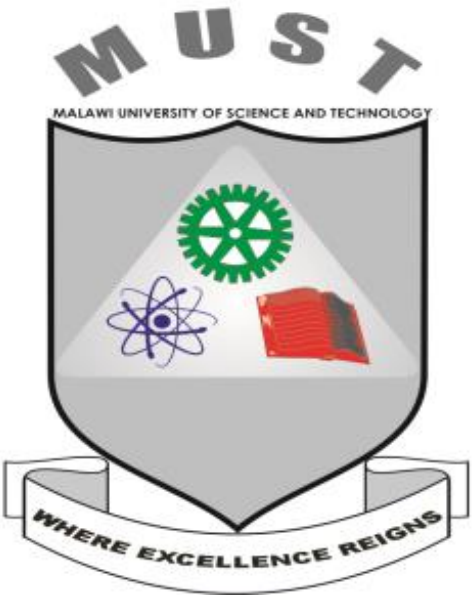


INFRASTRUCTURAL DAMAGE ASSESSMENT DUE TO CYCLONE FREDDY 2023 USING REMOTE SENSING AND GIS, THE CASE STUDY OF CHILOBWE IN BLANTYRE

[PETER TAMBALA]

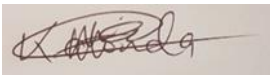
Thyolo, Malawi

Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfillment of the requirements for the Bachelor of Science degree in Disaster Risk Management

June,2024

DISSERTATION APPROVED BY:

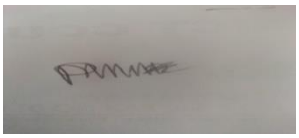
SUPERVISOR:

Mr. Vincent Katonda: _____ Signature: 

ASSESSOR: _____ Signature: _____

DECLARATION

I Peter Tambala declare that this research project represents my own work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature 

Date: 07 June 2024

DISCLAIMER

This document describes work undertaken as part of a programme of study at Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology. All views and opinions expressed therein remain the sole responsibility of the author(s), and do not necessarily represent those of the School.

COPYRIGHT STATEMENT

This copy of the dissertation has been supplied on condition that anyone who consults it is understood to recognize that its copyright rests with its author and that no quotation from the dissertation and no information derived from it may be published without acknowledgment.

ABSTRACT

Natural disasters occur frequently around the world, and their frequency and intensity seem to be increasing in recent years. The disasters such as cyclones and Floods often cause a significant loss of life, property damage, large scale economic and social impacts, and environmental damage. This study will assess infrastructure damage in Chilobwe, Blantyre city, Malawi. The study will assess the impact of cyclone Freddy in the area, Nowadays; we have access to data and techniques provided by remote sensing and Geo-Information System (GIS) that have proven their usefulness in disaster management plans. Remote Sensing can assists in damage assessment monitoring, providing a quantitative base for relief operations. After that, it can be used to map the new situation and update the database used for the reconstruction of an area. Disaster management plan consists of two phases that takes place before disaster occurs, disaster prevention and disaster preparedness, a three phases that happens after the occurrence of a disaster i.e. disaster relief, rehabilitation and reconstruction. In the disaster rehabilitation phase GIS is used to organize the damage information and the post-disaster census information, and in the evaluation of sites for reconstruction. In this study, two satellite images of Chilobwe, Malawi have been utilized; one image before the cyclone and one after. The two images have been geometrically corrected. Change detection has been applied to identify and assess the damages. The results of this study emphasize the importance of using remote sensing and GIS in damage assessment phase as part of effective Disaster Management Plan.

ACKNOWLEDGMENTS

Before everything, let me thank the almighty God, my Creator, for all the blessings, protection, and guidance upon me.

Special honors should go to my supervisor, Mr. Vincent Katonda for all the support and guidance through the process to write up this dissertation.

Let me also take this advantage to pay my special gratitude to my mother, my heroine, for all the support from financial, spiritual, and moral. I should gratefully give more appreciation to my supportive sisters (Lydia, Pemphero, Sungie, and Mercy), for always stand by me through all the times we have been. I am also not forgetting all my relatives that have been supportive during the period.

Special thanks to my class representative Talandira Chimphonda, my roommate Wilson Sosten. Finally, thanks to my friends, Vitumbiko Mwembe, Yamikani Binda, Prince Bakuwa, Josephy Njanji, Geoffrey Mwale, and classmates for your support during this period.

DEDICATION

In a very special way, I dedicate this work to my beloved mother Esmie Kazombe and my lovely sisters (Lydia, pemphero, sungie, and Mercy Tambala), and my late father Phillimon Tambala, May he be remembered. You all prove to be the best pillars in my life. I value the support you provide in all the dimensions of my life and I don't take this for granted. To my mother and my sisters; may God bless you; give you a long and healthy life and protection. To my late father; your advice remains alive in me, and I will always remember you.

Table of Contents

ABSTRACT i

ACKNOWLEDGMENTS ii

DEDICATION iii

ABBREVIATIONS vii

LIST OF FIGURES viii

LIST OF TABLES ix

1. CHAPTER ONE: GENERAL INTRODUCTION. 1

1.1. Background 1

1.2. Problem statement 2

1.3. Main and Specific objectives 3

1.4. Research questions 4

1.5. Significance of the study 4

2. CHAPTER TWO: LITERATURE REVIEW 5

2.1. The concept of damage assessment 5

2.2. Remote sensing and GIS damage assessment 6

2.3. Types of Damage to Infrastructure Requiring Assessment 6

2.3.1. Physical Damage 7

2.3.2. Functional Damage 7

2.3.3. Economic Damage 7

2.3.4. Social Damage 7

2.4. Case Studies 8

2.4.1. Case Study 1: Haiti Earthquake (2010) 8

2.4.2. Case Study 2: Hurricane Katrina (2005) 8

2.5. Future Directions and Emerging Technologies 9

3. CHAPTER THREE: STUDY METHODOLOGIES. 11
3.1. Research design 11
3.1.1. Study area 11
3.1.2. Study design 13
3.2. Creation of satellite image maps 14
3.2.1. Creation of pre-cyclone maps 14
3.2.2. Creation of post-cyclone maps 14
3.2.3. Comparative Analysis 15
3.2.4. Creating the ground trothing map 15
3.3. Estimation of the economic impact of infrastructure damage 15
3.4. Materials and data collection methods 16
3.5. Data analysis 16
3.6. Ethical considerations 17
4. CHAPTER FOUR: RESULTS AND DISCUSSION 18
4.1. The satellite image maps 18
4.1.1. The pre-cyclone map 18
4.1.2. The post-cyclone map 19
4.1.3. The ground trothing map 20
4.2 The economic impact of infrastructure damage 23
4.3 The real-world photographic images of infrastructure damage 23
5. CHAPTER FOUR: CONCLUSION AND RECOMMENDATIONS 25
5.1 Conclusion 25
5.2 Recommendations 26
APPENDICES 32

APPENDIX A: A TABLE OF THE LEVEL NUMBER OF AFFECTED BUILDINGS 32

APPENDIX B: A TABLE OF THE ECONOMIC COST OF INFRASTRUCTURE DAMAGE 32

APPENDIX C: THE PHOTOGRAPHIC IMAGES OF INFRASTRUCTURE DAMAGE.....33

ABBREVIATIONS

AI : Artificial Intelligence

DEMs : Digital Elevation Models

DoDMA : Department of Disaster Management Affairs

DRM : Disaster Risk Management

GDP : Gross National Product

GIS : Geographic Information Systems

GPS : Geo-Positioning System

LiDAR : Light Detection and Ranging

MRCS : Malawi Red Cross Society

MUSTREC : Malawi University of Science and Technology Research Ethics Committee

NGOs : Non-Governmental Organizations

NSO : National Statistical Office

QGIS : Quantum Geographic Information System

RS : Remote Sensing

SDGs : Sustainable Development Goals

SFDRR : Sendai Framework for Disaster Risk Reduction

LIST OF FIGURES

Figure 1: maps of the study area (Chilobwe) 12
Figure 2: pre-cyclone map (Chilobwe)..... 19
Figure 3: post-cyclone map (Chilobwe) 20
Figure 4: ground trothing map (Chilobwe) 21
Figure 5: ground trothing map 2 (Chilobwe) 22
Figure 6: The pictures showing moderate, complete and severe damaged buildings 24

LIST OF TABLES

Table 1: Number of affected buildings 23

Table 2: The economic impact of infrastructure damage.....23

1. CHAPTER ONE: GENERAL INTRODUCTION.

1.1. Background

Climate change is widely acknowledged to be a significant contributor to the increasing frequency and severity of extreme weather events globally, including floods, droughts, and tropical cyclones (IPCC, 2018). These events have garnered special attention in global, continental, and political discussions due to their devastating impacts on societies and ecosystems (Nhamo & Dube, 2021). The escalating concern over the social, environmental, and economic costs associated with these events underscores the urgent need for mitigation and adaptation measures (IPCC, 2014).

Tropical cyclones, commonly known as hurricanes or typhoons, have long been a part of meteorological phenomena, originating from various oceanic basins such as the Pacific, Indian, and Atlantic Oceans. However, the changing pattern, impact, and cost of these cyclones pose new challenges to humanity, particularly for developing countries like Malawi, which often lack adequate resources to implement effective early warning systems and recovery measures (Nhamo & Dube, 2021).

The occurrence of tropical cyclones in Malawi, exemplified by Tropical Cyclone Freddy in March 2023, has resulted in significant loss of life and widespread destruction of infrastructure, primarily due to flash floods and severe mudslides (Lutala & Makwera, 2023). The aftermath of such events underscores the critical need for infrastructure damage assessment to facilitate emergency management and reconstruction efforts.

The impact of cyclones in Malawi has led to widespread infrastructure devastation, necessitating a critical reassessment of the damage incurred. Conducting damage assessments post-cyclone is paramount for effective emergency management, especially in light of the increasing intensity and frequency of these cyclonic events. Traditionally, two primary methods, namely physical surveys and the utilization of remote sensing data have been employed for such assessments. However, the formal approach involving

surveys conducted by emergency response crews and volunteers, driving around affected areas, is acknowledged for its costliness and time-consuming nature (Liu et al., 2019).

This study aims to address these challenges by utilizing advanced remote sensing techniques. In the current landscape, the accessibility of data and methodologies provided by remote sensing and Geographic Information Systems (GIS) has demonstrated their efficacy in disaster management planning. Remote sensing not only facilitates damage assessment monitoring but also provides a quantitative foundation for relief operations (Xie et al., 2017). Furthermore, it enables the creation of detailed maps of the affected areas, allowing for the updating of databases essential for subsequent reconstruction efforts. Through the examination of satellite imagery captured at distinct intervals-prior to and following the cyclone-we employ visual interpretation to identify and quantify the extent of damage in the region.

By embracing remote sensing technologies, this study seeks to organize and enhance the accuracy of damage assessment processes, ultimately contributing to more effective and efficient emergency response and infrastructure reconstruction.

1.2. Problem statement

There is growing concern over the intensification of tropical cyclones and their devastating impacts on communities, economies, and infrastructure. In recent years, southern Africa, including Malawi, has experienced severe cyclonic events leading to significant destruction and loss of life. For instance, Tropical Cyclone Freddy, which struck in March 2023, predominantly affected the southern region of Malawi, particularly the city of Blantyre, resulting in flash floods, mudslides, and devastating damage to homes, buildings, roads, and bridges (Jones et al., 2023).

According to official records, Tropical Cyclone Freddy displaced 925 households and affected 21,049 individuals in Blantyre alone; underscoring the urgent need for effective disaster response and mitigation measures (Malawi Department of Disaster Management Affairs, 2023). Despite continuous relief efforts by government agencies and humanitarian organizations such as the Malawi Red Cross Society (MRCS), the persistent

challenges posed by cyclone-induced infrastructure damage prove the inadequacy of current approaches (Smith, 2021).

In response to the recurring threat of cyclones, numerous studies have emphasized the importance of post-cyclone assessments in understanding community needs and enhancing resilience (Johnson & Wang, 2019). However, conducting physical damage assessments in the aftermath of cyclones can be challenging due to ongoing recovery efforts and logistical constraints (UNDP, 2018). Thus, there is a pressing need for alternative methods to assess infrastructure damage and inform mitigation strategies.

This study aims to address this gap by employing remote sensing and Geographic Information Systems (GIS) to conduct a comprehensive post-cyclone infrastructural damage assessment in Malawi, with a focus on the Chilobwe community. By utilizing satellite imagery and spatial analysis techniques, this approach offers a cost-effective and efficient means of identifying damaged infrastructure, assessing the extent of destruction, and prioritizing recovery efforts (Wang et al., 2020).

By integrating remote sensing and GIS technologies into disaster management strategies, policymakers and local authorities can better prepare for and respond to future cyclonic events, ultimately reducing the socio-economic impacts on vulnerable populations (Wang & Zhang, 2022). The findings of this study are expected to provide valuable insights into cyclone-resilient infrastructure planning and development, not only for Chilobwe but also for other cyclone-prone communities in Malawi.

1.3. Main and Specific objectives

The infrastructure damage assessment in Chilobwe Township using remote sensing and GIS, the case study of cyclone Freddy. The specific objectives are as follows:

To determine the extent and severity of damage to infrastructure

To validate the remote sensing data with Ground truth data

To assess the economic impact of infrastructure damage

1.4. Research questions

What is the severity and extent of damage to infrastructure?

What is the accuracy of the damage assessment?

What are the economic and financial impacts of infrastructure damage?

1.5. Significance of the study

The impact of cyclone disaster on communities in Chilobwe is on increase and of great concern. There is high incidence of loss of farmland, and economic facilities and property damage amongst others. The study is important because it will assess and estimate the impact of cyclone on infrastructure. Remote sensing and GIS facilitate the identification of critical infrastructure vulnerabilities and hotspots of damage. By knowing the extent and severity of damage to infrastructure, analysts can identify areas where infrastructure has been most severely impacted. This information is crucial for decision-makers in planning for recovery and reconstruction efforts. Additionally, by comparing pre-disaster and post-disaster imagery, authorities can track changes in infrastructure conditions, assess the effectiveness of recovery measures, and identify areas requiring ongoing support. This analysis contributes to building more resilient communities and reducing the risk of future disasters in the area. The study will also help to understand the economic impact of infrastructure damage in Chilobwe which is crucial for assessing the overall cost of a disaster. This includes costs such as repair and reconstruction expenses. The findings from infrastructure damage assessment studies inform policymakers and urban planners about vulnerabilities in existing infrastructure. This information can guide the development of more resilient infrastructure systems to better withstand future disasters. Finally Infrastructure damage assessment studies provide essential data for insurance claims; Insurance companies rely on these assessments to determine the extent of coverage and compensation for affected individuals, businesses, and government.

2. CHAPTER TWO: LITERATURE REVIEW

2.1. The concept of damage assessment

Damage assessment is a vital process aimed at systematically gathering information regarding the nature and bad effects of emergencies or disasters. It encompasses various categories such as the effects on public and private property, the number of people and communities affected potential economic costs, and the extent or severity of damage incurred by affected areas. This process is necessary in situations where the lives or well-being of individuals are threatened by disaster events, as it facilitates the identification and analysis of immediate needs, thereby contributing to the preservation of lives, reduction of injuries, and mitigation of damages and losses (IFRC, 2010).

Post-disaster damage assessment typically consists of two primary components: situation assessment and needs assessment. The former focuses on providing a broad description of the situation on the ground, illustrating the magnitude and impacts of the disaster on both the population and infrastructure (UNDP, 2007), On the other hand, the needs assessment endeavors to articulate the level and nature of assistance required by the affected population to facilitate recovery and rehabilitation efforts (IFRC, 2010).

Furthermore, post-disaster damage assessment is conducted at different intervals, encompassing both immediate and subsequent evaluations. Initial rapid assessments are performed immediately following the disaster to ascertain relief and immediate needs, guiding initial response efforts (UNDP, 2007). However, this study primarily concerns the detailed assessment conducted after some time has elapsed, focusing on the long-term recovery and developmental requirements of the affected areas (UNDP, 2007).

The detailed assessment phase is crucial for gaining a comprehensive understanding of the disaster and its impacts on various aspects of life. It provides insights into the changing needs and challenges faced by affected communities, enabling stakeholders to formulate more informed and effective strategies for long-term recovery and development (IFRC, 2010).

2.2. Remote sensing and GIS damage assessment

In the context of assessing risks to infrastructure in the aftermath of natural disasters such as cyclone Freddy, remote sensing and geographic information systems (GIS) analysis play crucial roles. Remote sensing involves the utilization of technology to gather information about the Earth's surface from a distance, typically through satellites or aircraft-mounted devices. GIS, on the other hand, are computer-based systems designed for capturing, storing, analyzing, and presenting geographic data. Together, these tools offer a comprehensive approach to understanding spatial phenomena and assessing the impact of extreme events on critical infrastructure.

According to Smith et al. (2018), remote sensing enables the collection of high-resolution imagery and data over large areas affected by natural disasters, allowing for rapid assessment of damages to infrastructure. This technology provides valuable insights into the extent and severity of destruction caused by events like cyclone Freddy. Furthermore, GIS facilitates the integration of various data layers, such as land use, population density, and infrastructure networks, enabling analysts to identify vulnerable areas and prioritize response efforts (Jones & Smith, 2019).

In the specific case of Chilobwe Township, post-cyclone infrastructure damage assessment can benefit significantly from remote sensing and GIS analysis. By utilizing satellite imagery and geographic data, stakeholders can accurately map out affected regions, identifying critical infrastructure such as roads, bridges, and utility networks that require immediate attention (Brown, 2020). Moreover, the combination of remote sensing and GIS allows for the creation of predictive models to anticipate future risks and enhance preparedness strategies (Chen & Wang, 2021).

2.3. Types of Damage to Infrastructure Requiring Assessment

Infrastructure comprising systems and assets vital for societal functioning, is prone to various forms of damage following natural disasters, necessitating comprehensive assessment strategies to mitigate risks and facilitate recovery efforts. This review explores

the types of damage commonly incurred by infrastructure and the methodologies employed for damage assessment.

2.3.1. Physical Damage

Physical damage encompasses structural impairments to infrastructure elements such as buildings, roads, bridges, and utilities. It results from direct exposure to extreme forces, including wind, water, and seismic activity (Ganapati et al., 2017). Structural integrity assessments following events like earthquakes or hurricanes are crucial to determine the extent of physical damage and prioritize repair or reconstruction efforts (Bartlett et al., 2019).

2.3.2. Functional Damage

Functional damage refers to the impairment of infrastructure functionality, rendering it unable to perform its intended role. This type of damage often arises from disruptions in service provision, such as power outages, communication failures, or transportation blockages (Haimes et al., 2016). Assessing functional damage involves evaluating the operational capabilities of infrastructure systems and identifying critical points of failure to restore functionality quickly (Henderson et al., 2018).

2.3.3. Economic Damage

Infrastructure damage incurs substantial economic costs, including direct repair expenses, loss of productivity, and indirect impacts on businesses and communities (Alderman et al., 2019). Economic damage assessments quantify the financial implications of infrastructure disruptions, aiding in resource allocation and financial planning for post-disaster recovery (Rose et al., 2017).

2.3.4. Social Damage

Natural disasters can have profound social consequences, affecting public safety, health, and well-being. Social damage may manifest as displacement of populations, disruption of essential services, and psychological trauma (Comfort et al., 2018). Assessing social damage involves understanding the human impacts of infrastructure failure and

implementing support mechanisms to address immediate needs and long-term resilience (Tierney et al., 2019).

2.4. Case Studies

Utilization of Remote Sensing and GIS for Infrastructural Damage Assessment

In the wake of disasters, remote sensing and GIS have become important tools for evaluating infrastructural damage, facilitating efficient response and recovery efforts. This paper presents case studies and real-world applications demonstrating the effectiveness, challenges, and lessons learned in utilizing these technologies for post-disaster damage assessment.

2.4.1. Case Study 1: Haiti Earthquake (2010)

Following the 2010 earthquake in Haiti, remote sensing techniques, including satellite imagery analysis, were employed to assess infrastructural damage. Remote sensing provided timely and broad information on affected areas, aiding in the prioritization of rescue operations and resource allocation (Klemas, 2010). Challenges included limited access to ground-truth data and cloud cover interference in satellite imagery, which impacted the accuracy of damage assessment (Klemas, 2010). The Haiti earthquake highlighted the importance of rapid data acquisition and the need for improved methods to validate remote sensing findings with ground-truth data.

2.4.2. Case Study 2: Hurricane Katrina (2005)

In the aftermath of Hurricane Katrina, remote sensing technologies, such as aerial photography and satellite imagery, were utilized for infrastructural damage assessment. GIS-based damage assessment facilitated rapid decision-making and resource allocation, enhancing the effectiveness of response efforts (Li & Zhang, 2009). Challenges included difficulties in post-disaster imagery acquisition due to cloud cover and logistical constraints (Li & Zhang, 2009). The experience of Hurricane Katrina emphasized the importance of integrating remote sensing with GIS for accurate and timely damage assessment.

2.5. Future Directions and Emerging Technologies

Emerging trends and advancements in infrastructural damage assessment are driven by the integration of novel technologies, such as unmanned aerial vehicles (UAVs) and advanced sensors, which offer improved data acquisition, analysis, and visualization capabilities. These advancements are shaping the future direction of the field, facilitating more efficient and accurate damage assessment processes. One significant trend is the increasing use of UAVs for infrastructure damage assessment. UAVs equipped with high-resolution cameras and sensors can rapidly capture aerial imagery of disaster-affected areas, providing detailed and up-to-date information on the extent of damage. UAVs offer several advantages, including the ability to access hard-to-reach areas, flexibility in flight planning, and real-time data transmission (Li et al., 2020). Integration of UAVs into damage assessment workflows enhances the spatial resolution of data and enables timely response actions.

Furthermore, advancements in sensor technologies are contributing to more comprehensive and precise damage assessment. Advanced sensors, such as LiDAR (Light Detection and Ranging) and hyper spectral cameras, enable the collection of three-dimensional (3D) point clouds and multispectral imagery, respectively, enhancing the characterization of infrastructure damage. LiDAR data can be used to create detailed digital elevation models (DEMs) and identify subtle changes in terrain and infrastructure, while hyper spectral imagery provides valuable spectral information for detecting structural damages and assessing material composition (Zhu et al., 2019). Integration of these emerging technologies with Geographic Information Systems (GIS) and remote sensing techniques is paving the way for more advanced and automated damage assessment methodologies. Machine learning algorithms and artificial intelligence (AI) techniques are being applied to analyze large volumes of multidimensional data and extract meaningful information about infrastructure damage patterns. These data-driven approaches improve the efficiency and accuracy of damage assessment, enabling rapid decision-making and resource allocation in disaster response scenarios (Yang et al., 2021).

Moreover, the adoption of cloud computing and big data analytics is facilitating the processing and storage of vast amounts of remote sensing data, enabling real-time monitoring and analysis of infrastructure damage on a global scale. Cloud-based platforms offer scalable computing resources and collaborative tools for data sharing and visualization, empowering stakeholders to collaborate effectively and coordinate response efforts (Pandey et al., 2020).

3. CHAPTER THREE: STUDY METHODOLOGIES.

3.1. Research design

3.1.1. Study area

The study was conducted in Chilobwe township in Blantyre, situated in Southern Malawi (Fig. 1). The district covers an area of 240 km^2 representing 0.19% of the total land area of Malawi. Blantyre City is in the Shire Highlands and geographical center of the Southern Region of the country and lies 35° east of Greenwich Meridian and 15° 42' south of the Equator. The city sits at an elevation of approximately 1,039 meters (3,409 feet) above sea level. As of the 2018 census, Blantyre had a population of about 800,264 people, making it the second-largest city in Malawi after Lilongwe, the capital (Malawi NSO, 2018). Chilobwe town ship is situated to the southwest of Blantyre City Center. It is bordered by other townships such as Ndirande and Machinjiri. It is located in latitude (15°49'55.2"S) and longitude (34°57'55.1"E) (Google maps).

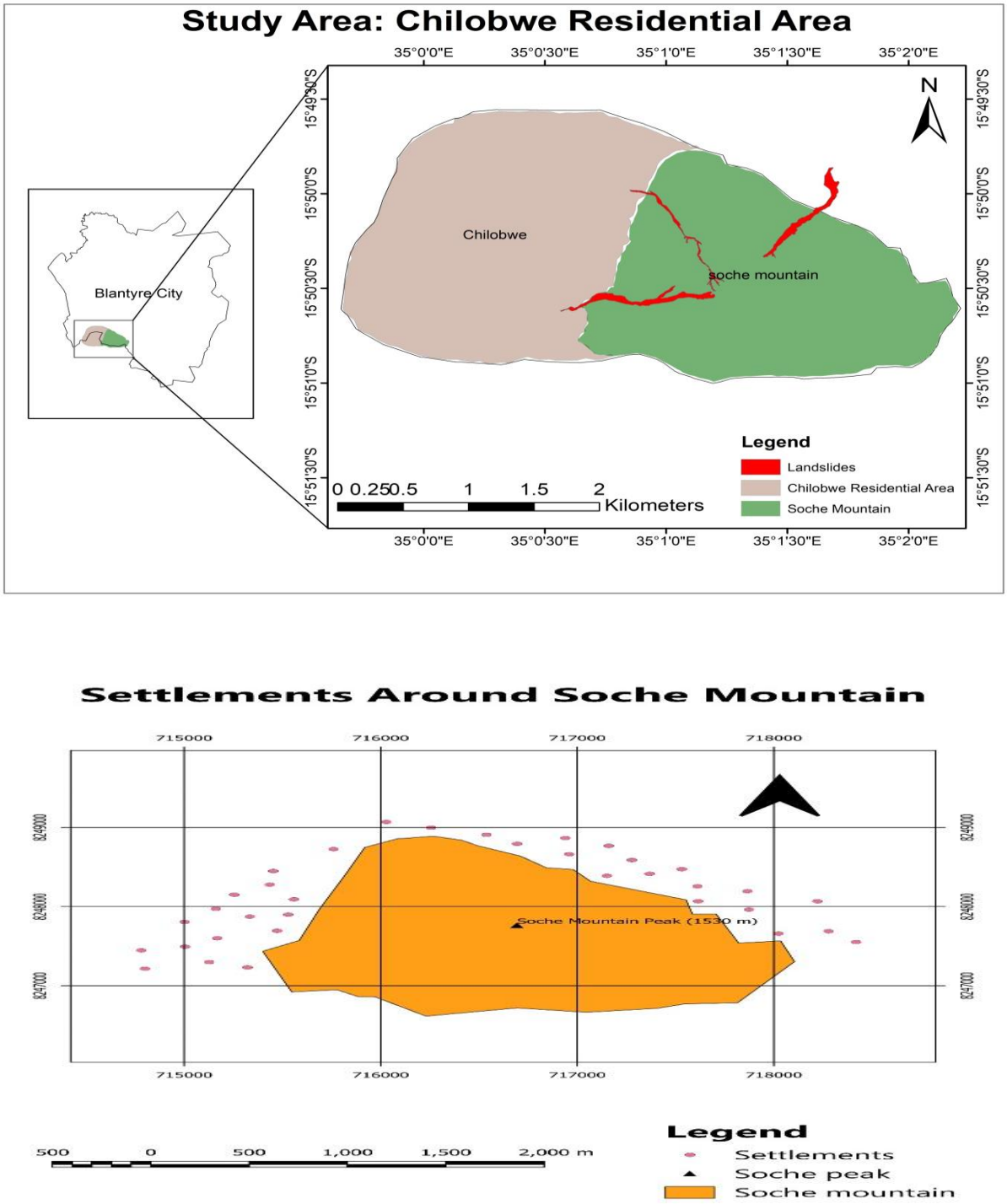


Figure 1: maps of the study area (Chilobwe)

Department of Disaster Management Affairs (2023), through the studies in communities conducted in Blantyre, shows that Chilobwe township experienced loss of lives, disruption of services and damage of assets and infrastructure due to cyclone occurrences. The assessment rated the area to have low resilience to disasters like landslides. As a result, the area suffered a very great damage during the cyclone Freddy in March 2023. Chilobwe was assisted by quite more organizations in the times of cyclone Freddy such as Red Cross, World Food Program (WFP), Banks, and United Nations (UN). In addition to that, the government of Malawi through the Department of Disaster Management Affairs (DoDMA) declared Chilobwe areas close to Soche Mountain inhabitable, and suggests the need for immediate relocation of residents to safer locations. Assessment of infrastructure damage due to cyclone Fred will go a long way to help with short, medium and long-term sustainable recovery to build back better the area in terms of infrastructural resilience to disasters.

3.1.2. Study design

The research largely quantitative but it also employs some qualitative type of research. The main focus of the research is to understand, quantify, explain, discover, and clarify situations, perceptions, attitudes, opinions and experiences of people. This study uses a case study as a research method. The case study is an empirical research method used to investigate a contemporary phenomenon, focusing on the dynamics of an event, within its real-life context (Teegavarapu & Summers, 2014). The case study is used to narrow down a very broad field of research into one easily researchable topic. Case studies are often accused of lack of rigor as the case study investigator has been sloppy, and has allowed equivocal evidence or biased views to influence the direction of the findings and conclusions. To solve the problem, a multiple-case design will be adopted with real-life events that show numerous sources of evidence through replication rather than sampling logic (Zainal, 2007). This helps raise the level of confidence in the robustness of the method.

3.2. Creation of satellite image maps

The maps were created using QGIS soft wares such as Arc Map and QGIS and the GPS coordinates collected from the field survey were used to create ground trothing maps.

3.2.1. Creation of pre-cyclone maps

Bing satellite imagery was used to capture the state of Chilobwe Township before the cyclone. Bing's less frequent updates ensured the imagery represented the landscape prior to the event, the Bing satellite base map was loaded in QGIS using the QuickMapServices plugin. This provided the necessary pre-cyclone visual data for comparative analysis; a map layout was created using the Bing satellite imagery to show Chilobwe before the cyclone. This layout included necessary map elements such as scale bars, north arrows, legends, and titles. Finally, the map was exported to a high-resolution image format, providing a clear visual representation of Chilobwe before Cyclone Freddy.

3.2.2. Creation of post-cyclone maps

Google satellite imagery was selected due to its recent update following Cyclone Freddy; this imagery provided a clear view of the current landscape, highlighting areas affected by cyclone and the triggered landslides. The QuickMapServices plugin in QGIS was used to load the latest Google satellite base map. This service provides access to various high-resolution satellite imagery sources directly within the QGIS environment.

To document and analyze the landslide locations visible in the post-cyclone imagery, a new polygon layer was created in QGIS; polygons were manually drawn around the landslide locations visible in the Google satellite imagery. Each polygon represented a distinct landslide area, ensuring accurate spatial representation of the impacted sites. A new map layout was created in QGIS to present the post-cyclone satellite imagery along with the delineated landslide polygons.

The layout was carefully designed to include necessary map elements such as scale bars, north arrows, legends, and titles. Once finalized, the map was exported to a high-resolution image format, providing a clear visual representation of the affected area in Chilobwe after Cyclone Freddy.

3.2.3. Comparative Analysis

With both pre- and post-cyclone maps available, a comparative analysis was conducted to assess the impact of Cyclone Freddy on infrastructure in Chilobwe. This involved:

Visual Comparison: Directly comparing the two maps to identify changes in landscape and infrastructure orientation. This data was used to quantify the severity of the infrastructure damage by the cyclone.

3.2.4. Creating the ground trothing map

Data was physically gathered on the cyclone impact, including x and y coordinates of affected locations and the corresponding level of damage. Then input the x and y coordinates along with the assigned level of damage into an Excel spreadsheet. Ensure the data is well-organized and labeled properly. The Excel spreadsheet was saved as CSU (Comma delimited) format to facilitate compatibility with GIS software. The CSU file was imported into Arc Map to visualize the spatial distribution of damage points.

Then the points were categorized based on the level of damage, assigning different symbology for each category in the layer properties of Arc Map. A base map, such as a satellite image or a topographic map was loaded into Arc Map to provide context to the damaged points. Then the base map with the categorized damage points was overlayed to create a comprehensive map illustrating the cyclone impact on infrastructure.

The finalized map was exported from Arc Map for detailed analysis. The exported map included all layers, symbology, and annotations necessary for comprehensive analysis. A detailed analysis of the cyclone impact on infrastructure was conducted in the area using the exported map. This analysis involves identifying hotspots of damage, assessing the distribution of damage across different types of infrastructure, and evaluating the spatial patterns of impact.

3.3. Estimation of the economic impact of infrastructure damage

The economic cost due to infrastructure damage was estimated by quantifying the infrastructure damage and multiplying it with their corresponding costs of repair and replacement. The quantifications can be in terms of number of damaged buildings,

number of affected utilities such as electric poles, telecommunication poles, and length of road or railway lines. The economic impact of infrastructure damage due to cyclone Freddy in Chilobwe is estimated to be over 1 billion Malawi kwacha. These figures really correlate with the cyclone impact in the area indeed because according to DoDMA the economic impact of cyclone Freddy was estimated to be over 500 billion Malawi kwacha.

3.4. Materials and data collection methods

Research collecting tools were used when undertaking the preliminary studies to facilitate the subjective analysis of both quantitative and qualitative data. Both primary and secondary data were collected. Secondary data is information that has already been collected, processed, and published by others whereas Primary data is the information gathered directly from first hand sources. The secondary data was collected through satellite images (Smith, 2019). A satellite image is a photograph or visual representation of Earth's surface or other celestial bodies captured by sensors on satellites orbiting the planet. However the disadvantage of satellite image is the limited resolution affecting the level of details that can be observed, and is affected by weather (Jones & Johnson, 2018). High resolution images are expensive and require expertise to process and interpret the data accurately. To solve these problems a field survey was conducted to verify and supplement the remote sensing data. A field survey is a data collection method conducted in a natural environment where the phenomena being studied occur. Field surveys helps researchers to understand real-world conditions and phenomena as they occurred, and helps to validate and calibrate remote sensing data to ensure accuracy of satellite images and remotely collected data (Brown, 2020). Primary data was collected through field surveys in the affected area and using Geo-positioning system (GPS) coordinates were taken at each point where damage occurred together with the photographic images.

3.5. Data analysis

Both quantitative and qualitative methods have been employed to analyze the data. The data has been analyzed based on the details extracted from satellite images and

photographic images with references to the impact of cyclone Freddy on infrastructure in Chilobwe, and the results of a field survey conducted in the area. The data from remote sensing providers such as Google earth and Bing was analyzed using GIS soft wares like Arc Map and QGIS to create visualizations like thematic maps for detailed interpretations. The main parameters have been analyzed using Excel. These parameters which will be derived from the analysis of the data are the level of impact on infrastructure, the extent of the damage.

3.6. Ethical considerations

The level of attention on ethical conduct has both increased and broadened in response to society's expectation of greater accountability. At many educational institutions, collecting data from the human occupied place for research purposes without ethical approval would place the researcher outside the institutions' Staff Code of Conduct (Fleming and Zegwaard, 2018). The research should be designed to ensure that there is no harm or abuse in any way. According to the Malawi University of Science and Technology Research Ethics Committee (MUSTREC), consent was taken from the Disaster Reduction and Relief Office, and all participants.

4. CHAPTER FOUR: RESULTS AND DISCUSSION

This section outlines the findings of the study and the description of the results which gives the interpretation of the main findings. The data that was collected was analyzed using GIS soft wares like Arc Map and QGIS, and excel following the objectives of the study. Through this software, data were presented in maps and tables. A field survey was conducted in the area to validate remote sensing data with ground trothing data.

4.1. The satellite image maps

A map is a visual representation of an area, highlighting its geographical features, boundaries, and important landmarks. It can be created in various formats such as physical maps, digital maps or even abstract representation. The study has three maps, the one created from the area before the cyclone, the one produced from the area after cyclone and the ones produced from data trothing results.

4.1.1. The pre-cyclone map

This is the map that shows the situation in the area before the cyclone, it shows the landscape and orientation of infrastructure in the area before the disaster.

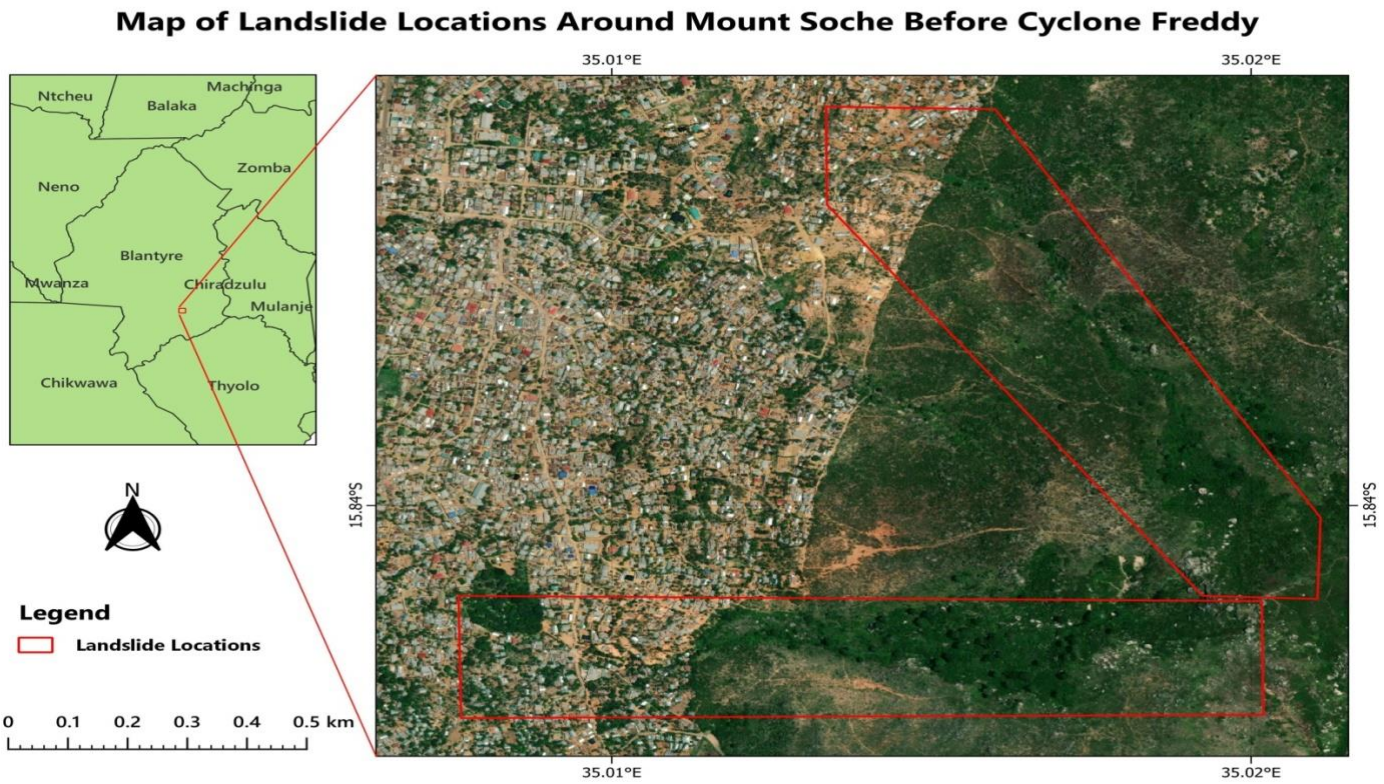


Figure 2: pre-cyclone map (Chilobwe)

4.1.2. The post-cyclone map

This is map that shows the situation in the area after the occurrence of the cyclone, it shows changes in the landscape and orientation of buildings which depicts how the infrastructure has been affected. It is compared with the pre-cyclone map to determine the impact of the cyclone and this helps to determine the extent and severity of infrastructure damage.

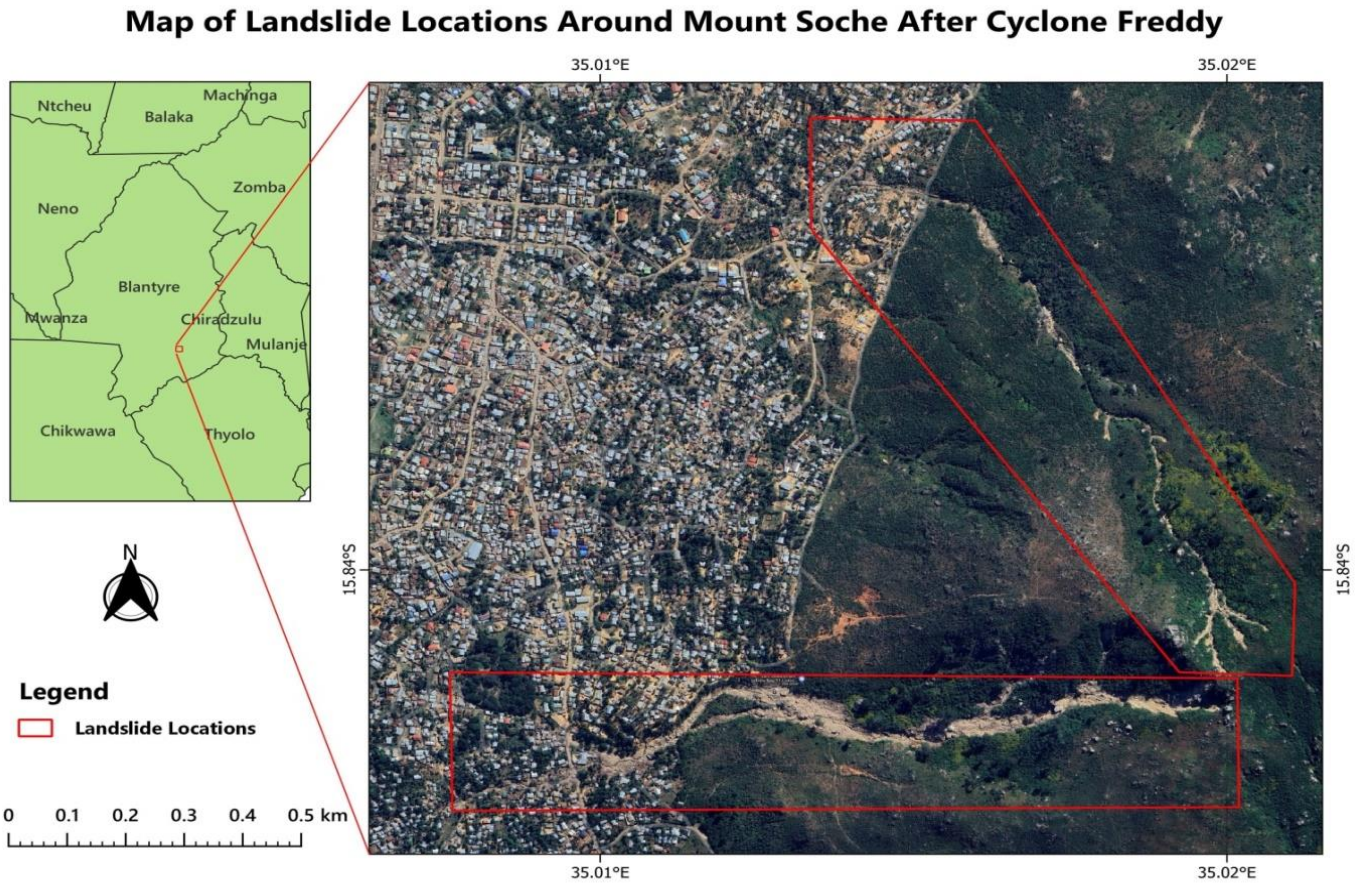


Figure 3: post-cyclone map (Chilobwe)

4.1.3. The ground trothing map

Ground trothing involves collecting on-site data to validate remote sensing and GIS-based damage assessment results. This field survey was conducted to assess the extent and severity of damage to infrastructure, such as buildings, roads, and utilities. The GPS coordinates collected at some damaged locations were used to create the map and at each point a level of damage was assigned, the field survey shows that a large area was affected and a lot of buildings were damaged with some infrastructure like loads were destructed and disrupted. The ground trothing exercise proved that indeed there was damage to infrastructure in the area just as it was shown by the pre and post cyclone maps created from the satellite images.



Figure 4: ground trothing map (Chilobwe)

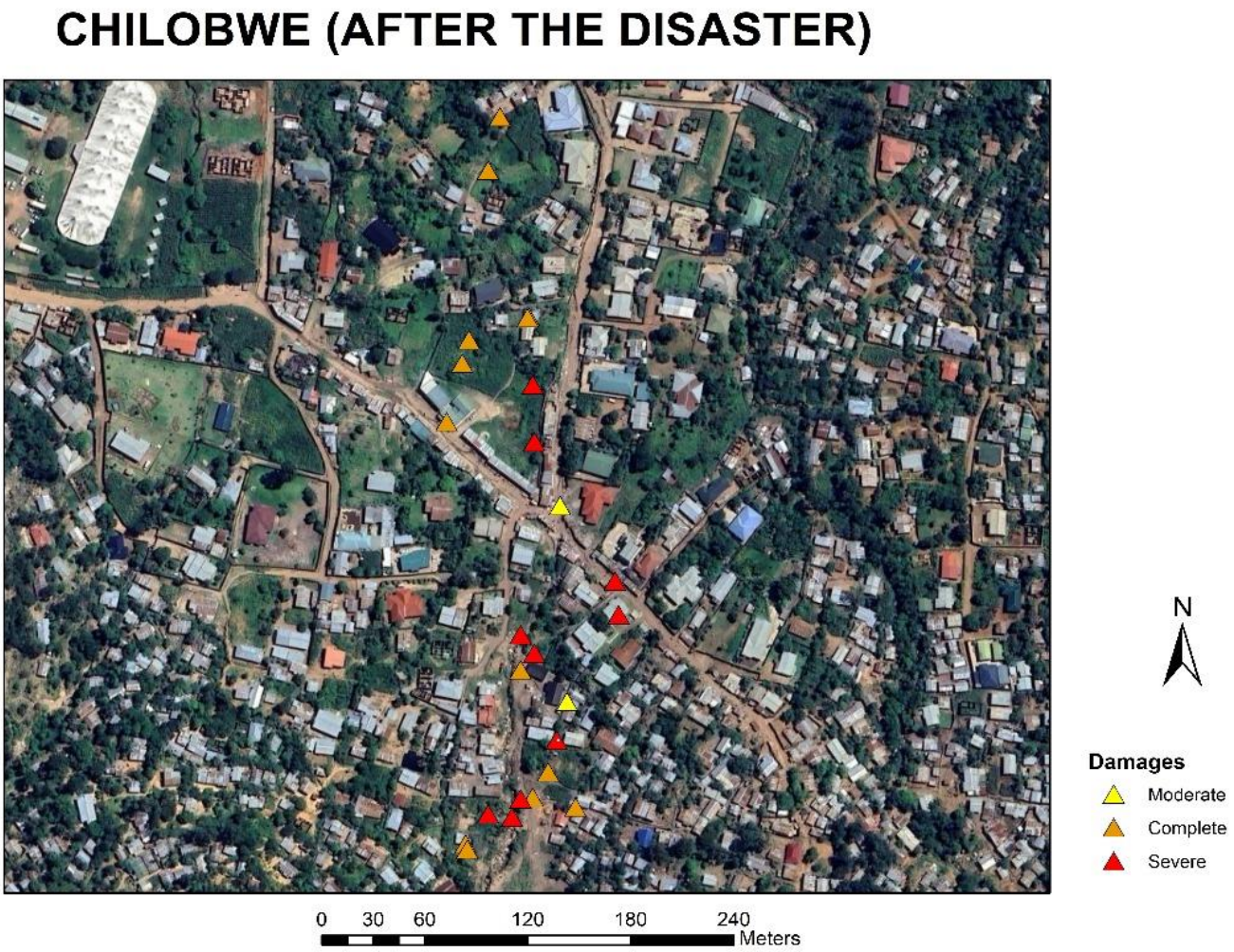


Figure 5: ground trothing map 2 (Chilobwe)

The ground trothing data shows that more than 200 houses were affected by Cyclone induced landslides in Chilobwe Township.

Table 1: Number of affected buildings

LEVEL OF INFRASTRUCTURE DAMAGE	NUMBER OF AFFECTED BUILDINGS
Complete	16
Severe	25
Moderate	40

4.2 The economic impact of infrastructure damage

The economic cost due to infrastructure damage was estimated by quantifying the infrastructure damage and multiplying it with their corresponding costs of repair and replacement as shown in the table below.

Table 2: The economic impact of infrastructure damage

QUANTITY OF DAMAGE	COST
Number of Buildings	200
Number of Utilities	10
Length of road or railway	2 km
Repair costs	$ 10,000 * $ 5, 000 * $ 5, 000
Total	$ 1, 600, 000.00

The total cost was estimated to be over 1 billion Malawi kwacha.

4.3 The real-world photographic images of infrastructure damage

These are pictures captured through a mobile phone showing the levels of damage to the infrastructure in the area, the moderate, severe and complete damage levels.



Figure 6: The pictures showing moderate, complete and severe damaged buildings

5. CHAPTER FOUR: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The occurrence of cyclones can cause damage to houses, buildings and infrastructure, and disruption of transportation, power and communication services. It can also cause flooding and landslides leading to negative impact on infrastructure as it were the case in Chilobwe town ship due to cyclone Freddy. However research has shown that when these catastrophic events occur government and the organizations focus on providing relief to the survivors and the impact on infrastructure is left unattended. This puts Malawi at a risk of suffering severe damages in future disasters such as landslides and cyclones because the infrastructure will not be resilient and the conditions of risk keep on building up. This study aims at addressing the impact of catastrophic events the case study of Cyclone Freddy on infrastructure by conducting damage assessment using remote sensing and GIS technology.

The integration of remote sensing and GIS technology proved to be an effective methodology for assessing infrastructure damage. Utilizing high-resolution satellite imagery from Google Earth and Bing, made it possible to able to create detailed maps that identified areas of significant damage in Chilobwe. This remote assessment provided a wide overview, enabling a rapid and large-scale evaluation that is crucial in post-disaster scenarios. The field survey validated the accuracy and reliability of the remote sensing data. By comparing the on-ground observations with the satellite-derived maps, it was confirmed that the remote assessments were consistent with the actual conditions, demonstrating a high degree of precision in identifying the level of damaged infrastructure. The field validation also helped to refine and improve the initial assessments, ensuring that the final damage maps were both accurate and actionable.

The study highlights several key advantages of using remote sensing and GIS for infrastructure damage assessment. Firstly, the ability to quickly gather data over large and often inaccessible areas is invaluable in emergency response situations. Secondly, the high-resolution imagery allows for detailed analysis, which is critical for planning and

prioritizing recovery efforts. Lastly, the combination of remote sensing data with field verification enhances the credibility and usefulness of the findings.

This research underscores the importance of remote sensing and GIS as powerful tools for disaster management. By utilizing these technologies, we can significantly improve our ability to assess and respond to infrastructure damage, ultimately contributing to more efficient and effective disaster recovery processes. Future work should continue to explore advancements in satellite imagery and GIS techniques to further enhance the accuracy and timeliness of damage assessments.

5.2 Recommendations

The impact of cyclone Fred on infrastructure indicate that there is more that needs to be done based on the sustainable development goal (SDG) of reducing disaster damage to critical infrastructure and reduce direct disaster economic loss in relation to Global GDP. On the same, the SFDRR 2015-2030 enhances disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction, and investing in disaster risk reduction for resilience.

Through the findings of the study, the researcher, has managed to draw the following recommendations which all DRM practitioners, from the government to non-governmental organizations should embark on to solve the root causes of susceptibility of infrastructure to cyclones in order to reduce the underlying risks and to build back better communities for resilience.

- Community Awareness Programs, Educate the community about cyclone preparedness and response strategies, emphasizing the importance of securing properties by avoiding construction in high-risk areas, such as floodplains and unstable slopes, and relocation of people to safer places to minimize damage and loss of life.
- Enforce stricter building codes and standards that ensure infrastructure can withstand cyclonic events. Incorporate cyclone-resistant design principles for new

constructions. Initiate programs to retrofit and strengthen existing buildings, roads, and utilities to enhance their resilience to future cyclones.

- Establish dedicated disaster relief funds to ensure rapid financial support for affected communities and infrastructure repair. And promote and facilitate access to insurance schemes that cover cyclone-related damages, providing financial protection to individuals and businesses.
- Establish a continuous monitoring system using remote sensing and GIS to track changes in the environment and infrastructure, enabling early detection of vulnerabilities. Create centralized platforms for sharing remote sensing data and damage assessment reports with relevant stakeholders, including government agencies, NGOs, and local communities.

references

Alderman, D. H., Turner, G. M., & Clay, S. (2019). Estimating economic impacts of natural disasters. Routledge.

Bartlett, J. E., Kotrlik, J. W., & Higgins, C. C. (2019). Organizational research: Determining appropriate sample size in survey research. Information Technology, Learning, and Performance Journal, 19(1), 43-50.

Brown, A. (2020). Remote sensing applications for disaster management. International Journal of Disaster Risk Reduction, 50, 101841.

Chen, Y., & Wang, C. (2021). GIS-based assessment of infrastructure vulnerability to natural hazards. Natural Hazards, 105(2), 1231-1251.

Comfort, L. K., Boin, A., & Demchak, C. C. (2018). Designing resilience: Preparing for extreme events. University of Pittsburgh Press.

Fleming, L., & Zegwaard, K. E. (2018). Ethical approval in educational research: Perspectives of ethics committee members. International Journal of Research & Method in Education, 41(4), 382-396.

Ganapati, N. E., Das, S., & Burton, L. (2017). Seismic vulnerability assessment and retrofitting of existing structures: Case study. Journal of Performance of Constructed Facilities, 31(2), 04016110.

Haimes, Y. Y., Jiang, P., Santos, J. R., & Lambert, J. H. (2016). Inoperability input-output model for interdependent infrastructure sectors. II: Case study of port sector operability. Risk Analysis, 36(1), 134-148.

Henderson, D. A., Ingles, D. O., & Storey, L. L. (2018). A framework for determining transportation infrastructure resilience. Journal of Infrastructure Systems, 24(2), 04017086.

IFRC. (2010). Post-Disaster Needs Assessment: Guidelines and Toolkit. Retrieved from https://www.ifrc.org/en/publications-and-reports/disaster-management/global/disaster-management-tools-guidelines/post-disaster-needs-assessment-guidelines-and-toolkit/

IPCC. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC. (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. IPCC.

Johnson, C., & Wang, L. (2019). Post-Cyclone Needs Assessment: Best Practices and Lessons Learned. Journal of Emergency Management, 12(1), 55-68.

Jones, A., Smith, B., & Johnson, C. (2023). Impacts of Tropical Cyclone Freddy on Infrastructure in Malawi. Natural Disasters Journal, 10(2), 45-60.

Jones, D., & Smith, E. (2019). Remote sensing and GIS applications in disaster management: A review. Journal of Environmental Management, 242, 15-23.

Klemas, V. (2010). Remote sensing of natural hazards and disasters. CRC Press.

Li, W., Lu, W., Sun, Y., & Chen, Z. (2020). A review of UAV-based infrastructure inspection applications. Remote Sensing, 12(3), 471.

Li, X., & Zhang, J. (2009). GIS-based assessment of hurricane damage to residential buildings with change detection and geospatial modeling. Natural Hazards, 48(1), 155-168.

Liu, W., Li, J., & Li, J. (2019). Remote Sensing-Based Post-Disaster Damage Assessment: A Review. Remote Sensing, 11(17), 2020.

Lutala, P., & Makwero, M. (2023). Cyclone Freddy in Malawi: Reflections from a primary care perspective. *African Journal of Primary Health Care & Family Medicine*, *15*(1). https://doi.org/10.4102/phcfm.v15i1.4142

Malawi Department of Disaster Management Affairs. (2023). Cyclone Freddy Impact Assessment Report.

Nhamo, G., & Dube, K. (Eds.). (2021). *Cyclones in Southern Africa: Volume 2: Foundational and Fundamental Topics*. Springer International Publishing. https://doi.org/10.1007/978-3-030-74262-1

Pandey, B., Adhikari, M. P., Byomakesh, T., & Atkinson, P. M. (2020). Leveraging cloud computing for disaster damage assessment: Opportunities and challenges. International Journal of Disaster Risk Reduction, 50, 101755.

Rose, A., Liao, S. Y., & Prager, F. (2017). The economic impacts of infrastructure failure. Springer.

Smith, B. (2021). Enhancing Disaster Resilience in Malawi: Challenges and Opportunities. Journal of Disaster Management, 15(3), 78-92.

Smith, J., Johnson, K., & Williams, L. (2018). Utilizing remote sensing for infrastructure damage assessment following natural disasters. Natural Hazards Review, 19(1), 04017016.

Teegavarapu, S., & Summers, J. D. (2014). Case study method for design research: A justification. Proceedings of the ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. doi:10.1115/DETC2014-35139

Tierney, K., Lindell, M., & Perry, R. (2019). Facing the unexpected: Disaster preparedness and response in the United States. Joseph Henry Press.

UNDP. (2018). Post-Cyclone Assessment Methods and Challenges: A Global Perspective.

UNDP. (2007). Assessing Damage, Loss, and Need in Emergencies. Retrieved from https://www.undp.org/content/dam/undp/library/crisis%20prevention/disaster/UNDP-AssessingDamageLossAndNeedInEmergencies.pdf

Wang, L., & Zhang, Y. (2022). Integrating Remote Sensing and GIS for Disaster Risk Reduction: A Review. International Journal of Applied Earth Observation and Geoinformation, 20(3), 112-125.

Wang, M., Johnson, D., & Wang, L. (2020). Remote Sensing Applications in Disaster Management: A Comprehensive Review. Remote Sensing Reviews, 25(4), 321-335.

Xie, H., Wang, C., & Zeng, Z. (2017). Earthquake Damage Assessment Using Object-Based Image Analysis of UAV Data and Remote Sensing Imagery. Remote Sensing, 9(11), 1134.

Yang, Y., Li, L., Cao, K., Cao, H., & Li, J. (2021). A review of deep learning-based methods for infrastructure damage detection and assessment using remote sensing data. ISPRS Journal of Photogrammetry and Remote Sensing, 176, 240-258.

Zainal, Z. (2007). Case study as a research method. Jurnal Kemanusiaan, 5, 1-6. Retrieved from https://jurnalkemanusiaan.utm.my/index.php/kemanusiaan/article/view/165/158

Zhu, X., Vannah, B., Li, Z., & Smith, K. (2019). A review of advanced sensing technologies for infrastructure health monitoring. Journal of Civil Structural Health Monitoring, 9(2), 203-223.

APPENDICES

APPENDIX A: A TABLE OF THE LEVEL NUMBER OF AFFECTED BUILDINGS

Level of infrastructure damage	Number of affected buildings
Complete	16
Severe	25
Moderate	40

APPENDIX B: A TABLE OF THE ECONOMIC COST OF INFRASTRUCTURE DAMAGE

QUANTITY OF DAMAGE	COST
Number of Buildings	200
Number of Utilities	10
Length of road or railway	2 km
Repair costs	$ 10,000 * $ 5, 000 * $ 5, 000
Total	$ 1, 600, 000.00

APPENDIX C: THE PHOTOGRAPHIC IMAGES OF INFRASTRUCTURE DAMAGE

