ASSESSING THE IMPACT OF LAND USE AND LAND COVER CHANGES ON INCREASING LANDSLIDE RISK IN NDIRANDE TOWNSHIP: USING GIS AND REMOTE SENSING APPROACH

CHIPILIRO KHONGONYOWA

DRM-016-20

THYOLO, MALAWI

Dissertation submitted to Ndata School of Climate and Earth Sciences at The Malawi University of Science and Technology in partial fulfilment of the requirements for the bachelor of science degree in disaster risk management

21st May , 2025

DISSERTATION APPROVED BY

SUPERVISOR:

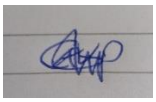
Madam T. Nthara Signature:

ASSESSOR:

Title, Initials, Name Signature: _____

DECLARATION

I **Chipiliro Khongonyowa** 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: 21st May, 2025

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 acknowledgement.

ABSTRACT

This study assessed the impact of Land Use and Land Cover Changes (LULCC) on increasing landslide risk in Ndirande Township, Malawi, utilizing Geographic Information Systems (GIS), remote sensing, and the Analytic Hierarchy Process (AHP). Through the analysis of temporal LULCC patterns of 2015, 2020 and 2024, the study identified significant deforestation (34% forest loss), agricultural encroachment, and the proliferation of informal settlements (68% on slopes steeper than 15°) as primary contributors to slope instability.

AHP was employed to systematically prioritize landslide risk factors, assigning the highest weights to LULC (35%), slope (19%), and rainfall (17%), with a consistency ratio of 0.08 confirming the reliability of judgments. GIS-based weighted overlay analysis produced detailed landslide susceptibility maps, highlighting high-risk zones in eastern Ndirande Hill where unplanned urbanization, steep slopes, and increased rainfall (8% rise since 2015) converge.

Model validation using a confusion matrix achieved 93.8% accuracy, underscoring the robustness of the approach. The research further linked socio-economic drivers such as rapid population growth, poverty-induced land scarcity, and weak urban planning to environmental degradation and heightened community vulnerability. Policy recommendations include reforestation, slope stabilization, and risk-informed urban planning aligned with SDGs 11 and 13. This integrative approach offers a replicable model for landslide risk mitigation in rapidly urbanizing regions of sub-Saharan Africa.

Keywords: Land Use and Land Cover Changes, Landslide Risk, GIS and Remote Sensing.

ACKNOWLEDGEMENTS

My utmost gratefulness to the Lord God Almighty, from whom all things are made possible.

I would like to express my heartfelt gratitude to everyone who has supported me in the development of this dissertation. My sincere thanks go to my supervisor, Mrs T. Nthara whose guidance, insights, and encouragement have been helpful throughout this process. Her expertise and constructive feedback have greatly enhanced the quality of my work.

I am also deeply thankful to my family and friends for their continuous encouragement and support, which has been a constant source of motivation. Additionally, I extend my appreciation to the Department of Ndata School of Climate and Earth Sciences for providing the resources and learning environment that made this proposal possible.

Lastly, I am grateful to my peers and colleagues who offered advice, shared resources, and helped refine my ideas. Your contributions have played an essential role in shaping this research, and I am truly grateful for your support

TABLE OF CONTENTS

DECLARATION III
DISCLAIMER IV
COPYRIGHT STATEMENT V
ABSTRACT VI
ACKNOWLEDGEMENTS VII
TABLE OF CONTENTS VIII
LIST OF ABBREVIATIONS AND ACRONYMS X
LIST OF FIGURES XI
LIST OF TABLES XII
CHAPTER 1: INTRODUCTION 1
1.1 Background 1
1.2 Problem Statement 2
1.3 Main Objective And Specific Objectives 3
1.3.1 Main Objective 3
1.3.2 Specific Objectives 3
1.4 Research Questions 3
1.5 Significance of Study 4
CHAPTER 2: LITERATURE REVIEW 5
2.1 Introduction 5
2.2 Landslide Risk and Land Cover/Land Use Change 5
2.3 The Relationship Between LULCC And Landslides 6
2.4 Application of GIS and Remote Sensing In Landslide Assessment 7
CHAPTER 3: METHODOLOGY 9
3.1 Study Design 9
3.2 Study Area 12
3.3 Site Selection 13
3.4 Sample Size 14
3.5 Target Population 14
3.6 Data Collection 15

3.7 Data Analysis 15
3.8 Data Presentation 15
3,9 Ethical Consideration 16
CHAPTER 4: RESULTS AND DISCUSSION 17
RESULTS 17
4.1 Historical & Current Land Use Patterns In Ndirande 17
4.1.1 Overview of Temporal LULCC Dynamics 17
4.1.2 Classification Accuracy and Data Validation 19
4.1.3 Key LULCC Transitions 20
4.1.4 Global Relevance and Local Integration 21
4.2 Socio-Economic and Environmental Drivers of LULCC 21
4.2.1 The Socio-Economic Drivers of LULCC 21
4.2.2 Findings on Socio-Economic Drivers of LULCC 22
4.2.3 Environmental Drivers Of LULCC 25
4.2.4 Ecological Tipping Points and SDG Relevance 31
4.2.5 Integrated Results: Spatial Dynamics of Drivers and LULCC 32
4.3 Hotspot Areas of Increased Landslide Risk in Ndirande Township 34
4.3.1 Geospatial Analysis in ArcGIS Pro 35
4.3.2 Weighted Overlay Function 35
4.3.3 Results of Spatial Distribution of Landslide Susceptibility 35
4.3.4 Landslide Susceptibility Map 36
4.3.5 Risk Classifications 37
DISCUSSIONS 40
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS 43
5.1 Conclusion 43
5.2 Recommendations 43
5.3 Policy Implications 45
REFERENCES 47
APPENDIX I 53
APPENDIX II 56

LIST OF ABBREVIATIONS AND ACRONYMS

UNDRR : United Nations Office for Disaster Risk Reduction

DODMA : Department of Disaster Management Affairs

LULCC : Land Use and Land Cover Changes

GIS : Geo-Information Systems

SPSS : Statistical Package for the Social Sciences

AHP : Analytical Hierarchy Process

ROC : Receiver Operation Characteristic

AUC : Area Under Curve Calculation

DEM : Digital Elevation Model

NSO : National Statistics Office

GEE : Google Earth Engine

NDVI : Normalised Vegetation Index

LEDAPS : Landsat Ecosystem Disturbance Adaptive Processing System

LIST OF FIGURES

FIGURE 1: SHOWING FLOW CHART FOR RESEARCH DESIGN 9
FIGURE 2: SHOWING MAP OF NDIRANDE TOWNSHIP..... 13
FIGURE 3: SHOWING LAND USE AND LAND COVER TRENDS (2015-2024) 18
FIGURE 4: SHOWING NDVI TREND IN DEFORESTED ZONES(2015-2024) 19
FIGURE 5: SHOWING KEY LULCC TRANSITIONS 20
FIGURE 6: PIE CHART SHOWING LIVELIHOOD STRATEGIES.....22
FIGURE 7: SHOWING SETTLEMENT ALONG NASOLO RIVER IN NDIRANDE 23
FIGURE 8: SHOWING AGRICULTURAL ENCROACHMENT ON NDIRANDE HILL.....24
FIGURE 9; MAP SHOWING RAINFALL DISTRIBUTION OF NDIRANDE.....26
FIGURE 10: SHOWING SLOPE MAP FOR NDIRANDE 27
FIGURE 11: SHOWING SOIL TYPES FOR NDIRANDE.....28
FIGURE 12: MAP SHOWING DISTANCE FROM STREAM FOR NDIRANDE 29
FIGURE 13: SHOWING ELEVATION MAP FOR NDIRANDE 30
FIGURE 14: SHOWING ASPECT MAP FOR NDIRANDE..... 31
FIGURE 15: SHOWING THE 2024 LANDSLIDE SUSCEPTIBILITY LEVEL FOR NDIRANDE.....37
FIGURE 16: TEMPORAL TRENDS IN LANDSLIDE SUSCEPTIBILITY FOR NDIRANDE(2015-2024) 39

LIST OF TABLES

TABLE 1; SHOWING DATA TYPES AND SOURCES 12

TABLE 2: SHOWING THE LULCC TRANSITION MATRIX 32

TABLE 3: SHOWING CRITERIA WEIGHTS 33

TABLE 4: SHOWING THE PAIRWISE COMPARISON MATRIX 34

Assessing the Impact of Land Use and Land Cover Changes on Increasing Landslide Risk in Ndirande Township Using GIS and Remote Sensing Approach

CHAPTER 1: INTRODUCTION

1.1 Background

Landslides are a major geological hazard affecting communities worldwide, causing significant loss of life, property damage, and economic disruption. Landslide are defined as the downslope movement of soil, rock and organic materials under the effects of gravity, which occurs when the gravitational driving forces exceed the frictional resistance of the material resisting on the slope. Landslides could be terrestrial or submarine (UNDRR, 2023).

Each and every year, landslides are responsible for hundreds of million dollars' worth of damage and on average it claims more than 1000 lives around the world(Clague & Stead, 2012). Landslide risks increase due to the large increase in global population, settlement and development of sparsely populated landslide prone areas. Alexander (1992) explains that they are three causes of landslides namely, natural causes, perceptions and human activities. Human interventions like deforestation and urbanisation are good examples of Land Use and Land Cover Changes which play an important role in shaping disaster risks and vulnerability. As land is converted from its natural state to serve urban, agricultural or industrial purposes, the altered landscapes often exacerbate the likelihood of disasters such as landslides(Lambin et al., 2001). This is particularly the case in rapidly urbanising regions where the expansion of cities and loss of vegetation disrupts the natural balance of ecosystems.

According to the Malawi National Disaster Risk Management Policy (2015),the country has experienced rainfall induced landslides especially the southern region over the past years. Districts like Zomba, Phalombe, Chiradzulu, Mulanje and Blantyre are major hotspots areas for landslide risks due to heavy rainfall, high terrain, high population density, urbanisation, deforestation as well as poor infrastructure. The Department of Disaster Management Affairs (DoDMA) indicates that landslides affect approximately

10,000 people annually as it causes significant damage to infrastructure, agriculture, and property.

Studies by Msilimba,(2007) show that there has been rapid population growth and urbanisation in both sparsely and dense vegetation and bare land in Lilongwe City due to Land Use and Land Cover Change however the study only focused on landslide mapping and classification in the Northern and Central region of Malawi hence this study aims to assess the relationship between Land Use/Land Cover Changes and landslide risk in Ndirande Township, Blantyre utilizing GIS and remote sensing techniques thereby enhancing the understanding of LULCC and landslides.

The use of Geographical Information Systems (GIS) offers an essential tool to monitor and evaluate LULCC patterns and their implications for disaster risk. Studies from other African cities such as Kira Municipality in Uganda(Busolo, 2023) and Lagos in Nigeria(Faisal Koko et al., 2021) mention the significance use of GIS and Remote sensing in this study as it will help in analysing and monitoring land cover changes and patterns while Remote sensing will be used to provide timely, high and medium resolution images for visual and quantitative assessment. In the context of Ndirande, this research will apply GIS technology to assess how LULCC has altered the landscape and evaluate its impact on landslide risks.

1.2 Problem Statement

Malawian cities are growing rapidly and most growth is in unplanned informal settlements(Riley, 2021). In Ndirande Township, there is high population density and rapid urbanisation which is forcing people to reside in informal areas i.e. Ndirande Hill. Furthermore, agricultural expansion is also increasing the risk of landslides in the area since most of the community members are being forced to cultivate in the hill due to limited lands. Recent studies have not yet addressed the impacts of these land use and land cover changes as far as landslides in Ndirande township are concerned. Despite the clear link between urban growth, environmental degradation and disaster vulnerability, there is

limited understanding of spatial analysis on how LULCC affects landslide risk in Ndirande. This lack of research hinders effective disaster management and urban planning leaving vulnerable populations at greater risk. Therefore, there is need to assess these changes using GIS to inform sustainable land management, disaster risk reduction strategies and understanding the socio-economic drivers of Land Use and Land Cover Change.

1.3 Main Objective And Specific Objectives

1.3.1 Main Objective

The main objective of this research was to assess how Land use and Land Cover Changes increase landslide risk in Ndirande township.

1.3.2 Specific Objectives

I. To analyse the historical and current land use patterns using GIS in Ndirande.
II. To identify the socio-economic and environmental drivers of Land Use and Land Cover Changes in Ndirande.
III. To identify hotspot areas of increased landslide risk in Ndirande.

1.4 Research Questions

I. How do Land Use and Land cover Changes in Ndirande contribute to increased disaster risks and vulnerabilities?
II. What are the spatial and temporal patterns of Land Use and Land Cover Changes in Ndirande over the recent years?
III. Which areas in Ndirande are most vulnerable to landslide disasters as a result of recent LULCC?

IV. What are key socio-economic and environmental factors driving Land Use and Land Cover Changes in Ndirande?

1.5 Significance of Study

According to SDG 11: Sustainable Cities and Communities, there is need to mainstream DRR in land use policy and urban planning in order to make our cities resilient by 2030. This study is crucial as it addressed the growing landslide risk associated with urbanisation and LULCC in Ndirande township, providing insights for urban planning and disaster risk reduction. Using GIS technology, the research has enhanced the understanding of LULCC and landslides by providing detailed spatial data on LULCC patterns and their impact on landslide vulnerability, informing disaster risk reduction strategies by provision of recommendations for policymakers and urban planners that mitigate disaster risks. Furthermore, the findings serve as a model for other rapidly urbanising cities in Malawi or Africa facing similar challenges.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The purpose of this study's literature review is to see what other researchers have already done on the impacts of land use and land cover changes on landslide risk. This review will also tackle on the existing landslide risk assessment frameworks and methodologies, the socio-economic drivers of land use and cover changes as well as the application of GIS and Remote sensing in landslide risk assessment. It will mainly focus on urban areas in developing countries looking at relevant case studies in the Sub-Haran Africa and Malawi. This literature will provide the foundation for understanding the relationships between land use and land cover changes and landslide risk in Ndirande Township, Blantyre.

2.2 Landslide Risk and Land Cover/Land Use Change

Land use/cover change refers to the alteration of the earth's surface due to human activities and natural processes. Land cover and land use change include deforestation, urbanisation, reservoir installation or polder drainage(Luyssaert et al., 2014). Furthermore, Luyssaert et al., states that the scarcity of land promotes the widespread intensification of land management changes in order to better satisfy societal demand for food, fibre, fuel and shelter. Despite the fact that Land use and land cover change work hand in hand, they differ in the sense that land use refers to the total arrangements, activities, and inputs undertaken in a certain land cover used in the sense of the social economic purposes i.e. grazing, timber, extraction, farming. On the other hand, land cover refers to physical elements covering the land surface and to their physical property which include vegetation, water and cities(Thiery et al., 2018).

According to Cruden & Varnes (1996), they defined landslides as natural and potentially hazardous phenomena that move rocks, debris or earth downslope under the influence of gravity. Landslide occurrence has increased greatly by the influence of human activities that have led to the change in land use and land cover(Pacheco Quevedo et al., 2023). Landslides have several triggering factors which include meteorological triggers, earthquakes, human

activities which lead to destructive landslides(Haque et al., 2019). The study further highlighted that population distribution and increased rainfall contributes to large numbers of landslides worldwide.

2.3 The Relationship Between LULCC And Landslides

Various researchers have indicated a number of relationships between the Land/land cover change. Deforestation as one of LULCC impacts landslide risk in the sense that the removal of trees and vegetation that stabilize soil through their root systems. Bare land and slopes tend to be more unstable hence increasing the chances of landslides. For instance, the Kedarnath landslide that occurred in India 2013, it was influenced by deforestation and unplanned construction in the region which resulted into massive landslides triggered by heavy rainfall(Martha et al., 2015).

In addition to that, LULCC and landslides can be linked in terms of urbanisation. Paving over natural land increases surface run-off leading to high water flow on slopes thereby influencing erosion. Construction activities such as building roads and houses often involve cutting into slopes hence altering their shape(Ozturk et al., 2022). This development of infrastructure literally destabilises slopes in the sense that the unplanned urban expansion leads to poor drainage systems as this increases the risk of landslides in those areas.

A review on understanding the drivers of Land Use and Land Cover Change in Africa by Assede et al., (2023), stipulated that the consequences of agricultural expansion influences LULCC. The loss of vegetation cover, soil erosion, and reduction of agricultural yields in specific areas have led to the encroachment of landslide prone areas. Agricultural practices in hilly areas literally weakens slopes and increase landslide susceptibility. For example, in Bududa, Uganda a landslide occurred in 2010 due to deforestation and agricultural expansion into Elagon Mountain. This landslide resulted into killing over 800 people and displacing thousands.

2.4 Application of GIS and Remote Sensing In Landslide Assessment

The integration of Geographic Information Systems (GIS) and Remote Sensing technologies plays an important role in landslide risk assessment especially in urban areas experiencing rapid land use and land cover changes. In African urban cities, GIS and remote sensing tools have been used to identify landslide prone areas, monitor land degradation and analyse the impacts of LULCC on landslide risk.

For instance, a study conducted by Hafashimana, (2020) in Nyabihu district in Rwanda, aimed at assessing the land cover change effects on landslide occurrences and prediction of the occurrence of landslides in the study area using GIS and Remote sensing. Land use/cover maps of 2005 and 2015 were generated and overlaid with mapped landslides while maximum likelihood classification was used to classify the Landsat satellite images. The results of the study show a decrease of agricultural land indicating that most of the landslides occurred in agricultural land.

In Kenya, Said et al., (2021)used time series LULC and selected spatial metrics to predict changes for Kikafu-Weruweru-Karanga watershed on the slopes of Kilimanjaro Mountain. The study's simulated LULC shows the expansion in built up area by 32.55%/27.04km^2 and agriculture 39.52%/52.0km^2 from 2018 to 2030. The Cellular Automata and Markov Chain (CA-Markov) analysis approach was used to model and predict spatial-temporal patterns of LULC using time series images.

A similar study was conducted in Malawi where woodland/forests were assessed using LULC classification. This study covered the whole country such that it depicted that woodlands have been degraded due to illegal human activities(Gondwe et al., 2019). According to Gondwe et al., (2019), in the years 1999 to 2018 woodland net losses 8.4% (4.39–3.39 million ha) were to plantation, grassland, agriculture transition intensities. This study utilized GIS and Google earth for image classification of satellite images into six IPCC LULC as well as change detection.

Looking at all the studies done by different researchers in Malawi, Ndirande township still remains vulnerable to the impacts of LULCC which is affecting landslide risk. Therefore, there is a need to assess the impacts of LULCC in the area as well as finding out how socio-economic factors have influenced LULCC over the past decades in order to come with better urban planning strategies to reduce vulnerability of the community to Landslide risk.

CHAPTER 3: METHODOLOGY

3.1 Study Design

The purpose of this study was to assess the impact of LULCC on landslide risk in Ndirande Township. This study adopted a spatial analysis approach using GIS tools. It employed both qualitative and quantitative research methods for comprehensive analysis. The qualitative technique was utilized to gain a better understanding of the behavior and attitude of the selected sample size in the study area, while the quantitative method was used to quantify and analyze the data by using GIS, Microsoft Excel, and statistics packages (SPSS).

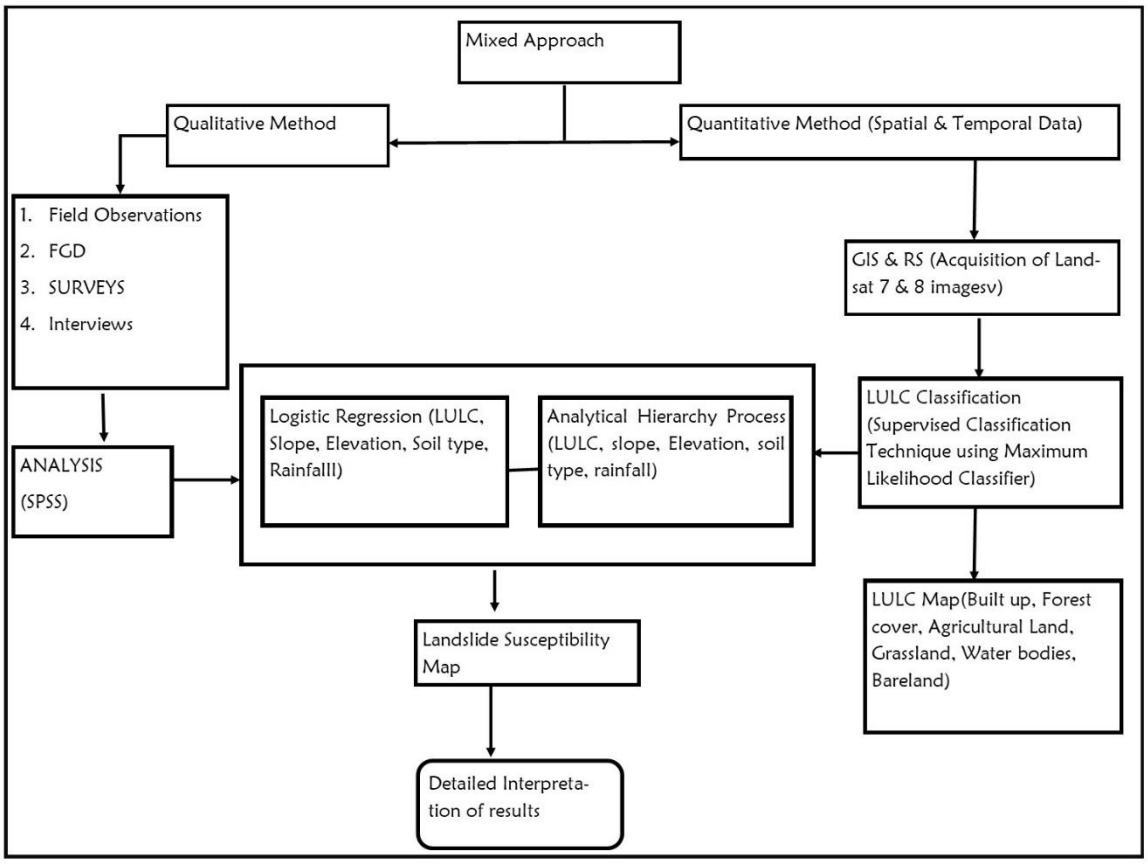


Figure 1: Showing Flow Chart for Research Design

LULC Classification

On image classification, a Landsat 5, 8 and sentinel-2 images for Ndirande were obtained from USGS. The GIS software was utilised for image analysis for the years (2015, 2020 and 2024) thus classifying it into six IPCC LULC I,e, Built up area, Forest cover, Agricultural land Grassland, Water bodies and Bare land using the supervised classification technique.

Methods of Integrating LULC and Landslide Risk

A study by Abedini et al.,(2017) in Iran provides an overview of the relevance of using the Analytical Hierarchy Process(AHP) and Logistic Regression models in Landslide susceptibility. The AHP was used in this study to assign weights to the factors that influence landslides such as LULC, slope, elevation, rainfall, Soil type whilst the Logistic Regression was used in analysing the relationship between LULC and Landslide occurrence thus predicting the probability of landslide occurrence basing on the LULC categories. For model validation, the Receiver Operation Characteristic(ROC) curve analysis and Area Under the Curve calculation(AUC) were calculated.

Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a decision-making methodology that was developed by Thomas L. Saaty in the 1970s(R. W. SAATTY, 1987). It provides a structured approach for organizing and analyzing complex decisions involving multiple criteria and alternatives. AHP is particularly useful in situations where decision-makers need to make choices among diverse options and consider various factors that may have different levels of importance.

Hierarchy Construction: A decision problem is decomposed into a hierarchical structure comprising a goal, criteria, sub-criteria, and alternatives(Acharya et al., 2022b). This hierarchical representation helps in breaking down the complexity of the decision into more manageable components. Pairwise Comparisons: Decision-makers are asked to compare each element in a given level of the hierarchy with every other element in terms of their

importance. These comparisons are expressed using a numerical scale. Several AHP scales has been developed based on user preferences,

On this project the scale ranged from 1 to 5 where 1 was for equally preferred, 2 for mildly preferred, 3 for moderately preferred, 4 for greatly preferred and 5 for always preferred. when the AHP is used to deal with spatial decision making in GIS field it is called spatial AHP(Bunruamkaew & Murayam, 2011d).

Steps For Pair-Wise Comparison

As long as a pairwise matrix is introduced the relative weight was calculated by the following procedures

- Normalize and calculate the total values in each column of the pairwise matrix.
- Divide each value element in the matrix by its column to introduce the normalized pairwise matrix
- Do the division method for the sum of the normalized row of the matrix by the number of factors used (n) to come up with a weight matrix

Data Type and Source

The table below shows the data type and their sources respectively.

Data	Source
Topographic Data (Elevation, Slope, Aspect)	From USGS Earth Explorer (30m SRTM DEM)
Geological Data (Soil type)	Obtained from Department of Geological Survey.
Hydrological Data (Annual Rainfall)	CHRS data portal
Land-use/ Land cover	Satellite imagery (Landsat 5 and 8 image -30m)
Historical Landslide data and Inventory maps	From Blantyre district disaster Office
Field observations	Field visits

Table 1; Showing data types and sources

3.2 Study Area

Ndirande Township is an urban area located in Blantyre District, Southern Region, Malawi. It is situated approximately 5 km southwest of Blantyre City Centre. Ndirande is a densely populated area, characterized by informal settlements, steep slopes, and poor infrastructure. The township is located at Latitude 15.7833° S, and Longitude 35.0167° E with an elevation 1,044 meters (3,425 ft) above sea level. According to the National Statistical Office of Malawi,(2018), Ndirande has a total population of 135,617 and a total area of approximately 12.5 km².

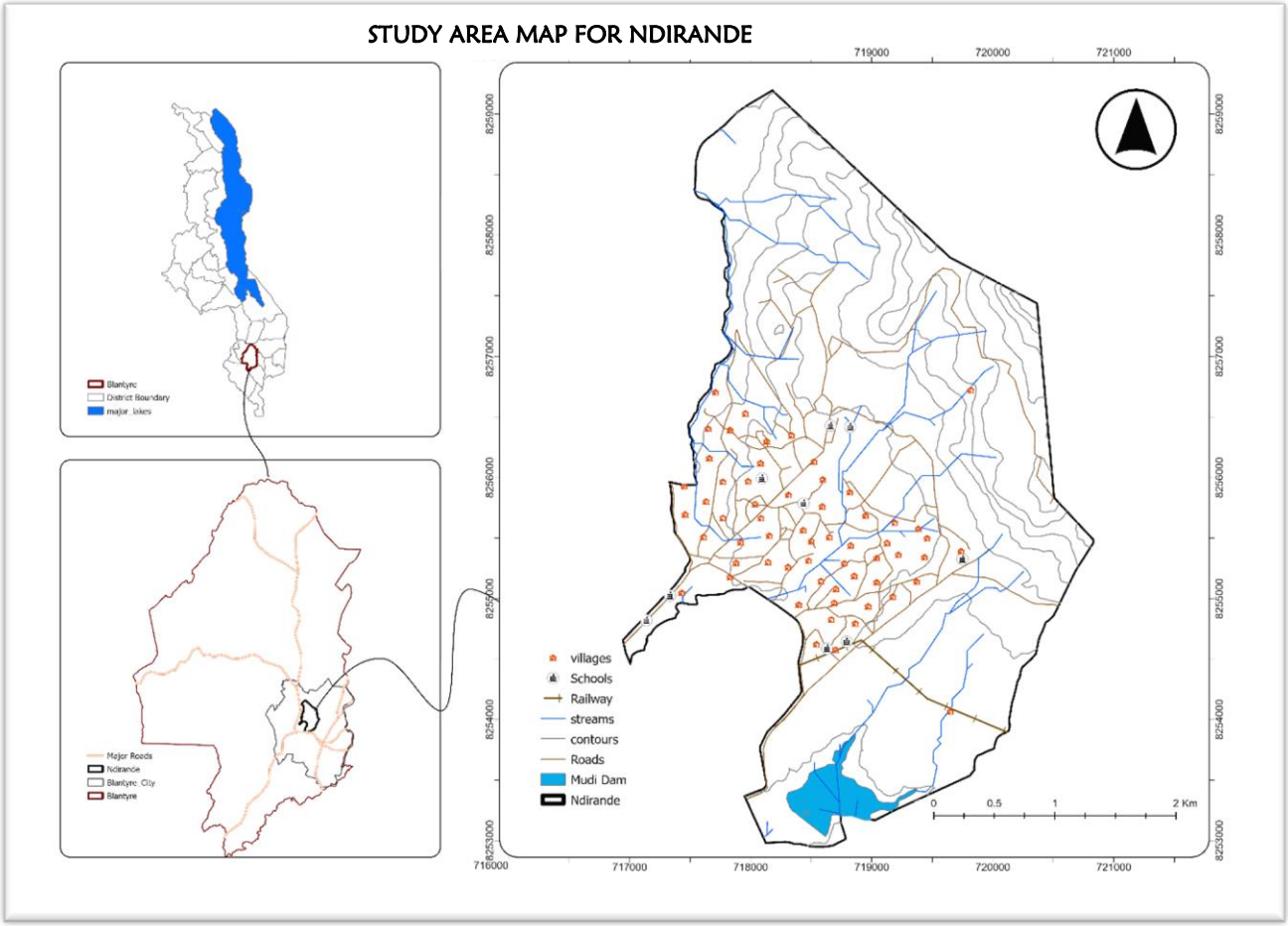


Figure 2: Showing Map of Ndirande Township

3.3 Site Selection

The area was chosen due to the fact that it has a high population density(10000/km^2) which subjects it to rapid urbanisation. Community members have also encroached Ndirande hill hence informal settlements in high risk areas with poor infrastructure and agricultural expansion. Ndirande has also a history of rainfall induced landslides resulting from the recent effects of cyclone.

3.4 Sample Size

To get the respondents, a multi-stage sampling technique was used. The sample size for the study was determined using the Taro Yamane's formula for the determination of sample size for known population. The formula is:

$$n = \frac{N}{1+N(e)^2}$$

Where n = sample size

N = population

1 = constant

e = error margin (at 15%)

Population of Ndirande = 135,617 (NSO, 2018)

$$n = \frac{135,617}{1 + 135,617(0.15)^2}$$

n=44.42

Therefore, 44 subjects were involved in the study using random sampling

3.5 Target Population

The study specifically focused on household heads or any other elder person available per household, who had knowledge about land use and cover change and has an overall view of the household activities. To avoid gender bias, both males and females were included.

3.6 Data Collection

The data for the chosen sample size were collected using interviews (for qualitative data) and a well-designed questionnaire (for quantitative data) that was separated into sections and the questions were based on the specific objectives.

GIS datasets (DEMs, Shapefiles) as well as satellite imagery (Landsat, Sentinel or google earth pro) were obtained from relevant sources respectively.

3.7 Data Analysis

Descriptive analysis was conducted which characterised households according to their demographic household income and socio-economic drivers of LULCC. The data collected from this study was manually checked for missing, irrelevant, and inaccurate information. The quantitative data collected was analyzed using Microsoft Excel and the Statistical Package for Social Sciences (SPSS). The data was loaded into Microsoft Excel and then imported into SPSS, where descriptive statistics was used to analyze the data. GIS and Remote sensing were used in image classification using supervised techniques. The tools also were used for change detection of the past decade as well as accuracy assessment.

3.8 Data Presentation

The data analysed by Microsoft excel and Statistical Package for Social Sciences (SPSS) were presented in graphs, tables, bar charts and pie charts. The data analysed by GIS and Remote sensing were presented on maps.

3,9 Ethical Consideration

The Malawi University of Science and Technology Research Ethics Committee (MUSTREC), department of Ndata School of Climate and Earth Sciences, approved this study, and the Group village head granted authorization to conduct the research. Because confidentiality and privacy are vital, the names of the respondents were replaced with numbers. First, the participants were informed about the questionnaire, as well as the importance of conducting the study. Participants were permitted to participate in the study voluntarily rather than being forced to do so.

CHAPTER 4: RESULTS AND DISCUSSION

RESULTS

4.1 Historical & Current Land Use Patterns In Ndirande

Land Use and Land Cover Change (LULCC) is a critical factor influencing environmental hazards in rapidly urbanizing landscapes such as Ndirande Township. This section presented a systematic analysis of LULCC from 2015 to 2024, using geospatial tools to map spatial transitions, quantify landscape fragmentation, and correlate land use shifts with landslide susceptibility.

4.1.1 Overview of Temporal LULCC Dynamics

Over the past decade, Ndirande has undergone significant land cover transformations characterized by the rapid expansion of informal settlements, deforestation, and agricultural encroachment. Landsat 5 (2015), Landsat 8 (2020), and Sentinel-2 (2024) satellite imagery were analysed through supervised classification in ArcGIS Pro and Google Earth Engine. The selected dry-season imagery minimized cloud cover, enhancing classification accuracy.

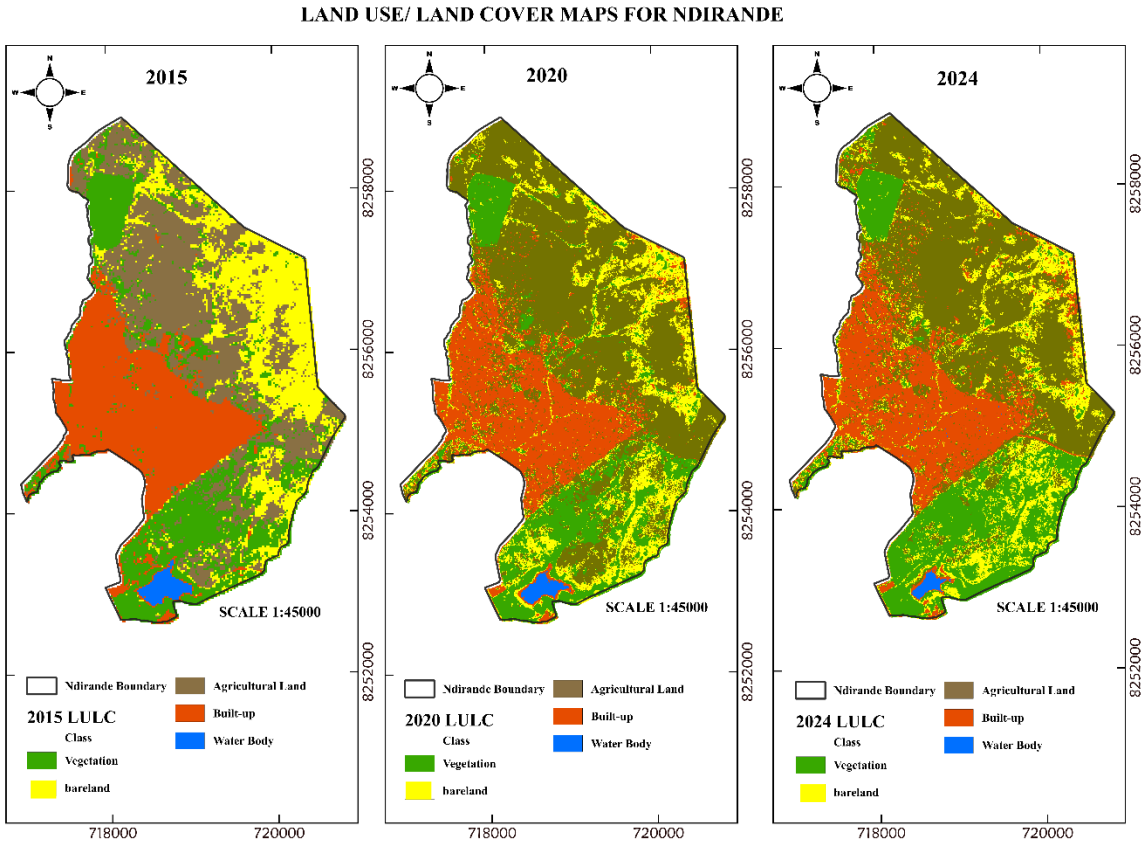


Figure 3: Showing Land Use and Land Cover trends (2015-2024)

Results showed that built-up areas expanded by 23.5% between 2015 and 2024, mainly on slopes exceeding 15°, reflecting housing pressure in hazard-prone zones, forest cover declined by 34%, particularly along Ndirande Hill while agricultural land increased by 9.2%, often replacing natural vegetation and grasslands.

NDVI Trend Analysis

NDVI (Normalized Difference Vegetation Index) is a measure of vegetation greenness. Analysing NDVI trends provided insights into vegetation health and deforestation patterns. NDVI declined by 0.25 (2015: 0.68 → 2024: 0.43) in deforested zones, correlating

(R^2 = 0.76) with landslide incidents reported in Blantyre District Disaster Office records.

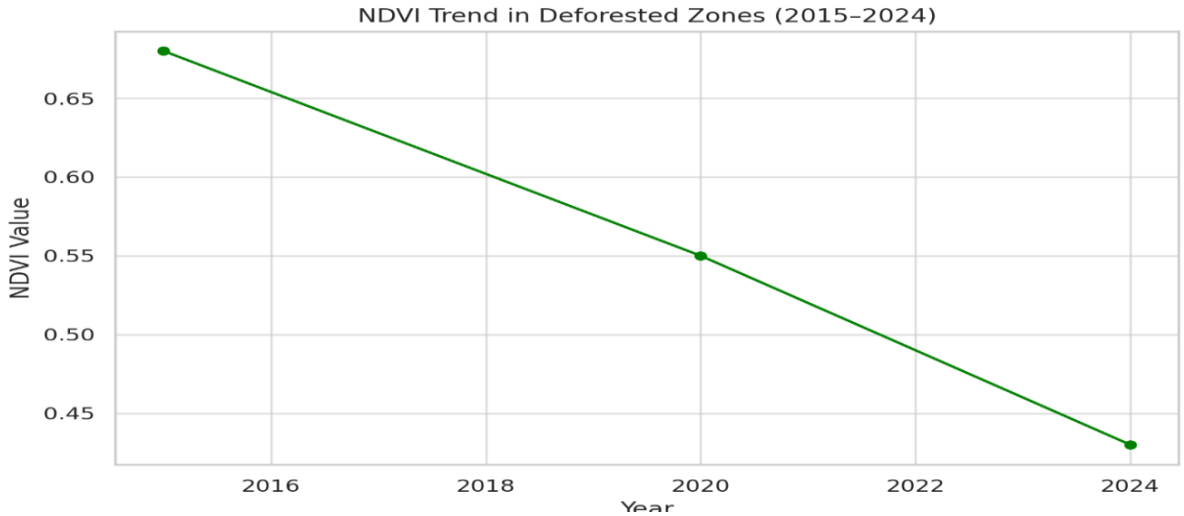


Figure 4: Showing NDVI Trend in Deforested Zones(2015-2024)

This line graph shows the decline in NDVI (Normalized Difference Vegetation Index) over the years. The decline from 0.68 to 0.43 indicates a reduction in vegetation health and density directly correlated with deforestation and increased landslide risk.

4.1.2 Classification Accuracy and Data Validation

The classification achieved high accuracy, with overall values improving from 89.2% (2015) to 93.8% (2024), supported by a kappa coefficient of 0.91. Validation involved 550 GPS-referenced ground truth points and NDVI analysis, which showed a notable decline (from 0.68 to 0.43) in vegetation density in deforested areas, strongly correlating with reported landslide events (R^2 = 0.76).

4.1.3 Key LULCC Transitions

The graph below shows a bar graph with LULC Transitions within the years in Ndirande.

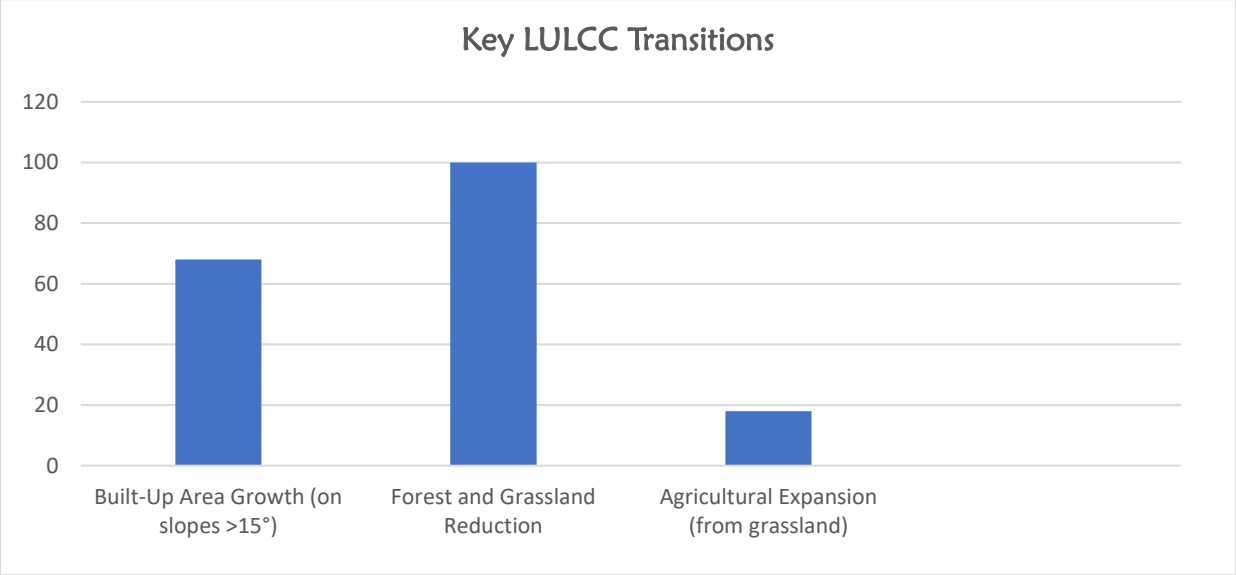


Figure 5: Showing Key LULCC transitions

The graph indicates an increase in built up areas due to encroachment into steep terrains with 68% of new settlements located on slopes >15°. These developments encompass poor infrastructure with poor drainage systems hence increasing landslide risk. In addition, There is forest and grassland reduction contributing to soil instability. Agricultural expansion which led to 18% loss of grasslands being converted to subsistence agriculture through unreinforced terracing on marginal slopes.

These changes align with broader patterns observed in comparable urban regions across Sub-Saharan Africa, where informal development and land scarcity drive occupation of ecologically fragile zones.

4.1.4 Global Relevance and Local Integration

These findings reinforce global calls for risk-informed urban planning (SDG 11) and demonstrate how localized LULCC analysis can inform resilient land use policies. The integration of community insights and traditional knowledge is essential for tailoring interventions to the local context.

4.2 Socio-Economic and Environmental Drivers of LULCC

4.2.1 The Socio-Economic Drivers of LULCC

A mixed-methods research design was employed to comprehensively identify the socio-economic and environmental drivers of Land Use and Land Cover Changes (LULCC) in Ndirande.

It involved Quantitative analysis findings. Logistic regression conducted in SPSS v28 revealed a statistically significant relationship between household income levels and residential location. Specifically, low-income households were found to be over ten times more likely to settle on high-risk slopes (>15°), where land is significantly cheaper ($0.5/m²) compared to safer zones ($5/m²). Between 2015 and 2024, informal settlements expanded by 23.5%, with a majority occurring on steep slopes. This trend reflects similar patterns observed in other Sub-Saharan African cities, such as Nairobi's Mathare Valley (UN-Habitat, 2020).

On the other hand, Qualitative analysis findings from focus group discussions and interviews highlighted land scarcity, poverty, and insecure tenure as major drivers of LULCC. Approximately 45% of households rely on charcoal production as their main source of income, contributing to extensive deforestation. This aligns with findings in Uganda's Kira Municipality, where charcoal dependence has driven environmental degradation (Busolo, 2023).

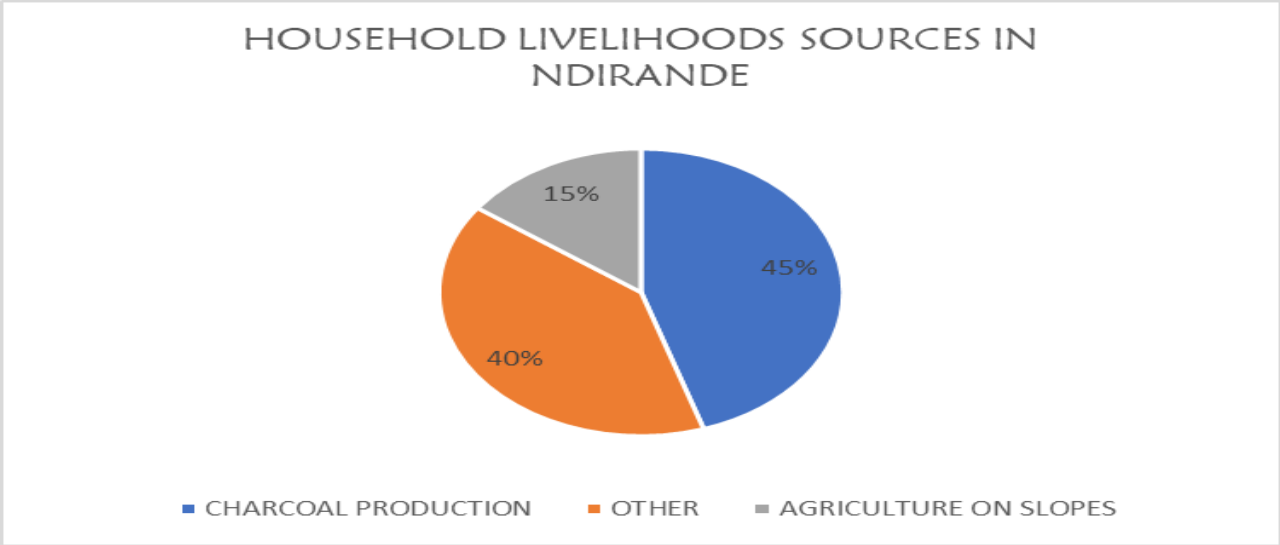


Figure 6: Pie Chart showing Livelihood Strategies

This pie chart breaks down livelihood strategies among surveyed households. It shows that 45% rely on charcoal production, a key driver of deforestation and environmental degradation in Ndirande.

The socio-economic and environmental drivers of Land Use and Land Cover Change (LULCC) in Ndirande Township revealed the link between poverty, rapid urbanization, and environmental degradation.

4.2.2 Findings on Socio-Economic Drivers of LULCC

i. Urbanization and Informal Settlements

Urban expansion in Ndirande over the past decade has been both rapid and spatially unregulated, particularly on steep and environmentally sensitive slopes. Between 2015 and 2024, built-up areas in Ndirande increased by 23.5%, with 68% of new developments occurring on slopes steeper than 15°. This expansion is largely attributed to cost disparities in land pricing. Land in high-risk areas (e.g., steep slopes) is significantly cheaper ($0.5/m²) compared to land in safer zones ($5/m²), creating financial incentives for low-income

households to occupy hazard-prone areas. The picture below shows some of the informal settlement along Nasolo river that were interviewed.



Figure 7: Showing settlement along Nasolo river in Ndirande

ii. Livelihood Strategies and Environmental Degradation

Household survival strategies in Ndirande, particularly among low-income groups, have contributed to extensive environmental changes that further exacerbate landslide risk. Approximately 45% of surveyed households depend on charcoal production as their primary source of income. Remote sensing analysis revealed that this activity is a major contributor to forest degradation, accounting for an estimated 34% loss in forest cover since 2015. The removal of vegetation significantly undermines slope stability by eliminating root systems that bind the soil.

Due to land scarcity, 22% of households engage in subsistence farming on slopes ranging from 15° to 25°. These farming activities, often carried out without soil conservation measures, have led to the conversion of 18% of grasslands into agricultural plots. Unregulated terracing

and cultivation in these areas further weaken slope integrity, making them more susceptible to erosion and landslides. Image below Shows Agricultural Encroachment of Ndirande Hill



Figure 8: Showing Agricultural Encroachment on Ndirande Hill

iii. Demographic Pressure

Rapid population growth and limited land availability have intensified land-use pressures in Ndirande, with a population density of approximately 10,000 people per square kilometre, Ndirande significantly exceeds Malawi's urban average of 2,200 people/km². This demographic pressure fuels land competition, leading to the occupation of unsuitable and hazardous terrain. The resultant informal urban sprawl further disrupts ecological stability and increases the township's exposure to landslide risk.

4.2.3 Environmental Drivers Of LULCC

i. Rainfall and Climate Variability

Data from the Department of Disaster Management Affairs (DoDMA, 2023) show an 8% increase in annual rainfall since 2015. Extreme events (>50mm/day) now account for nearly 45% of all reported landslides. Using ArcGIS Pro, rainfall raster data were extracted and analyzed, revealing annual precipitation ranging from 1005 mm to 1142 mm, which elevates landslide susceptibility through increased pore pressure and slope saturation.The Rainfall Distribution Map, generated using ArcGIS Pro, presents annual precipitation extracted via the "Extract by Mask" tool, ranging between 1005 mm and 1142 mm. This spatial visualization helps to highlight zones with higher rainfall accumulation, which correlate with reported landslide hotspots. Areas with rainfall >1100 mm showed a strong spatial overlap with slope failures, justifying rainfall as a primary landslide trigger. The map provides an essential baseline for hydrological modelling and risk zoning.

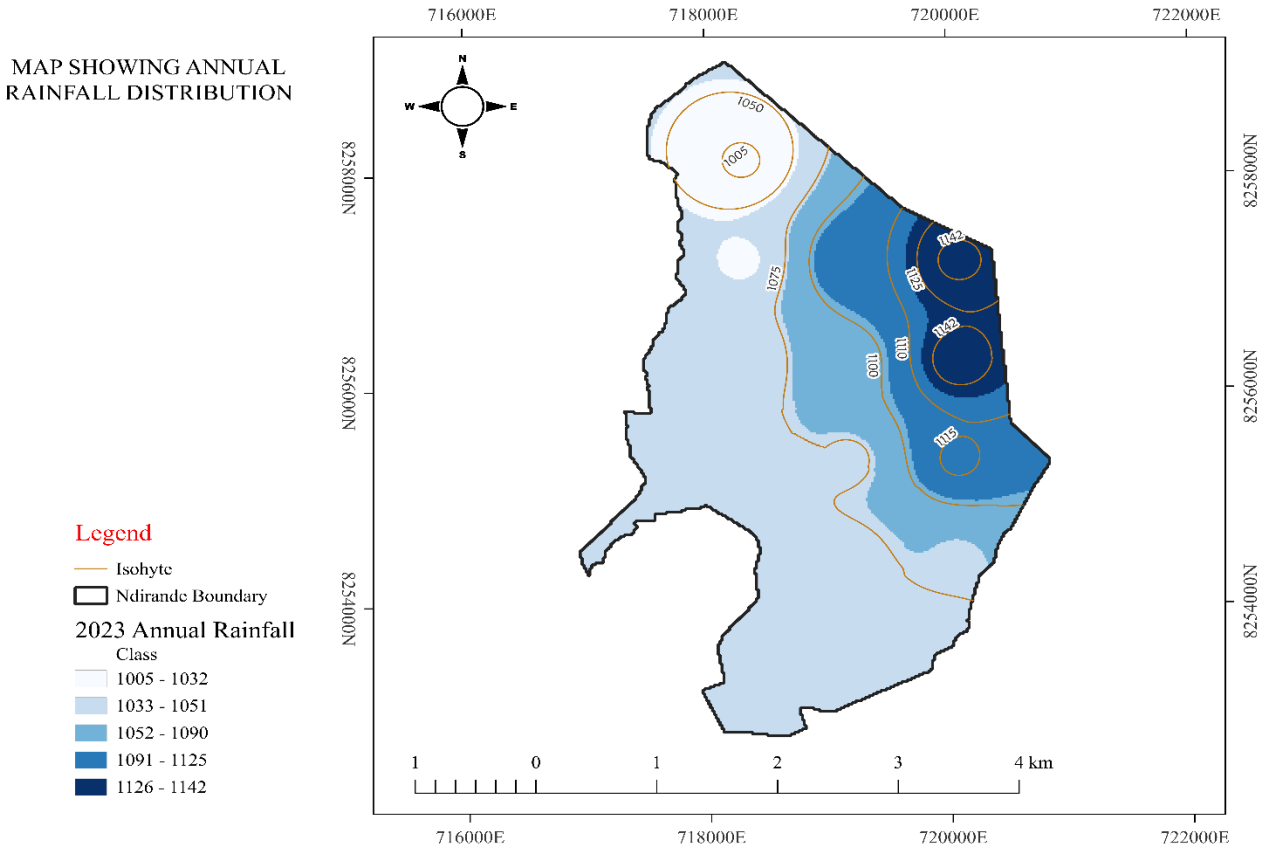


Figure 9; Map showing rainfall distribution of Ndirande

ii. Slope Gradient

Using DEM-based modeling and field validation, slope angles were categorized into five classes. Slopes exceeding 28° were most associated with landslides, consistent with slope stability theory (Yalcin and Bulut, 2007). The dominant soil ,sandy-loam loses up to 25% of its shear strength when saturated. The Slope Classification Map delineates areas by gradient classes, clearly identifying the steeper slopes predominantly on eastern Ndirande Hill. Over 39% of landslide incidents occurred in areas classified as >28°, visually reinforcing slope

steepness as a critical risk factor. The map aids in prioritizing zones for engineering stabilization or construction restrictions.

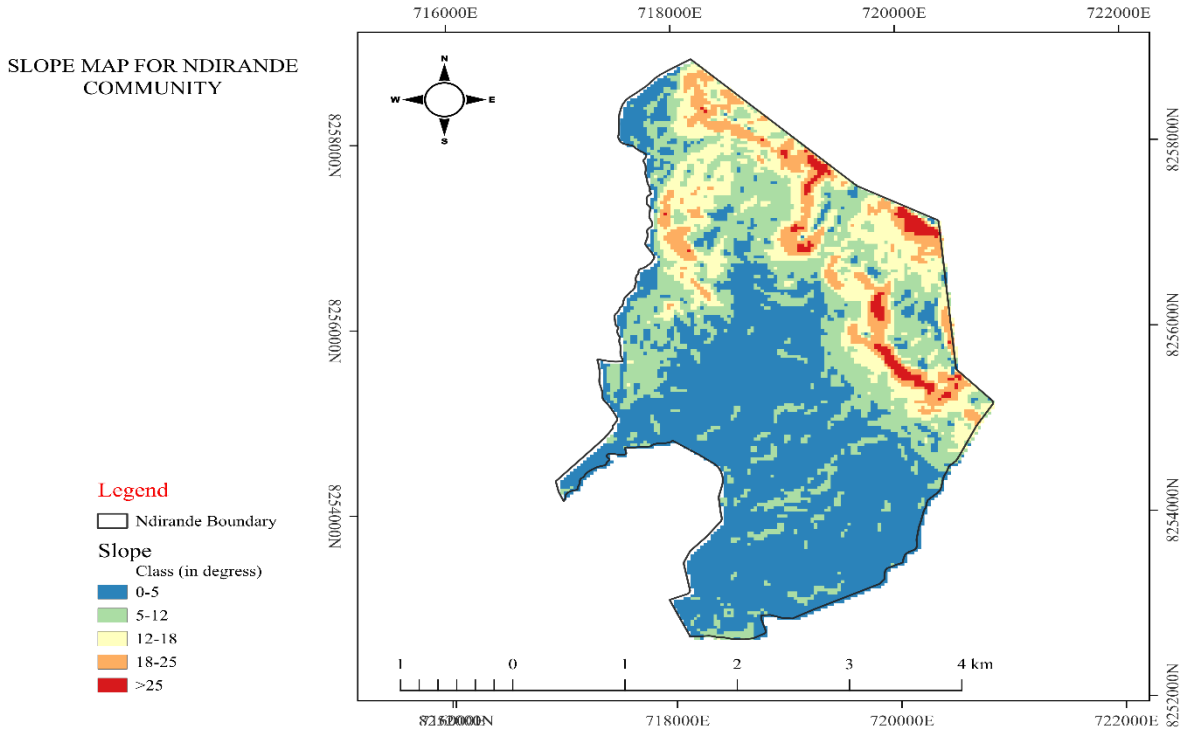


Figure 10: Showing Slope Map for Ndirande

iii. Soil Characteristics

Landslide susceptibility is influenced by soil type. The soil type map below illustrates the distribution of soil types within Ndirande Township, highlighting two primary soil classes: Eutric Cambisols and Leptosols. Eutric Cambisols dominate the central and southern parts of the area, while Leptosols are mostly found along the northern and eastern margins. These soil types play a critical role in influencing landslide susceptibility. Leptosols, typically shallow, poorly developed, and found on steep slopes, have low water retention capacity and are structurally weak, making them highly prone to landslides, especially during intense rainfall events. On the other hand, Eutric Cambisols are deeper and better developed but may still

contribute to slope instability when saturated due to their moderate permeability and structure. The spatial relationship between soil type and slope gradient is vital, as areas dominated by Leptosols often coincide with steeper terrains, thus increasing the overall risk of landslides. Understanding soil distribution is therefore essential in evaluating and mitigating landslide hazards in Ndirande (Sarkar et al., 2016)

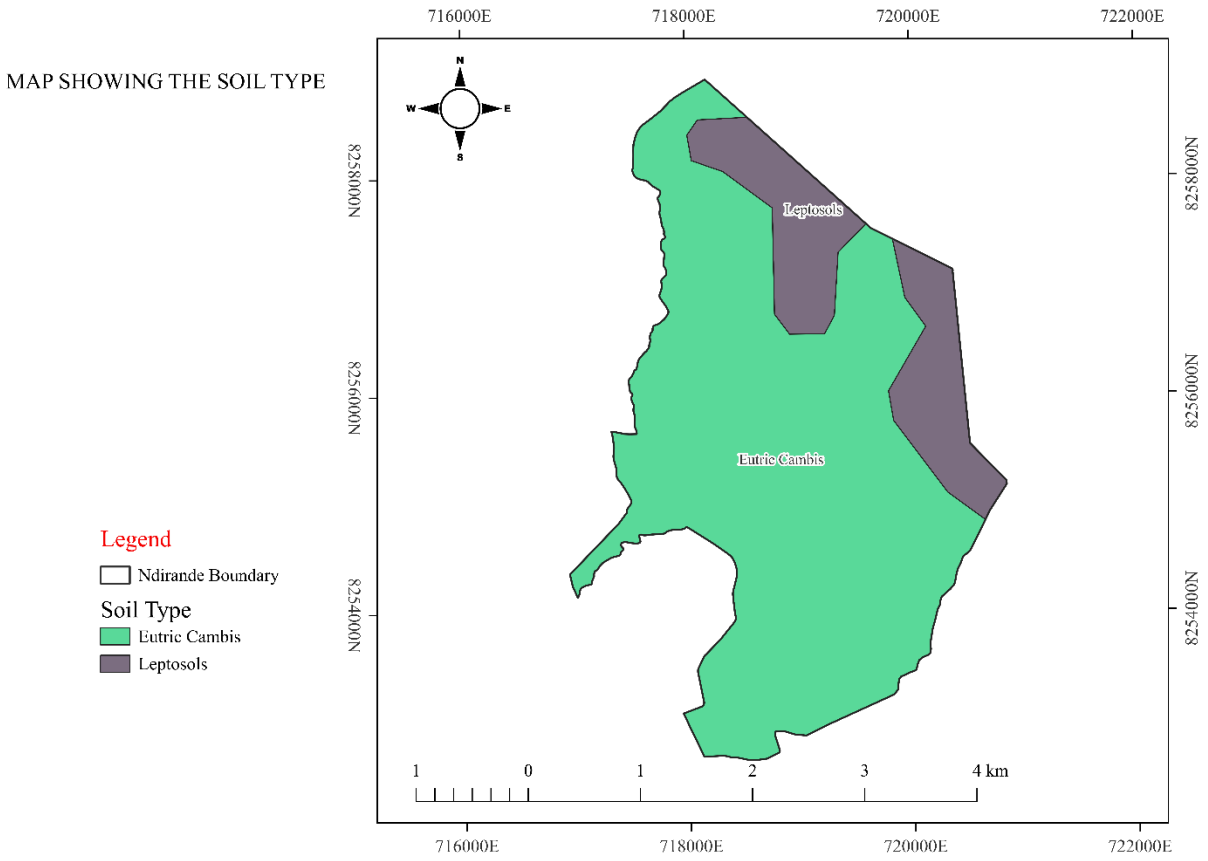


Figure 11: Showing Soil Types for Ndirande

iv. Proximity to Streams

Stream buffer zones were delineated using flow accumulation and Euclidean distance tools in ArcGIS. Most landslide events were located within 150m of first- to third-order streams, where water saturation and toe erosion are prevalent (Akgun and Turk, 2011). The Distance to

Streams Map revealed a concentration of landslide events within 150 meters of primary and secondary stream channels. These proximity classes highlight areas where toe erosion and undermining of slope bases occur, leading to destabilization. This spatial layer is crucial for identifying riparian zones needing buffer protection or controlled development.

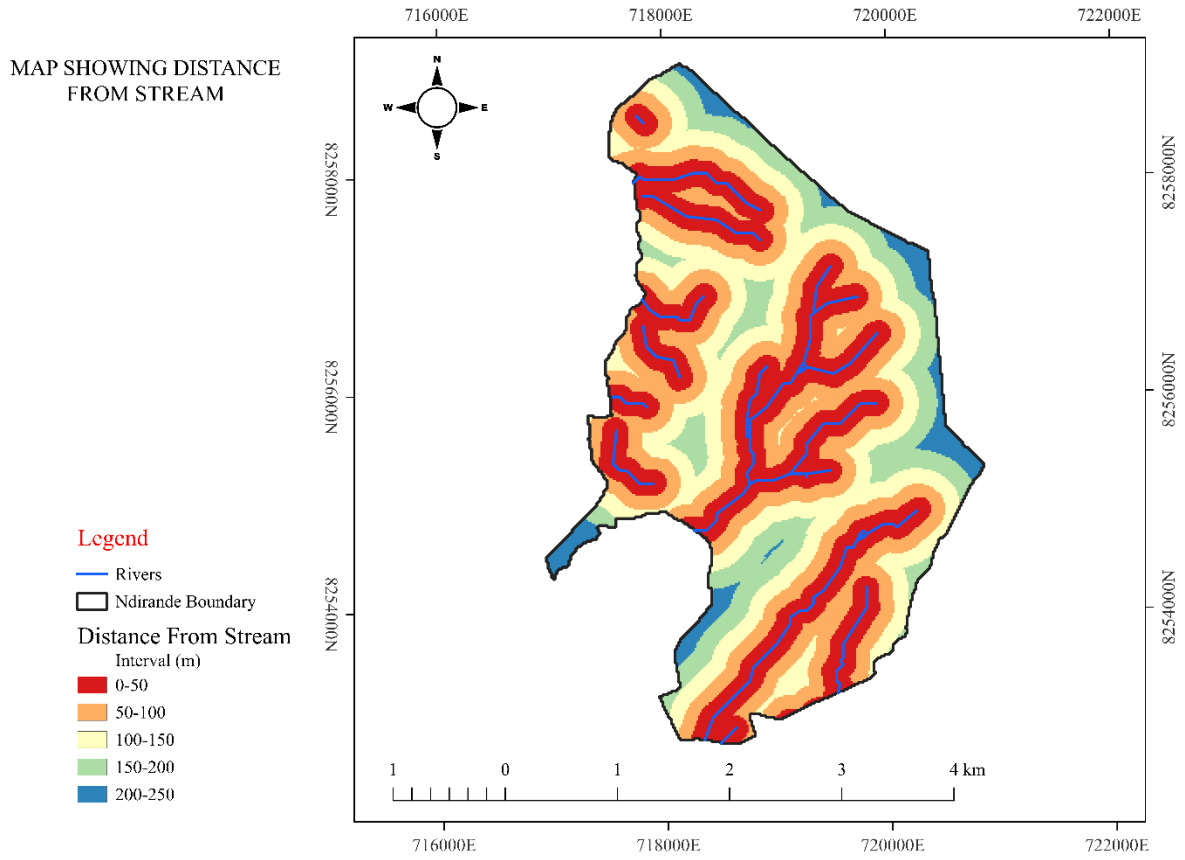


Figure 12: Map showing Distance from stream for Ndirande

v. Elevation

Elevation data reclassified using natural breaks indicated that mid-altitude zones (1138–1336m) experienced the highest incidence of landslides. Slope aspect analysis identified eastern and southeastern exposures as more vulnerable due to higher rainfall and wind-driven

erosion (Komac, 2006). The Elevation Map helps illustrate mid-altitude dominance of landslide activity, often where slope transitions are sharp and runoff is high.

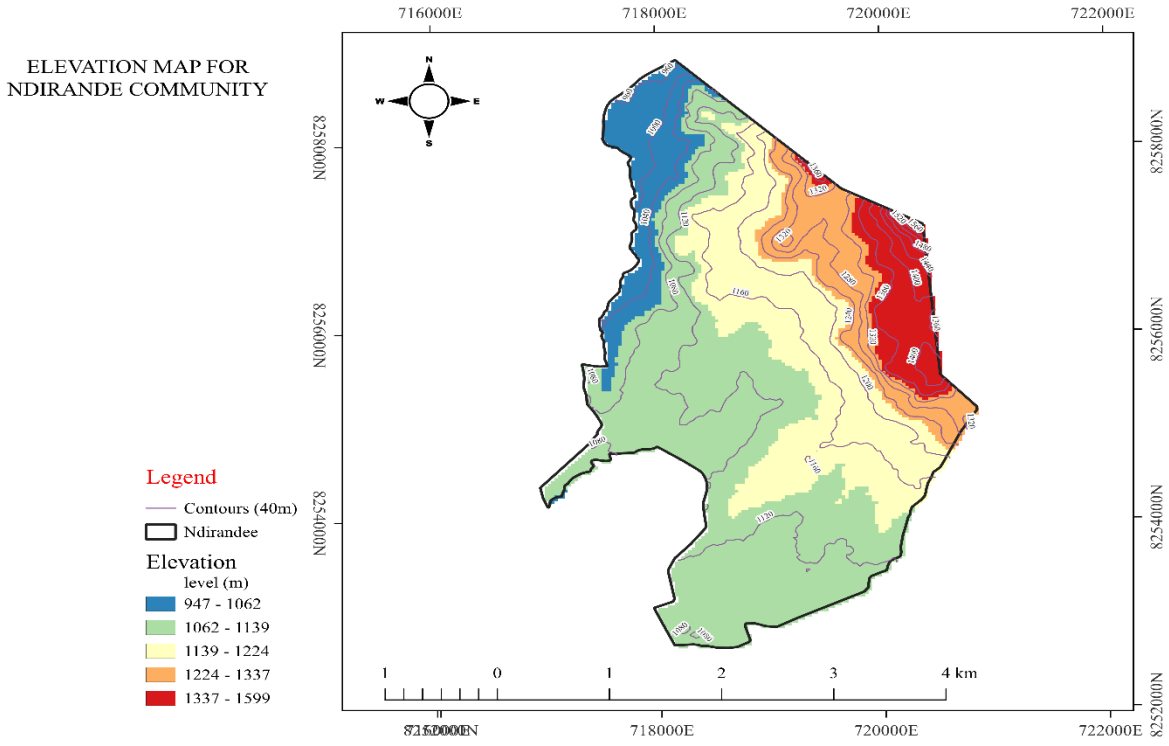


Figure 13: Showing Elevation map for Ndirande

vi. Aspect

The Aspect Map of Ndirande reveals that east and south-east facing slopes are particularly susceptible to landslides due to their exposure to prevailing rainfall and wind patterns which increase soil moisture and reduce slope stability. These orientations are more likely to experience saturation, erosion, and vegetation loss which are key factors that trigger landslides especially when combined with unstable soil types like Leptosols. Additionally, while flatter areas may not be prone to landslides directly, they remain vulnerable to waterlogging and

debris flow from higher slopes. This highlights the critical role of aspect in influencing local hydrological conditions and landslide risk (Regmi et al., 2014).

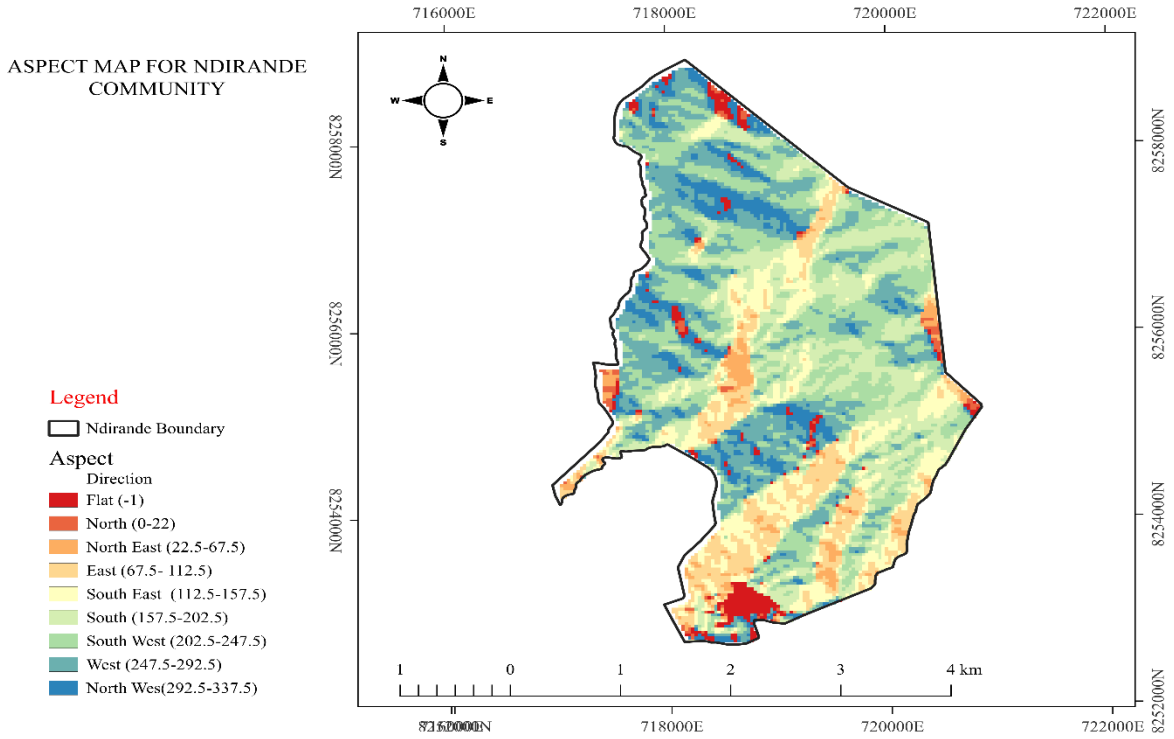


Figure 14: Showing aspect map for Ndirande

4.2.4 Ecological Tipping Points and SDG Relevance

The findings of this study affirmed the Ecological Tipping Points Theory (Scheffer et al., 2001), which states that ecosystems can undergo abrupt and irreversible degradation when anthropogenic pressures exceed certain thresholds. In Ndirande Township, unsustainable land use practices particularly deforestation, poor agricultural methods, and unregulated urban expansion have collectively pushed the local landscape toward such a tipping point, increasing its vulnerability to landslides.

This theory is directly relevant to key Sustainable Development Goals (SDGs) such as Climate Action (SDG 11) where there is observed increase in extreme rainfall events and their correlation with landslides aligning with IPCC projections for Southern Africa. Life on

Land(SDG 15), A 34% reduction in forest cover since 2015 indicates the urgent need for reforestation and slope stabilization programs to protect ecosystems and reduce disaster risk.

4.2.5 Integrated Results: Spatial Dynamics of Drivers and LULCC

LULCC Patterns and Transition Matrix (2015–2024)

Land cover analysis between 2015 and 2024 revealed significant transitions:

LULC Class	2015 (%)	2024 (%)	Net Change (%)
Forest	4.03	4.50	+0.47
Built-Up	33.08	39.68	+6.60
Agriculture	5.67	14.87	+9.20
Bare Land	55.38	39.75	−15.63

Table 2: Showing The LULCC Transition matrix

The data show a clear shift from bare land to built-up and agricultural use, highlighting increased human pressure on the landscape particularly on slopes, where 68% of new settlements were established.

Analytic Hierarchy Process (AHP) for Landslide Risk Weighting

The AHP was used to quantify the influence of seven factors contributing to landslide risk. Expert pairwise comparisons were conducted using a modified Saaty scale (1–5), and criteria weights were calculated after matrix normalization.

Final Criteria Weights:

Criterion	Weight (%)	Rationale
Land Use/Land Cover	35	Dominant role of urban expansion and deforestation
Slope	19	High correlation with landslide incidence (>28° slopes)
Rainfall	17	8% increase in rainfall intensity since 2015
Elevation	10	Mid-altitudes linked with terrain instability
Distance to Streams	9	Toe erosion and saturation effects within 150m buffer zones
Soil Type	5.6	Sandy-loam soils with low cohesion and high permeability
Aspect	4.4	East/southeast-facing slopes more prone to erosion

Table 3: Showing Criteria Weights

The Consistency Ratio (CR) = 0.08 confirmed the reliability of the comparisons.

Implications of the AHP Results

The AHP findings emphasized that human-induced land cover changes are the most significant factor in landslide risk. The high weight of LULC (35%) reflects extensive deforestation and informal development, while the weights for slope and rainfall highlight the interaction between topography and climate variability.

4.3 Hotspot Areas of Increased Landslide Risk in Ndirande Township

Landslide risk hotspots in Ndirande are shaped by socio-ecological dynamics. As a peri-urban area of Blantyre, Ndirande hosts a high population density (10,000/km²), significantly above Malawi's urban average, driving informal settlements onto geotechnically unstable slopes. Cyclone Freddy (2023), which displaced 200 households through slope failures, underscored the urgency of identifying high-risk zones. This section integrated geospatial modeling, socio-economic data, and hydrological analysis to identify landslide-prone areas.

Criteria	LULC	Slope	Distance to the stream	Elevation	Rainfall	Aspect	Soil
LULC	1	4	3	3	3	5	5
Slope	0.25	1	4	2	2	4	3
Distance to the stream	0.3333	0.25	1	0.3333	0.3333	2	4
Elevation	0.3333	0.5	3	1	0.3333	2	2
Rainfall	0.3333	0.5	3	3	1	4	3
Aspect	0.2	0.25	0.5	0.5	0.25	1	0.5
Soil	0.2	0.3333	0.25	0.5	0.3333	2	1
SUM	2.415	6.833	14.75	10.333	7.2493	20	18.5

Table 4: Showing the Pairwise Comparison Matrix

The Analytic Hierarchy Process (AHP) was employed for its interpretability and capacity to incorporate both qualitative and quantitative inputs, enabling transparent landslide risk assessment(Saaty, T.L. 1977). Seven criteria were selected based on a review of African landslide studies and local fieldwork: LULC, slope, rainfall, soil type, proximity to streams, elevation, and aspect. Pairwise comparisons were performed using expert judgment from

literature and local knowledge. A Consistency Ratio (CR) of 0.08 confirmed the matrix's logical consistency.

4.3.1 Geospatial Analysis in ArcGIS Pro

Terrain analysis using Digital Elevation Model (DEM) data provided critical insights into slope gradients, aspect orientations, and hillshade patterns, which are key determinants of landslide susceptibility in Ndirande. These terrain parameters helped identify areas where slope steepness and directional exposure increase vulnerability to slope failures. Concurrently, supervised land use and land cover (LULC) classification was performed using high-resolution, pan-sharpened Landsat and Sentinel-2 imagery. This classification enabled precise mapping of land cover types across the study period. Change detection analysis revealed a 23.5% increase in built-up areas from 2015 to 2024, primarily at the expense of forested and agricultural land, illustrating the rapid urban encroachment into ecologically sensitive zones and its implications for increased lands

4.3.2 Weighted Overlay Function

Each criterion was reclassified on a 1–10 scale, and weights derived from AHP were used in a weighted overlay model.The landslide susceptibility index was then computed using the following formula:

$$\text{Index} = \sum(W_i \times S_i)$$

Where W_i represents the weight assigned to each criterion based on the AHP analysis, and S_i denotes the score assigned to each class within each criterion.

4.3.3 Results of Spatial Distribution of Landslide Susceptibility

Eastern Ndirande Hill emerged as the primary hotspot for landslide risk due to the convergence of several interrelated stressors. Although forest cover slightly increased from 4.03% to 4.50% between 2015 and 2024, this marginal gain conceals significant degradation

driven by widespread charcoal dependence, which affects approximately 45% of households. Settlement expansion has also exacerbated the risk, with around 68% of new houses built on slopes steeper than 20°, largely due to the affordability of such land ($0.5/m² compared to $5/m² in safer areas). Hydrological vulnerability further compounds the issue, as 62% of reported landslides occurred within 150 meters of streams, where toe erosion from flowing water undermines slope stability. Additionally, soil instability plays a critical role; SLOPE/W simulations indicate that during intense rainfall events exceeding 50mm per day, the sandy-loam soils in the area can lose up to 25% of their shear strength, significantly increasing the likelihood of slope failure.

4.3.4 Landslide Susceptibility Map

The landslide susceptibility map of Ndirande Township was generated using weighted overlay analysis and classified the area into five distinct risk zones based on LULC, slope, land use, soil type, and proximity to hydrological features.

Below is a landslide susceptibility map for Ndirande.

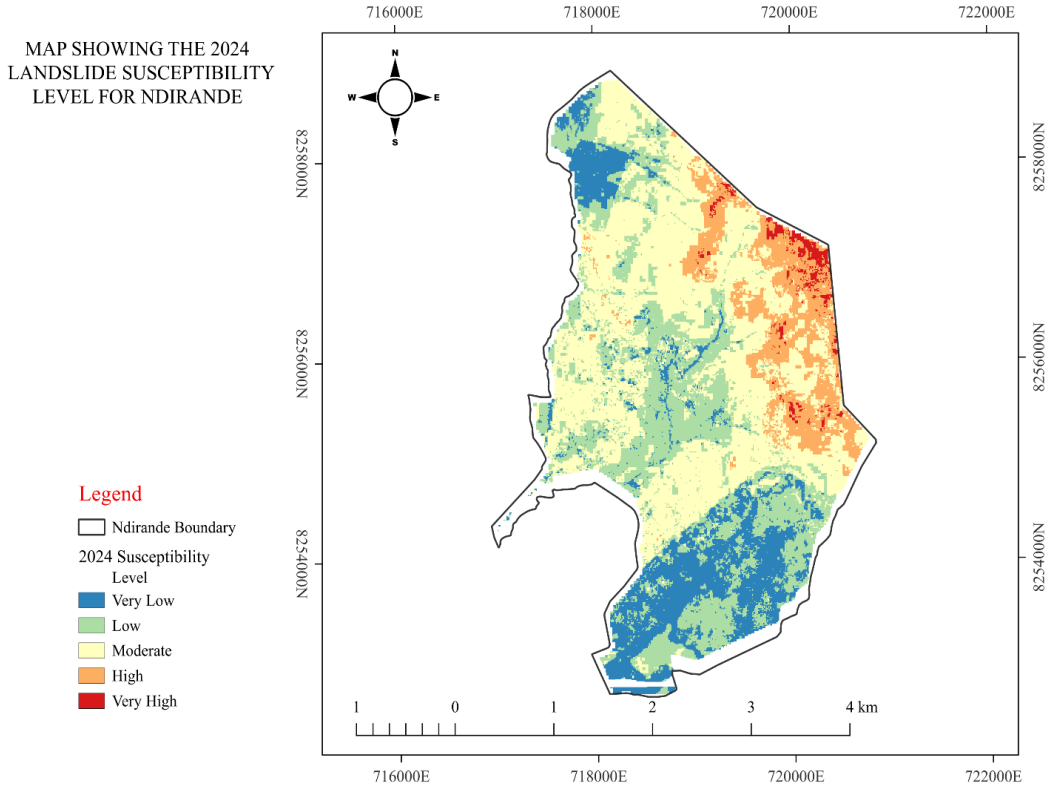


Figure 15: Showing the 2024 Landslide Susceptibility Level For Ndirande

4.3.5 Risk Classifications

Very High-Risk zones (12%) are primarily found on steep slopes exceeding 28°, where gravitational failures are common due to extensive deforestation often from charcoal production and dense informal settlements. The absence of vegetation and inadequate drainage further increased landslide susceptibility in these areas. High Risk zones (18%) are typically located on mid-slopes (15°–25°), where terraced farming occurs but often lacks sufficient soil conservation measures. Their closeness to stream channels makes them vulnerable to soil erosion and saturation, with the moderate slopes and human activity heightening the risk. Moderate Risk zones (25%) feature mixed land use, including partially intact vegetation, and lie on slopes ranging from 12°–18°.

Although less steep, these areas still face risk due to expanding built-up areas and vegetation clearance, particularly during intense rainfall. Low Risk zones (30%) are concentrated in urban cores on flat to gently sloping land (<12°), where improved drainage systems, formal housing, and road infrastructure reduce landslide potential. Very Low Risk zones (15%) are mainly within protected forests and riparian buffers, where mature vegetation and limited development provide natural stabilization and minimize slope failure risks.

4.3.6 Temporal Trends in Landslide Susceptibility (2015–2024)

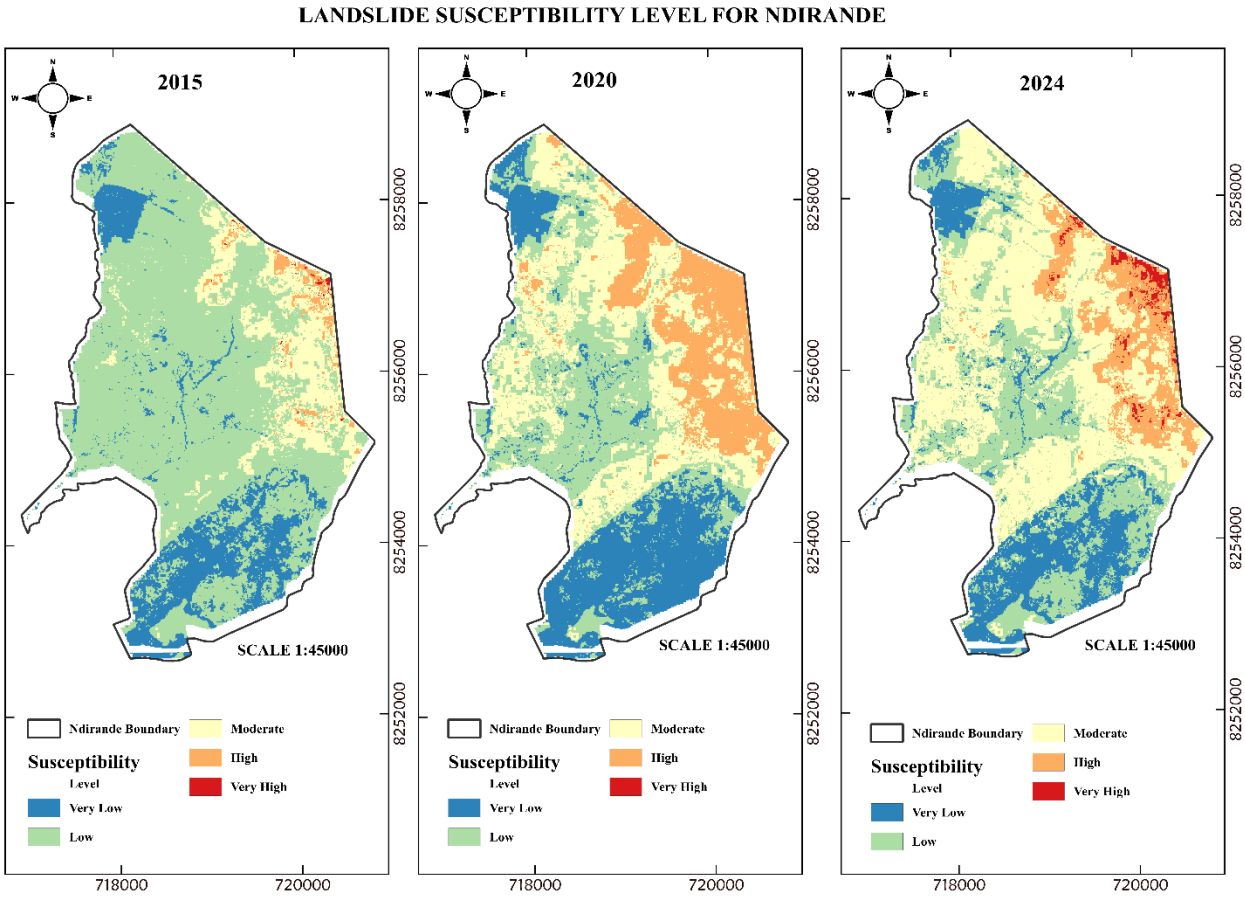


Figure 16: Temporal Trends in Landslide Susceptibility for Ndirande(2015-2024)

In 2015, most of Ndirande exhibited low to moderate susceptibility. Forest cover was relatively higher, and settlement expansion was still limited to the central and western regions. In 2020, there was a noticeable shift to moderate risk zones due to increased deforestation and settlement growth on slopes. Informal farming on marginal land also became more widespread. In 2024, high and very high-risk zones intensified, particularly on the eastern slopes. However, local reforestation efforts and protective measures in some areas contributed to a slight reduction in very high-risk coverage, highlighting the effectiveness of targeted interventions.

DISCUSSIONS

This study investigated the spatial and socio-environmental dynamics contributing to landslide risk in Ndirande Township, Malawi, using a GIS-based Multi-Criteria Decision Analysis (MCDA) supported by remote sensing and field-based validation. The findings revealed a clear pattern of increasing landslide susceptibility over the period 2015–2024, strongly associated with anthropogenic pressure, particularly unregulated urban expansion, deforestation, and cultivation on unstable slopes.

The landslide susceptibility map produced through the Analytic Hierarchy Process (AHP) and weighted overlay identified five distinct risk zones, with 30% of Ndirande falling into high or very high-risk categories. These zones are overwhelmingly located on steep slopes exceeding 15°, particularly the eastern flanks of Ndirande Hill, where informal settlements and agricultural activities dominate. The study's integrated approach merging geospatial, socio-economic, and environmental data provided robust, location-specific insights into the drivers and spatial patterns of landslide hazards.

The land use and land cover change (LULCC) analysis revealed a 23.5% increase in built-up areas between 2015 and 2024, primarily replacing forest and bare land. Approximately 68% of these new developments occurred on slopes greater than 15°, demonstrating a trend of human encroachment into topographically sensitive zones. These findings mirror regional studies, such as in Nairobi's Mathare Valley (UN-Habitat, 2020), where informal housing pressure pushed urban growth into hazard-prone terrain. Concurrently,

NDVI analysis indicated a sharp vegetation decline (from 0.68 in 2015 to 0.43 in 2024), closely correlating with reported landslide events ($R^2 = 0.76$). This affirms that forest loss is a critical destabilizing factor, reducing slope cohesion and increasing erosion potential. Similar findings have been documented in other parts of Sub-Saharan Africa, such as Uganda's Kira

Municipality (Busolo, 2023), underscoring the transboundary nature of urban ecological degradation.

Soil and hydrological factors were also found to be central to slope instability. Sandy-loam and colluvial soils, predominant in the area, were shown to lose up to 25% of shear strength when saturated heightening failure potential during extreme rainfall. DEM-based terrain analysis further emphasized slope gradient as a key variable; over 39% of landslide incidents occurred on slopes exceeding 28°, validating slope angle as a high-weight criterion in the AHP model. Hydrological analysis also revealed that 62% of landslides occurred within 150 meters of stream channels, where toe erosion and water saturation weakened slope bases. These patterns are consistent with global research (Akgun & Turk, 2011), highlighting the necessity of protecting riparian buffers.

The study also looked at the role of socio-economic drivers in amplifying environmental vulnerability. Logistic regression results revealed that low-income households are over ten times more likely to settle on hazardous slopes due to the affordability of land ($0.5/m² compared to $5/m² in safer areas. Approximately 45% of households relied on charcoal production, directly contributing to the 34% decline in forest cover since 2015. These findings demonstrate the link between livelihoods and environmental degradation, reinforcing the need for policies that bridge ecological and economic resilience.

The rainfall analysis showed an 8% increase in annual precipitation since 2015, with extreme events (>50mm/day) now linked to nearly 45% of all reported landslides. This aligns with climate change projections for Southern Africa and supports the applicability of the Ecological Tipping Points Theory (Scheffer et al., 2001). Ndirande appears to be at or near such a tipping point, where continuous anthropogenic pressure and climatic shifts may induce irreversible landscape degradation unless proactive measures are taken.

Field-validated susceptibility mapping provided a spatially explicit visualization of risk zones. Very high-risk areas (12%) were concentrated on steep, deforested slopes with dense informal settlements and poor drainage. High-risk zones (18%) aligned with mid-slopes under agricultural pressure, often lacking conservation structures. Conversely, very low-risk zones (15%) were found within protected forest patches and riparian buffers, demonstrating the stabilizing influence of vegetation and low human disturbance. These results affirm the accuracy and reliability of the AHP-weighted overlay model, evidenced by the model's strong alignment with known landslide hotspots.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study has shown that landslide susceptibility in Ndirande Township is the result of a complex relationships between socio-economic stressors and environmental variables. Rapid urbanization into steep, deforested, and hydrologically sensitive zones, driven by poverty and informal land tenure, has significantly increased landslide risk. GIS-based multi-criteria decision analysis effectively identified spatial hotspots and validated key risk factors such as slope, land cover change, rainfall intensity, soil type, and proximity to streams. These findings not only align with global trends observed in other vulnerable urban settings like Freetown and Nairobi but also offer context-specific insights essential for local policy formulation.

The study highlights the necessity for integrated, risk-informed land use planning that addresses both ecological sustainability and human development needs. Moving forward, future research should explore dynamic risk modeling under climate change scenarios and integrate socio-cultural factors such as community resilience and adaptive capacity. Only through such holistic, interdisciplinary approaches can disaster risk in urban Africa be meaningfully reduced.

5.2 Recommendations

Based on the findings of this study, a number of actionable recommendations have been formulated. These recommendations aim to support sustainable land management, enhance community resilience, and reduce vulnerability to landslides. They are targeted at key stakeholders, including government agencies, local authorities, community members, and development partners, to promote coordinated and effective responses to the challenges identified in this research.

i. **Relocation of communities living in high and very high-risk zones**

In areas identified as being at very high risk of landslides especially on steep slopes or areas with unstable soil. This strategy aims to reduce the potential for loss of life and property. The relocation process should be carried out in a participatory manner involving affected residents in planning and decision making. It should also be supported by government and relevant stakeholders to ensure that those relocated have access to essential services and opportunities for livelihood restoration.

ii. **Implementation of community-based risk monitoring and awareness campaigns**

In areas identified as being at very high risk of landslides especially on steep slopes or areas with unstable soil. This strategy aims to reduce the potential for loss of life and property. The relocation process should be carried out in a participatory manner, involving affected residents in planning and decision-making. It should also be supported by government and relevant stakeholders to ensure that those relocated have access to essential services and opportunities for livelihood restoration.

iii. **Introduction of alternative sources of energy to reduce deforestation**

One of the key drivers of LULCC and increased landslide risk in Ndirande is deforestation often driven by the dependence on firewood and charcoal as primary energy sources. Introducing alternative and affordable energy options such as improved cookstoves, solar energy, and biogas can significantly reduce the pressure on forest cover.

iv. **Strengthening local capacity in land use planning**

Effective land use planning is critical for managing LULCC and minimizing landslide risk. Local authorities and community leaders must be equipped with the necessary knowledge, tools, and legal frameworks to guide sustainable development. Capacity building programs should focus on training in spatial planning, enforcement of zoning regulations, and integrating disaster risk reduction (DRR)

strategies into local development plans. Community participation should also be encouraged to ensure that land use decisions are inclusive and reflect local needs and priorities.

5.3 Policy Implications

The findings of this study carry significant implications for urban planning, environmental governance, and disaster risk reduction in Malawi and similar contexts across the Global.

I. Zoning and Land Use Regulation: There is an urgent need to integrate landslide susceptibility maps into Blantyre City's urban planning frameworks. Settlements on slopes greater than 15° should be regulated or restricted, with relocation schemes considered for the most at-risk communities. Enforcing land use zoning could prevent further occupation of hazardous terrain.

II. Alternative Livelihood Programs: Reducing charcoal dependency is critical. National and local governments should incentivize the adoption of cleaner energy sources and support agroecological farming practices to alleviate the environmental burden of current livelihoods.

III. Disaster Risk Management: The establishment of community-based early warning systems and slope monitoring programs is vital. These systems, paired with mobile-based alerts and local training, can improve preparedness and reduce casualties during extreme weather events.

IV. Environmental Restoration: Reforestation of degraded slopes, especially in high-risk areas, must be prioritized. Structural measures such as contour bunds, check dams, and vegetative buffers can be implemented using labor-intensive public works programs, simultaneously addressing unemployment and ecosystem degradation.

V. SDG Integration: This study directly supports Sustainable Development Goals 11 (Sustainable Cities), 13 (Climate Action), and 15 (Life on Land). The risk maps and socio-ecological insights generated can guide national efforts toward more resilient urban development aligned with global sustainability frameworks.

VI. Data-Driven Planning Tools: The use of geospatial modeling tools like ArcGIS Pro and AHP should be institutionalized within Malawi's urban development and disaster preparedness agencies. Capacity-building programs can help local planners and community leaders apply these tools in real-time decision-making.

REFERENCES

Abedini, M., Ghasemyan, B., & Rezaei Mogaddam, M. H. (2017). Landslide susceptibility mapping in Bijar city, Kurdistan Province, Iran: A comparative study by logistic regression and AHP models. *Environmental Earth Sciences*, *76*(8), 308. https://doi.org/10.1007/s12665-017-6502-3

Alexander, D. (1992). On the causes of landslides: Human activities, perception, and natural processes. *Environmental Geology and Water Sciences*, *20*(3), 165–179. https://doi.org/10.1007/BF01706160

Assede, E. S. P., Orou, H., Biaou, S. S. H., Geldenhuys, C. J., Ahononga, F. C., & Chirwa, P. W. (2023). Understanding Drivers of Land Use and Land Cover Change in Africa: A Review. *Current Landscape Ecology Reports*, *8*(2), 62–72. https://doi.org/10.1007/s40823-023-00087-w

Busolo, P. (2023). *Effects of land use and land cover change on people's livelihoods in Kira municipality, central Uganda* [Thesis, Kyambogo University [unpublished work]]. https://kyuspace.kyu.ac.ug/handle/20.500.12504/1926

Clague, J. J., & Stead, D. (2012). *Landslides: Types, Mechanisms and Modeling*. Cambridge University Press.

Faisal Koko, A., Yue, W., Abdullahi Abubakar, G., Hamed, R., & Noman Alabsi, A. A. (2021). Analyzing urban growth and land cover change scenario in Lagos, Nigeria

using multi-temporal remote sensing data and GIS to mitigate flooding. *Geomatics,*

Gondwe, M. F., Cho, M. A., Chirwa, P. W., & Geldenhuys, C. J. (2019). Land use land cover change and the comparative impact of co-management and government-management on the forest cover in Malawi (1999-2018). *Journal of Land Use Science*, *14*(4–6), 281–305. https://doi.org/10.1080/1747423X.2019.1706654

Hafashimana, N. (2020). *Modelling the effects of land use/cover change and rainfall variability on landslide hazards: The case of Nyabihu district, Rwanda*. https://ubrisa.ub.bw/handle/10311/2470

Haque, U., da Silva, P. F., Devoli, G., Pilz, J., Zhao, B., Khaloua, A., Wilopo, W., Andersen, P., Lu, P., Lee, J., Yamamoto, T., Keellings, D., Wu, J.-H., & Glass, G. E. (2019). The human cost of global warming: Deadly landslides and their triggers (1995–2014). *Science of The Total Environment*, *682*, 673–684. https://doi.org/10.1016/j.scitotenv.2019.03.415

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., … Xu, J. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change*, *11*(4), 261–269. https://doi.org/10.1016/S0959-3780(01)00007-3

Landslide or Debris Flow (Earthquake Trigger) | UNDRR. (2023, June 7). https://www.undrr.org/understanding-disaster-risk/terminology/hips/gh0007

Luyssaert, S., Jammet, M., Stoy, P. C., Estel, S., Pongratz, J., Ceschia, E., Churkina, G., Don, A., Erb, K., Ferlicoq, M., Gielen, B., Grünwald, T., Houghton, R. A., Klumpp, K., Knohl, A., Kolb, T., Kuemmerle, T., Laurila, T., Lohila, A., … Dolman, A. J. (2014). Land management and land-cover change have impacts of similar magnitude on surface temperature. *Nature Climate Change*, *4*(5), 389–393. https://doi.org/10.1038/nclimate2196

Malawi National Disaster risk Management Policy 2015—Malawi | ReliefWeb. (2015, April 29). https://reliefweb.int/report/malawi/malawi-national-disaster-risk-management-policy-2015

Martha, T. R., Roy, P., Govindharaj, K. B., Kumar, K. V., Diwakar, P. G., & Dadhwal, V. K. (2015). Landslides triggered by the June 2013 extreme rainfall event in parts of Uttarakhand state, India. *Landslides*, *12*(1), 135–146. https://doi.org/10.1007/s10346-014-0540-7

Msilimba, G. G. A. C. (2007). *A comparative study of landslides and geohazard mitigation in Northern and Central Malawi* [University of the Free State]. http://hdl.handle.net/11660/1756

National Statistical Office of Malawi. (n.d.). Retrieved October 4, 2024, from https://www.nsomalawi.mw/publications/population/ihs5-fifth-integrated-household-survey-2019-2020

Ozturk, U., Bozzolan, E., Holcombe, E. A., Shukla, R., Pianosi, F., & Wagener, T. (2022). How climate change and unplanned urban sprawl bring more landslides. *Nature*, *608*(7922), 262–265. https://doi.org/10.1038/d41586-022-02141-9

Pacheco Quevedo, R., Velastegui-Montoya, A., Montalván-Burbano, N., Morante-Carballo, F., Korup, O., & Daleles Rennó, C. (2023). Land use and land cover as a conditioning factor in landslide susceptibility: A literature review. *Landslides*, *20*(5), 967–982. https://doi.org/10.1007/s10346-022-02020-4

Riley, L. (2021). Malawian urbanism and urban poverty: Geographies of food access in Blantyre. In *Exploring Food and Urbanism*. Routledge.

Said, M., Hyandye, C., Komakech, H. C., Mjemah, I. C., & Munishi, L. K. (2021). Predicting land use/cover changes and its association to agricultural production on the slopes of Mount Kilimanjaro, Tanzania. *Annals of GIS*, *27*(2), 189–209. https://doi.org/10.1080/19475683.2020.1871406

Thiery, W., Davin, E. L., & Seneviratne, S. I. (2018). *Land Use, Land Cover and Land Management Change: Definitions, Scenarios, and Role in the Climate System* (pp. 9780199363445–0103) [Dataset]. https://doi.org/10.1093/obo/9780199363445-0103

Gorelick, N., Hancher, M., Dixon, M., Li, L., Roma, E., & Milesi, C. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18–27.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information systems and science*. John Wiley & Sons.

Acharya, P., et al. (2022). *Landslide susceptibility assessment using the analytic hierarchy process*. Journal of Earth Sciences, 33(2), 1-15.

Bunruamkaew, K., & Murayama, Y. (2011). *Landslide susceptibility mapping using GIS and remote sensing: A case study in Phetchabun Province, Thailand. International Journal of Geoinformatics*, 7(2), 1-12.

DoDMA. (2023). *Disaster data from the Department of Disaster Management Affairs, Malawi*.

IPCC. (2023). *Climate Change 2023: Synthesis Report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Saaty, T. L. (1977). *The analytic hierarchy process: Planning, priority setting, resource allocation*. McGraw-Hill.

Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At risk: Natural hazards, people's vulnerability and disasters*. Routledge.

DoDMA. (2023). *Malawi Disaster Risk Profile*.

Glade, T., Anderson, M., & Crozier, M. J. (2005). *Landslide Hazard and Risk*. Wiley.

IPCC. (2023). *Sixth Assessment Report – Climate Change Impacts in Africa*.

Petley, D. (2012). *Global Landslide Risk in Urbanizing Regions. Geomorphology*, 15(3), 199–210.

Scheffer, M., et al. (2001). *Catastrophic Shifts in Ecosystems. Nature*, 413(6856), 591–596.

UN-Habitat. (2020). *Informal Settlements and Climate Resilience*.

Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At Risk: Natural Hazards, People's Vulnerability and Disasters*. Routledge.

APPENDIX I

QUESTIONAIRE

ASSESSING THE IMPACT OF LAND USE AND LAND COVER CHANGES ON INCREASING LANDSLIDE RISK IN NDIRANDE TOWNSHIP: USING GIS AND REMOTE SENSING APPROACH

Introduction

Good morning/ afternoon,

My name is Chipiliro Khongonyowa and am a student at the Malawi University of Science and Technology. Am in fourth year of my study pursuing Bachelor of Science in Disaster Risk Management. I am working on a project concerning: Assessing the Impact of Land Use and Land Cover Changes on Increasing Landslide Risk in Ndirande Township: Using GIS And Remote Sensing Approach.

The purpose of this study is to understand how changes in land use and land cover (LULCC) influence disaster risks, particularly landslides, in Ndirande. Your responses will help identify key environmental and socio-economic factors driving these changes, assess the impact on disaster vulnerability, and contribute to recommendations for better land management and disaster risk reduction.

The information you provide will remain **confidential and used solely for academic purposes**. Your participation is **entirely voluntary**, and you may skip any question you are **not comfortable** answering.

Do you agree to participate in this interview?

☐ Yes ☐ No (*if Yes, continue with the interview. If **No** stop the interview*)

If you have any questions, please feel free to ask before proceeding.

SECTION A: DEMOGRAPHIC INFORMATION

Assessing the Impact of Land Use and Land Cover Changes on Increasing Landslide Risk in Ndirande Township Using GIS and Remote Sensing Approach

Age:

☐ Below 18 ☐ 18-30 ☐ 31-45 ☐ 46-60 ☐ Above 60

Gender:

☐ Male ☐ Female

Occupation:

☐ Farmer ☐ Business Owner ☐ Civil Servant ☐ Unemployed ☐ Other (Specify)

Education Level:

☐ No formal education ☐ Primary ☐ Secondary ☐ Tertiary

How long have you lived in Ndirande?

☐ less than 5 years ☐ 5-10 years ☐ 10-20 years ☐more than 20years

SECTION B: LAND USE CHANGES IN NDIRANDE

Have you noticed changes in land use/cover in Ndirande over the past 10-20 years?

☐ Yes ☐ No

If yes, what type of changes have you observed? (Select all that apply)

☐ Deforestation

☐ Expansion of settlements

☐ Increase in commercial activities

☐ Loss of farmland

☐ Increase in unplanned housing

☐ Other (Specify) ____

What do you think are the main reasons for these changes? (Rank 1-5, 1 = most important)

☐ Population growth

☐ Economic activities (business expansion, markets)

☐ Government policies

☐ Climate change impacts

☐ Other (Specify) ____

SECTION C: ENVIRONMENTAL CHANGES AND DISASTER RISK

What are the main economic activities in your area?

☐ Farming ☐ Business ☐ Formal employment ☐ Informal trade ☐ Other: _____

Has the availability of land for farming or settlement changed over the years?

☐ Increased ☐ Decreased ☐ Remained the same

Do you think deforestation and urbanization have affected the local environment?

☐ Yes ☐ No ☐ Not sure

Have you or your community experienced environmental changes linked to land use changes?

☐ Yes ☐ No

If yes, what types of environmental changes have occurred?

☐ Increased soil erosion

☐ More frequent landslides

☐ Reduced vegetation cover

☐ Water sources drying up

☐ Other (Specify) ____

Assessing the Impact of Land Use and Land Cover Changes on Increasing Landslide Risk in Ndirande Township Using GIS and Remote Sensing Approach

Have you witnessed or been affected by a landslide in Ndirande?

☐ Yes ☐ No

If yes, when was the last major landslide that occurred?

☐ Less than 5 years ago ☐ 5-10 years ago ☐ More than 10 years ago

In your opinion, which areas in Ndirande are at the highest risk of landslides?

____

What measures has the community or local government taken to reduce landslide risk?

☐ Tree planting

☐ Drainage improvements

☐ Construction regulations

☐ No measures taken

☐ Other (Specify) ____

What recommendations would you give to prevent or reduce landslide risks in Ndirande?

____

APPENDIX II

FOCUS GROUP DISCUSSIONS

Assessing the Impact of Land Use and Land Cover Changes on Increasing Landslide Risk in Ndirande Township: Using GIS And Remote Sensing Approach

Introduction

Good morning/ afternoon,

My name is Chipiliro Khongonyowa and am a student at the Malawi University of Science and Technology. Am in fourth year of my study pursuing Bachelor of Science in Disaster Risk

Assessing the Impact of Land Use and Land Cover Changes on Increasing Landslide Risk in Ndirande Township Using GIS and Remote Sensing Approach

Management. I am working on a project concerning: Assessing the Impact of Land Use and Land Cover Changes on Increasing Landslide Risk in Ndirande Township: Using GIS And Remote Sensing Approach.

The purpose of this focus Group Discussion is to understand how changes in land use and land cover (LULCC) influence disaster risks, particularly landslides, in Ndirande. Your responses will help identify key environmental and socio-economic factors driving these changes, assess the impact on disaster vulnerability, and contribute to recommendations for better land management and disaster risk reduction.

The insights you provide will remain confidential and used solely for academic purposes. Your participation is entirely voluntary, and you may skip any question you are not comfortable answering and feel free to withdraw from the discussion at any time.

Facilitator:----------

Date:----------

Number of participants:----------

Group type:----------

1. **Historical and Current Land Use Changes**

• How has land use in Ndirande changed over the past 10-20 years?	

• What are the main activities driving these changes?	
• How have these changes affected livelihoods and the environment?	

2. Socio-Economic and Environmental Drivers

• What are the key socio-economic reasons behind these changes? (e.g., population growth, housing demand, business expansion)	
• What environmental issues have arisen due to these changes?	
• Have government policies or interventions played a role in influencing land use changes?	

3. Landslide Risks and Hotspot Identification

• Which areas in Ndirande do you consider high-risk for landslides? Why?	
• Have there been major landslides in recent years? What were the impacts?	
• What strategies has the community used to reduce the risk of landslides?	
• What do you think should be done at the community or government level to prevent further disasters?	

4. If you could change one thing about land use management in Ndirande, what would it be?

_____

_____

5. What support do you think the community needs to make Ndirande safer and more sustainable?

_____

_____