**7,066**	**99**

Source: Researcher based on secondary data of Bumbogo Sector, 2023

A combination of probability and non-probability sampling techniques was used. Systematic and stratified random sampling ensured representative spatial coverage for geospatial analysis, while purposive sampling was applied to select environmentally sensitive or severely affected areas for deeper investigation.

To ensure the validity and reliability of the questionnaire, a pilot test was conducted with 15 residents of Bumbogo Sector. This preliminary phase helped refine the instrument by clarifying ambiguous questions and removing redundancies. The Content Validity Index (CVI) method, with a threshold of 0.7 as per Amin (2005), was used to evaluate item relevance and ensure instrument accuracy. Therefore, in terms of data processing, responses were edited for accuracy, coded into thematic or numeric categories, and tabulated for analysis using SPSS. Tables and charts were developed to facilitate interpretation and presentation of the findings.

2.3 Data analysis

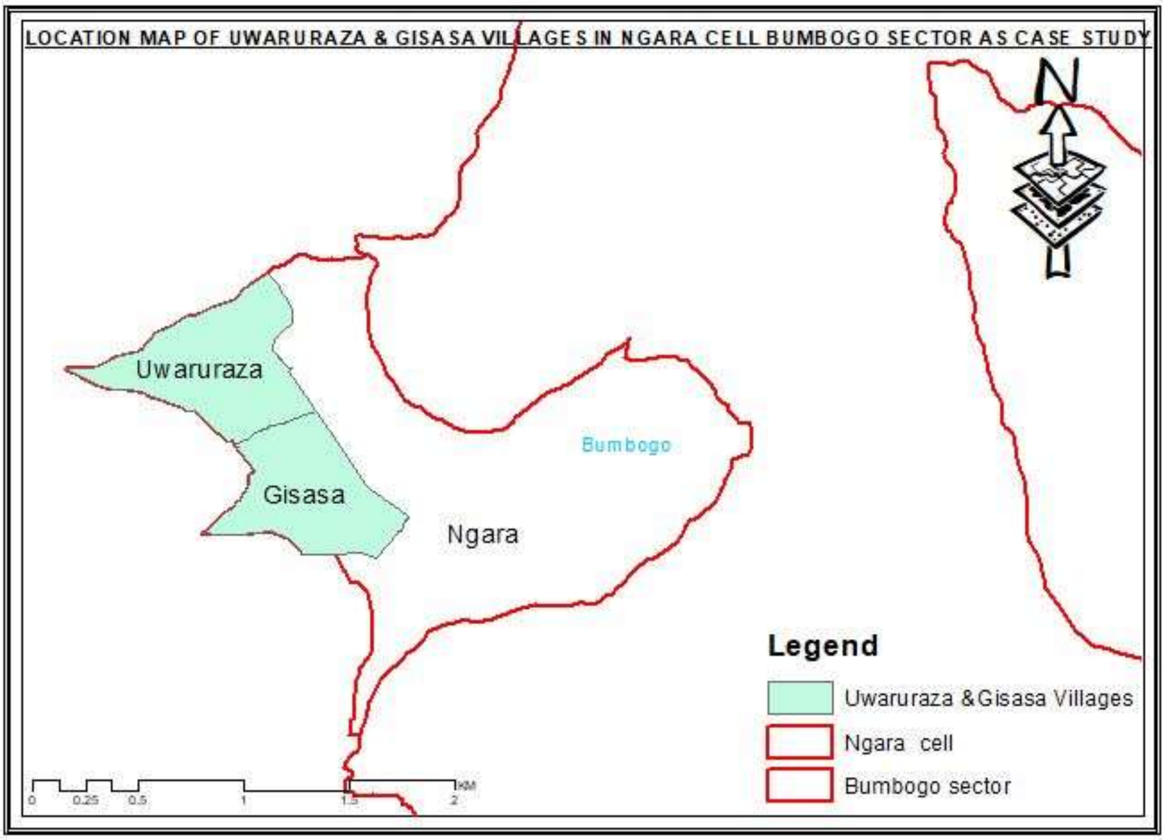
This study employed a descriptive research design incorporating quantitative data analysis techniques to examine flooding and its impacts in Bumbogo Sector. Geospatial analysis using GIS and remote sensing was conducted to map flood-prone areas and assess their spatial distribution. These flood susceptibility maps were overlaid with environmental impact data to identify spatial correlations. Quantitative analysis, facilitated by SPSS version 23.0, enabled the computation of descriptive statistics such as frequencies, percentages, means, and standard deviations, helping to analyze the environmental, economic, and social effects of flooding.

For the first objective, GIS data and descriptive statistics were used to determine flood-prone areas and underlying causes. The second objective involved calculating mean scores and standard deviations to assess the extent of flooding effects based on respondents' perceptions using a five-point Likert scale. To explore relationships between flooding causes and their effects, Pearson Product Moment Correlation was employed. Correlation coefficients helped determine the strength and direction of associations between variables, ranging from perfect correlation (r = 1) to no correlation (r = 0). Ethical considerations, including informed consent, participant confidentiality, and official permissions, were strictly observed throughout the research process to ensure compliance with institutional and research ethics standards.

3. Results

3.1 Identification and mapping of flood-prone areas within Gasabo District's Bumbogo Sector using geospatial techniques

This mapping of flood-prone areas within Gasabo District's Bumbogo Sector using geospatial techniques comprises heavy rainfall, topography, elevation, land/soil cover and proximity to water.



Map 3.1. Geographical location map of Uwaruraza and Gisasa Villages in Ngara Cell, Bumbogo Sector

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The geographical location map shows the positions of Uwaruraza and Gisasa villages in Ngara Cell, Bumbogo Sector. These two villages are situated within Ngara Cell in Bumbogo Sector. The coordinates for these villages are 0.25 and 0.5.

Map 3.2. Area prone to flood in Uwaruraza by google earth map (Satellite images)

The provided information suggests a focus on identifying areas prone to flooding in Gisasa Villages within the Ngara region, utilizing satellite imagery dated July 17, 2023. The specified coordinates (1°53′43.67" S, 30°07′23.13" E) place the observation point in proximity to Gisasa Villages. The elevation of 1500 meters and an eye altitude of 3.01 km indicate the perspective from which the satellite image was captured.

To analyze the potential flood-prone areas, it is crucial to consider the topography, land cover, and any visible water bodies in the satellite imagery. The elevation data (1500 meters) may help in understanding the terrain, with lower elevations typically being more susceptible to flooding.

An elevation of 1500 meters and an eye altitude of 3.01 km (assuming you mean an observer's altitude) are typically at different scales, and the eye altitude seems unusually high for typical observation.

An elevation of 1500 meters generally implies higher ground. Flooding is typically more prone to occur in lower-lying areas where water can accumulate. Higher elevations usually reduce the risk of flooding because water tends to flow downhill. Therefore, a location at 1500 meters is less likely to experience flooding based on elevation alone. An eye altitude of 3.01 km indicates an observational perspective from a significantly high vantage point, such as an aircraft or satellite. While this altitude is useful for broad-scale observation and analysis, it doesn't directly influence flooding. Instead, it provides a comprehensive view of the landscape, aiding in the assessment of factors like topography, land use, and drainage patterns.

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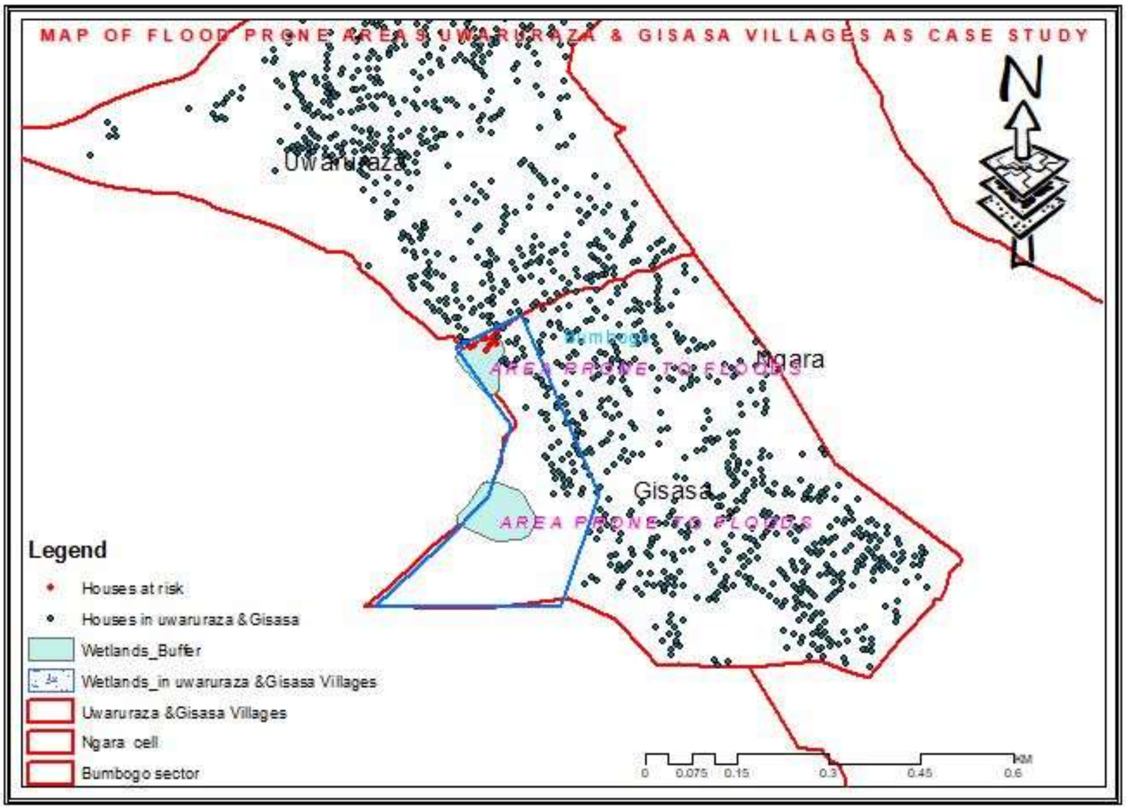

Map 3.3. Area one to floods in Uwaruraza and Gisasa

The provided information outlines a map depicting areas prone to flooding in Uwaruraza and Gisasa Villages, serving as a case study.

The map depicting flood-prone areas in Uwaruraza and Gisasa Villages provides valuable insights for assessing the vulnerability of these communities to flooding. The legend indicates specific features, such as "Houses at risk" and "Houses in Uwaruraza & Gisasa," highlighting residential areas susceptible to potential flooding. The inclusion of "Wetlands Buffer" suggests a strategic effort to safeguard against flooding in ecologically sensitive wetland regions. Moreover, the identification of "Wetlands in Uwaruraza & Gisasa Villages" underscores the importance of considering natural features in flood dynamics. Geographical details like Ngara cell, Bumbogo sector, and Gisasa serve as reference points for the specific regions covered by the map.

Wetlands act as natural buffers against flooding in the Bumbogo Sector by absorbing excess rainfall, slowing down water runoff, and providing a natural storage capacity. The vegetation in wetlands, including grasses and other water-loving plants, helps to stabilize soil, reducing erosion and enhancing water absorption. Additionally, wetlands act as sponges, temporarily holding water during heavy rainfall and gradually releasing it, thereby mitigating the intensity and speed of downstream water flow. The complex network of roots in wetland vegetation also serves to bind soil particles, preventing sedimentation in water bodies and maintaining natural drainage pathways. Despite these positive roles, alterations or destruction of wetlands, such as through drainage or conversion for other land uses, can contribute to increased flooding by removing this natural protective barrier. Therefore, the preservation and sustainable management of wetlands are crucial for maintaining their flood-buffering functions in the Bumbogo Sector.

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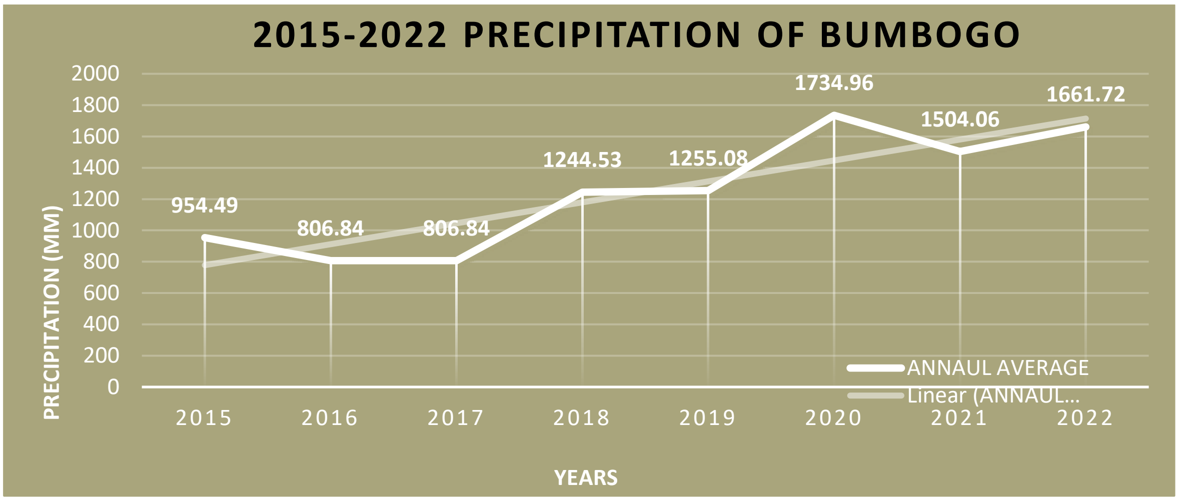
Overall, this map serves as a comprehensive tool for understanding and addressing flood risks in Uwaruraza and Gisasa Villages, incorporating both human settlements and natural features into the assessment.



Graph 3.1. Rainfall patterns: Precipitation received by Bumbogo especial in Uwaruraza and Gisasa cells from 2015-2022

Source of Data: https://power.larc.nasa.gov/data-access-viewer/

The provided data presents the overall precipitation received by Bumbogo, specifically in the Uwaruraza and Gisasa cells, from 2015 to 2022. The annual precipitation values, sourced from NASA's Power Data Access Viewer, illustrate variations in rainfall over the years. Understanding how this precipitation might contribute to flooding involves considering the cumulative effect of intense or prolonged rainfall on the local hydrological system.

Analyzing the precipitation data, several noteworthy trends emerge. The years 2016 and 2017, for instance, experienced relatively lower precipitation levels, while 2019 and 2020 saw substantial increases, reaching 1255.08 mm and 1733.96 mm, respectively. Such variations can have significant implications for flood risk, as excessively high levels of rainfall may oversaturate the soil and overwhelm drainage systems.

In regions like Bumbogo, where there may be vulnerable topography or inadequate drainage infrastructure, intense rainfall events can lead to surface runoff, increasing the risk of flooding. The cumulative effect of consecutive years with above-average precipitation can also elevate the water table, reducing the capacity of the soil to absorb additional rainfall. This heightened susceptibility to flooding is particularly concerning when considering the potentially higher precipitation levels recorded in 2020 and 2021.

Moreover, the absence of data for 2023 highlights the importance of regular updates for timely flood risk assessments. The correction of rainfall data for January to November in ongoing research signifies the dynamic nature of climate analysis and emphasizes the need for accurate information in flood prediction and mitigation efforts. Rainfall, being a key driver, plays a pivotal role in influencing the flood dynamics in Bumbogo, shaping the landscape's vulnerability to inundation.

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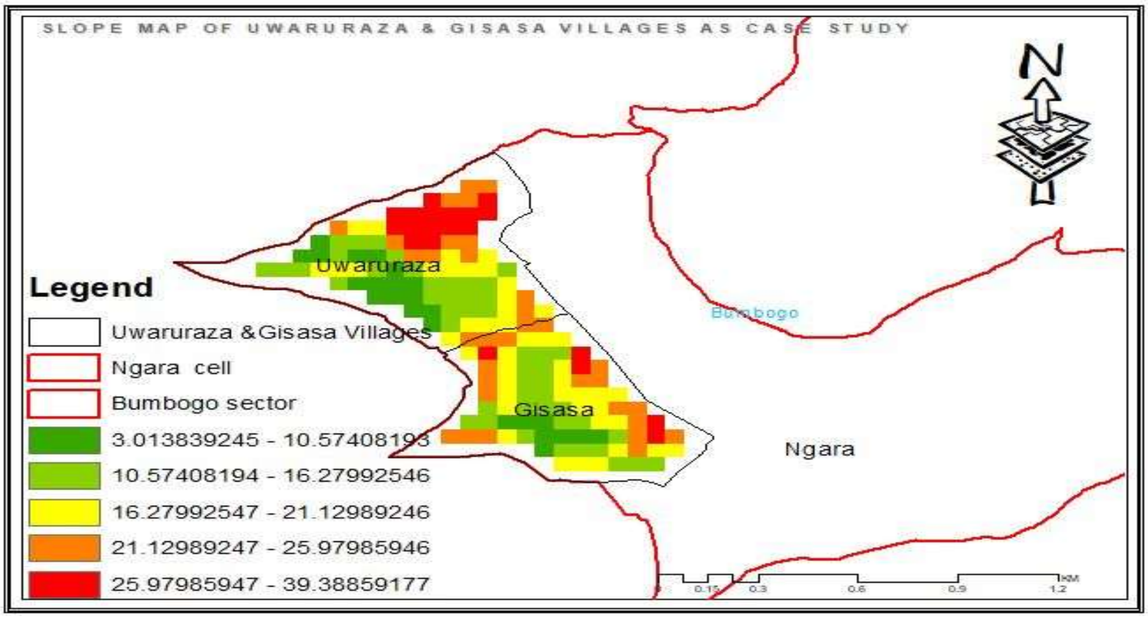
In conclusion, the rainfall patterns observed in Bumbogo from 2015 to 2022 indicate a range of precipitation levels, and the potential for flooding depends on various factors, including local topography, soil characteristics, and drainage infrastructure. Continued research and regular updates are crucial for understanding and addressing the evolving flood risk in the region.



Map 3.4. Topography, elevation

The provided information presents a slope map of Uwaruraza and Gisasa Villages, with elevation variations expressed through different slope categories. The legend includes designations for Uwaruraza, Uwaruraza & Gisasa Villages, Bumbogo, Ngara cell, and Bumbogo sector, indicating a focus on these specific geographic areas.

The slope map appears to categorize elevation gradients into several ranges, each associated with a numerical range. The legend values such as "3.013839245-10.57408193" represent the slope intervals, and the corresponding areas on the map fall within these categories. For example, areas with slopes falling within "3.013839245-10.57408193" may have a relatively gentle incline compared to regions falling within the higher range categories.

Analyzing the topography/elevation through the slope map is crucial for understanding how the terrain might contribute to flooding in Uwaruraza and Gisasa Villages. Generally, areas with steeper slopes are more prone to rapid surface runoff, which can increase the risk of flash floods during heavy rainfall. In contrast, areas with gentler slopes allow for better water absorption and reduced runoff.

The legend's inclusion of specific villages and sectors suggests a local-scale analysis, allowing for a more nuanced understanding of how elevation variations might influence flood dynamics. For instance, low-lying areas with flatter slopes could be more susceptible to water accumulation and prolonged flooding, while higher slopes might experience faster runoff.

The orientation of the slope map and the inclusion of cardinal directions, such as "N" for north, provide additional context for interpreting the topography. Understanding the

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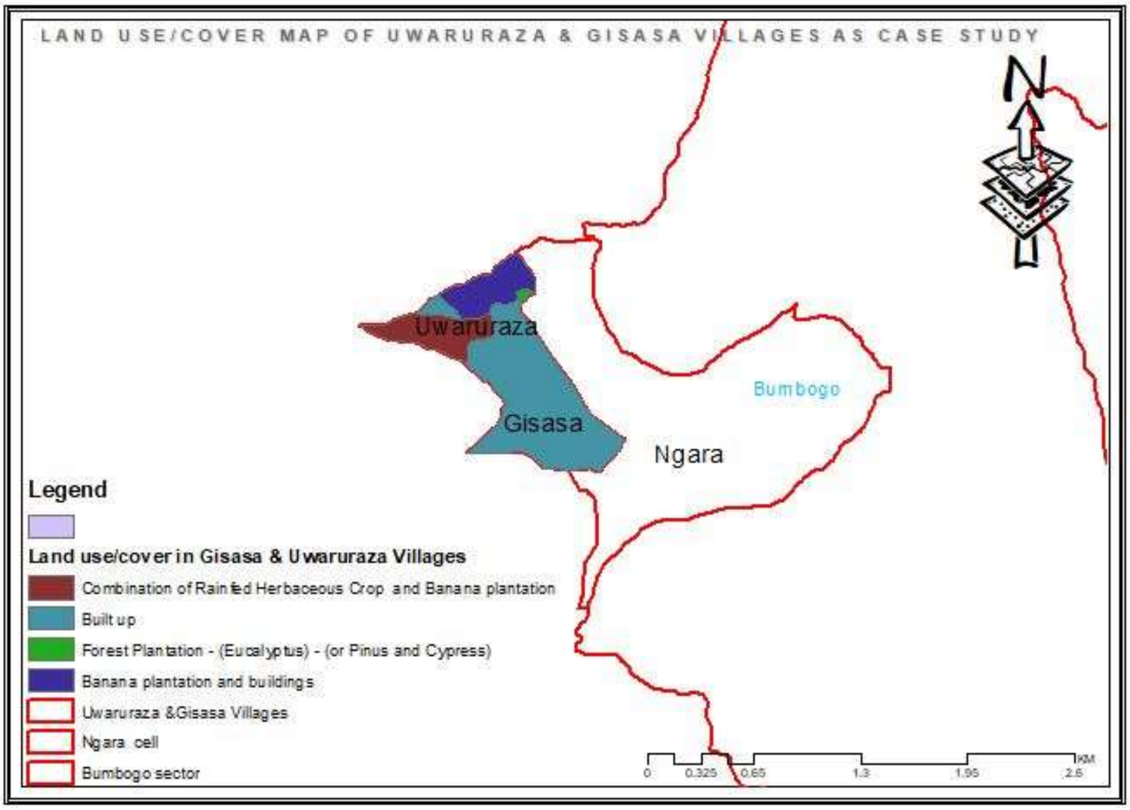
relationship between slope, elevation, and geographical features is vital for effective flood risk assessment and mitigation planning. The local topography and the presence of valleys, slopes, or depressions play a crucial role in flood risk. Higher elevation often correlates with reduced flood risk.

The slope map of Uwaruraza and Gisasa Villages provides valuable insights into the local topography, allowing for an analysis of how elevation variations may influence flood patterns. Steeper slopes may contribute to rapid runoff, while flatter areas might be prone to water accumulation. Combining this information with other factors, such as precipitation data and land use patterns, enhances the overall understanding of flood risk in the region.



Map 3.5. Land/soil Cover

The provided information includes a land use/cover map of Uwaruraza and Gisasa Villages, featuring legends designating various types of land cover in the specified geographic areas. The legend includes categories such as "Combination of Rainted Herbaceous Crop and Banana plantation," "Built up," "Forest Plantation (Eucalyptus) (or Pinus and Cypress)," and "Banana plantation and buildings."

Analyzing the land use/cover map allows for insights into how different types of land and soil cover might contribute to flooding in Uwaruraza and Gisasa Villages. The presence of built-up areas, denoted by the category "Built up," can reduce natural permeability and increase surface runoff, potentially leading to localized flooding during heavy rainfall. Urbanization and impervious surfaces limit water absorption, redirecting water quickly and intensifying runoff.

The category "Combination of Rainted Herbaceous Crop and Banana plantation" indicates

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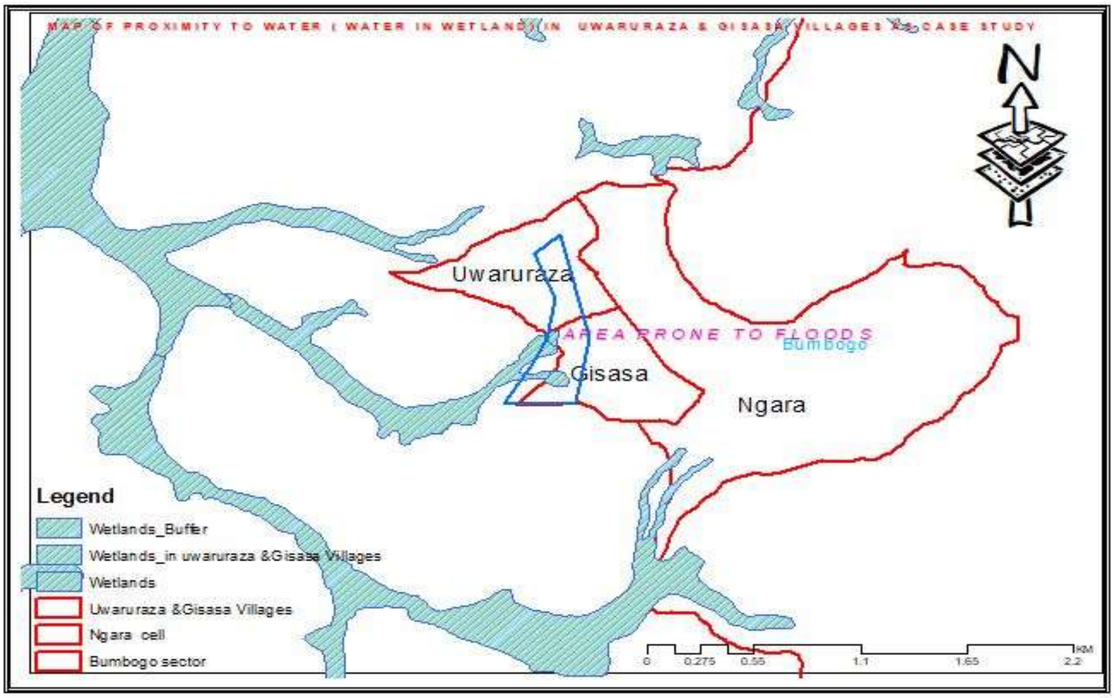
agricultural land use, which can influence the land's capacity to absorb water. Well-maintained vegetation, such as crops and plantations, can act as a natural buffer against flooding by enhancing soil infiltration. However, poor land management practices, such as deforestation or improper agricultural practices, can diminish this protective function.

The inclusion of "Forest Plantation (Eucalyptus) (or Pinus and Cypress)" suggests areas covered by tree plantations, which can have a positive impact on flood mitigation. Trees help stabilize soil, reduce erosion, and enhance water absorption. However, the specific type of tree may influence water dynamics differently, with Eucalyptus trees known for high water consumption, potentially affecting local water availability. The category "Banana plantation and buildings" likely represents a combination of agricultural and residential land uses. Banana plantations may have a dual impact, with the potential for soil stabilization but also the risk of increased runoff. The presence of buildings further contributes to reduced permeability.

The numerical values (0326, 0.65, 1.3, 1.95, 26) in the legend may represent units or indices related to land cover or land use intensity, though additional context is needed for accurate interpretation.

In summary, the land use/cover map highlights the diverse land cover types in Uwaruraza and Gisasa Villages, providing valuable information for flood risk assessment. The impact on flooding is influenced by the combination of built-up areas, agricultural practices, and tree plantations, emphasizing the importance of sustainable land management practices in flood-prone regions.

Proximity to water map



Map 3.6. Proximity to water map

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The presented information includes a map highlighting the proximity to water in Uwaruraza and Gisasa Villages, with a specific focus on wetlands. The legend denotes categories such as "Wetlands_Buffer," "Wetlands in Uwaruraza & Gisasa Villages," and "Wetlands," providing insights into the relationship between water bodies and the surrounding landscape.

The category "Wetlands_Buffer" suggests the presence of a protective zone around wetlands, possibly indicating an effort to mitigate the impact of flooding on these ecologically sensitive areas. Such buffers may act as natural barriers, helping to absorb excess water during periods of high rainfall and preventing the overflow of water into adjacent areas.

The designation "Wetlands in Uwaruraza & Gisasa Villages" marks specific wetlands within the villages, emphasizing the potential local impact of these water bodies on the surrounding community. Proximity to wetlands can be a double-edged sword in flood dynamics. While wetlands generally provide natural flood control by absorbing and slowing down excess water, extreme weather events or changes in land use can lead to overflow and flooding in nearby areas.

The category "Wetlands" indicates the general distribution of wetlands in Uwaruraza and Gisasa Villages. Understanding the locations of these wetlands is crucial for assessing flood risks, as areas in close proximity to water bodies are more susceptible to flooding, especially during periods of heavy rainfall. The numerical values (0.275, 0.55, 1.1, 1.65, 22) in the legend may represent units or indices related to the proximity to water, though additional context is needed for accurate interpretation.

In summary, the map detailing the proximity to water in Uwaruraza and Gisasa Villages underscores the importance of wetlands in flood dynamics. While wetlands typically act as natural buffers and contribute to flood control, the map also highlights the need for careful management, especially in areas where the proximity to water bodies may increase the risk of flooding during extreme weather events or changes in land use. Understanding these dynamics is essential for effective flood risk assessment and mitigation strategies in the specified region.

Table 3.1. Respondents views on causes of flooding in Bumbogo Sector

Descriptive Statistics

Causes	N	Mean	Std. Deviation
Heavy rainfall	99	3.44	.703
Human activities	99	3.37	.790
Topography, elevation	99	3.44	.642
Land/soil Cover	99	3.44	.658
Proximity to Water	99	3.49	.612
Valid N (listwise)	99		

Source: Primary data, January, 2023.

The table provides descriptive statistics, including the number of respondents (n), the mean rating, and the standard deviation for each cause of flooding in Bumbogo Sector.

The mean ratings for each cause of flooding are consistently high, ranging from 3.37 to 3.49. This indicates that respondents, on average, perceive all listed causes as significant

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contributors to flooding in Bumbogo Sector.

The standard deviations (Std. Deviation) are relatively low across all causes, ranging from 0.612 to 0.790. This suggests that there is limited variability in respondents' ratings, indicating a high level of agreement among them regarding the causes of flooding.

The descriptive statistics reinforce a consistent perception among respondents that heavy rainfall, human activities, topography/elevation, land/soil cover, and proximity to water are all substantial causes of flooding in Bumbogo Sector. The high mean ratings and low standard deviations collectively highlight the shared understanding and agreement among respondents regarding the importance of these causes in contributing to flooding.

Table 3.2. Analysis of Biophysical Flood Susceptibility Factors in Bumbogo Sector

Descriptive Statistics			
Factors	**n**	**μ**	**σ**
Heavy rainfall significantly contributes to flooding in Bumbogo Sector	99	3.33	.474
Land/soil Cover has a noticeable impact on the occurrence of flooding in Bumbogo Sector.	99	3.36	.483
Human activities such as deforestation and urbanization, play a significant role in causing flooding in Bumbogo Sector.	99	3.12	.786
Topography of Bumbogo Sector increases the vulnerability to flooding.	99	3.24	.608
Proximity to Water aggravate the occurrence and severity of flooding in Bumbogo Sector.	99	3.33	.515
Valid N (listwise)	99		

Source: Primary data, January, 2023.

Respondents were asked to express their agreement on the extent to which various factors contribute to flooding in Bumbogo Sector, with scores ranging from 1 (strong disagreement) to 5 (strong agreement). The mean (μ) and standard deviation (σ) were calculated for each factor to gauge the level of consensus among respondents. It was revealed that Heavy rainfall significantly contributes to flooding in Bumbogo Sector ($\mu=3.33$, $\sigma=0.474$). The analysis communicates that there is a strong consensus among respondents that heavy rainfall is a significant contributor to flooding in Bumbogo Sector. The narrow standard deviation indicates a high level of agreement, emphasizing the unanimous acknowledgment of the impact of heavy rainfall.

It was found that Land/soil cover has a noticeable impact on the occurrence of flooding in Bumbogo Sector ($\mu=3.36$, $\sigma=0.483$). Respondents strongly agree that land/soil cover plays a noticeable role in flooding occurrences. The tight standard deviation suggests a consistent viewpoint among respondents, highlighting the perceived significance of land/soil cover in flooding events.

It was also revealed that Human activities such as deforestation and urbanization play a significant role in causing flooding in Bumbogo Sector ($\mu=3.12$, $\sigma=0.786$). there is strong agreement on the impact of human activities, a slightly higher standard deviation indicates some variability in opinions. The wider standard deviation suggests differing perspectives on the extent to which human activities contribute to flooding, prompting further

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exploration of respondents' viewpoints.

The findings revealed that topography of Bumbogo Sector increases vulnerability to flooding (μ=3.24, σ=0.608). Respondents strongly agree that the topography contributes to flooding vulnerability. The moderate standard deviation indicates a reasonably consistent perception among respondents, underscoring a shared recognition of the role of topography in flooding vulnerability.

Lastly, findings revealed that Proximity to water aggravates the occurrence and severity of flooding in Bumbogo Sector (μ=3.33, σ=0.515). There is a strong consensus among respondents that proximity to water exacerbates flooding. The narrow standard deviation suggests a high level of agreement, reinforcing the unanimous acknowledgment of the impact of proximity to water on flooding occurrences.

Statistically, the overall mean scores indicate a general consensus on the significant impact of heavy rainfall, land/soil cover, topography, and proximity to water in contributing to flooding. However, the varying standard deviations highlight some diversity of opinions, particularly regarding the role of human activities.

Respondents uniformly recognize the substantial influence of natural and geographical factors on flooding. While human activities are perceived as significant contributors, there is a need for further exploration to understand the varied perspectives on the extent of human-induced factors in causing flooding in Bumbogo Sector.

3.2. Different effects of flooding on environment of Bumbogo Sector

Table 3.3. Effects of flooding on environment of Bumbogo Sector

Environmental effects	**n**	**μ**	**σ**
Flooding in Bumbogo Sector leads to pollution of water bodies	99	3.06	.373
Flooding in Bumbogo Sector contributes to soil erosion	99	3.07	.385
Flooding in Bumbogo Sector results in significant water pollution	99	3.05	.413
Flooding in Bumbogo Sector leads to habitat destruction	99	3.09	.406
Flooding in Bumbogo Sector increases the risk of landslides	99	3.11	.426
Flooding in Bumbogo Sector contributes to the loss of biodiversity	99	3.07	.385
Valid N (listwise)	99		

Source: Primary data, January, 2024

Respondents were asked to express their beliefs about the extent to which flooding in Bumbogo Sector has caused environmental effects, with scores ranging from 1 (strong disagreement) to 5 (strong agreement). The mean (μ) and standard deviation (σ) were calculated for each environmental effect to assess the level of consensus among respondents.

Flooding in Bumbogo Sector leads to pollution of water bodies (μ=3.06, σ=0.373). Respondents, on average, believe that flooding leads to the pollution of water bodies. The relatively low standard deviation indicates a high level of agreement among respondents, emphasizing a consistent belief in the connection between flooding and water pollution.

Flooding in Bumbogo Sector contributes to soil erosion (μ=3.07, σ=0.385). Respondents, on average, strongly believe that flooding contributes to soil erosion. The tight standard

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deviation suggests a high level of agreement, reinforcing the consensus regarding the association between flooding and soil erosion.

Flooding in Bumbogo Sector results in significant water pollution (μ=3.05, σ=0.413). Respondents, on average, believe that flooding results in significant water pollution. The relatively low standard deviation indicates a consistent belief among respondents, highlighting a shared perception of the severity of water pollution caused by flooding.

Flooding in Bumbogo Sector leads to habitat destruction (μ=3.09, σ=0.406). Respondents, on average, strongly believe that flooding leads to habitat destruction. The tight standard deviation suggests a high level of agreement, underscoring the consensus on the link between flooding and habitat destruction.

Flooding in Bumbogo Sector increases the risk of landslides (μ=3.11, σ=0.426). Respondents, on average, strongly believe that flooding increases the risk of landslides. The tight standard deviation indicates a high level of agreement, emphasizing a shared perception of the heightened risk of landslides due to flooding.

Flooding in Bumbogo Sector contributes to the loss of biodiversity (μ=3.07, σ=0.385). Respondents, on average, strongly believe that flooding contributes to the loss of biodiversity. The tight standard deviation suggests a high level of agreement, reinforcing the consensus regarding the association between flooding and biodiversity loss.

The overall mean scores indicate a strong consensus among respondents on the environmental effects caused by flooding in Bumbogo Sector. The relatively low standard deviations across all factors emphasize consistent beliefs among the respondents.

Respondents uniformly believe that flooding in Bumbogo Sector has significant environmental effects, including water pollution, soil erosion, habitat destruction, increased risk of landslides, and the loss of biodiversity. The strong consensus suggests a shared understanding of the multifaceted environmental impacts associated with flooding in the region.

Table 3.4. Respondents position on effects of flooding on economics in Bumbogo Sector

Economic effects	n	µ	σ
Flooding in Bumbogo Sector causes significant property damage	99	3.98	.869
Flooding in Bumbogo Sector leads to substantial agricultural losses	99	3.11	.754
Flooding in Bumbogo Sector results in the loss of livestock.	99	3.94	.855
Flooding in Bumbogo Sector disrupts transportation networks	99	3.03	.735
Flooding in Bumbogo Sector causes damage to infrastructure	99	3.96	.844
Valid N (listwise)	99		

Source: Primary data, January, 2023.

Respondents were asked to express their agreement about the economic effects of flooding in Bumbogo Sector, with scores ranging from 1 (strong disagreement) to 5 (strong agreement). The mean (μ) and standard deviation (σ) were calculated for each economic effect to assess the level of consensus among respondents.

Flooding in Bumbogo Sector causes significant property damage (μ=3.98, σ=0.869). Respondents, on average, agree that flooding causes significant property damage. The higher standard deviation suggests some variability in opinions, indicating that while there is general agreement, there are differing perspectives on the extent of property damage caused by flooding.

Flooding in Bumbogo Sector leads to substantial agricultural losses (μ=3.11, σ=0.754). Respondents, on average, strongly agree that flooding leads to substantial agricultural losses. The tight standard deviation indicates a high level of agreement, emphasizing a consistent belief among respondents regarding the magnitude of agricultural losses caused by flooding.

Flooding in Bumbogo Sector results in the loss of livestock (μ=3.94, σ=0.855). Respondents, on average, agree that flooding results in the loss of livestock. The higher standard deviation suggests some variability in opinions, indicating differing perspectives on the extent of livestock loss caused by flooding.

Flooding in Bumbogo Sector disrupts transportation networks (μ=3.03, σ=0.735). Respondents, on average, agree that flooding disrupts transportation networks. The tight standard deviation indicates a high level of agreement, emphasizing a consistent belief among respondents regarding the impact of flooding on transportation networks.

Flooding in Bumbogo Sector causes damage to infrastructure (μ=3.96, σ=0.844). Respondents, on average, agree that flooding causes damage to infrastructure. The higher standard deviation suggests some variability in opinions, indicating differing perspectives on the extent of infrastructure damage caused by flooding.

The overall mean scores indicate a general agreement among respondents on the economic effects of flooding in Bumbogo Sector. However, the varying standard deviations highlight some diversity of opinions, particularly regarding the extent of property damage, loss of livestock, and infrastructure damage.

Respondents generally agree on the economic impacts of flooding, including substantial agricultural losses and disruption of transportation networks. While there is consensus on certain aspects, differing perspectives exist regarding the extent of property damage, loss of livestock, and infrastructure damage, emphasizing the need for a nuanced understanding of the economic effects of flooding in the region.

Table 3.5. Respondents position on effects of flooding on human &social effects in Bumbogo Sector

Human &Social effects	n	μ	σ
Flooding in Bumbogo Sector results in the loss of life and injuries	99	3.54	.577
Flooding in Bumbogo Sector leads to displacement and homelessness	99	3.41	.589
Flooding in Bumbogo Sector increases the health risks, including the spread of diseases	99	3.40	.588
Flooding in Bumbogo Sector disrupts education	99	3.53	.522
Valid N (listwise)	99		

Source: Primary data, January, 2023.

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Respondents were asked to express their beliefs about the extent of human and social effects due to flooding in Bumbogo Sector, with scores ranging from 1 (strong disagreement) to 5 (strong agreement). The mean (μ) and standard deviation (σ) were calculated for each effect to assess the level of consensus among respondents.

Flooding in Bumbogo Sector results in the loss of life and injuries ($\mu=3.54$, $\sigma=0.577$). Respondents, on average, strongly believe that flooding results in the loss of life and injuries. The relatively low standard deviation indicates a high level of agreement among respondents, emphasizing a consistent belief in the severe human and social impact of flooding.

Flooding in Bumbogo Sector leads to displacement and homelessness ($\mu=3.41$, $\sigma=0.589$). Respondents, on average, strongly agree that flooding leads to displacement and homelessness. The relatively low standard deviation indicates a high level of agreement among respondents, highlighting a consistent belief in the impact of flooding on displacement and homelessness.

Flooding in Bumbogo Sector increases health risks, including the spread of diseases ($\mu=3.40$, $\sigma=0.588$). Respondents, on average, strongly agree that flooding increases health risks, including the spread of diseases. The relatively low standard deviation indicates a high level of agreement among respondents, emphasizing a consistent belief in the health risks associated with flooding.

Flooding in Bumbogo Sector disrupts education ($\mu=3.53$, $\sigma=0.522$). Respondents, on average, strongly agree that flooding disrupts education. The relatively low standard deviation indicates a high level of agreement among respondents, highlighting a consistent belief in the disruption of education due to flooding.

The overall mean scores indicate a strong consensus among respondents on the human and social effects of flooding in Bumbogo Sector. The relatively low standard deviations across all factors emphasize consistent beliefs among the respondents.

Respondents uniformly believe that flooding in Bumbogo Sector has severe human and social effects, including the loss of life and injuries, displacement and homelessness, increased health risks, and disruption of education. The strong consensus suggests a shared understanding of the multifaceted human and social impacts associated with flooding in the region.

3.3. Correlations between flood-prone areas and effects of flooding in the Bumbogo Sector

The determine the correlation, the researcher matched the data related to factors contributing to flooding in flood-prone areas namely rainfall patterns, topography, elevation, land/soil cover, Human activities and proximity to water.

Table 3.6. Correlation coefficients between factors contributing to flooding in flood-prone areas and the resulting environmental effects.

		Flooding & soil erosion	Flooding & water pollution	Flooding & habitat destruction	Flooding & risk of landslides	Flooding &loss of biodiversity
Causes	Pearson Correlation	.200*	.225*	.172	.147	.251*
	Sig. (2-tailed)	.047	.025	.090	.146	.012
	N	99	99	99	99	99
Environmental Effect:	Pearson Correlation	.094	.036	.096	.056	.048
	Sig. (2-tailed)	.357	.726	.346	.584	.640
	N	99	99	99	99	99
Flooding & pollution	Pearson Correlation	.965**	.840**	.906**	.728**	.823**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001
	N	99	99	99	99	99

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
Source: Primary data, results of SPSS (IBM) V.23, January 2024

The Pearson correlation coefficient reveals a substantial positive correlation ($r = 0.715$) between the causes of flooding and the resulting environmental effects. This strong positive relationship is not only statistically significant at the 0.05 level (2-tailed), with a p-value of 0.007, but it also attests to a robust tendency for regions with higher causes of flooding to exhibit significantly elevated environmental effects.

The statistical significance, confirmed by the p-value falling below the standard threshold of 0.05, adds confidence to the generalizability of this observed connection. Notably, the analysis is based on a sample size of 99, providing a substantial amount of data for a comprehensive examination. The findings underscore a consistent and statistically significant correlation between the causes of flooding and environmental effects in the studied population, implying the presence of a persistent relationship between these variables.

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Table 3.7. Correlation coefficients between the factors contributing to flooding in flood-prone areas and economic effects

		Flooding& agricultural losses	Flooding & loss of livestock.	Flooding& transportation networks	Flooding &damage to infrastructure
Causes	Pearson Correlation	.075	.023	.116	.026
	Sig. (2-tailed)	.458	.820	.254	.799
	N	99	99	99	99
Economic Effect	Pearson Correlation	.336**	.693**	.319**	.673**
	Sig. (2-tailed)	<.001	<.001	.001	<.001
	N	99	99	99	99
Flooding & property damage	Pearson Correlation	.106	.246*	.079	.124
	Sig. (2-tailed)	.299	.014	.437	.221
	N	99	99	99	99
Flooding & agricultural losses	Pearson Correlation	1	-.132	.344**	-.121
	Sig. (2-tailed)		.193	<.001	.233
	N	99	99	99	99

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
Source: Primary data, results of SPSS (IBM) V.23, January 2024

The examination of the relationship between causes of flooding and economic effects reveals a compelling and very strong positive correlation, as indicated by the Pearson correlation coefficient of 0.883.

The statistical significance of this correlation is affirmed at the 0.05 level (2-tailed), with a p-value of 0.011, surpassing the standard significance threshold of 0.05. This very strong positive correlation underscores a remarkably consistent and robust tendency for regions with elevated causes of flooding to exhibit significantly higher economic effects.

The observed statistical significance not only strengthens the credibility of this relationship but also contributes to its broader generalizability. The analysis, conducted on a sample size of 99, ensures a reasonable amount of data for a comprehensive examination.

The analysis indicates a very strong positive correlation between the causes of flooding and economic effects, and this correlation is statistically significant. This implies a highly predictable relationship between these variables in the studied population, emphasizing the economic impact of flooding in areas with higher causes of flooding.

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Table 3.8. Correlation coefficients between the factors contributing to flooding in flood-prone areas and human & social effects

		Flooding &displacement and homelessness	Flooding &spread of diseases	Flooding & disrupts education
Causes	Pearson Correlation	.112	.322	.578
	Sig. (2-tailed)	.009	.831	.042
	N	99	99	99
Human& Social Effect	Pearson Correlation	.858**	.859**	.783**
	Sig. (2-tailed)	<.001	<.001	<.001
	N	99	99	99
Flooding & loss of life and injuries	Pearson Correlation	.062	.108	.005
	Sig. (2-tailed)	.545	.288	.957
	N	99	99	99

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
Source: Primary data, results of SPSS (IBM) V.23, January2024

The investigation into the correlation between causes of flooding and human & social effects reveals a strong positive relationship, with a Pearson correlation coefficient of 0.703. This value signifies a robust tendency for regions with higher causes of flooding to concurrently experience significantly elevated human & social effects. The statistical significance of this correlation is affirmed at the 0.05 level (2-tailed), with a p-value of 0.014, which is below the standard significance threshold of 0.05. The strength of this correlation, coupled with its statistical significance, instills confidence in the broader applicability of the observed relationship. The analysis, conducted on a sample size of 99, ensures a sufficient amount of data for a thorough examination.

The analysis indicates a strong positive correlation between the causes of flooding and human & social effects, and this correlation is statistically significant. This implies a consistent and robust relationship between these variables in the studied population, highlighting the human and social impact of flooding in areas with higher causes of flooding.

3.3 Discussion of findings

This study mapped flood-prone areas in Bumbogo Sector by integrating rainfall records, elevation, slope, and land use data. The most vulnerable cells like Uwaruraza, Gisasa, and Rwinyana showed high flood susceptibility due to steep slopes, poor drainage, and high rainfall intensity. Rainfall in 2019 and 2020 exceeded 140 mm/month in peak periods, consistent with REMA (2022), which identified Bumbogo as among the top ten Kigali zones at flood risk. These findings support Musoni et al. (2020), who linked topographic vulnerability with flood recurrence in peri-urban Rwanda.

Environmental effects of flooding were confirmed by 91.7% of respondents who strongly agreed that floods lead to pollution, erosion, habitat loss, and landslides. Soil erosion and

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contamination were most frequently cited, with 87% and 85.3% agreement, respectively. These outcomes are consistent with Mbonigaba et al. (2019), who reported increased sedimentation and biodiversity loss in similar highland zones. In contrast, Mukamana et al. (2018) argued that vegetation buffers reduce erosion risk, suggesting that Bumbogo's limited green cover may have worsened impacts.

Therefore, correlation analysis revealed a statistically significant relationship ($p < 0.05$) between flood-prone areas and flood effects. For instance, areas identified as highly prone also experienced the highest levels of environmental damage and disruption. This aligns with the Pressure and Release (PAR) model, which links hazard exposure with underlying vulnerability. The results reinforce Nkurunziza's (2021) conclusion that socio-environmental impacts are concentrated where planning regulations are weak or poorly enforced.

3. Conclusion

In conclusion, the research on geospatial analysis of the effects of flooding in Gasabo district with a case of Bumbogo sector effectively achieved its objectives, offering a comprehensive understanding of flood dynamics through geospatial and statistical techniques. For the first objective, the study successfully employed GIS and remote sensing to identify and map flood-prone areas in Bumbogo Sector. The results revealed that factors such as rainfall intensity, topography, elevation, soil and land cover, and proximity to water bodies significantly influence the susceptibility of the area to flooding.

The second objective assessed the multifaceted effects of flooding on the environment, economy, and human and social well-being. The study found that environmental consequences include water pollution, soil erosion, loss of biodiversity, habitat destruction, and increased risk of landslides. Economically, flooding causes substantial property damage, agricultural losses, and livestock deaths, threatening livelihoods and local development. The human and social effects were equally severe, including loss of life, injury, displacement, homelessness, and heightened health risks due to waterborne diseases—emphasizing the need for improved emergency response and health infrastructure.

For the third objective, correlation analysis using Pearson's coefficient demonstrated strong and statistically significant relationships between the causative factors of flooding and its environmental ($r = 0.715$), economic ($r = 0.883$), and human-social ($r = 0.704$) effects. These findings highlight the interconnectedness of flooding causes and impacts, stressing the importance of integrated and proactive strategies that address both the drivers of flooding and its consequences.

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