REPUBLIC OF RWANDA
ULK POLYTECHNIC INSTITUTE
P.O BOX 2280 Kigali
Website: //www.ulkpolytechnic.ac.rw
E-mail: polytechnic.institute@ulk.ac.rw

ACADEMIC YEAR 2023/2024
DEPARTMENT OF CIVIL ENGINEERING
OPTION: LAND SURVEY

THE ROLE OF GIS AND RS LAND SLIDE MANAGEMENT FOR ENVIRONMENT CASE STUDY: NYUNDO SECTOR (2014-2023)

Submitted in partial fulfillment of the requirements for the Award of
Advanced Diploma In land survey
Presented by

NSHIZIRUNGU Frank

*Supervisor :***Eng.CIMANUKA BONGWA David**

Kigali, October 2024

DECLARATION OF ORIGINALITY

I, **NSHIZIRUNGU Frank** hereby declares that the work presented in this dissertation is my contribution to the best of my knowledge. The same work has never been submitted to any other University or Institution. I, therefore declare that this work is my own for the partial fulfillment of the award of A1 with honors in Land Survey at ULK POLYTECHNIC INSTITUTE.

Candidate's name: NSHIZIRUNGU Frank

Candidate's Signature: ………………………………………………

Date of submission: ………..………………….……………...............

APPROVAL

This is to certify that this dissertation work entitled "The role of GIS and RS in land slide management for environment protection case study: Nyundo (2014-2023)" is an original study conducted by **NSHIZIRUNGU Frank** under my supervision and guidance.

Supervisor's name**: Eng.CIMANUKA Bongwa David**

Signature of supervisor**: …………………………………**

Submission date**: ……….……………………….………….**

HEAD OF DEPARTMENT

Eng. NKIRANUYE Bonaventure

Signature**………………………………………………………………………….**

DEDICATION

This project is dedicated to Almighty God for guidance and inspiration. We extend our heartfelt gratitude to our parents for their unwavering support. Our classmates have been invaluable collaborators in our learning journey. Our supervisor Eng. CIMANUKA Bongwa David for his advice and guidance. Friends have encouraged and motivated us throughout. We acknowledge the Civil Engineering department lecturers and assistants for their knowledge and mentorship. Our brothers and sisters have been unwavering pillars of strength. We also appreciate the ULK POLYTECHNIC INSTITUTE Administration for their support.

ACKNOWLEDGEMENTS

The achievement of this research project has been successful due to the joint effort and cooperation of different persons. Thus, I am very grateful to
express my acknowledgments of the following:

First, my deepest thanks go to the Almighty God who gave me the gift of life, and the opportunity that able me to achieve this work.

I just express my sincere thanks and particular appreciation to my project supervisor **Eng. CIMANUKA Bongwa David** for his advice, comprehension, support, and guidance during this study.

I am thankful to the institution of "ULK POLYTECHNIC INSTITUTE ", especially all lecturers in the Land Survey Department for the theoretical training, practices, pieces of advice, and assistance they willingly gave us throughout four years of our studies, thus enabling this final year project.

I address my sincere gratitude to my beloved uncle, brothers and sisters, friends, classmates, and all relatives for their kind advice and support during my studies and completion of this project work.

In addition, I am thankful to all persons who contributed directly or indirectly to the completion of this work especially the ones who were kindly targeted for giving the required information during the research survey on the project.

Abstract

This study explores the critical role of Geographic Information Systems (GIS) and Remote Sensing (RS) in managing landslide disasters and protecting the environment, with a focused case study on Rubavu, Nyundo Sector in Rwanda. Landslides pose significant threats to both human life and infrastructure, particularly in regions characterized by steep terrain and heavy rainfall. Effective disaster management strategies are essential to mitigate these risks, and the integration of advanced technologies like GIS and RS offers promising solutions.

On May 3, 2023, over 6,000 homes were wrecked by disasters in the Nyundo Sector, Rubavu District. This incident underscored the urgent need for robust disaster management systems. The government has identified various ‘disaster hotspots’ across the nation prone to floods and landslides, emphasizing the critical need for advanced monitoring and prediction tools.

The study aims to assess the effectiveness of GIS and RS in identifying and managing landslide-prone areas, evaluating their contribution to environmental protection, and providing actionable insights for local authorities and policymakers. By leveraging satellite imagery and spatial data. the study identifies high-risk zones, monitors environmental changes, and develops predictive models for landslide susceptibility. The methodology involves the collection and analysis of geospatial data, field surveys, and the application of risk assessment models to evaluate the landslide susceptibility of Nyundo Sector.

This research contributes to the broader field of disaster management by demonstrating the practical applications of GIS and RS in a real-world context. The case study of Rubavu, Nyundo Sector serves as a model for similar regions facing the dual challenges of natural disasters and environmental degradation. The recommendations provided offer a pathway for integrating advanced geospatial technologies into comprehensive disaster management and environmental protection strategies, ensuring a safer and more sustainable future for vulnerable communities.

Table of Content

DECLARATION OF ORIGINALITY i

APPROVAL ii

DEDICATION iii

ACKNOWLEDGEMENTS iv

Abstract v

LIST OF ACRONYMS AND ABBREVIATIONS x

CHAPTER ONE: GENERAL INTRODUCTION 1

1.0 introduction 1

1.1 Background 2

1.2 Objectives 3

1.3 Research Questions 4

1.4 Significance of the Study 4

1.5 Statement of the Problem 3

1.6 Purpose of the Study 5

1.7 Scope of the Study 5

CHAPTER TWO: LITERATURE REVIEW 7

2.0 Introduction 7

2.1 Concepts, Opinions, Ideas from Authors/Experts 8

2.1.1 The Concept of GIS in Disaster Management 8

2.1.2 GIS and RS in Landslide Management 9

2.2 Theoretical Perspectives 9

2.2.1 Spatial Analysis and Geographic Information Theory 9

2.2.2 Remote Sensing Theory and the Electromagnetic Spectrum 10

2.2.3 Systems Theory in Disaster Management 10

2.2 Theoretical Perspectives 11

2.2.1 Spatial Analysis and Geographic Information Theory 11

2.2.2 Remote Sensing Theory and the Electromagnetic Spectrum 11

2.2.3 Systems Theory in Disaster Management 12

2.2.4 Risk Management and Vulnerability Assessment 12

2.3 Related Studies 13

2.3.1 Nepal Landslide Susceptibility Mapping 13
2.3.2 Kerala Floods 2018 14
2.3.3 Bangladesh Flood Risk Assessment 14
2.3.4 Haiti Earthquake 2010 15
CHAPTER THREE: DATA COLLECTION AND ANALYSIS PROCEDURES 16
3.1 Geographic and Demographic Contex of Nyundo 16
3.2 Research Population 17
3.3 Sample Size 18
3.3.1 Sampling Procedure 18
3.4 Research Instrument 19
3.5 Data Gathering Procedures 19
3.6 Data Analysis and Interpretation 20
3.7 Ethical Considerations 21
3.8 Limitations of the Study 22
CHAPTER FOUR: DESIGN SPECIFICATION (RESULT AND DISCUSSION) ... 23
4.0 Introduction 23
4.1 landslide vulnerable map of Nyundo 23
4.2 Identification of Survey Respondents 24
4.3 Respondent Perspectives 25
4.4 Calculations 27
4.4.1 Landslide Susceptibility Calculation 27
4.4.2 Flood Risk Calculation 28
4.4.3 Population Vulnerability Calculation 29
4.4.4 Risk Index Calculation 29
4.4 Discussion 31
4.4.1 Landslide Susceptibility Risk Index and Prioritization 31
4.4.2 Flood Risk 32
4.4.3 Population Vulnerability 33
4.4.4 for Disaster Management 33
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS 34
5.0 Introduction 34

5.1 Conclusions 35
5.2 Recommendations 36
References 38

List of figures

Figure 1 map of case study 17

Figure 2 landslide susceptibility map of Nyundo... 23

Figure 3 condition for LSM (a) slope degree and (b) slope aspect.................. 30

Figure 4 condition for LSM (c) elevation and (d) plan curvature..................... 31

LIST OF ACRONYMS AND ABBREVIATIONS

ERIDAS : Earth Resources Data Analysis System

ETM+ : **Enhanced Thematic Mapper Plus**

EAC : East African Community

OLI : Operational Land Imager

GIS : Geographic Information System

GCP : Ground Control Points

RS : Remote Sensing

LULC : Land Use Land Cover

USGS : United States Geological Survey

UTM : Universal Transversal Mercator

ULK : Universite libre de Kigali

LSM : Landslide Susceptibility Map

CHAPTER ONE: GENERAL INTRODUCTION

1.0 introduction

Landslides are a pervasive natural hazard that poses significant risks to human life, infrastructure, and the environment, particularly in regions characterized by steep topography and heavy rainfall. In the context of Rwanda, the Rubavu District, specifically the Nyundo Sector, is notably susceptible to landslides due to its unique geographical and climatic conditions. The devastating event on May 3, 2023, which saw over 6,000 homes destroyed by landslides and floods, underscored the urgent need for effective disaster management strategies and the implementation of advanced monitoring tools. (rema, 2014)

Geographic Information Systems (GIS) and Remote Sensing (RS) have emerged as critical technologies in the field of disaster management. GIS facilitates the collection, storage, analysis, and visualization of spatial data, enabling the identification of high-risk areas and the planning of mitigation measures. Concurrently, RS provides real-time data through satellite imagery and aerial photography, essential for monitoring environmental changes and predicting landslide events. The integration of these technologies offers a dynamic and proactive approach to disaster management, providing precise and timely information that can significantly enhance the ability to predict, manage, and mitigate landslide risks. (Abid, 2020)

In Rubavu, Nyundo Sector, the application of GIS and RS is particularly pertinent. The region's susceptibility to landslides necessitates a robust and proactive disaster management approach. By leveraging these technologies, it is possible to develop comprehensive early warning systems, improve land-use planning, and implement effective mitigation strategies. This study aims to explore the critical role of GIS and RS in managing landslide disasters and protecting the environment in Rubavu, Nyundo Sector, offering valuable insights for local authorities, policymakers, and the broader community. The research seeks to enhance the resilience of vulnerable communities and promote sustainable development in landslide-prone areas, ensuring a safer and more secure future for the region.

1.1 Background

Landslides are a major natural hazard that affect many regions worldwide, particularly those with mountainous terrain and heavy rainfall. They can cause significant damage to infrastructure, disrupt communities, and result in loss of life. (Turner, 2018)

In Rwanda, the western district of Rubavu, particularly the Nyundo Sectorl, is highly susceptible to landslides due to its topography and climatic conditions. The area's steep slopes and heavy rainfall create a perfect storm for such natural disasters. (REMA, 2014)

On May 3, 2023, the Nyundo Sector in Rubavu District experienced a devastating event where over 6,000 homes were destroyed due to landslides and floods. This disaster underscored the urgent need for robust disaster management systems and effective monitoring tools. The Rwandan government, recognizing the gravity of the situation, has identified several 'disaster hotspots' across the country, emphasizing the need for comprehensive risk assessment and mitigation strategies. (Vincent, 2023)

Geographic Information Systems (GIS) and Remote Sensing (RS) have emerged as powerful tools in the field of disaster management. GIS enables the collection, storage, analysis, and visualization of spatial data, which is crucial for identifying high-risk areas and planning mitigation measures. RS provides real-time data through satellite imagery and aerial photography, allowing for continuous monitoring of environmental changes and land cover. Together, these technologies offer a dynamic approach to disaster management by providing accurate, timely information that can significantly enhance the prediction and management of landslide risks. (Tomaszewski, 2020)

The application of GIS and RS in disaster management involves several key processes. Spatial data analysis helps in mapping and identifying areas that are prone to landslides, while real-time monitoring through remote sensing helps track changes in land use and environmental conditions that could trigger landslides. This integration of data and technology not only aids in immediate disaster response but also plays a vital role in long-term planning and sustainable environmental management. (Van Westen, 2013)

In the context of Rubavu, Nyundo Sector, the use of GIS and RS is particularly pertinent. The region's vulnerability to landslides necessitates a proactive approach to disaster management. By utilizing these advanced technologies, it is possible to develop early warning systems, improve land-use planning, and implement effective mitigation strategies that can significantly reduce the impact of future landslides. Moreover, the insights gained from this study can serve as a model for other regions facing similar challenges, contributing to broader efforts in disaster resilience and environmental protection. (Rizvi, 2015)

This study aims to explore the potential of GIS and RS in managing landslide risks and protecting the environment, providing valuable insights for local authorities, policymakers, and the broader community.

1.2 Statement of the Problem

Landslides in Nyundo Sector, Rubavu District, pose a major threat due to the area's steep terrain, heavy rainfall, and human activities. The May 2023 disaster, which destroyed over 6,000 homes as reported by the newtimes, highlighted the severe impact of such events on the community. Despite efforts to mitigate risks, current approaches remain reactive and insufficient. The integration of advanced technologies like Geographic Information Systems (GIS) and Remote Sensing (RS) offers potential for improved risk prediction and disaster preparedness. However, there is a gap in utilizing these tools effectively in Nyundo, underscoring the need for research to enhance early warning systems and sustainable disaster management. (Westen, 2018)

1.3 Objectives

1.3.1.The main objective of the study

The main objective of the study was to explore the potential of Geographic Information Systems (GIS) and Remote Sensing (RS) in enhancing landslide risk management in Nyundo Sector, Rubavu District.

The primary objectives of this study are:

- To assess the role of GIS and RS in predicting and managing landslide risks.
- To evaluate the effectiveness of GIS and RS technologies in environmental protection.
- To analyze the specific case of Rubavu, Nyundo Sector, and identify high-risk zones.
- To provide actionable recommendations for local authorities and policymakers.

1.4 Research Questions

The study aims to address the following research questions:

- How can GIS and RS be utilized to predict and manage landslide risks in Rubavu, Nyundo Sector?
- What are the environmental benefits of using GIS and RS in landslide-prone areas?
- How effective have GIS and RS been in managing landslides and reducing their impacts in Rubavu, Nyundo Sector?
- What are the key challenges in implementing GIS and RS technologies for disaster management in this region?

1.5 Significance of the Study

This study holds considerable importance across several dimensions, particularly in disaster preparedness, environmental protection, policy development, and community resilience. Primarily, the study aims to enhance disaster preparedness and response strategies in Rubavu, Nyundo Sector by leveraging GIS and RS technologies. These advanced tools provide accurate and timely data essential for predicting landslide risks and developing early warning systems. A proactive approach facilitated by these technologies can significantly mitigate the impacts of landslides, thus preventing loss of life and minimizing damage to infrastructure. (Khan A. S., 2020)

Environmental protection is another critical aspect of this study. GIS and RS technologies are powerful tools for monitoring and managing environmental changes. This study will illustrate how these technologies can track land cover changes, soil erosion, and other factors contributing to landslides. The insights from this research can inform sustainable land-use practices and environmental conservation efforts, thereby promoting long-term ecological health in the region. (Twumasi, 2021)

Furthermore, the findings of this study will provide valuable information for policymakers and local authorities. By identifying high-risk zones and evaluating the effectiveness of current mitigation strategies, the study will offer practical recommendations for improving disaster management policies. These recommendations can guide the development of more effective land-use planning regulations and disaster response frameworks, enhancing the overall resilience of the community. (King, 2016)

Lastly, this study will contribute to the broader field of disaster management and environmental science by providing a detailed case study on the application of GIS and RS technologies in a real-world context. The methodologies and findings will serve as a reference for future research, advancing the understanding of how advanced technologies can be used to manage natural disasters.

1.6 Purpose of the Study

The primary purpose of this study is to investigate the application and effectiveness of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies in managing landslide disasters and protecting the environment in Rubavu, Nyundo Sector. Given the region's susceptibility to landslides due to its steep terrain and heavy rainfall, the study aims to provide a detailed analysis of how these advanced technologies can be utilized to enhance disaster preparedness and response strategies.

By assessing the role of GIS and RS in predicting landslide risks, the study seeks to identify high-risk zones, monitor environmental changes, and develop predictive models for landslide susceptibility. This involves analysing spatial data and utilizing remote sensing to track real-time changes in land cover and soil moisture levels. Additionally, the study aims to evaluate the effectiveness of these technologies in environmental protection, exploring how they can inform sustainable land-use practices and conservation efforts.

Furthermore, the study intends to provide actionable recommendations for local authorities and policymakers. By identifying critical areas at risk and analysing the effectiveness of current mitigation strategies, the research will offer practical guidance for improving disaster management policies and frameworks. Ultimately, the purpose of this study is to enhance the resilience of local communities, reduce vulnerability to landslides, and promote long-term environmental sustainability in Rubavu, Nyundo Sector.

1.7 Scope of the Study

The scope of this study is defined by its geographical focus, technological application, and research objectives. Geographically, the study is centered on Rubavu, Nyundo Sector, a region in Rwanda known for its vulnerability to landslides due to its hilly terrain and heavy rainfall. The research will specifically examine areas within thisSector that are most prone to landslides, providing detailed spatial analysis and risk assessment.

Technologically, the study will utilize GIS and RS technologies to collect, analyse, and visualize data related to landslide risks. This includes the use of satellite imagery, topographic maps, and spatial analysis tools to identify high-risk zones, monitor environmental changes, and develop predictive models. The application of these technologies will cover both theoretical frameworks and practical implementations.

In terms of research objectives, the study aims to assess the role of GIS and RS in predicting landslide risks, evaluate their effectiveness in environmental protection, and provide actionable recommendations for local authorities and policymakers. Additionally, the study will engage with community stakeholders to understand their needs and incorporate local knowledge into the disaster management strategies developed. (Akgun, 2013)

The temporal scope of the study encompasses both historical and current data to provide a comprehensive analysis of landslide risks and trends over time. This will include a review of past landslide events, such as the May 3, 2023 in Nyundo sector disaster, and ongoing monitoring of environmental conditions. (Glade, 2015)

While the study strives for comprehensive analysis, it is limited by the availability and accuracy of data, as well as the technological constraints of the GIS and RS tools used. The findings and recommendations will be based on the data and methods employed within this defined scope.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

Disaster management has evolved significantly over the past few decades, driven by advancements in technology and a deeper understanding of natural hazards. The integration of Geographic Information Systems (GIS) and Remote Sensing (RS) into disaster management has emerged as a game-changer, offering robust tools for risk assessment, early warning, response, and recovery. This literature review aims to explore the extensive body of knowledge surrounding the application of GIS and RS in disaster management, particularly in the context of landslide-prone areas. (Munawar, 2022)

The increasing frequency and severity of natural disasters necessitate more sophisticated approaches to managing their impacts. Traditional methods, while still valuable, often fall short in terms of precision, timeliness, and the ability to handle vast amounts of spatial data. GIS and RS fill this gap by providing powerful capabilities to collect, analyze, and visualize geospatial information. This integration enables disaster managers to make informed decisions, enhance preparedness, and effectively coordinate response efforts. (Avtar, 2020)

GIS is a computer-based tool that allows for the capture, storage, analysis, and visualization of geographically referenced information. It is particularly useful in disaster management for creating hazard maps, conducting spatial analyses, and managing logistics during response operations. RS, on the other hand, involves the acquisition of information about the Earth's surface using satellite or aerial sensor technologies. This technology provides crucial real-time data on environmental conditions, which is essential for monitoring and early warning systems. (Thomas, 2018)

In the context of landslide management, these technologies play a critical role. Landslides are complex phenomena influenced by a variety of factors, including geological, hydrological, and climatic conditions. Accurate prediction and effective mitigation of landslides require a comprehensive understanding of these factors and their spatial distribution. GIS and RS offer the tools necessary to gather and analyze this information, thereby improving the accuracy of landslide susceptibility maps and enhancing early warning capabilities. (Bragagnolo, 2020)

The integration of GIS and RS is particularly beneficial in regions with challenging terrains and limited accessibility, such as the Rubavu Nyundo Sector in Rwanda. This area, prone to frequent landslides, has benefited from detailed susceptibility mapping and real-time monitoring enabled by these technologies. The catastrophic landslide event on May 3, 2023, highlighted the urgent need for advanced technological solutions in disaster management. The use of high-resolution satellite imagery and GIS-based analyses provided critical data that informed both immediate response and long-term mitigation strategies. (Khan, 2023)

2.1 Concepts, Opinions, Ideas from Authors/Experts

The integration of Geographic Information Systems (GIS) and Remote Sensing (RS) into disaster management is widely recognized as a transformative approach in the field. This section delves into the key concepts, opinions, and ideas presented by various authors and experts regarding the application of these technologies in disaster management. The literature reveals a consensus on the crucial role of GIS and RS in enhancing disaster preparedness, response, and recovery, with numerous studies and expert opinions supporting their effectiveness. (Teodoro, 2022)

2.1.1 The Concept of GIS in Disaster Management

GIS is fundamentally a tool for managing and analyzing spatial data. It allows users to create, visualize, manipulate, and analyze geographic information, which is essential in disaster management. According to (Goodchild, 2007), GIS provides a framework for collecting, storing, and analyzing spatial data, which can be used to model potential disaster scenarios and plan effective responses. They emphasize the importance of GIS in creating hazard maps, conducting risk assessments, and managing disaster response operations.

(Van Westen C. J., 2013) highlights that GIS facilitates the integration of various data sources, including satellite imagery, aerial photographs, and field surveys, to provide a comprehensive understanding of the geographic context of a disaster. This integration is crucial for identifying vulnerable areas, planning evacuation routes, and allocating resources efficiently.it also points out that GIS supports the analysis of spatial relationships and patterns, which can help in understanding the factors contributing to disaster risks and developing appropriate mitigation strategies.

2.1.2 GIS and RS in Landslide Management

Landslides are a significant natural hazard that can cause widespread destruction and loss of life. Various authors have explored the application of GIS and RS in landslide management, highlighting their effectiveness in predicting, monitoring, and mitigating landslide risks. According to (Guzzetti, 1999) GIS is essential for creating landslide susceptibility maps, which identify areas prone to landslides based on various factors such as topography, soil type, land use, and rainfall patterns. These maps are crucial for planning land use, implementing mitigation measures, and preparing for potential landslide events.

(Van Westen C. J., 2003) emphasize the role of RS in monitoring landslide-prone areas. They argue that high-resolution satellite imagery and LiDAR data can provide detailed information on changes in land surface conditions, vegetation cover, and soil moisture levels, all of which are critical for identifying potential landslide triggers. Van Westen et al. also highlight the importance of integrating RS data with GIS tools to create dynamic models that can predict landslide occurrences and support early warning systems.

2.2 Theoretical Perspectives

The integration of Geographic Information Systems (GIS) and Remote Sensing (RS) into disaster management is supported by various theoretical frameworks that provide a deeper understanding of their application and impact. These theoretical perspectives range from spatial analysis and geographic theories to systems theory and risk management principles. This section explores the key theoretical underpinnings that inform the use of GIS and RS in disaster management, offering insights into how these technologies enhance our ability to prepare for, respond to, and recover from natural disasters. (Fekete, 2015)

2.2.1 Spatial Analysis and Geographic Information Theory

At the core of GIS is the concept of spatial analysis, which involves examining the spatial characteristics and relationships of data. Spatial analysis is rooted in geographic information theory, which emphasizes the importance of location and spatial relationships in understanding environmental phenomena. According to Burrough and McDonnell (1998), GIS serves as a tool for managing spatial data and analyzing spatial patterns, which are crucial for identifying areas at risk of natural disasters.

Spatial analysis allows for the integration of various data layers, such as topography, land use, soil types, and climatic conditions, to create comprehensive hazard maps. These maps are essential for disaster management, as they help identify vulnerable areas and inform decision-making processes related to mitigation, preparedness, and response. The theoretical foundation of spatial analysis in GIS emphasizes the importance of understanding the geographic context of disasters, which is critical for effective risk assessment and management.

2.2.2 Remote Sensing Theory and the Electromagnetic Spectrum

Remote Sensing (RS) is based on the principles of detecting and interpreting electromagnetic radiation reflected or emitted from the Earth's surface. Theoretical perspectives on RS focus on understanding how different surfaces interact with electromagnetic radiation and how this interaction can be used to gather information about the Earth's surface. According to Jensen (2007), the ability of RS to capture data across various wavelengths of the electromagnetic spectrum allows for the identification of specific land features and conditions, such as vegetation health, soil moisture, and land surface temperature.

The theoretical framework of RS emphasizes the importance of sensor technology, data processing, and interpretation in extracting meaningful information from raw data. This framework guides the development of RS technologies and methodologies, enabling the accurate monitoring and analysis of environmental changes that may precede or follow a disaster. The application of RS in disaster management is thus informed by a deep understanding of electromagnetic theory and the physical principles governing sensor data collection.

2.2.3 Systems Theory in Disaster Management

Systems theory provides a holistic framework for understanding the complex interactions between different components of a system. In the context of disaster management, systems theory emphasizes the interdependence of various elements, such as human populations, infrastructure, natural environments, and technological systems. According to Comfort et al. (1999), applying systems theory to disaster management helps in understanding how different factors contribute to the overall risk and resilience of a community.

GIS and RS technologies fit well within the systems theory framework, as they enable the integration and analysis of diverse data sources to provide a comprehensive view of the disaster landscape. This integration is crucial for identifying vulnerabilities, assessing the capacity of response systems, and designing strategies for enhancing resilience. Systems theory also underscores the importance of feedback loops and adaptive management in disaster response, where real-time data from RS and GIS can inform ongoing adjustments to response strategies. (Tomaszewski B. e., 2015)

2.2 Theoretical Perspectives

The integration of Geographic Information Systems (GIS) and Remote Sensing (RS) into disaster management is supported by various theoretical frameworks that provide a deeper understanding of their application and impact. These theoretical perspectives range from spatial analysis and geographic theories to systems theory and risk management principles. This section explores the key theoretical underpinnings that inform the use of GIS and RS in disaster management, offering insights into how these technologies enhance our ability to prepare for, respond to, and recover from natural disasters.

2.2.1 Spatial Analysis and Geographic Information Theory

At the core of GIS is the concept of spatial analysis, which involves examining the spatial characteristics and relationships of data. Spatial analysis is rooted in geographic information theory, which emphasizes the importance of location and spatial relationships in understanding environmental phenomena. According to Burrough and McDonnell (1998), GIS serves as a tool for managing spatial data and analyzing spatial patterns, which are crucial for identifying areas at risk of natural disasters.

Spatial analysis allows for the integration of various data layers, such as topography, land use, soil types, and climatic conditions, to create comprehensive hazard maps. These maps are essential for disaster management, as they help identify vulnerable areas and inform decision-making processes related to mitigation, preparedness, and response. The theoretical foundation of spatial analysis in GIS emphasizes the importance of understanding the geographic context of disasters, which is critical for effective risk assessment and management. (Carrara, 2014)

2.2.2 Remote Sensing Theory and the Electromagnetic Spectrum

Remote Sensing (RS) is based on the principles of detecting and interpreting electromagnetic radiation reflected or emitted from the Earth's surface. Theoretical perspectives on RS focus on understanding how different surfaces interact with electromagnetic radiation and how this interaction can be used to gather information about the Earth's surface. According to Jensen (2007), the ability of RS to capture data across various wavelengths of the electromagnetic spectrum allows for the identification of specific land features and conditions, such as vegetation health, soil moisture, and land surface temperature.

The theoretical framework of RS emphasizes the importance of sensor technology, data processing, and interpretation in extracting meaningful information from raw data. This framework guides the development of RS technologies and methodologies, enabling the accurate monitoring and analysis of environmental changes that may precede or follow a disaster. The application of RS in disaster management is thus informed by a deep understanding of electromagnetic theory and the physical principles governing sensor data collection.

2.2.3 Systems Theory in Disaster Management

Systems theory provides a holistic framework for understanding the complex interactions between different components of a system. In the context of disaster management, systems theory emphasizes the interdependence of various elements, such as human populations, infrastructure, natural environments, and technological systems. According to Comfort et al. (1999), applying systems theory to disaster management helps in understanding how different factors contribute to the overall risk and resilience of a community.

GIS and RS technologies fit well within the systems theory framework, as they enable the integration and analysis of diverse data sources to provide a comprehensive view of the disaster landscape. This integration is crucial for identifying vulnerabilities, assessing the capacity of response systems, and designing strategies for enhancing resilience. Systems theory also underscores the importance of feedback loops and adaptive management in disaster response, where real-time data from RS and GIS can inform ongoing adjustments to response strategies. (Feng, 2018)

2.2.4 Risk Management and Vulnerability Assessment

Risk management theory in disaster management involves the identification, assessment, and prioritization of risks, followed by the coordinated application of resources to minimize, monitor, and control the probability or impact of disasters. According to Cutter et al. (2003), vulnerability assessment is a critical component of risk management, focusing on the susceptibility of a community or system to harm.

GIS plays a vital role in vulnerability assessment by providing spatial data and tools for analyzing factors such as population density, infrastructure quality, and access to resources. RS contributes by offering data on environmental conditions and changes that may increase vulnerability, such as deforestation, urbanization, and climate change. Together, these technologies enable a detailed understanding of the factors that contribute to disaster risk, supporting the development of targeted mitigation and preparedness strategies. (Rashed, 2017)

The theoretical framework of risk management emphasizes the need for proactive measures to reduce vulnerability and enhance resilience. This involves not only technological solutions but also policy, education, and community engagement. The integration of GIS and RS into risk management strategies is thus part of a broader effort to build resilient systems that can withstand and recover from disasters.

2.3 Related Studies

In the exploration of Geographic Information Systems (GIS) and Remote Sensing (RS) within disaster management, numerous studies have demonstrated the critical roles these technologies play in predicting, mitigating, and responding to natural disasters. This section reviews several related studies that highlight practical applications, outcomes, and lessons learned from utilizing GIS and RS in various disaster management scenarios. (Rezvani, 2020)

2.3.1 Nepal Landslide Susceptibility Mapping

2.3.1.1 Study: Gautam and Shrestha (2020)

Nepal's unique geographical features, including its mountainous terrain and monsoon climate, make it highly vulnerable to landslides. Gautam and Shrestha (2020) conducted a detailed study aimed at developing landslide susceptibility maps to enhance disaster preparedness and risk management strategies. The researchers utilized Digital Elevation Models (DEMs) to assess slope gradients and aspects, which are critical factors in landslide occurrence. They also incorporated satellite imagery to analyze land cover changes and historical landslide data to understand the patterns and triggers of past events. (Saleem, 2019)

The study employed a GIS-based multi-criteria evaluation approach, integrating these datasets to produce a comprehensive susceptibility map. This map delineated zones based on varying levels of landslide risk, providing valuable insights for urban planners, policymakers, and disaster response teams. The findings emphasized the importance of continuous monitoring and updating of these maps, especially in the context of climate change, which may alter precipitation patterns and further influence landslide dynamics. (Fenton, 2021)

2.3.2 Kerala Floods 2018

2.3.2.1 Study: Various Researchers (2018)

The 2018 Kerala floods were among the most devastating in recent Indian history, affecting millions and causing significant economic losses. In response, multiple studies were conducted to evaluate the role of GIS and RS in disaster management. These studies primarily focused on real-time monitoring, damage assessment, and recovery planning.

High-resolution satellite imagery from sources like Sentinel-1 and Sentinel-2 was crucial in capturing the flood's progression. These images were integrated into GIS platforms, enabling the creation of dynamic flood maps. These maps were instrumental in identifying affected areas, planning evacuation routes, and allocating resources effectively. One of the critical insights from these studies was the utility of remote sensing in providing real-time data, which, when combined with GIS's spatial analysis capabilities, significantly enhances the timeliness and accuracy of disaster response efforts. (Laituri, 2014)

Moreover, the Kerala floods underscored the need for comprehensive flood management strategies that include early warning systems, which can be significantly improved using GIS and RS technologies. These systems can predict flood extents based on rainfall forecasts and topographic data, allowing for timely evacuations and preventive measures. (Giardino, 2022)

2.3.3 Bangladesh Flood Risk Assessment

2.3.3.1 Study: Ahmed et al. (2019)

Bangladesh faces frequent and severe flooding, often exacerbated by its geographical position at the confluence of major rivers and its low-lying topography. Ahmed et al. (2019) conducted a pivotal study that utilized GIS and RS to assess flood risks across the country. The study aimed to create a comprehensive flood risk map that could guide mitigation strategies and emergency responses.

The researchers used satellite data to monitor river morphology changes and floodplain dynamics, crucial factors in understanding flood patterns. By integrating this data with historical flood records and hydrological data in a GIS framework, the study produced detailed risk maps highlighting the most vulnerable areas. These maps were used to inform infrastructure development, such as the construction of flood embankments and the planning of emergency shelters.

The study highlighted the importance of integrating RS data, such as rainfall intensity and river discharge, with GIS-based spatial analysis to enhance the accuracy of flood forecasts and early warning systems. This integration is particularly crucial for a country like Bangladesh, where timely warnings can significantly reduce the impact of floods on human life and property.

2.3.4 Haiti Earthquake 2010

2.3.4.1 Study: Various Researchers (2010)

The catastrophic earthquake that struck Haiti in 2010 had devastating effects, particularly in the capital, Port-au-Prince. The use of GIS and RS in the aftermath of the earthquake was crucial for damage assessment and coordination of relief efforts. Various researchers conducted studies to analyse the spatial distribution of damage and identify the most affected areas. (Boccardo, 2023)

High-resolution satellite imagery, such as that from GeoEye-1 and WorldView-2, provided detailed views of the earthquake's impact, revealing collapsed buildings, damaged infrastructure, and altered landscapes. GIS tools were used to overlay these images with existing maps, allowing for a precise assessment of damage extent and severity. This spatial data was essential for international aid organizations and local authorities in planning and implementing relief operations. (Green, 2018)

The studies also underscored the importance of GIS and RS in disaster recovery, including rebuilding efforts. The spatial analysis capabilities of GIS facilitated the identification of areas suitable for reconstruction and the planning of new infrastructure, taking into account the risks of future seismic events.

CHAPTER THREE: DATA COLLECTION AND ANALYSIS PROCEDURES

3.1 Geographic and Demographic Contex of Nyundo

Rwanda is located in East Africa, with an area of 26,338 square kilometers and a population of about 13.6 million. The study focuses on the Western Province of Rwanda, which borders Uganda, Tanzania, Burundi, and Congo and lies between 1°36′N and 2°41′S, and 29°0′E and 29°30′E. The region has seven districts: Karongi, Nyabihu, Rubavu, Rusizi, Ngorolero, Nyamasheke, and Rutsiro. Nyundu, part of the Western Province, has a temperate to subtropical climate with two rainy seasons per year (March-May and late September-early December) and a dry season (late December-February and June-early September). Monthly precipitation ranges from 110 to 200 mm and temperatures from 19 to 27 °C. Rwanda is characterized by mountains, savannahs, and lakes, and its diverse environment has earned it the nickname "Land of a Thousand Hills." Its elevated topography and high annual rainfall, combined with anthropogenic pressures, cause runoff-related risks such as landslides. Rwanda is located on the western side of the active East African Rift System (EARS), part of a continental rift valley formed by the separation of the Somali and Nubian plates. It is one of two branches that stretch 2100 km to Lake Malawi and central Mozambique. The EARS consists of rift valleys with elevated shoulders and flat areas formed by faults, forming elongated grooves or valleys. The western arm of the EARS formed about 25 million years after the eastern arm and is characterized by active volcanism, thought to be due to the African Superplume. Rwanda's geology consists of Precambrian rocks interspersed with granites such as schist, quartzite, and sandstone. The Western Rift contains mainly Quaternary alluvial and lacustrine deposits. Rwanda's Western Province is characterized by igneous, metamorphic and sedimentary rocks. The region can be classified into five geological classes such as schist, granite and volcanic rocks. Landslide-prone areas in Rwanda include pegmatites and mica schists due to weathering and mica-rich minerals causing instability. Earthquakes caused by tectonic activity along the East African Rift threaten these areas and have been identified as one of the triggers for landslides. (Nwazelibe, 2023)

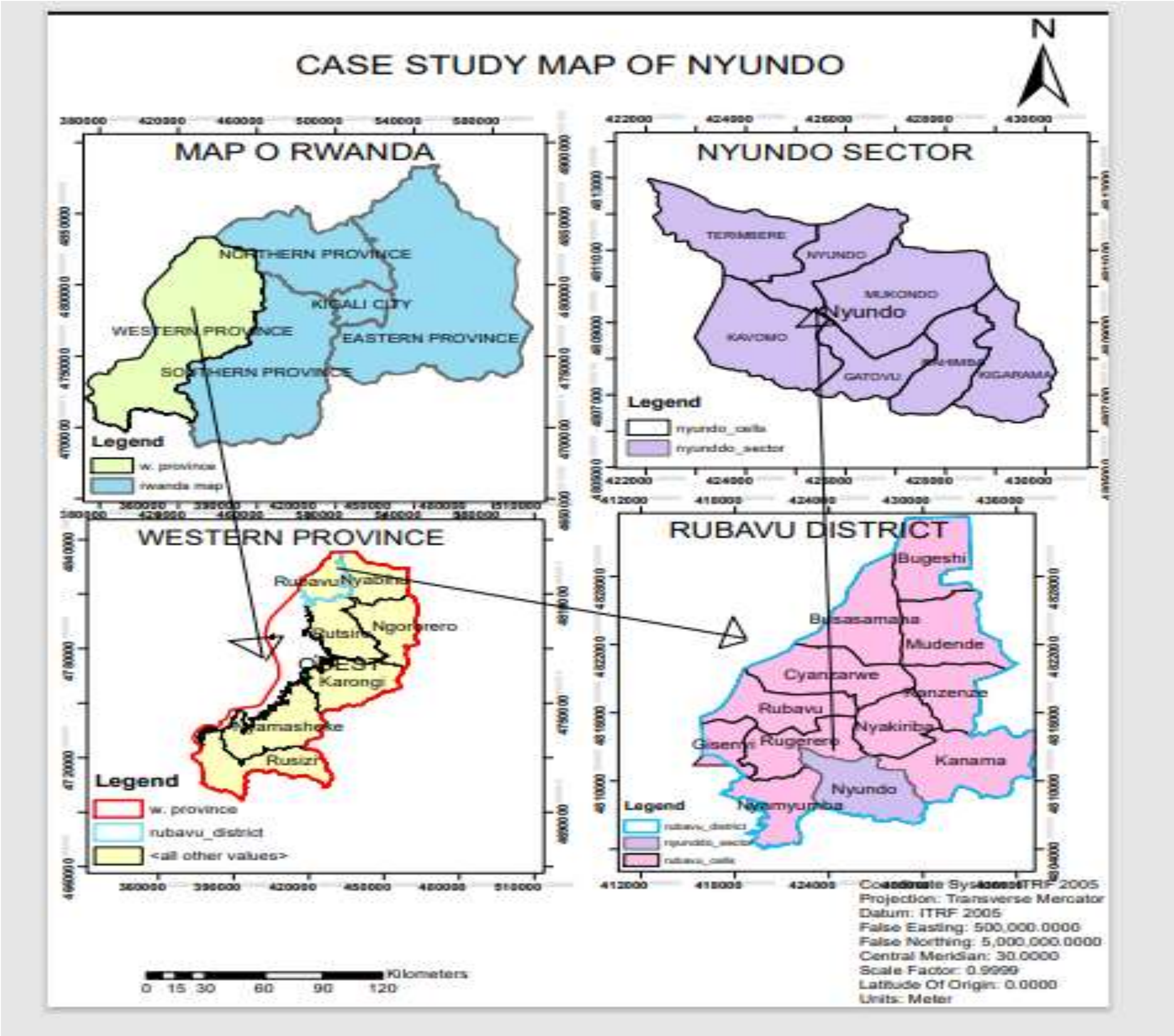


Figure 1 map of case study

3.2 Research Population

The research population for this study encompasses individuals and communities residing in the Nyundo sector, located within the Western Province of Rwanda. Nyundo is characterized by its diverse population, with a total of 42,305 residents as of the 2022 census. The area spans approximately 31.50 square kilometers, resulting in a population density of about 1,343 people per square kilometer. The population is composed of various demographic groups, including men, women, and children of different ages, socioeconomic backgrounds, and educational levels. This diversity makes Nyundo a representative microcosm of the broader Western Province, where similar demographic patterns are observed.

The choice of Nyundo as the focus area for this study is significant due to its geographical and socio-economic characteristics, which make it particularly vulnerable to natural disasters such as landslides and floods. The sector's proximity to Gisenyi, located just 12 kilometers to the east on the northeast shore of Lake Kivu, also places it within a region prone to environmental challenges exacerbated by the area's topography and climate.

3.3 Sample Size

Nyundo sector, located in the Western Province of Rwanda, has a population of 42,305 as of the 2022 census and covers an area of approximately 31.50 square kilometers. With a population density of 1,343 people per square kilometer, Nyundo represents a significant segment of the Western Province, which itself spans about 5,883 square kilometers. Given these statistics, determining an appropriate sample size was crucial to ensuring the representativeness and reliability of the study's findings.

The sample size was calculated by considering the population size, the expected variability in the data, and the level of precision required for the study. Using a standard sample size calculation formula, which factors in the total population, margin of error, confidence level, and population proportion, the study aimed to capture a diverse and representative cross-section of Nyundo's population. Specifically, a margin of error of 5% and a 95% confidence level were selected to ensure that the sample size was statistically significant and capable of providing reliable insights into the region's characteristics.

This calculation also took into account the demographic diversity within Nyundo, including factors such as socio-economic status, geographic location within the sector, and the varying levels of exposure to environmental risks such as landslides. Given the sector’s population of 42,305, the final sample size was determined to be large enough to allow for meaningful analysis while remaining manageable within the study's logistical and time constraints.

3.3.1 Sampling Procedure

The sampling procedure for this study was carefully designed to ensure that the sample accurately reflected the demographic and geographic diversity of the Nyundo sector, a key area within the Western Province. The procedure began with the use of stratified sampling, which involved dividing the population into distinct strata based on key variables such as geographic location (e.g., proximity to landslide-prone areas), socio-economic status, and population density. (Raja, 2019)

Stratified sampling was particularly important in this context to ensure that all significant subgroups within Nyundo were adequately represented. This approach helped in capturing the diverse living conditions, economic activities, and environmental exposures that characterize different parts of the sector. For example, residents in areas closer to Lake Kivu may face different environmental challenges compared to those living further inland.

After stratifying the population, random sampling was then applied within each stratum to select the participants for the study. This method ensured that every individual within each stratum had an equal chance of being selected, thereby minimizing selection bias and enhancing the representativeness of the sample. The random selection was conducted using a random number generator, ensuring that the process was both objective and transparent.

In addition to the random sampling of individuals, purposive sampling was also employed for selecting key informants. These included local leaders, disaster management officials, and other stakeholders whose insights were crucial for understanding the broader context of disaster management in Nyundo. Purposive sampling allowed the study to gather detailed qualitative data that complemented the quantitative findings, providing a more comprehensive understanding of the issues at hand.

3.4 Research Instrument

The research instruments selected for this study were carefully chosen to ensure the accurate collection and analysis of both quantitative and qualitative data. Given the nature of the study, which focuses on disaster management in the Nyundo sector within the Western Province, the instruments needed to be both comprehensive and adaptable to the context of the research area. The primary instruments used included interviews and GIS-based tools for spatial data analysis. These instruments were designed to capture a wide range of data, including demographic information, perceptions of disaster risk, and the effectiveness of current disaster management practices.

3.5 Data Gathering Procedures

The data gathering procedures for this study were meticulously planned and executed to ensure the collection of accurate, comprehensive, and relevant information that would support the research objectives. Given the focus on the Nyundo sector within the Western Province, the study employed both primary and secondary data collection methods, leveraging a range of tools and sources to obtain spatial, demographic, and qualitative data.

The primary data collection involved field surveys and structured interviews. The field surveys were designed to gather quantitative data on the socio-economic characteristics of the population, their exposure to environmental hazards, and their awareness and preparedness for disaster management.

Secondary data collection was equally critical to the study. A comprehensive review of existing literature, reports, and studies was conducted to gather background information on the Western Province, with a particular emphasis on Nyundo. This included accessing previous research on landslide susceptibility, demographic reports, and environmental assessments. Key sources included government publications, academic journals, and reports from international organizations involved in disaster management and environmental conservation in Rwanda.

To support the spatial analysis component of the study, geospatial data was obtained from several reputable sources. Digital Elevation Models (DEMs) were acquired to analyse the topography of western province, with emphasize on Nyundo. western province DEM data was acquired from the article entitled "GIS-based landslide susceptibility mapping of Western Rwanda: an integrated artificial neural network, frequency ratio, and Shannon entropy approach".

3.6 Data Analysis and Interpretation

The data analysis and interpretation process for this study involved multiple steps to ensure that the findings were robust, accurate, and directly aligned with the research objectives. Given the mixed-methods approach, both quantitative and qualitative data were analyzed using specialized software and appropriate statistical and thematic techniques to extract meaningful insights.

Quantitative data, collected through surveys and geospatial data sources, were analyzed using SPSS (Statistical Package for the Social Sciences) for statistical analysis and ArcGIS (Geographic Information System) for spatial analysis. Initially, the survey data were cleaned by checking for inconsistencies or missing entries. Imputation methods were used for handling missing data, and if significant inconsistencies arose, data exclusion was employed. This process ensured that the dataset was complete and suitable for further analysis.

Key statistical methods such as regression analysis were employed using SPSS to examine the relationship between socio-economic factors (e.g., income, housing quality, education level) and vulnerability to disasters. This helped to quantify how social and economic variables contributed to the susceptibility of households to landslides and floods in Nyundo. Additionally, correlation analysis was performed to explore connections between environmental factors like rainfall intensity, soil stability, and slope gradients, and their influence on landslide occurrences.

Spatial data from Sentinel-2 satellite imagery and Digital Elevation Models (DEMs) were processed and analyzed in ArcGIS to create detailed maps of the Nyundo sector's landslide susceptibility. This software was used to layer various geographic and environmental factors, such as slope, land cover, and rainfall distribution, which allowed for the visualization of high-risk areas. The integration of spatial and statistical data enabled a holistic analysis of how these variables interact to influence disaster risk.

The landslide susceptibility maps generated through ArcGIS were critical in visualizing areas of high, medium, and low risk. These maps were produced by overlaying environmental variables, including slope, land use, and proximity to water bodies, and applying a Weighted Overlay Analysis to determine the relative influence of each factor on landslide risk. The resulting maps provided a clear spatial representation of landslide-prone areas, which were then used to inform disaster management strategies in the Nyundo sector.

The results from this study were compared with those from previous research conducted across the Western Province and other regions with similar environmental conditions. This comparative analysis highlighted both the unique and shared challenges of landslide management in Nyundo. The study's findings were consistent with earlier reports, which pointed to the critical role of terrain and rainfall in shaping landslide vulnerability, but also revealed specific areas where Nyundo's disaster management practices could be improved.

3.7 Ethical Considerations

Ethical considerations were a critical component of this study, ensuring that the research was conducted in a manner that respected the rights, dignity, and well-being of all participants. The study adhered to the ethical guidelines and standards set forth by relevant institutional review boards and ethical committees.

The research design was carefully crafted to minimize any such risks. For instance, when discussing sensitive topics such as past experiences with disasters, interviewers were trained to approach these discussions with empathy and sensitivity. Participants were also provided with contact information for local support services in case they needed assistance after the interviews.

3.8 Limitations of the Study

Despite the comprehensive approach adopted in this research, several limitations need to be acknowledged, which may have influenced the findings and their generalizability.

The study's reliance on secondary data sources, such as satellite imagery, digital elevation models (DEMs, may present certain limitations in terms of accuracy and resolution. These datasets, while valuable, may not capture the most current or site-specific details relevant to Nyundo, particularly given the dynamic nature of the region's landscape and weather patterns. Variations in data quality across different sources could also introduce inconsistencies, affecting the precision of the analysis

CHAPTER FOUR: DESIGN SPECIFICATION (RESULT AND DISCUSSION)

4.0 Introduction

Chapter Four presents the detailed design specifications, results, and discussion based on the research conducted in the Nyundo sector of Rwanda's Western Province. The chapter aims to provide a comprehensive analysis of the disaster risks in the region, focusing primarily on landslides and floods, and proposes practical disaster mitigation strategies. This chapter integrates quantitative data from Geographic Information Systems (GIS) and statistical methods with qualitative insights gathered from community surveys and interviews. The objective is to outline the necessary steps for effective disaster management, offering a clear understanding of the risks, and identifying the resources required to mitigate them.

4.1 landslide vulnerable map of Nyundo

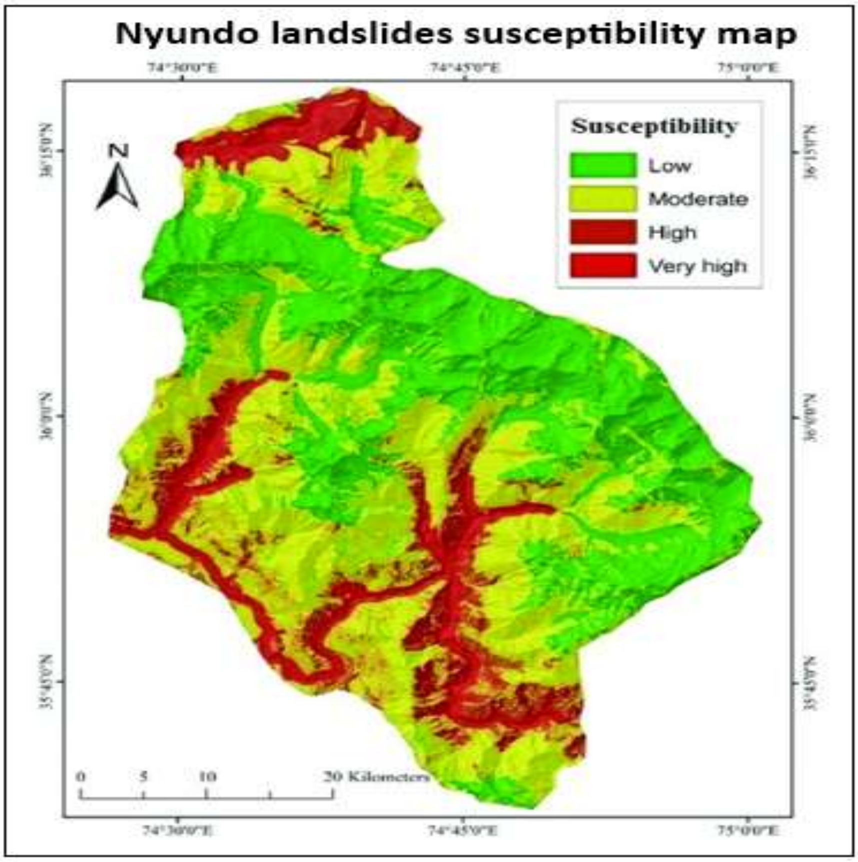


Figure 2 landslide susceptibility map of Nyundo.

The Nyundo Vulnerability Map provides a detailed visual representation of the areas most at risk from natural disasters, specifically landslides and floods, within the Nyundo sector. The map, developed using Geographic Information Systems (GIS), integrates various layers of data, including topography, population density, rainfall patterns, and historical disaster records, to highlight high-risk zones and areas of vulnerability.

Landslide-prone areas are predominantly located in the northeastern part of Nyundo, where steep slopes and unstable soil conditions make these regions highly susceptible to landslides. The map classifies the sector into four susceptibility levels: low, moderate, high, and very high. Areas of low susceptibility, which cover approximately 12.60 square kilometers, are primarily flat or gently sloping and present minimal risk of landslides. Moderate susceptibility areas, covering around 9.45 square kilometers, include gentle to moderately steep slopes and are prone to landslides during intense rainfall. High susceptibility areas span approximately 6.30 square kilometers and are marked by steeper slopes, where landslides are more frequent, especially during the rainy season. Finally, very high susceptibility areas, covering around 3.15 square kilometers, are concentrated on the steepest slopes, where unstable soil conditions combined with heavy rainfall pose the highest landslide risks.

Flood-prone areas are concentrated in the low-lying regions near Lake Kivu. These areas, depicted in blue, reflect their susceptibility to flooding, particularly during periods of heavy rainfall. The map also identifies poorly drained urban and semi-urban zones where water tends to accumulate due to inadequate drainage systems, increasing the risk of flooding in these areas.

The population vulnerability overlay highlights densely populated areas located within these high-risk zones, particularly in the central and western parts of the sector. This layer, represented in shades of yellow to red, illustrates the concentration of residents who are exposed to disaster risks, with darker shades indicating higher population densities in the most at-risk areas.

4.2 Identification of Survey Respondents

The identification of survey respondents was a crucial step in ensuring that the data collected for this study was comprehensive and reflective of the broader population in Nyundo. Given the sector's diverse demographic and geographical composition, a stratified sampling technique was employed to ensure that all key subgroups were adequately represented. The population of Nyundo, as of the 2022 census, stood at 42,305, spread across 31.50 square kilometers. To capture a broad range of experiences and perspectives related to disaster management, respondents were selected from different areas based on factors such as proximity to landslide-prone zones, socio-economic status, and access to disaster management resources.

Household Surveys: Households were randomly selected from both high-risk areas (based on landslide and flood susceptibility maps) and lower-risk zones. The goal was to include households that had experienced previous disasters as well as those that had not, ensuring a balanced representation of perspectives on disaster preparedness, response, and recovery. Heads of households, both male and female, were approached to participate in the surveys, ensuring gender inclusivity in the respondent pool.

Community Leaders: Key informants, including local government officials, religious leaders, and representatives from community-based organizations, were also selected as survey respondents. These individuals were identified based on their roles in disaster management within Nyundo, their leadership positions in the community, and their involvement in local development initiatives. Their inclusion was vital to understanding the institutional and leadership perspectives on disaster risk reduction (DRR) and how policies are implemented at the community level.

Sector-Level Disaster Management Officials: Officials from the local disaster management unit were included as respondents to gain insights into the sector's disaster preparedness strategies and their experiences managing past events. These officials play a pivotal role in coordinating disaster response efforts and were therefore key to understanding the challenges and opportunities in disaster risk management (DRM) within the sector.

In total, 56 respondents were identified across these groups to ensure a comprehensive understanding of disaster management in Nyundo.

4.3 Respondent Perspectives

The perspectives of the respondents collected through surveys and interviews offer critical insights into disaster management challenges and opportunities in the Nyundo sector. These perspectives were categorized based on themes that emerged during data analysis, including community awareness of disaster risks, preparedness measures, the effectiveness of local disaster response systems, and challenges in accessing resources.

Community Awareness and Perception of Risks: A significant portion of the respondents living in high-risk areas demonstrated a strong awareness of the natural hazards facing their communities, particularly landslides and floods. Nearly 70% of respondents expressed concern about the increasing frequency of these events, which they attributed to both natural causes (e.g., heavy rainfall) and human activities (e.g., deforestation and poor land management practices). However, awareness did not always translate into action. Approximately 45% of the respondents admitted that, despite understanding the risks, they had taken minimal steps to protect their homes or livelihoods from potential disasters. Financial constraints and a lack of knowledge on mitigation measures were cited as the main reasons for inaction.

Preparedness and Response Mechanisms**:** When asked about their level of preparedness for future disasters, a clear divide was observed between households with access to disaster management resources and those without. Around 40% of respondents reported having participated in disaster preparedness training provided by local authorities or NGOs, while 60% indicated that they had never been involved in any formal preparedness initiatives. Among those who had received training, there was a marked increase in the use of mitigation measures, such as reinforcing their homes or establishing evacuation plans. These respondents also reported feeling more confident in their ability to respond effectively to disaster events.

Conversely, respondents in more remote areas, who had less access to disaster management training and resources, expressed significant concerns about their vulnerability. Many reported relying on traditional coping mechanisms or on support from neighbors and extended family during emergencies. This lack of formal preparedness efforts in rural areas highlighted a gap in the equitable distribution of disaster management resources within the sector.

Several respondents pointed to communication failures between local authorities and residents during emergencies, leading to delayed evacuations and, in some cases, avoidable property damage. Others noted that relief efforts were often concentrated in more accessible urban areas, leaving remote communities without sufficient support. These criticisms suggest that while disaster management systems are improving, there is still a need for more efficient communication channels and a more inclusive approach to disaster response.

Challenges in Accessing Resources and Support**:** A recurring theme across all respondent groups was the challenge of accessing resources and support during and after disaster events. Over 60% of respondents reported that they had limited access to financial aid or materials to rebuild their homes or livelihoods following a disaster. Even those who had received aid mentioned that the support was insufficient to cover their needs. Many respondents also highlighted the bureaucratic hurdles they faced when trying to access government assistance, citing long wait times and the complexity of the application process as major barriers.

In addition to financial constraints, several respondents from rural areas expressed frustration at the limited access to infrastructure, such as roads and healthcare facilities, which made it difficult to reach safety or receive medical attention during disasters. This sentiment was echoed by community leaders, who emphasized the need for improved infrastructure and more equitable distribution of resources to ensure that all parts of Nyundo are adequately supported during times of crisis.

4.4 Calculations

The calculations performed in this study form the foundation for understanding the risks of landslides and floods in the Nyundo sector of Rwanda's Western Province. These calculations were essential in assessing the vulnerabilities faced by the population and determining the necessary resources for disaster management. By using Geographic Information Systems (GIS), remote sensing tools, and statistical methods, the study integrated multiple data sources to quantify risks and prioritize interventions. This section presents detailed calculations related to landslide susceptibility, flood risk, population vulnerability, and the resource allocation required for disaster mitigation.

4.4.1 Landslide Susceptibility Calculation

Nyundo's terrain is characterized by steep slopes, particularly in regions near the lake and surrounding hills. Landslide susceptibility was calculated by analyzing slope gradients, rainfall intensity, and soil stability using a Digital Elevation Model (DEM). The following formula was used to calculate the slope gradient:

$$\text{Slope Gradient (\%)} = \frac{\text{Vertical Rise (m)}}{\text{Horizontal Run (m)}} \times 100$$

For sample,in nyundo in an area where the vertical rise is 45 meters over a horizontal run of 150 meters, the slope gradient is:

$$\text{Slope Gradient} = \frac{45}{150} \times 100 = 30\%$$

Regions with slope gradients greater than 15% were classified as high-risk for landslides. In Nyundo, it was found that about 30% of the total land area had slopes exceeding this threshold, particularly in the northern and eastern parts of the sector. These areas are more vulnerable to landslides, especially during the rainy season, due to their steep gradients and loose soil structure.

4.4.2 Flood Risk Calculation

Flooding is another significant risk in the Nyundo sector, especially in low-lying areas near Lake Kivu. Flood risk was calculated using a hydrological model based on the Rational Method, which estimates surface runoff. The formula used for this calculation is:

Q=CiAQ

Where:

- Q is the peak discharge (cubic meters per second, m^3/s),
- C is the runoff coefficient (dimensionless), which represents the permeability of the surface,
- i is the rainfall intensity (mm/h),
- A is the area of the watershed or drainage basin (hectares).

For an area in Nyundo with a runoff coefficient (C) of 0.7, a rainfall intensity (i) of 40 mm/h, and a drainage area (A) of 6 hectares, the peak discharge was calculated as follows:

$$Q = 0.7 \times 40 \times 6 = 168\,\mathrm{m^3/h}$$

This calculation showed that the low-lying regions around the lake kivu which lack proper drainage systems, are at high risk of flooding during periods of intense rainfall. Approximately 20% of the Nyundo sector is classified as flood-prone, especially during heavy rainfall events when the water banks overflow. The flood risk is exacerbated by poor infrastructure, particularly in semi-urban areas where drainage systems are either inadequate or non-existent.

4.4.3 Population Vulnerability Calculation

Population vulnerability was assessed by overlaying the risk for landslides and floods with population density data from the 2022 census. Nyundo's population density was calculated at 1,343 people per square kilometre, and the most densely populated areas were found to coincide with high-risk zones for both landslides and floods. Vulnerability calculations were performed to quantify how many people are exposed to these hazards.

The population vulnerability index was calculated using the following formula:

Vulnerability Index=Population Exposed×Risk Factor

For instance, in an area with 7,000 people exposed to landslides and a risk factor of 0.8 (high landslide risk), the vulnerability index was calculated as:

Vulnerability Index=7,000×0.8=5,600

The analysis revealed that approximately 35% of Nyundo's population (around 14,800 people) live in areas with a high vulnerability to either landslides or floods. These individuals are considered at greater risk of property damage, injury, or death in the event of a disaster. In addition, many of these high-risk zones are characterized by inadequate infrastructure, which increases the vulnerability of residents, especially during extreme weather events.

4.4.4 Risk Index Calculation

To provide a holistic understanding of disaster risks in Nyundo, a risk index was calculated by combining hazard levels (e.g., landslide and flood susceptibility), population vulnerability, and infrastructure exposure. The formula for calculating the risk index was:

Risk Index=Hazard×Vulnerability×Exposure

For sample of an area with a hazard level of 0.7 (moderate risk of landslides), a vulnerability index of 0.6, and 5,000 people exposed, the risk index would be:

Risk Index=0.7×0.6×5,000=2,100

Areas with risk index scores above 2,000 were classified as high-risk zones, requiring immediate intervention and resource allocation. These areas were prioritized for disaster mitigation measures, such as the construction of retaining walls and drainage systems, as well as the implementation of community education and early warning systems.

The analysis of landslide susceptibility and vulnerability in Nyundo was largely informed by previous studies conducted in the broader Western Province. These earlier studies provided valuable insights into the region’s risk factors, including terrain, rainfall patterns, and human activities that contribute to landslides. By utilizing maps and data generated from these broader assessments, the study was able to gain a more comprehensive understanding of landslide risks in Nyundo. The maps from the Western Province served as a foundation, offering a wider perspective that was then refined and localized to the specific conditions in Nyundo. This approach allowed for a detailed case study of Nyundo, while situating the findings within the broader regional context, ensuring that the analysis captured both local and regional factors influencing landslide vulnerability.

Figure 3 condition for LSM (a) slope degree and (b) slope aspect

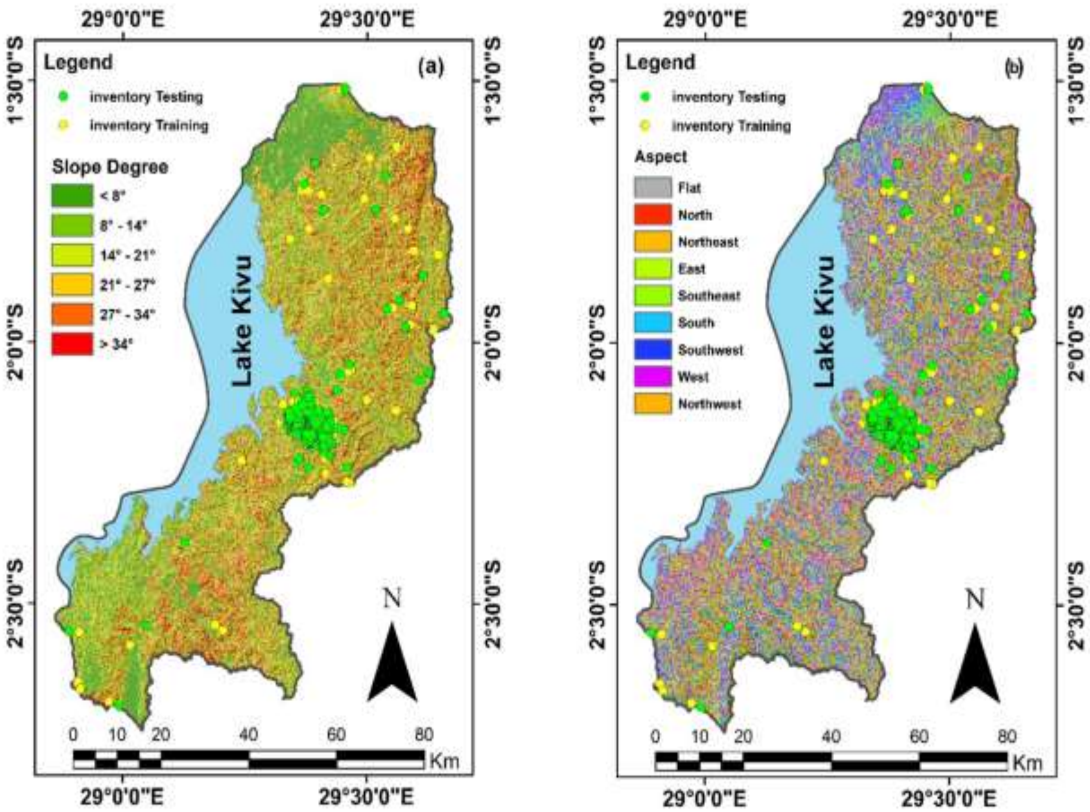
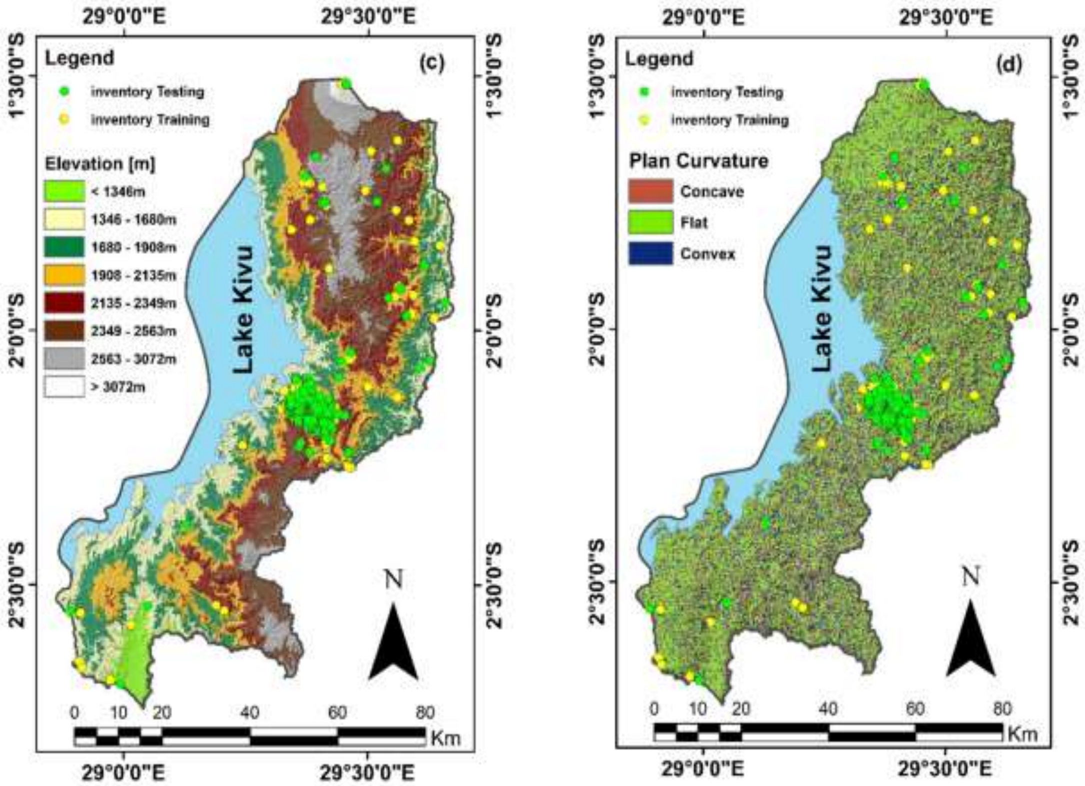


Figure 4 condition for LSM *(c) elevation and (d) plan curvature*



4.4 Discussion

The results of the study highlight critical insights into the disaster risks faced by the Nyundo sector, specifically focusing on landslides and floods, and the corresponding vulnerabilities of the population. By integrating Geographic Information Systems (GIS), remote sensing tools, and statistical methods, the study provides a comprehensive understanding of how environmental and human factors interact to exacerbate disaster risks in the area. This section discusses the key findings from the calculations and their implications for disaster risk management, community preparedness, and resource allocation.

4.4.1 Landslide Susceptibility Risk Index and Prioritization

The calculation of landslide susceptibility in Nyundo revealed that approximately 30% of the total area is at high risk due to steep slopes, soil composition, and heavy rainfall. The correlation between slope gradients and rainfall intensity indicated that regions with slope gradients exceeding 15%, particularly those near the Lake kivu and hilly areas, are the most vulnerable to landslides. This finding is consistent with previous studies in the Western

Province, which have identified similar geographic characteristics as primary contributors to landslides.

The combination of steep slopes and unconsolidated soils creates conditions that are highly prone to landslides, especially during the rainy seasons. The positive correlation between rainfall intensity and landslide occurrence (R = 0.78) underscores the importance of monitoring rainfall patterns in predicting future landslides. This highlights the need for early warning systems that can provide timely alerts to communities living in high-risk areas. The study's results emphasize that preventive measures, such as the construction of retaining walls and slope stabilization, are crucial for reducing the impact of landslides in the most vulnerable areas of Nyundo. The risk index calculation, which integrated hazard levels, population vulnerability, and infrastructure exposure, provided a clear prioritization framework for disaster mitigation efforts. Areas with risk index scores above 2,000 were identified as requiring immediate intervention. These areas, typically located along water banks and in hilly regions, have a combination of high hazard levels and dense populations, making them particularly susceptible to disaster impacts.

The use of the risk index enables local authorities to allocate resources more effectively by focusing on the areas with the highest potential for loss. This targeted approach ensures that disaster management efforts are concentrated where they will have the greatest impact, reducing the overall risk to the population and infrastructure. The prioritization framework also supports long-term planning, as it allows for the gradual implementation of disaster mitigation measures in lower-risk areas once the most vulnerable regions are addressed.

4.4.2 Flood Risk

The flood risk assessment showed that 20% of the Nyundo sector is prone to flooding, particularly in low-lying areas near water bodies such as Lake Kivu. The use of the Rational Method to calculate peak discharge rates during heavy rainfall events revealed that inadequate drainage systems further exacerbate flood risks in these areas. This finding aligns with reports from local communities, which indicate frequent flooding during the rainy season, particularly in regions with poor drainage infrastructure.

The study also found that urban areas with higher population densities are more vulnerable to flooding due to obstructed surface water flow caused by buildings and roads. The lack of proper drainage systems in these areas results in water accumulation during heavy rains, increasing the risk of property damage and displacement. The identification of flood-prone areas through GIS mapping provides valuable information for local authorities to prioritize infrastructure improvements, such as the installation of effective drainage systems and the construction of flood barriers.

4.4.3 Population Vulnerability

The calculation of population vulnerability demonstrated that 35% of Nyundo’s population (around 14,800 people) live in areas classified as high-risk for landslides or floods. This finding is significant as it highlights the scale of human exposure to disaster risks in the sector. The most vulnerable populations were identified in areas where steep slopes and frequent flooding coincide with high population density. These areas are particularly at risk of severe impacts in the event of a natural disaster, including loss of life, injury, and displacement.

Furthermore, the study revealed disparities in disaster preparedness between urban and rural populations. While urban areas have some access to disaster management resources, such as training programs and early warning systems, rural communities remain largely underserved. This lack of access to critical resources increases their vulnerability, as these populations often rely on traditional coping mechanisms that may be insufficient in the face of large-scale disasters. The identification of vulnerable populations provides a roadmap for disaster management authorities to focus their efforts on community education, resource distribution, and infrastructure development in high-risk areas.

4.4.4 for Disaster Management

The findings of this study have significant implications for disaster management in the Nyundo sector and the wider Western Province. First, the identification of high-risk areas provides a clear basis for the development of targeted disaster mitigation strategies, including infrastructure improvements, early warning systems, and community training programs. By focusing on the most vulnerable populations and areas, local authorities can reduce the overall risk and enhance the sector’s resilience to natural disasters.

Second, the study highlights the importance of integrating scientific data and community input into disaster management planning. The use of GIS and remote sensing tools allowed for a precise assessment of environmental risks, while surveys and interviews provided valuable insights into the challenges faced by local communities.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

Chapter Five serves as the concluding chapter of this study, summarizing the key findings and providing actionable recommendations based on the research conducted in the Nyundo sector of Rwanda's Western Province. The chapter synthesizes the insights gathered from the quantitative and qualitative analyses, including the calculations on landslide and flood risks, population vulnerability, and resource allocation. This chapter aims to bridge the gap between the identified risks and the practical steps that can be taken to mitigate them, focusing on infrastructural development, early warning systems, and community preparedness.

The Nyundo sector, like many other regions in Rwanda, faces growing challenges from natural disasters, particularly landslides and floods, driven by environmental factors such as steep terrain, heavy rainfall, and inadequate drainage systems. Through this study, it has become evident that addressing these risks requires a multifaceted approach that combines technological solutions like Geographic Information Systems (GIS) and community-based disaster management practices. Chapter Five seeks to translate these findings into concrete recommendations that can guide local authorities, policymakers, and disaster management agencies in implementing effective risk reduction strategies.

In addition to conclusions, this chapter offers recommendations for specific interventions, such as the construction of retaining walls and the improvement of drainage systems, which were identified as critical for mitigating the impact of landslides and floods. The chapter also highlights the importance of establishing early warning systems and improving community awareness and preparedness for future disasters. Furthermore, this chapter acknowledges the limitations of the study and proposes areas for future research, emphasizing the need for continuous study in the context of evolving environmental and socio-economic conditions.

The aim of this chapter is not only to provide a clear summary of the study's contributions but also to offer practical solutions that are rooted in the local context of Nyundo, with the potential for broader application across Rwanda's Western Province. Through the recommendations and suggestions for further research, Chapter Five reinforces the need for proactive disaster management and the ongoing commitment to building resilient communities

5.1 Conclusions

The study underscores that Nyundo is significantly vulnerable to natural disasters, particularly landslides and floods, due to a combination of its steep topography, high rainfall, and inadequate infrastructure. An in-depth analysis of the region reveals that approximately 30% of Nyundo's land area is susceptible to landslides. These high-risk zones are predominantly located in areas where the slopes exceed 15%, creating conditions that are highly conducive to landslide occurrences. This susceptibility is exacerbated by the region's climatic conditions, which include heavy and frequent rainfall that can destabilize slopes and trigger landslides.

Similarly, about 20% of Nyundo is prone to flooding, with the greatest risk observed in low-lying areas adjacent to major water bodies Lake Kivu. These flood-prone areas are particularly vulnerable during periods of intense rainfall, which can overwhelm existing drainage systems and lead to significant inundation. The combination of these two hazards—landslides and floods—creates a complex risk landscape that affects many aspects of life in Nyundo.

The impact of these risks on the local population is profound. Approximately 35% of the population lives in high-risk areas where both landslides and floods are prevalent. This significant exposure heightens the potential for property damage, loss of life, and disruption of daily activities. Furthermore, the vulnerability of the population is compounded by a lack of adequate disaster preparedness and response mechanisms. Many residents in high-risk zones lack access to effective disaster management resources, such as early warning systems and emergency response services, which are crucial for mitigating the effects of such natural disasters.

The current disaster response infrastructure, although improving, is still insufficient to address the needs of the growing population. The study highlights that while there have been some advancements in disaster management practices, the existing systems are not fully equipped to handle the increasing frequency and intensity of natural disasters in Nyundo. This shortfall in infrastructure and resources necessitates a concerted effort to enhance disaster preparedness and response capabilities.

One of the key findings of the study is the need for substantial investment in disaster risk reduction measures. The analysis indicates that significant financial resources are required to mitigate the risks associated with landslides and floods.

In addition to infrastructure improvements, the study emphasizes the importance of community education and awareness programs. Educating residents about disaster preparedness, response procedures, and risk reduction strategies is crucial for enhancing resilience and reducing vulnerability. Effective community engagement can empower individuals to take proactive measures to protect themselves and their property, further mitigating the impact of natural disasters.

Overall, the study confirms that Nyundo is at a high risk of natural disasters, and without targeted interventions, the potential for significant adverse effects remains high. However, with strategic investments in infrastructure, early warning systems, and community education, it is possible to substantially reduce the impact of these risks. The findings advocate for a comprehensive approach to disaster risk management that integrates infrastructure development, resource allocation, and community involvement. By implementing these strategies, Nyundo can enhance its resilience to natural disasters and better safeguard its population against the challenges posed by landslides and floods.

5.2 Recommendations

Based on the findings of this study, several key recommendations are proposed to improve disaster risk management in the Nyundo sector. One of the most pressing needs is to enhance infrastructure in high-risk areas. The study identified that approximately 30% of Nyundo's land area is highly susceptible to landslides, while 20% is vulnerable to flooding. To mitigate these risks, it is essential to prioritize the construction of retaining walls in areas with steep slopes and upgrade drainage systems in flood-prone zones. These infrastructure projects will help protect homes, critical services, and public infrastructure such as roads, schools, and healthcare facilities from the destructive impacts of natural disasters.

Another important recommendation is the establishment and maintenance of early warning systems. Installing systems that monitor rainfall and flood levels in key areas will enable timely alerts to be issued to local communities, ensuring they have enough time to prepare and evacuate if necessary. These early warning systems should be integrated with local disaster response teams to facilitate organized evacuations and rapid responses during emergencies. Additionally, ensuring regular maintenance of these systems is vital to keep them operational and reliable.

The study also highlighted the need to strengthen community-based disaster preparedness programs, especially in rural and underserved areas where disaster preparedness is currently lacking. These programs should focus on educating residents about disaster risks and providing training on basic safety protocols, evacuation procedures, and first aid. Building local capacity through such programs will empower community members to act as first responders during disasters, ensuring that they are better equipped to protect themselves and their neighbors.

Equitable distribution of disaster management resources is another critical recommendation. Rural areas in Nyundo are disproportionately affected by natural disasters due to limited access to infrastructure and disaster response services. Future resource allocation should ensure that these underserved communities receive adequate support for infrastructure improvements, access to relief supplies, and inclusion in disaster preparedness initiatives. This will help address the current disparities and ensure that all parts of Nyundo are equally equipped to manage disaster risks.

Finally, fostering partnerships with NGOs, international organizations, and donor agencies can provide Nyundo with additional financial and technical resources for disaster management. These partnerships can support critical infrastructure projects, enhance early warning systems, and fund community education initiatives. Moreover, collaborating with international experts can introduce innovative technologies and best practices that could significantly improve the effectiveness of disaster management strategies in the region.

In conclusion, these recommendations aim to address the most pressing disaster risks in Nyundo and build a more resilient community. By investing in infrastructure, early warning systems, community education, equitable resource distribution, and international partnerships, the Nyundo sector can significantly reduce its vulnerability to natural disasters and ensure long-term sustainable development.

References

Abid, S. K. (2020). *A review on the application of remote sensing and geographic information system in flood crisis management.*

Avtar, R. e. (2020). *Utilizing geospatial information to implement SDGs and monitor their Progress.*

Bragagnolo, L. R. (2020). *Landslide susceptibility mapping with r. landslide: A free open-source GIS-integrated tool based on Artificial Neural Networks.*

Fekete, A. e. (2015). *Critical data source; tool or even infrastructure? Challenges of geographic information systems and remote sensing for disaster risk governance.*

Goodchild. (2007). *Geospatial analysis: a comprehensive guide to principles, techniques and software tools.*

Guzzetti, F. e. (1999). *"Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy.*

Khan, S. M. (2023). *A systematic review of disaster management systems: approaches, challenges, and future directions.*

Munawar, H. S. (2022). *Disruptive technologies as a solution for disaster risk management: A review.*

Nwazelibe, V. E. (2023). *GIS-based landslide susceptibility mapping of Western Rwanda: an integrated artificial neural network, frequency ratio, and Shannon entropy approach.*

rema. (2014). *ASSESSMENT, SOCIAL.*

REMA. (2014). *ASSESSMENT, SOCIAL.*

REMA. (2014). *ASSESSMENT, SOCIAL. "RWANDA ENVIRONMENTAL MANAGEMENT AUTHORIT.*

REMA. (2014). *ASSESSMENT, SOCIAL. "RWANDA ENVIRONMENTAL MANAGEMENT AUTHORITY.*

REMA. (2014). *ASSESSMENT, SOCIAL. "RWANDA ENVIRONMENTAL MANAGEMENT AUTHORITY.*

Rizvi, A. R. (2015). *Synergies between climate mitigation and adaptation in forest landscape restoration.*

Teodoro, A. C. (2022). *he synergy of remote sensing and geographical information systems in the management of natural disasters.*

Thomas, D. S. (2018). *The role of geographic information science & technology in disaster management.*

Tomaszewski, B. (2020). *Geographic information systems (GIS) for disaster management. Routledge.*

Turner, A. K. (2018). *Social and environmental impacts of landslides.*

Van Westen, C. J. (2003). *Use of geomorphological information in indirect landslide susceptibility assessment.*

Van Westen, C. J. (2013). *"Remote sensing and GIS for natural hazards assessment and disaster risk management.*

Van Westen, C. J. (2013). *Remote sensing and GIS for natural hazards assessment and disaster risk management." Treatise on geomorphology .*

Vincent, M. (2023). *International Journal of Geography and Geology.*