FLOOD RISK AND SPATIAL INEQUITY:

EXPLORING THE RELATIONSHIP BETWEEN MARGINALIZED COMMUNITIES' SPATIAL DISTRIBUTION AND SUSCEPTIBILITY TO FLOODING IN BLANTYRE, MALAWI

by

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Abstract

Malawi, an independent nation since 1964, has experienced a significant wave of urbanization influenced by its historical and socio-political context. This urbanization has profoundly impacted the vulnerability of its citizens to climate change. The southern region, home to the commercial hub of Blantyre, is particularly at risk from climate hazards such as flash floods and landslides, exacerbated by intense rainfall from events like Tropical Cyclone Freddy in 2023. Previous climate impact studies in Malawi have primarily focused on agriculture, overlooking urban vulnerabilities, especially among marginalized communities. Constrained by historical and ongoing socio-economic processes, these communities often reside in flood-prone areas due to limited land access, thereby highlighting the environmental injustices deeply rooted in colonial-era planning practices. In my study, I explore the spatial legacies of colonial urban planning in Blantyre, how these arrangements heighten flood vulnerability, and the effectiveness of current flood management policies in addressing these vulnerabilities. Utilizing a mixed-methods approach, including historical analysis, surveys, and GIS technology, I uncover the complex interplay between historical legacies, urban planning, and vulnerability in informal settlements. My findings reveal that vulnerable communities in Traditional Housing Areas (THAs) and informal settlements are unequally exposed to climate-induced disasters like floods in Blantyre, Malawi. I emphasize that colonial-era planning laws, perpetuated post-independence, continue to shape urban vulnerabilities. The study also highlights critical gaps in disaster governance, suggesting that current policies, including the 2023 Disaster Risk Management Bill, must address to better address the needs of marginalized communities. By mapping flood-prone areas and examining policy effectiveness, my study provides insights for developing inclusive flood management strategies that enhance resilience and reduce risks for Blantyre's vulnerable populations.

Acknowledgments

I would like to express my genuine and endless gratitude to my advisors, Asligul Göçmen and Mathew Turner, for their constant and constructive guidance throughout the study. Professor Paul Block, as a committee member, your suggestions have greatly enriched this work by adding the essential hydrological piece it was missing. This study would not have been possible without the committee's encouragement, insight, and uplifting words. Thank you, Clinton, for contributing to this thesis's geospatial analysis work. You made work that seemed like a mountain to climb a lot easier to go through.

I would also like to express my deepest gratitude to my husband, Austin. Your unwavering support, even during those late nights with the baby and my laptop, has been a pillar of strength for me. Your personal sacrifices, often unseen, have been instrumental in my journey, and I will forever be indebted to you.

Lastly, I would like to acknowledge the contributions of Turner and Göçmen lab groups. Your discussions and reflections have been invaluable, shaping my understanding and enriching the depth of this study. Your input has been priceless.

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List of Abbreviations and Acronyms

BCC: Blantyre City Council

DODMA: Department of Disaster Management Affairs

DRM: Disaster Risk Management

DRR: Disaster Risk Reduction

GoM: Government of Malawi

THA: Traditional Housing Authority

Chapter 1: Introduction

1.1 Background and Context

Malawi, a landlocked country in southeastern Africa covering 118,480 km², has been self-governed for 60 years since gaining independence from British colonial rule in 1964. During this period, the country's physical, historical, and political-economic factors have contributed to high urbanization rates and affected its citizens' vulnerability to climate change. Malawi's southern region is the most densely populated and diverse, where the former colonial capital of Zomba and Malawi's major commercial city, Blantyre, are located (Conroy et al., 2006).

Blantyre City, like many high drainage density areas in the country, is particularly prone to high-energy flash floods and debris flows (mudslides), triggered primarily by periods of intense rainfall. This was evident when Tropical Cyclone Freddy entered Southern Malawi on Sunday 12th March 2023, dumping a significant amount of rainfall accompanied by strong winds, causing heavy flash flooding and landslides over the southern and eastern regions. These specific climate hazards, coupled with the city's geographical and socio-economic factors, contribute to the high vulnerability of its residents, particularly those in marginalized communities.

Climate change impact studies in the country have predominantly focused on biophysical aspects, with attention given to crop yield and livestock production impact (Coulibaly et al., 2015). Despite their vulnerability, much less work has focused on the impacts on urban residents. Extreme climate-induced weather events in the city have led to the loss of life, housing, and property and to precarious livelihoods for marginalized city residents who are the most vulnerable to these disasters.

Floods, a climate-induced phenomenon, have been occurring repeatedly in Blantyre City, significantly impacting communities, with marginalized groups bearing the brunt. Climate impacts are fundamentally shaped by the processes that create the city (Zimba, 2022). The processes that direct marginalized communities to settle in flood-prone areas exacerbate the communities' vulnerability. In Malawi, land access processes have restricted low-income earners from purchasing and building in safe spaces, creating environmental injustices for marginalized communities. The present-day has seen the inequalities from the colonial era led to “a disproportionate amount of land, infrastructure, and services benefit a few while the majority are congested with few or no services” (Zimba, 2022; UNHSP et al., 2010)

Figure 1. below shows the percentage distribution of housing sector losses after Cyclone Freddy. Among over a dozen settlements impacted by Cyclone Freddy, Blantyre is the most impacted, having nearly three-fourths of housing losses caused by the storm.

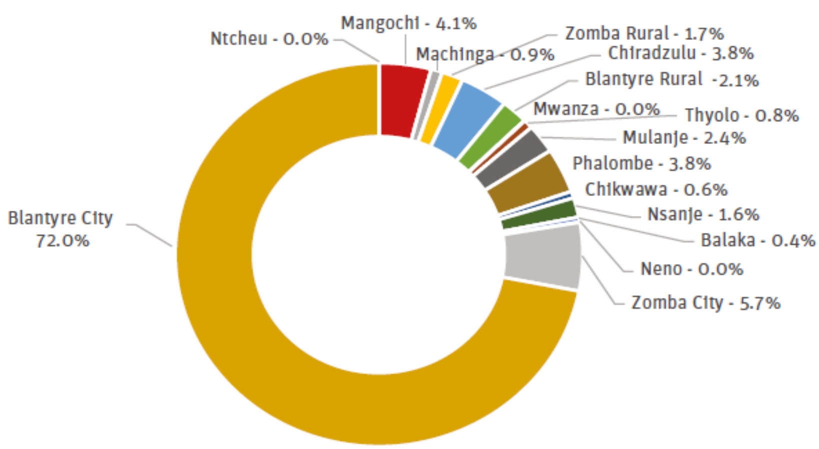

Figure 1. Percentage Distribution of Losses in Housing Subsector due to Tropical Cyclone Freddy, by District (GoM 2023; PDNA 2023 Team).

The extent of damage in Blantyre was devastating. In Blantyre, Cyclone Freddy triggered torrential rains that led to flooding, mudslides, and massive devastation (Bahaji, 2023). Bahaji (2023) quotes a Blantyre resident Alex Mattias saying:

> "The first wave was water sweeping down the hill. But the second came with a mudslide which had rocks and trees,"

As pictured in Figure 2, Figure 3 and Figure 4 below, many houses built with poor building materials collapsed and were swept away by mudslides from elevated areas. The government utilized schools as camps for those affected with nowhere to go. An estimated 2,267,458 people were affected, including 659,278 people who were displaced (336,252 female; 323,026 male), 679 killed, and over 530 people declared missing by mid-March 2023 (GoM, 2023). The floods extensively washed away and submerged houses, destroyed roads, bridges, and power supply and irrigation infrastructure, and damaged mature crops (GoM, 2023).

Figure 2. Shows property damage in Blantyre Malawi during Cyclone Freddy. (Photo credit: Malumbo Simwaka).

Figure 3. Shows roads becoming impassable in Blantyre Malawi during Cyclone Freddy. (Photo credit: Malumbo Simwaka).

Figure 4. shows gulleys formed during Cyclone Freddy (Photo credit: Malumbo Simwaka).

The Malawi government has continued to uphold and expand upon city planning laws and strategies from the colonial era. These colonial planning laws effectively segregated Africans and excluded them from urban spaces. I am interested in exploring the possibility that the current city planning regulations and disaster risk management approaches, by maintaining colonial planning practices, still fail to provide comprehensive protection to marginalized communities against flood hazards in Blantyre City.

1.2 Research Questions

Marginalized communities in Blantyre City face significant socio-physical vulnerability to flooding due to potentially inadequate city planning zoning and disaster risk management processes. This research aims to provide essential information for developing effective flood management strategies and creating more inclusive policies that reduce flood risk and enhance community resilience by focusing on the needs and perspectives.

This study seeks to address the following questions:

1. How does the location of marginalized communities reflect the legacies of colonial urban planning?
2. In what ways does the location of marginalized communities in Blantyre contribute to their heightened vulnerability to flooding?
3. To what extent do flood management policies and strategies reduce vulnerability for marginalized communities in Blantyre?

1.3 Climate Vulnerability in Southern African Cities

1.3.1 Informal Settlements and Their Susceptibility to Climate Risk

Urban areas in low and middle-income countries, where financial and institutional resources are often scarce, are very vulnerable to the impacts of weather and climate-related events (Fraser, 2014; Bicknell et al., 2009). These countries' limited financial resources mean they struggle to recover from impacts and have low institutional capacity to carry out recovery or mitigation programs. Additionally, an increased rate of urbanization increases the population density in cities, which increases the rate of deforestation, leading to significant environmental degradation. Once urbanization occurs, low-income earners tend to settle into unsafe dwelling locations which are mostly not zoned for residence.

Vulnerability to disasters has multiple and interconnected causes, shaped by physical, social, economic, political, or environmental conditions (Kita, 2017; Wisner et al., 2004). Insecure employment and unemployment, poverty, the lack of alternate housing opportunities, social and economic exclusion, and the need to be located close to urban resources and job opportunities result in poor people claiming daily access to the city through the establishment of informal settlements (Williams et al., 2019). Henceforth, informal settlements can be defined as unplanned settlements where housing, shelter, and services have been constructed on land to which the occupants have no legal claim (UNHCR, 2014-18).

A city's vulnerability to disaster risk is multi-faceted in that addressing urban risks requires looking at the various core components and functions of a city that can be at the center of vulnerability, including urban planning, public service delivery, disaster risk management (DRM), governance, safety and crime (Kita, 2017; Surjan et al., 2015). Flood risk in southern cities is a social and political construct (Zimba, 2022; Hildago et al., 2020). The legacy of colonial encounters and subsequent governance processes have contributed to the current flood vulnerabilities of particular social groups in specific urban locations (Zimba, 2022).

The geographical pattern of cities in Malawi, particularly Blantyre and Lilongwe, is characterized by a high density of informal settlements in low-lying areas prone to flooding. These informal settlements are often located on the banks of rivers and streams or land unsuitable for construction, such as wetlands or floodplains. Over 65% of Blantyre City's population lives in informal settlements, which occupy about 23% of the unplanned land (Banda, 2015). The average population density in Blantyre City is 3,509.93 persons per square kilometer (GoM et al., 2023; National Statistical Office, 2018). The high-density, low-income areas of the city are where 70% of the City's population lives, but they only account for 23% of all land zoned for residential purposes. This means that 30% of the city's population occupies 77% of the city's residential land (GoM et al., 2024). Urban planning in Malawi has traditionally been based on the structural planning concept of demarcating urban space into land-use zones (UN-HABITAT, 2024). Land demarcated into land use zones in the National Physical Development Plan is considered as planned areas. The remaining unplanned areas are where informal settlements are located. Figure 5. below shows the location of these informal settlements in Blantyre City.

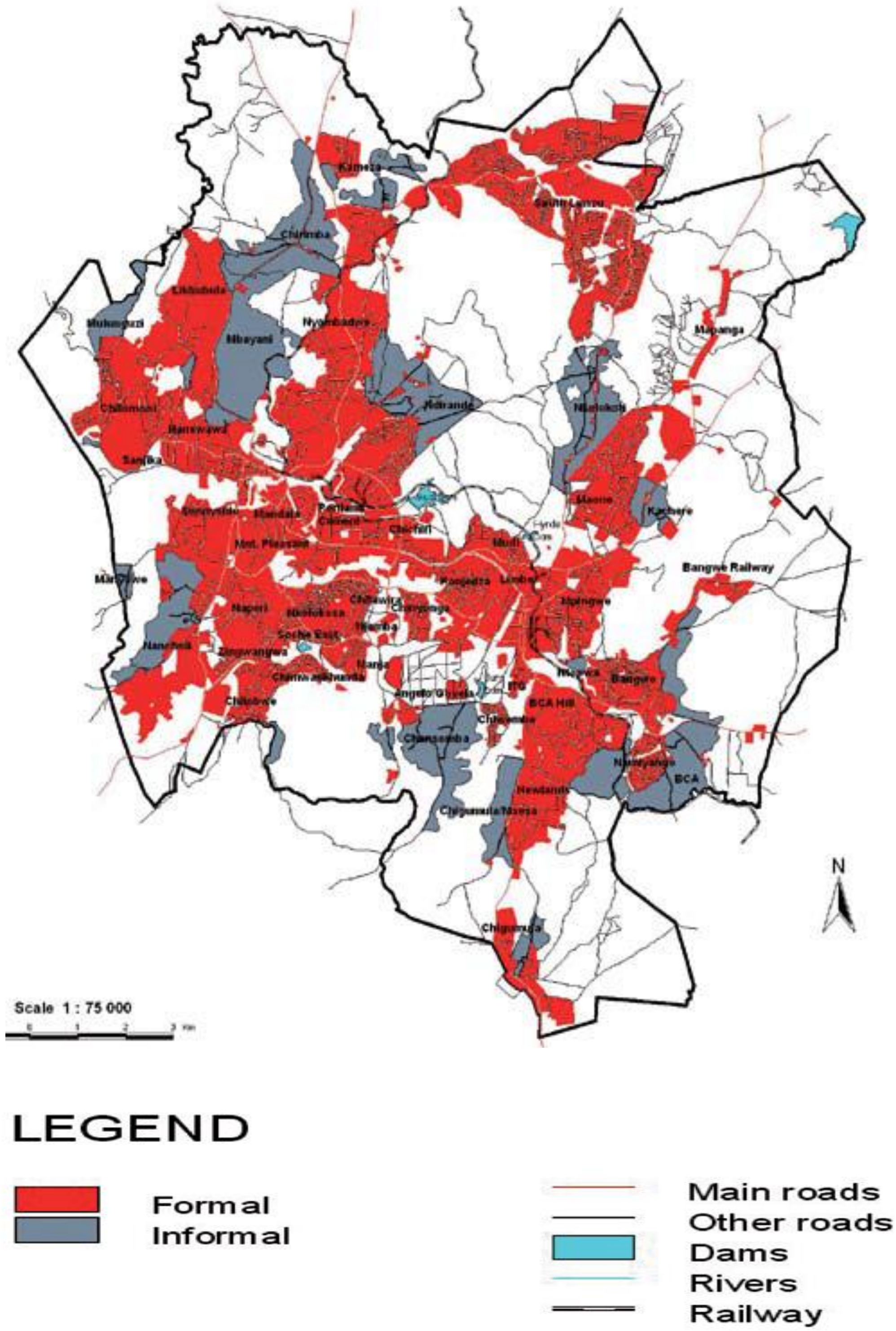

Figure 5. Formal and Informal Settlements in Blantyre City ((UN-Habitat, 2011).

1.3.2 Climate Vulnerability in African Cities

The EU Commission's risk assessment guideline defines vulnerability as 'the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard' (Herslund et al., 2016; UNISDR, 2009). Many scholars have acknowledged the lack of appropriate vulnerability assessment frameworks and policies, questioning the efficiency and effectiveness of the tested models in Africa (Salami et al., 2017). This understanding has, thus, led to a call for researchers in climate and disaster risk studies to go beyond focusing on "root causes of vulnerability" by including "root causes of the hazardscape" when researching and managing flood risk in southern cities (Zimba, 2022; Benjamin, 2008). Root causes of vulnerability focus on underlying factors that render a community vulnerable to hazards, while the hazard landscape constitutes the extent of hazards present in the geographical area. Understanding how people realize and respond to natural hazards in an urban-dominated landscape and integrating such knowledge into planning efforts is crucial (Kaźmierczak & Cavan, 2011). This is important because it can enhance the understanding of planners and policy makers in risk assessment, enabling them to come up with tailored interventions for the community in question.

As illustrated in Figure 6. below, flooding is a prominent climate hazard in all highlighted cities. Except for Addis Ababa, all the other cities presented in Figure 4 share the common characteristic of having been colonized.

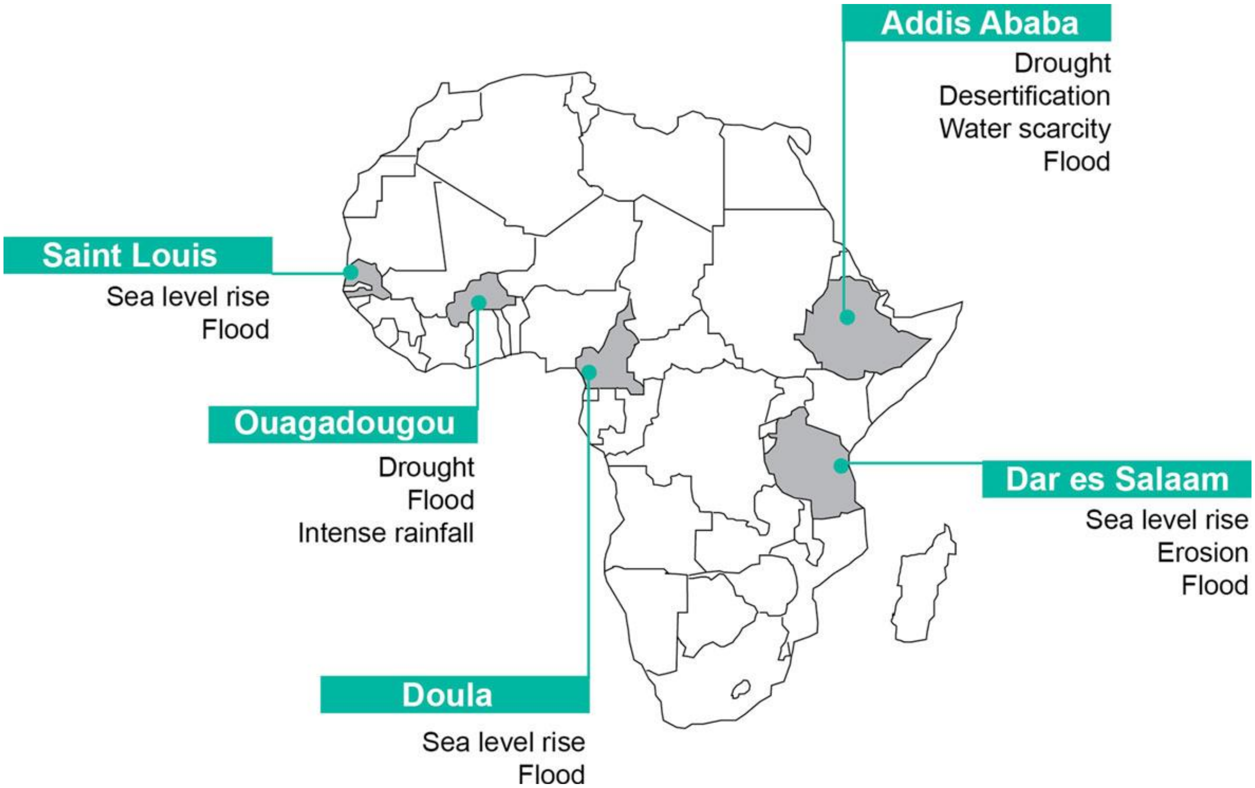

Figure 6. Five African case cities and the main hazards they face (Herslund et al., 2016; Jean-Baptiste & Kabisch, 2013).

Africans who have settled in hazard-prone spaces face climate risks partially due to the impact of colonialism and capitalist economics, which have shaped their geographic spaces and socio-economic conditions (Whyte, 2016). The primary institutional responses to address colonized peoples' vulnerability have focused on direct impacts of hazards on livelihoods, in most cases omitting the historical factors that determine vulnerability and affect their capacity to respond (Carmona, 2023; Belfer et al., 2017). It has been argued that the vulnerability of residents in African cities is closely linked to the marginalization stemming from past and ongoing colonial dynamics (Carmona, 2023; IPCC, 2022). As the original inhabitants of an area, colonized people experienced significant land loss and political economic marginalization. Colonial administrative laws and policies frequently displace and marginalize these original communities, leading to disparities in land distribution among the different groups.

Consequently, Africans often find themselves compelled to relocate to hazard-prone areas, exacerbating their vulnerability.

In 2002, heavy rains caused by unusually high temperatures over the Indian Ocean killed more than 112 people in East Africa (Douglas et al., 2012). Floods and mudslides forced tens of thousands of people to leave their homes in Rwanda, Kenya, Burundi, Tanzania, and Uganda. Rwanda suffered the heaviest toll, with over 50 deaths in 10 days, many caused by landslides (Douglas et al., 2012). The vulnerability of ecosystems and people to climate change differs substantially among and within regions driven by intersecting socioeconomic development, unsustainable ocean and land use, inequity, marginalization, and historical and ongoing patterns of inequity such as colonialism and governance (IPCC, 2022). In addition to depriving colonized people of their right to living in a safe space, this marginalization has excluded them from decision-making processes and pushed them to inhabit territories with extreme geographical and climatic characteristics (Humphreys Bebbington, 2013). In this thesis, marginalized communities are characterized as those residing in informal settlements, vulnerable to climate-induced events, and compelled to inhabit such areas as a result of the history of urban planning practices dating from the colonial period.

The existing literature is yet to fully grasp the intricate relationship between colonial urban planning and the heightened susceptibility of marginalized communities to climate-induced disasters in Sub-Saharan Africa. In cities of the global South, the remnants of colonial encounters and subsequent governance processes manifest as current vulnerabilities to floods experienced by specific social groups in particular city locations (Zimba, 2022). This thesis is a pioneering response to the pressing need for a comprehensive examination of postcolonial theory and the specific ways in which colonial relations and rationalities persist in the present (Lawhorn

& Truelove, 2020). Therefore, this study is uniquely dedicated to explicitly uncovering the motivations behind colonial city planning and its legacy in amplifying the vulnerability of post-colonial cities.

1.4 Research approach

This study explores the connections between colonial urban planning practices and policy to climate-induced flooding vulnerability for marginalized communities. In so doing, it will aid in assessing the impact of the current flood management policies on reducing vulnerability for marginalized communities.

Survey responses and the development of a flood risk map and geo-visualizations of flood risk through GIS analysis will be used to identify the physical and social vulnerabilities of marginalized communities in the informal settlements of Blantyre. This mixed methodological approach will assist in assessing professionals' perspectives on disaster risk management, colonial planning history, and flooding. Flood mapping using GIS will assist in developing visualizations and analyzing surface conditions that increase flood vulnerability. This process will assist in building an understanding of the factors that exacerbate vulnerability. Geospatial layers of soil type, elevation, and infrastructure will be overlayed and integrated to provide terrain analysis. This information will assist in identifying communities at risk which can inform preparedness and mitigation efforts towards vulnerable communities.

The second chapter will provide a detailed description of the methods used in the study, including the online survey and visualizations and flood risk map development. Chapters three, four, and five will then answer the three research questions below:

- Chapter 3: How does marginalized communities' location reflect colonial urban planning's legacies?
- Chapter 4: In what ways does the location of marginalized communities in Blantyre contribute to their heightened vulnerability to flooding?
- Chapter 5: To what extent do flood management policies and strategies reduce vulnerability for marginalized communities in Blantyre?

Chapter 6 will then follow to discuss all findings. After discussion in that chapter, the thesis will conclude by considering the practical implications of my findings for city planning and disaster response in Blantyre and Malawi, underscoring their potential to shape real-world strategies and policies.

Chapter 2: Methods

After residing in Malawi and encountering the elements discussed in the literature review, I conceptualize that the vulnerability to floods in informal settlements within Blantyre City is an element linked to the segregative colonial planning regulations. I therefore conducted this study as it is very personal to me. A literature review revealed significant gaps in our understanding of how colonial planning regulations continue to shape the vulnerability of informal settlements to climate-induced hazards and how these vulnerabilities can be effectively managed.

This study involved a mixed methods approach in which I incorporated a historical analysis, a survey, and a geospatial analysis to leverage the strengths of these different disciplines in answering the research questions. Historical analysis was essential to get qualitative data from literature and policy documents, while the survey was crucial in obtaining qualitative and quantitative data for analysis. This survey's data is complemented and supported by visualizations developed using GIS. These visualizations have been used to build a foundation for the discussion on the study area.

2.1 Historical Analysis

The historical analysis included a review of literature on Malawi's colonial historical geography, climate vulnerability, and urban planning policies. This provided context on the study and provided a basis for the survey and GIS analysis. This literature review did not include any archival research and was focused on books, peer-reviewed articles and grey literature.

In the review, I set out to examine and unearth the chronological developments of urban planning settlements and informal settlements development in Blantyre. My research was dedicated to examining the chronological developments of urban planning settlements and informal settlements in Blantyre. To achieve this, I constructed a timeline that traced the key events that shaped planning laws and the spatial location of settlements. This timeline served as a valuable resource, offering a contextual background of the present spatial location of marginalized communities in the city. Equally important was the literature review, which played a pivotal role in the study by identifying trends and shedding light on unresolved issues that had been overlooked, thereby enriching the study.

2.2 Survey for professionals involved in Disaster Risk Management

An online survey (refer to Appendix A) was conducted to delve into the understanding of Blantyre City's colonial history, its influence on zoning, the vulnerability of informal settlements, and the effectiveness of the existing legislation aimed at risk management. This survey targeted professionals and decision-makers in Disaster Risk Management (DRM), encompassing urban planners, civil society members, land surveyors, NGO representatives, and government officials. Two field assistants administered the survey titled ‘Spatial Risk and Flood Vulnerability in Blantyre Malawi’ online through WhatsApp, email, and in person. The survey administration commenced on March 11, 2024, and ended on March 19, 2024. During this period, the field assistants shared an online Qualtrics survey link with respondents. I also shared the survey through email to my contacts during this period. The locations of interest were Blantyre and Lilongwe. Lilongwe was included in the study sites because many organizations involved in disaster risk management are based there, as well as various ministries.

Participants aged 18-70 were recruited through word of mouth, email, and WhatsApp. Data collected from the survey has been organized into three main sections: colonial history and spatial arrangement, factors contributing to vulnerabilities, and the impact of flood management policies and strategies. These three sections encompass the three research questions presented earlier in the thesis and are presented in the findings chapter and the discussion chapter

The sample selection was purposeful and interdisciplinary in that the respondents who were targeted belonged to a profession that was related to disaster risk management (DRM). I selected this sampling method to target professionals who had knowledge of the survey aspects and could provide helpful insight.

Due to the diversity of professionals in the population of interest and non-existent records detailing the number of these professionals, it was challenging to deduce a measurable sample from the population. Hence forth, a sample size of 100 (50 in Lilongwe and 50 in Blantyre) was set.

The data collected from the online survey were analyzed using descriptive statistical analysis methods. I used SPSS and R Studio software to clean, recode, and perform these analyses. In this thesis, I present the findings of 87 participants out of 100 who completed the survey. The data, which includes 60 (69.0%) male respondents, 25 (28.7%) female respondents, 1 (1.2%) who preferred not to say, and 1 (1.1) who did not respond, represents a comprehensive range of professions. The largest group of respondents, 22 (26.8%), are professionals working with the Ministry of Lands, followed by 13 (15.9%) from the Department of Disaster Management Affairs (DODMA). **Error! Reference source not found.**. below provides a comprehensive distribution of respondents across organizations and occupations, with 22 urban planners, the largest professional group represented.

Table 1. Distribution of respondents' professions

Organization	**Occupation**											
	Planners	DRM	Land Mgt	Civil Service	Env. Mgt	Edu.	Health	NGO	Business	Com. Devt	NA	Total
Min. of Lands	8		10	2							2	22
Blantyre City Council	4				3						1	8
Dpt of Disaster Management Affairs		5		4		1	1		1		1	13
NGO	1						1	1	3			6
DPT OF Physical Planning	3											3
District Council	3		2		3	1					1	10
Malawi Housing Corporation	2		1									3
Min. of Resources & Climate Change			1	2					2		2	7
Min. of Health							3					3
Environmental Affairs					2				1	3	1	7
NA	1			1		1			1		1	5
Total	22	5	14	9	8	3	5	1	8	3	9	87

2.3 Geospatial Analysis of Flood Risk in Blantyre

I worked with Clinton Nkolokosa, a Geospatial Analyst from Malawi Liverpool Wellcome Trust, to develop a flood risk map and visualizations. Clinton has a solid academic background and work experience in using GIS, remote sensing, and numerical tools in environmental research, achieving a distinction in GIS at Sheffield Hallam University and a merit in Natural Resources Management at Lilongwe University of Agriculture and Natural Resources (LUANAR)- highly respectable and accredited universities in UK and Malawi, respectively. Clinton's current activities focus on developing high-performance statistical modeling techniques and geospatial tools within public health.

Currently based in Malawi, Clinton had access to local GIS data necessary for the project's base maps. Therefore, I outlined and designed the GIS project while Clinton sourced most of the data needed and executed the work. Clinton used QGIS and R studio to develop visualizations and reclassify layers for the flood risk map. I used ArcGIS to go over the work produced by Clinton and reproduce some of the work as needed. During the development of visualizations, these tools allowed us to visualize informal settlements in Blantyre City and highlight their vulnerability to flooding by examining the topography, geological conditions, and land cover. Clinton combined various GIS shapefiles, including the Blantyre boundary, informal settlements, buildings, population, elevation, and soil layers for overlay. Satellite imagery was used to digitize mudslide paths in Ndirande, Bangwe, and Soche hills following Cyclone Freddy. Gullies that formed were visible on the satellite imagery, so we used a post-Cyclone Freddy satellite image to digitize the outline of these gullies, illustrating the mudslide paths. Once overlaid with the other layers, these mudslide sites were used to identify hazard-prone areas in the communities of interest (Ndirande, Chilobwe, and Bangwe).

Topographic and demographic data overlaid on the map to produce visualizations enhanced the interpretation of survey findings. An overlay technique placed a GIS layer showing the building footprints below a layer with the digitized mudslide paths. This helped identify the number of buildings or houses directly in the mudslide path. Additionally, a buffer was created to highlight households within and near the path. We worked on the assumption that households close to the mudslide path were affected since some still had to relocate even though their houses were not directly damaged. During the cyclone, the government advised people susceptible to the flood to relocate to nearby schools established as camps. We used a population layer and household data to come up with an estimate of the population affected by the mudslides.

Thereafter, in order to produce a Flood Risk Map, Clinton sourced NDVI[1] , soil and slope layers. He used R studio (refer to Appendix B for the R script) to classify[2] slope to assist in identifying areas with high, medium and low range of degree of slope. The soil[3] layer was clipped with Blantyre boundaries and reclassified. I used the reclassified layers, overlaid them, and analyzed them using the ArcGIS Pro raster calculator to develop a simple flood risk map showing Blantyre's high, moderate, and low-risk areas.

Figure *7*. below shows the slope layer that was used for reclassification.

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[1]Layer obtained from GEE open-source community. https://gee-community-catalog.org/projects/gimms_ndvi/?h=ndvi https://drive.google.com/file/d/1PTQpvAoFwXBpwq-LPPIpirFaP39BJ1bV/view?usp=drive_link . NDVI Classification obtained from https://ipad.fas.usda.gov/cropexplorer/Definitions/spotveg.htm

[2] Classification directions adopted from https://geographyfieldwork.com/SlopeSteepnessIndex.htm

[3] Soil Layer and classes obtained from an RMSI based on FAO which Clinton Shared with me.

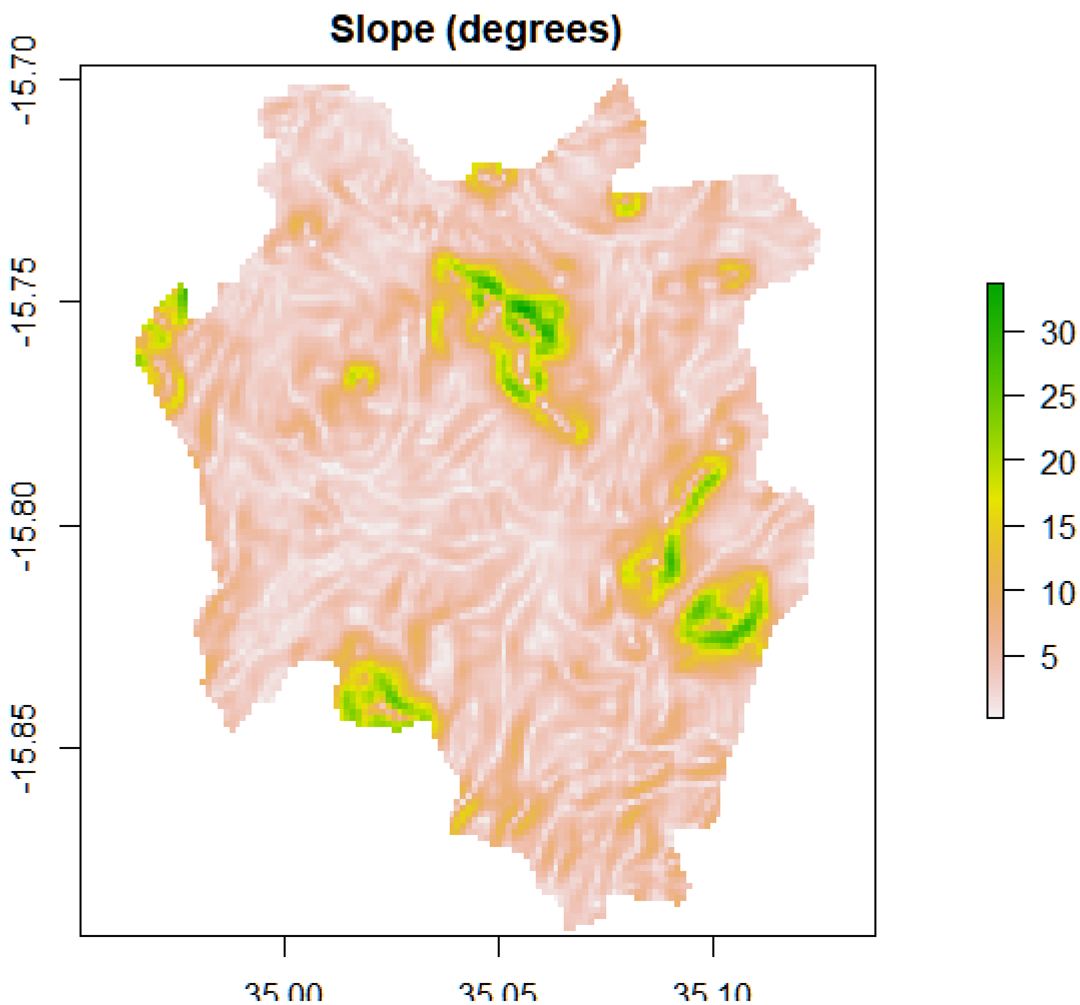

Figure 7. Slope in Blantyre Malawi

Under my direction, he reclassified the three layers to present high, moderate and low physical risk. He derived the slope steepness calculations from a standard slope steepness descriptors index[4] below.

He then used the scale in Table *2*. below to group them to present low, medium and high risk with low risk representing level and nearly level slope, moderate representing very gentle, gentle and moderate slope. High risk represented strong to very steep slope.

[4] Source: Barcelona Field Studies Center, Website : https://geographyfieldwork.com/SlopeSteepnessIndex.htm

Table 2. Slope flood risk categories based on percentage slope ranges

Classification	Slope Ranges (degrees)
1 (low)	0.01 to 1.1
2 (moderate)	1.12 to 8.50
3 (High)	8.50 to 40.0

After reclassification, Figure 8 below shows the areas that were identified to present high, medium and low risk depending on their reclassified group of slopes.

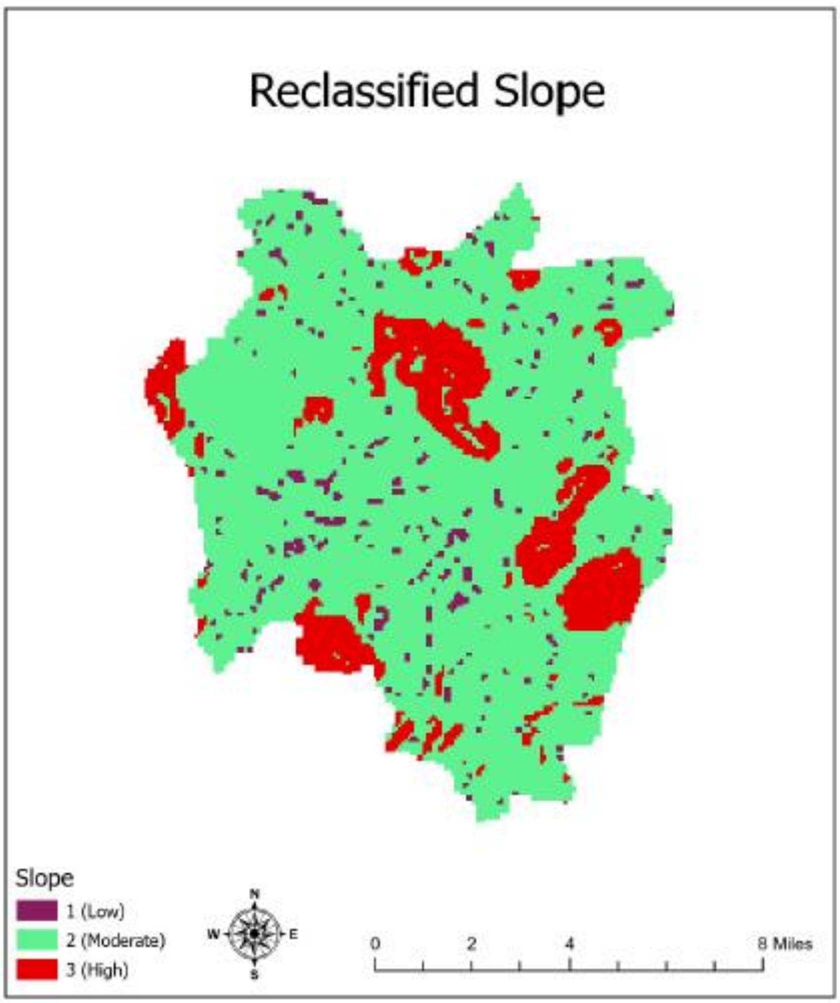

Figure 8. Reclassified slope layer used for risk index calculation

For vegetation, he used the NDVI Figure 9 below which is the layer that was used for classification

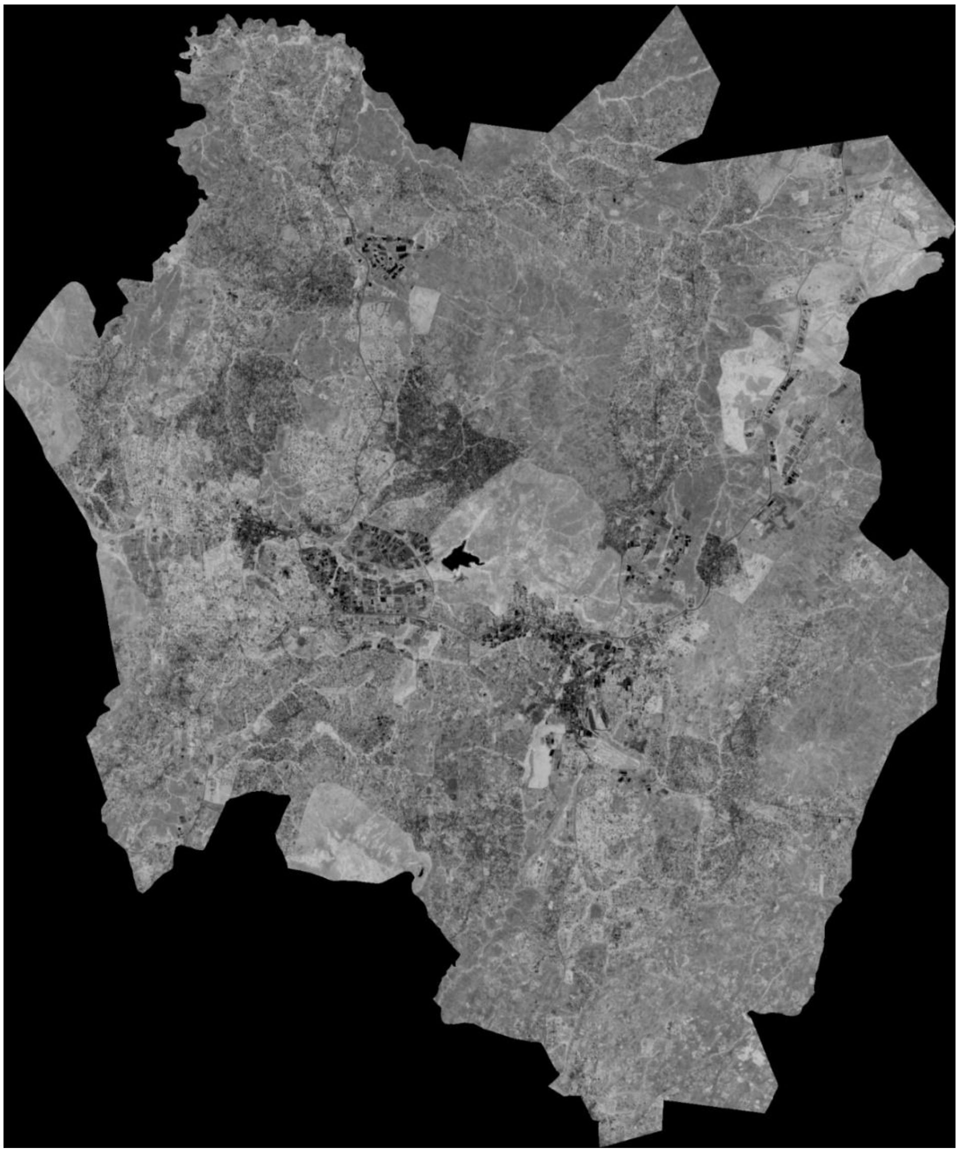

Figure 9. Normalized Difference Vegetation Index (NDVI) layer for Blantyre (March, 2023)

The NDVI layer was rematched using a color palette of red, yellow and green. The reclassification process was adopted from USDA classification[5] which stipulates:

> "NDVI values range from -1.0 to 1.0, with negative values indicating clouds and water, positive values near zero indicating bare soil, and higher positive values of

[5] Website: https://ipad.fas.usda.gov/cropexplorer/Definitions/spotveg.htm

NDVI ranging from sparse vegetation (0.1 - 0.5) to dense green vegetation (0.6 and above)".

The reclassification as illustrated Table *3*. included grouping the values stated in the above quote and grouping them to present low, medium and high risk. Hence producing the reclassified NDVI in Figure 10.

Table 3. Vegetation flood risk categories based on NDVI values

Classification	NDVI Range
3 (High risk)	0.1
2 (medium risk)	0.1 to 0.50
1 (Low risk)	0.50 to 1.0

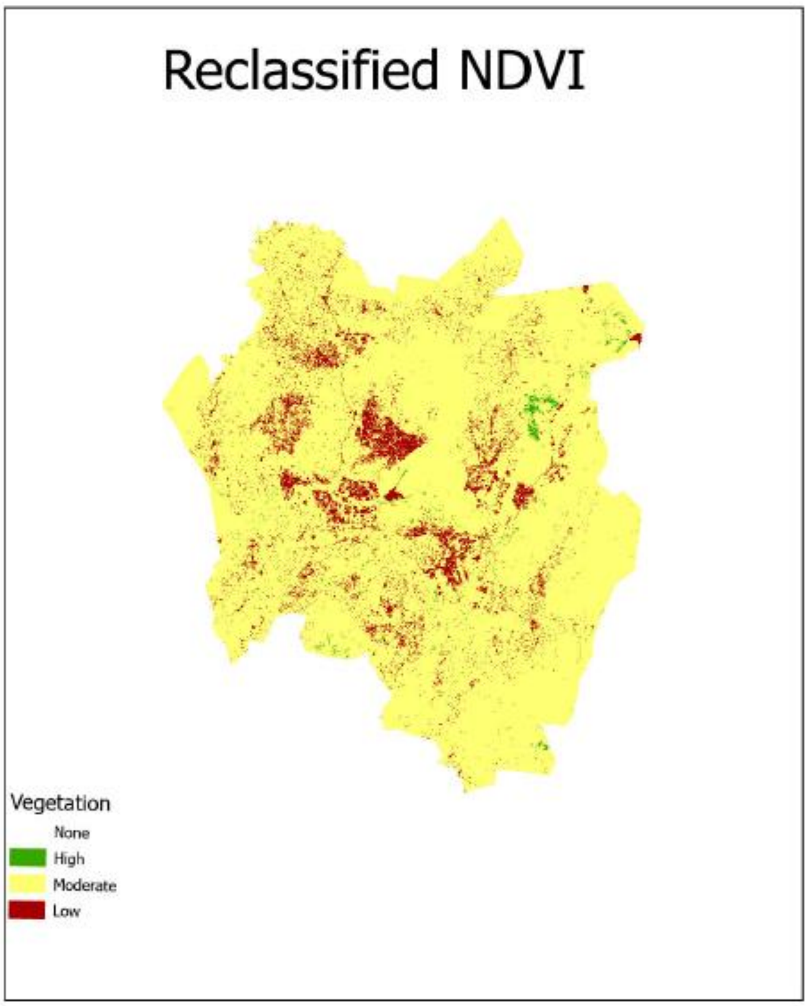

Figure 10. Reclassified vegetation cover map used for risk index calculation

For soils, Figure 11 below shows the soil classification map that was clipped to Blantyre boundaries and reclassified.

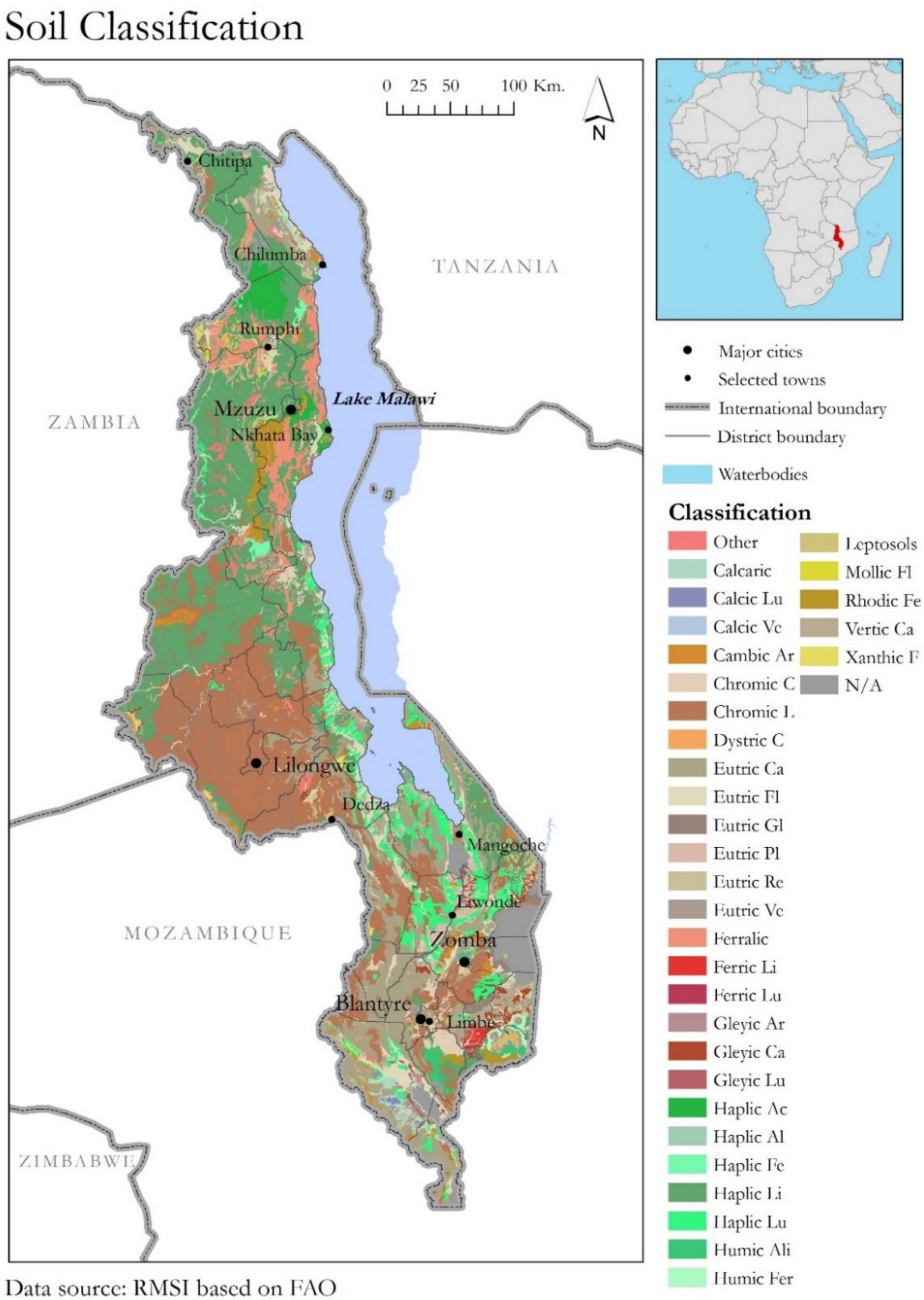

Figure 11. Soil type layer used for reclassification

Reclassification of soils involved clipping the map to show Blantyre's boundaries. Within

Blantyre, the soils that were identified in Blantyre were sandy loam, loam sandy, sandy clay and clay. Table 4 below shows the grouping of the soils into soil types that present low, medium and high risk.

Table 4. Soil flood risk classification based on soil type

Classification	Soil Type
1. Sandy Soil	Sandy loam, loam sandy (Mollic FL)
2. Intermediate Soils	Sandy clay (Haplic Li)
3. Clayey soils	Clay (Gleyic Ca)

As illustrated in Figure 12 below, the reclassified layer showed areas that presented high (3), moderate (2) and low risk (1) depending on the soil type.

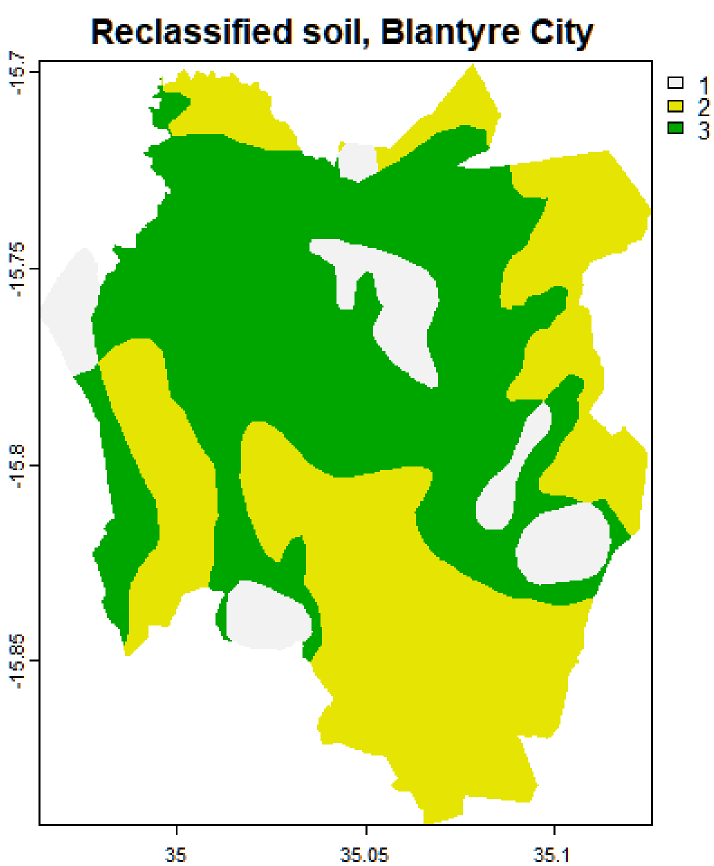

Figure 12. The reclassified soil layer used for calculation of the flood risk index

After reclassification, I transferred all reclassified layers into ArcGIS Pro to perform the analysis. I analyzed all three layers by doing a simple summation in raster calculator to identify areas that displayed high, moderate and low risk in consideration of slope, vegetation and soil factors. The raster calculator aggregated the three risk factors into a single flood risk index with higher values indicating higher risk.

2.4 Methods Conclusion

The mixed methods used in the study that incorporated the historical analysis, survey and geospatial analysis produced information that is needed to interpret, inform and address the research questions. Henceforth, the synthesis of literature review findings and survey data sheds light on the complex interplay between historical colonial legacies, urban planning regulations, and the vulnerability of marginalized communities in informal settlements to floods within Blantyre City, Malawi. This study has reviewed and clarified critical gaps in disaster governance by meticulously examining Malawi's colonial historical geography and its enduring influence on spatial arrangements. It also explored the socio-economic and political processes underlying social vulnerability. The online survey, targeting a diverse range of stakeholders in Disaster Risk Management, provides valuable insights into the perceptions of key actors regarding the effectiveness of existing legislation in Malawi and the policies available aimed at mitigating flood risks. Furthermore, integrating GIS technology, facilitated by collaboration with local expertise, enriches our understanding of the physical vulnerability of informal settlements to flooding events. By mapping mudslide paths and identifying hazard-prone areas within communities such as Ndirande, Chilobwe, and Bangwe, this study contributes to a nuanced understanding of the spatial dynamics of vulnerability.

Chapter 3: Unraveling the Evolution of Urbanization and Planning Vulnerabilities

This chapter addresses the first research question: How does the location of marginalized communities reflect the legacies of colonial urban planning? It starts by examining the historical events that have shaped urban planning policies in the study area. It then focuses on the pre- and post-independence political, social, and economic factors, which have significantly influenced the policy landscape. Lastly, it presents the current perspectives of professionals on the legacies of these policies and strategies on the current flood vulnerability of marginalized communities in Blantyre City.

3.1 Political and Spatial Planning during the Colonial Period in Malawi

Malawi was colonized by the British from 1891 to 1964. Scottish missionaries first settled in Blantyre, Malawi, in 1876, which contributed to Blantyre becoming Malawi's oldest city and its primary industrial center. David Clement Scott, born in 1857 in Edinburgh, was sent to Blantyre by the Foreign Mission Committee of the Church of Scotland in 1881 to work at the Blantyre mission, which was involved in scandal and depleted by staff resignations and the dismissal of its leader, Rev. Duff Macdonald (Statham, 2014). Figure 13 below shows the mission's church which is called the St. Michael and All Angels Church as it stands today. Upon arriving at Blantyre, Scott set to work repairing relationships with local chiefs that had been damaged in preceding years by the deleterious conduct of the mission staff (Statham, 2014; Hinchliff, 1984).

Figure 13. St. Michael and All Angels Church. Constructed from 1888 to 1891 in Blantyre[6]

In 1877, following the missionary settlement and the construction of the church of Scotland, James Stewart, a civil engineer, produced a layout for the mission centered on a wide square surrounded by Indian-style bungalows and a terraced garden (Tanser, 1963). In 1894, plans for a township were prepared and approved by local landowners in the current location of the Blantyre Central Business District (CBD) area. During this period, European traders and estate owners staked out land claims in the valley neighboring the Church of Scotland Mission, and it was them, rather than the government now based at the administrative capital of Zomba, who were to play a leading role in laying down roads and in defining the racially segregated character of the settlement (McCracken, 2012) with Africans only having access to build on low-lying areas on the city's periphery and, Indian traders being confined to the crowded 'Asiatic Ward.' Africans were effectively banned from housing in the central business district through

[6] Figure 2. Construction managed by Rev. David Clement Scott. Photo taken on 12 February 2022. Source: Malawi-Nyasaland Historical Moments Facebook Page
https://www.facebook.com/photo/?fbid=287829120256038&set=pb.100070868562883.-2207520000

by-laws that stipulated that no house should be built in the township for less than 50 pounds – a value Africans could not afford (McCracken, 2012).

Figure 14 below illustrates Blantyre's layout during the colonial period, a pattern that still echoes in present-day Blantyre City as shown in Figure *15*. Both figures depict the evolution of development from 1934 till the present.

Figure 14. Blantyre Aerial View of the town 1937 (Ameer Mussa[7]).

[7] Figure 8: Blantyre Aerial View of the town 1937_Photo Credit Ameer Mussa. Source: Malawi-Nyasaland Historical Moments Facebook Page

Figure 15. Present-day aerial view of Blantyre (Source: Google Earth, Accessed on 4/2/2024)

Ndirande, an informal settlement strategically located near the mission, began to take shape during the earlier colonial period. Ndirande became important with the arrival of European settlers, mainly because of the Church of Scotland Mission, since the mission was powerful and known for helping and protecting people who escaped slavery (Bettison & Apthorpe, 1961). The proximity of Ndirande to the Mission instilled a sense of security among its residents (Bettison & Apthorpe, 1961).

Nyasaland adopted the British legal system and planning law as a British colony. The enactment of the Town and Country Planning Act (1947) in Britain resulted in the colonial authorities ‘importing’ that Act to the colony of Nyasaland in 1948. As King (1977) rightly puts it, ‘the missionary zeal of the nineteenth century which saw imperialism as a means of bringing the benefits of Western civilization and material wealth (through Free Trade) to 'the darkest corners of the earth' was reflected in the boldness with which metropolitan institutions, including 'town and country planning,' were introduced abroad.’ Although the Act was ‘imported’ to

Malawi, the two countries' social, cultural, and economic circumstances differed vastly.

The first town council for Blantyre was elected in 1897, and only male Europeans were allowed to stand in the council elections. Following the establishment of the Blantyre Township, a new township was opened at Limbe, approximately eight kilometers east of the township. In this thesis, a township refers to a planned urban center established by the colonial government. The Shire Highlands Railway Company established its headquarters in Limbe in 1908, followed by the Imperial Tobacco Company's decision to locate its factory in Limbe to take advantage of the railway services. In the 1920s, both Blantyre and Limbe faced a growing housing crisis in which few Africans were allowed to live in the townships, and they had started to build simple dwellings in the peri-urban areas (McCracken, 2012).

> "Prior to colonialism, Malawi was a confederation of independent tribes trading in ivory with the Portuguese with whom they had been in contact as early as the 16th century," Manda (2019).

The population of Blantyre's peri-urban villages was `remarkably stable, 'with some 71 percent of adults in 1957 having been born in or close to the villages in which they were residing (McCracken, 2012; Bettison, 1995). Thirty-six percent of Africans in Blantyre were from the Yao tribe, meaning that they were descended from people who had moved into the district prior to the founding of the township, while other thirty-four percent described themselves as `Ngoni,' meaning that their relatives had come from the Ntcheu and Dedza districts of the central region (McCracken, 2012). Other Africans moved to the Blantyre Township to be porters employed to carry loads for the European settlers; however, the number of porters significantly reduced following the opening of the railway station (McCracken, 2012). Figure 16 below shows the map of Blantyre as it was in the late 1950s.The figure shows a basic layout of the city can be seen with Ndirande being situated in proximity to the church of Scotland (present-day St Michaels and All Angels Church).

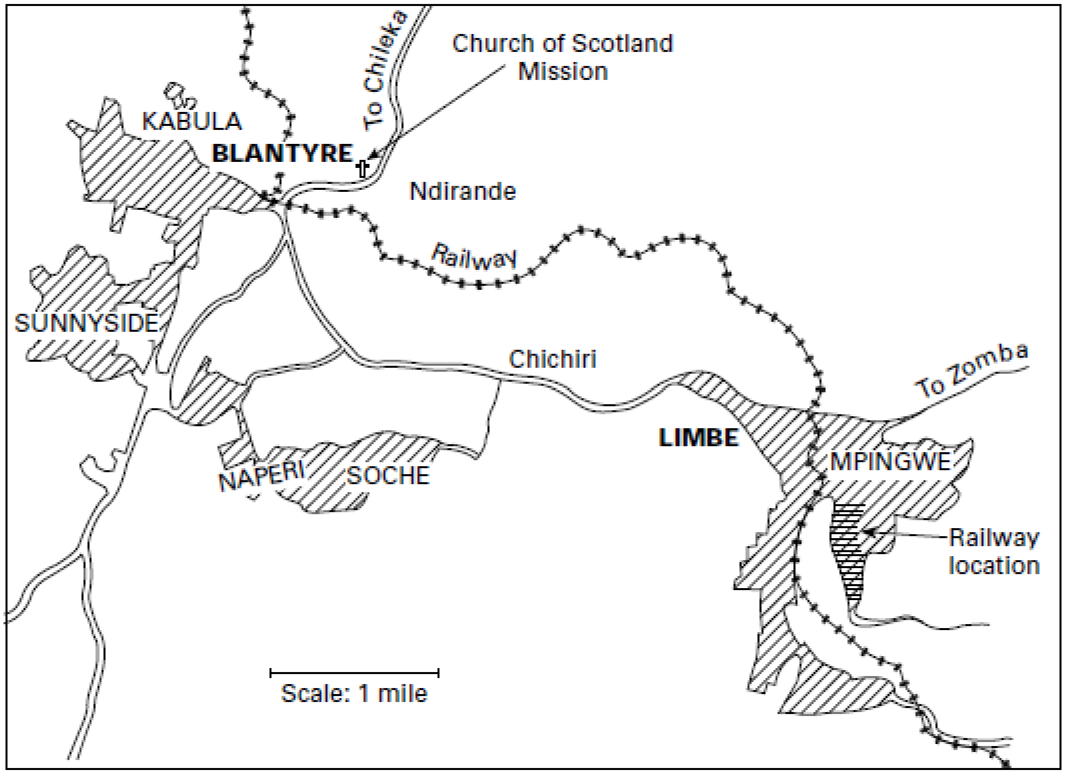

Figure 16. Map of Blantyre late 1950s (McCracken, 2012)

The European population living in Blantyre in Sunnyside[8] remained small, rising from 192 in 1907 to only 379 in 1947. Ndirande settlement originated from several African villages in the vicinity of the Church of Scotland mission from the mid-1870s (McCracken, 2012). By the 1950s, Ndirande had become the home of more than 3,000 inhabitants, but it remained officially invisible, absent, for example, from any town map prior to the 1960s (McCracken, 2012).

The Colonial Government did not implement a coherent housing policy specifically

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8 Sunnyside was a residential area mainly settled in by Europeans. In 2024, it is still a wealthy neighborhood, housing high income residents.

targeting the African low-income group (Nyasulu & Cloete; Jambo, 2002). As a result, this need was left to Limbe and Blantyre councils to produce plans for native locations. However, due to the unwillingness of the settlers and the government to pay for the native settlements, it was not until 1936 that the first native houses (30) were constructed in the neighborhood of Naperi which was unsettled in at the time (McCracken, 2012). The houses were of poor standard, consisting of windowless brick and a thatched roof (Luka, 2017.)

During the next 15 years, the number of unplanned settlements increased to 22, most of which were located at the periphery of the city and at the base of hill slopes. The 1940s brought rapid economic growth in Blantyre, which was largely accelerated by the rise in cash crop prices, notably for tobacco, and the resulting increase in the number and size of processing factories (McCracken, 1998). By the end of the Second World War, a substantial number of Asian traders had established their shops in both Blantyre and Limbe. By 1948, African business people had combined their resources to enter the construction industry as subcontractors to European construction firms in which they supplied lime to European builders and contractors in Blantyre and Limbe, playing a pivotal role in the region's booming commerce (Luka, 2017). This led to the expansion of European-owned transport and commercial companies in the two townships. As the economy expanded, new jobs were created, and many more Africans moved to town. Between 1948 and 1956, Blantyre's dusty and potholed roads surfaced, hundreds of houses were built, and work began on several projects, including the 400-bed Queen Victoria Hospital, completed in 1958 (McCracken, 1998). The colonial government and Asian traders opened factories producing soap, cement, and other goods (McCracken, 1998).

With the increasing number of low-income Africans migrating to Blantyre to work in the township, the colonial government experimented with providing housing for the Africans by developing a scheme to facilitate access to cheap, affordable housing with basic urban amenities. On the recommendation of the Nyasaland Traditional Housing Committee set up in 1961, the colonial government issued a policy position on peri-urban housing advocating the provision, at its cost with a nominal service charge passed on to the beneficiaries, of basic urban services affordable to the poor urban masses in planned housing layouts – a precursor to the current Traditional Housing Areas (THAs) (Luka, 2017). Three pilot THAs were developed at Bangwe, Chilomoni, and Zingwangwa. The THAs were initially managed through the Blantyre Urban Office, which deployed an administrative officer and a clerical officer to oversee the allocation of land plots, the development of allocated plots, and the monitoring of illegal developments. Later, the responsibility for the development and management of THAs fell to the Malawi Housing Corporation (MHC), in August 1963 (Luka, 2017). By 1993, these settlements accommodated 82% of the population of Blantyre (Nyasulu & Cloete, 2005).

Due to rising sanitation issues in these African settlements, the colonial government introduced in 1951 a radical new plan to divide the town's residential areas into high, medium, and low-density residential areas, much to the strong opposition of the African population as they were highly segregated. As illustrated in Figure 17 below, the government did not provide extensive service aside from the plot of land for building and the stipulation that owners are only allowed to build on house on the plot. The plots lacked water and sanitation services, so residents had to fetch water from communal sources and dig their own pit latrines and outside bathrooms. To quote Norwood 1972.

> "In Malawi, it is a basic principle that the plot holder should build as he thinks fit provided the basic rules such as construction of only one house on each plot are adhered to…The biggest incentive to the provision of good houses on site and service principles is to give a man a plot with water nearby, a market within a mile, and his place of employment within reasonable distance. "

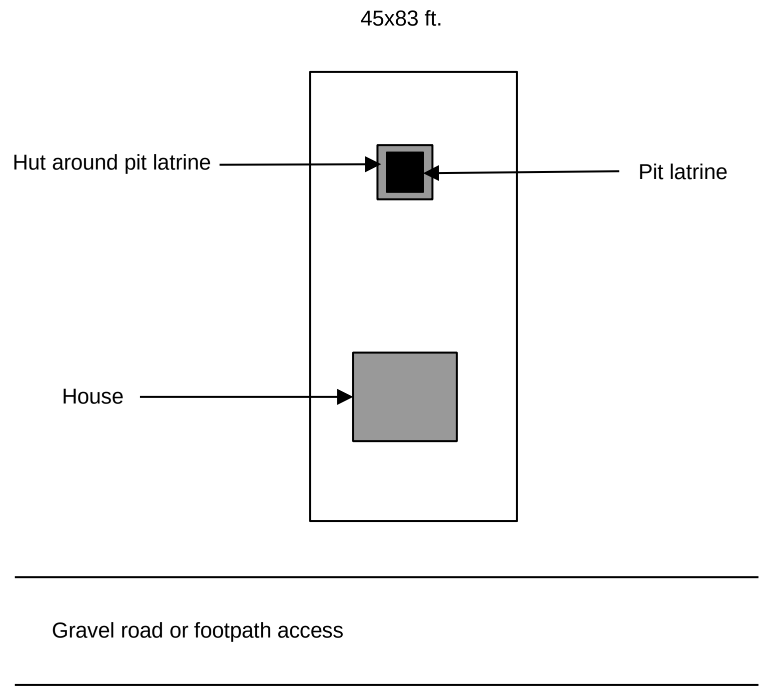

Figure 17. Basic principles of site and service housing (later to be known as THAs) (recreated Norwood, 1972).

However, despite the provision of these services and rules; a survey in one established site and services area in Blantyre showed that in 1971, 51.6% of plots had more than one house (Norwood, 1972). This has continued to date with many THA plots having more than one house, encroaching onto access roads, increasing population density, and thus resulting in “planned” settlements resembling informal settlements.

The Blantyre City’s colonial-era plans primarily aimed to serve the interests of the colonizers rather than the needs of the local population. Since it was initially planned during the colonial era, the post-independence government continued to build and maintain the existing plans and infrastructure. In the first quarter of the twentieth century, the presence of Europeans was the dominant factor behind the changes that took place in the population density pattern (Baker, 1959).

3.2 Blantyre's Evolving Economy

Before independence, Africans in Blantyre were mostly employed as railway workers, domestic workers, and load carriers. A survey on wages in Blantyre-Limbe conducted in 1958 found that the average cash wage for the Africans employed was 3.11 British Pounds per month, equivalent to $114.03 per month (Bettison, 1958).

Malawi is currently struggling with low economic development, overdependence on agricultural goods for exports, high poverty levels, and significant challenges in providing basic services to its population. Similarly, Malawi's economy during its colonial period was marked by a heavy dependence on agricultural exports, in which the colonial government encouraged the export of tobacco, coffee, tea, and cotton as the main cash crops. Because of this, many planters settled around Blantyre and Zomba to grow cotton and coffee. However, there were not enough carriers to transport these crops to the Shire River, where they could be put on the river steamers and transported (Tansier, 1963). These transportation problems encouraged Sir Harry Johnston (the British commissioner and colonial administrator) to advocate for a railway station to be built from Chiromo and pass through Cholo, Blantyre, and Zomba by the African Lakes Company (Crosby, 1974). The joining of the Blantyre and Limbe townships started an economic boom within the corridor.

In 1945, Blantyre (population 4600) and Zomba (population 7100) had relatively low populations. Far more Malawians had experienced urban areas in Johannesburg or Salisbury, where an estimated 10,000 Malawians were living in 1938, than they did working at home (McCracken, 2012). The two decades from 1945 marked the economic transformation of Blantyre and Limbe. Prices for most commercial crops rose, new tobacco factories were opened in Limbe, and the United Tobacco Company opened operations at Chichiri (McCracken, 2012). In addition, many Asian traders had set up shops in both Blantyre and Limbe by the end of the Second World War, which led to the expansion of European-owned transport and commercial companies in the two townships. As the economy expanded, new jobs were created, and many more Africans flocked to the towns, thus bringing the total population of Blantyre-Limbe close to 55,000 in 1956 and 110,000 by 1966 (McCracken, 2012).

After independence in 1964, Malawi's economy grew relatively fast, mainly driven by agricultural exports since the economy was based on the established colonial agricultural model (Conroy, 2006). However, the country's economy was heavily dependent on a few primary exports, leaving it vulnerable to fluctuations in commodity prices in the global market. Moreover, this growth was not sustained when a catastrophic drought occurred in 1979-80, and a civil war in Mozambique disrupted external transport routes. Structural adjustment policies introduced by the IMF and World Bank in the 1980s signaled a start to debt and foreign aid dependence for Malawi that has persisted to the present. During the post-colonial period, Blantyre's urban economy stagnated. With the relocation of the capital city of the country from the southern to the central region, Lilongwe saw an economic boost post-independence while Blantyre's economy stayed the same with similar unequal divisions of wealth that existed during the colonial era. To quote McCracken (1998).

> "Most inhabitants still remained trapped in a web of stifling poverty; most still suffered from starvation wages which probably increased slightly in real terms from a very low level in the decade up to 1963 but then fell by as much as 30 per cent by 1977. Segregation at an economic level persisted through the continued dominance of the European and Asian sector over African businesses. But continuity here was combined with significant change in that, with independence, privileged African businessmen were able to use their access to state power in order to enhance their economic position."

3.3 History of Independent Malawi's Town Planning Laws and Zoning Strategies

The current planning law in Malawi is modeled after the British legal system. This originates from Malawi's adoption of the British legal system and planning laws, owing to its history as a former British colony. The post-colonial period can be divided into the independence/one-party rule (1964-1993) and multiparty (1994-current) eras (Manda, 2019). Although the current crisis and disputes over urban land in Malawi can be laid on the doorstep of its British colonial history, the post-colonial failure to deal with land policy has also contributed to the situation (Mwathunga & Donaldson, 2018; Chome & McCall, 2005). Land ownership in Malawi has transitioned from primarily being held by chiefs to diverse entities, including the central government, Blantyre City Council, the private sector, and the Malawi Housing Corporation (MHC). After attaining independence in 1964, land reforms were carried out under Dr. Kamuzu Banda's one-party rule in 1967, but these reforms perpetuated the unequal distribution of land by converting customary land into leasehold by the government (Mwathunga & Donaldson, 2018; Chirwa & Chinsinga, 2008). Through this conversion, the Malawian cities quickly absorbed customary land controlled by chiefs on their peripheries.

Estates (large farms) which were formed during colonial times and controlled by white farmers included large tracts of underutilized land (USAID, 2010). At Independence, ownership of the estates passed into the hands of the political elites, with the Banda regime (Independence in 1994) reinforcing the colonial-era dual structure of an agricultural sector consisting of large estates and smallholders (USAID, 2010). These large tracts of land were not redistributed to citizens, creating a complex situation where the concept of land ownership was caught between government-managed and customary-owned land.

The Town and Country Planning Act of 1988 (which replaced the 1946 Act and was meant to undo the British planning ideology) was an outdated and rigid legislation that ignored local traditions, customs, and practices; it has since been replaced by the Physical Planning Act of 2016 (Mwathunga & Donaldson 2018). The Imported 1946 Act allowed European settlers to acquire large tracts of land in rural areas and transform them into estates, leading to unofficial privatization of rural land, resulting in the loss of land for many. To quote Manda (2019)

> "The land law in Malawi had been received soon after the imposition of colonial rule and was based on principles and concepts applicable in England where, as outlined by McAuslan (2003), the land was owned by the crown and all other people owned interests or estates in the land based on history of conquest. In other words, by transferring these concepts it implied that Malawi had been conquered and its land confiscated by the British monarch."

The loss of customarily owned land in the rural areas encouraged Africans to move to the city to seek employment and improve their livelihoods. This increased the urbanization rate, hence increasing population densities in informal settlements. The unplanned areas of the city attracted squatters, and villages formed and were now managed through customary law.

The Town and Country Planning Act of 1988, a pivotal moment in Malawi's planning legislation, brought about significant changes. This Act, which mirrored Britain's Town and Country Planning Act of 1968, introduced the concept of preparing structure plans. These plans, comprehensive documents outlining a city or region's long-term development vision and spatial organization, serve as strategic frameworks guiding an area's growth, land use, infrastructure, and environmental management over a specific period, typically spanning several decades.

The Town Planning Act of 1988 introduced national-level planning and institutionalized three levels of physical development plans to be prepared in the country, namely, a National Physical Development Plan (NPDP), District Physical Development Plans (DPDP), and Local

Physical Development Plans (LPDP) (GoM, 1988). The NPDP, first introduced in 1987, was now seen as a mechanism for national development rather than solely for urban development control. Until 1970, physical planning was limited to local planning only, involving the preparations of plans for urban centers, selected special areas and the exercise of development control in statutory planning areas (GoM, 1987). It is worth mentioning that both the NPDP and the Town Planning Act (1988) were formulated simultaneously, with the NPDP being ratified by parliament in 1987, followed by the enactment of the Town Planning Act one year later. During the colonial period, planning focused on laying out basic infrastructure like roads, water, and sewerage to serve the European settlements. The NPDP sought to include the whole country in its planning processes. Figure 18 below provides a timeline of key events in the planning history related to this thesis, offering a quick overview of the changes and developments over time.

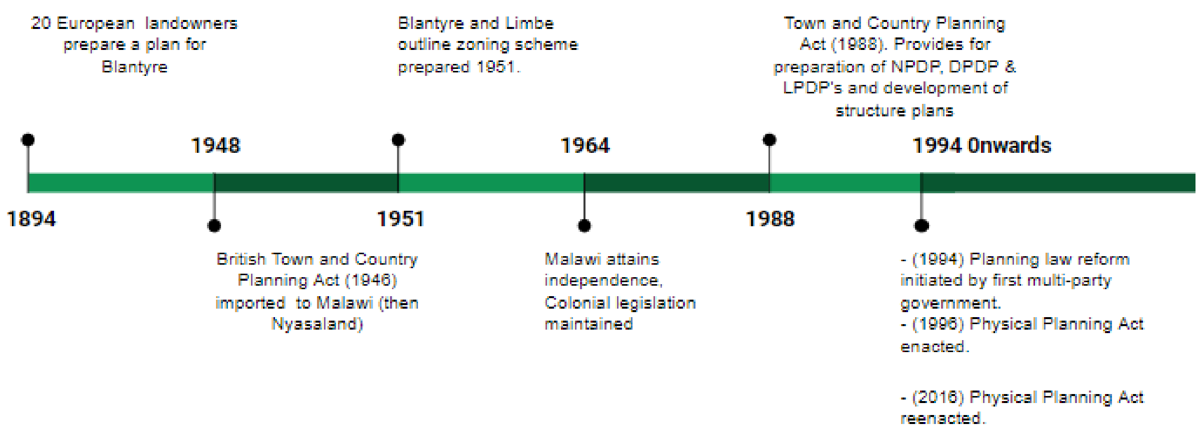

Figure 18. Planning Legislation in Malawi timeline.

The Colonial Era initial planning laws, with their segregated nature, prioritized the interests of the (white) settler community and their business interests (commercial and farming). This led to uneven development and a loss of rural land previously under customary control pushing the African residents into informal settlements near towns offering employment. These settlements were typically located at the base of hills, valleys, and unserviced land unsuitable for residential settlement. The transfer of the British Town and Planning Act of 1947 to Malawi (then Nyasaland) introduced zoning by designating commercial, residential, and industrial areas. The colonial government in Malawi enforced urban development control rules that prohibited other races from building within the city, further exacerbating segregation. To quote McCracken (2012)

> "Indian traders were forbidden to purchase property outside the centrally located but increasingly crowded `Asiatic Ward.' And Africans were banned from providing housing for themselves by the provision that no wattle and daub houses be allowed within the Township and that only buildings of brick, wood or iron be allowed, and that such houses should be of no less value than £50." The 1947 Town and Planning Act encouraged infrastructure development, mainly favoring European residential areas. The provision of road infrastructure, water, and sanitation services was central to European settler communities."

3.3.1 Housing and Spatial Transformations

After independence, urban housing and neighborhoods previously owned by white settlers were now occupied by Malawian elites. These elites were politicians and influential people in the government. Independence in 1964 was followed by actions to replace colonists with African people in government and other positions of power (Manda, 2019). However, independence did not lead to significant changes as the planning process was still informed by colonial ideologies and planning approaches that claimed expert neutrality (Manda, 2019; Baffour et al., 2014; Silva,2015). The Malawi government-maintained Blantyre's colonial-era layout, characterized by a mix of commercial and residential areas. The central business district (CBD) is in the heart of the city and is home to most of the city's major businesses and financial institutions.

> "Under colonial rule the townships were managed by the colonial government and were meant for the colonizers while the areas outside the urban boundaries were for indigenous people and were managed by chiefs," (Manda, 2019)

Until Malawi gained independence in 1964, population concentration gravitated toward the Southern Region (Kalipeni, 1997). Banda's government (1964-1994) developed an implicit program during his tenure that aimed to arrest large cities' growth while encouraging the proliferation and growth of smaller urban centers throughout the country (Kalipeni, 1997). The Rural Growth Centers Project targeted rural centers and provided infrastructure and services in rural areas. This was meant to spread the 'fruits of development' to all parts of the country. President Banda's government used to balance development geographically and, therefore, implicitly redistribute the population, yielded the intended results, especially in slowing down the growth of large cities and propelling the growth of smaller and medium-sized cities (Kalipeni, 1997). However, the second regime during Bakili Muluzi's[9] rule (10 years) brought significant disruption to the urban space. Multiparty politics during the second regime, whose slogan was 'freedom for all,' was interpreted by citizens as the freedom to squatter and not adhere to planning rules, leading to a decline in urban order and development.

Therefore, during the multi-party rule, people saw this new freedom as a chance to invade large estate lands that were thought to have been grabbed or acquired unfairly by colonialists (Manda, 2019; Kishindo, 2004). Multiparty politics changed people's perceptions of urban space; people felt that democracy and freedom meant the right to appropriate any free piece of urban space (Mwathunga & Donaldson, 2018). At the national level, the Bakili Muluzi

[9] Bakili Muluzi was the president of Malawi from 1994 to 2004. He also chaired the United Democratic Front (UDF) political party.

administration (the second government) discarded the spatial policy recommendations outlined in the NPDP. This period in Malawi's governance contributed to changing notions of rights, be it rights to land versus economic rights (Mwathunga & Donaldson, 2018). Numerous informal settlements surfaced in urban regions while the existing ones expanded in size and population. The majority of Malawi's urban land conflicts since independence in 1964 has taken place on public land because this is the land that most of the citizens consider as no man's land and think that they have the right as citizens to occupy and make a living on, as a protected right under the Republican constitution, which states that every citizen has a right to an economic activity (Mwathunga & Donaldson, 2018).

Henceforth, racial segregation, a high urbanization rate, and increased informality during colonial and postcolonial periods led to large numbers of people settling in areas that were unplanned. The discriminatory land use policies, specifically targeting marginalized residents, predispose them to disaster or flood vulnerability (Phiri, 2019).

3.4 Malawi's Vulnerability to Climate Change-Induced Hazards

In recent years, Malawi has had a predominantly rural population with a high urbanization rate. Malawi is considered "one of the fastest urbanizing countries" (World Bank, 2016; UN-HABITAT, 2012). The 2008 Population Census (World Bank, 2016; NSO 2008, pp. 26) reports that Malawi's urban population growth rate was 5.3 percent per year during 1987-1998 but only 3.7 percent per year during 1998-2008 (World Bank, 2016). At this rate, by 2030, one in every five Malawians (or around 20% of the population) will be city or town dwellers, and by 2050, the share will reach 30 percent of the population (World Bank, 2016). The cities in Malawi have proliferated without sufficient infrastructure investments and improvements, making them particularly vulnerable to climate change hazards like floods. To quote Kalipeni (1997, p.61);

> "The environmental impact of urban growth has been severe. Today the formerly beautiful hills around the city of Blantyre lie bare and denuded; stripped of their majestic, lush cover."

Malawi's climatic geography exacerbates the people's vulnerability to climate-related hazards. The southern region is savannah-like and primarily consists of plains and valleys. Being in a tropical wet/dry region, Malawi experiences two main annual seasons: the hot and rainy season from November to April and the cool and dry season from May to October. Malawi depends on rainfed agriculture such that this high dependence on the short rainy season renders the country very vulnerable to weather hazards; as a result, erratic rainfall has increased water scarcity, rising temperatures, and extreme weather events such as floods and droughts have increased in magnitude and frequency (Coulibaly et al., 2015).

A study conducted in 2015 on socio-economic and spatial factors exacerbating vulnerability to climate change risks and the districts' adaptive capacities showed that Blantyre and Chikwawa have the weakest capacities to adapt consistently to climate-related risks (Coulibaly et al., 2015). Indicators used in the study to determine adaptive capacity were farm income, education of the household head, and rate of change (Coulibaly et al., 2015). Findings in the study showed that Blantyre and Chikwawa have the weakest capacities to adapt consistently since they are the poorest neighboring districts in southern Malawi in that they face numerous problems, including food insecurity, high illiteracy rate, poor access to safe water and sanitation, high prevalence of HIV/AIDS (Coulibaly et al., 2015; MMNRE, 2006). In addition, the high urbanization rate caused by rural-to-urban migration increases the number of people settling in informal settlements prone to flooding and other climate-related risks.

Since Blantyre City was initially planned during the colonial era, the post-independence government has continued to build and maintain the existing plans and infrastructure. In the first quarter of the twentieth century, the presence of Europeans was the dominant factor behind the changes that took place in the population density pattern (Baker, 1959). The city’s colonial-era plans primarily aimed to serve the interests of the colonizers rather than the needs of the local population. As a result, the city's urban planning policies have contributed to the vulnerability of the underprivileged to climate-related hazards.

3.5 Current Understandings of the Effect of Colonial History on Urban Spatial Arrangement

Response to survey show that the participants are familiar with Blantyre City with 40% of respondents expressing their general familiarity and 25.3% expressing that they were very familiar with the city. Knowledge of the city and its informal settlements was paramount in finding out their overall knowledge of the colonial history of the city and the vulnerability of the informal settlements of interest. Survey respondents were asked whether they were familiar with the informal settlements and their development (how the settlements got established in those locations). As illustrated in Table *5* below, findings show that participants were more knowledgeable of the history of development of Ndirande settlement as compared to Chilobwe.

Table 5. Participant’s familiarity of the informal settlements of Ndirande and Chilobwe

	Familiarity %	Settlement Development %
Ndirande	95%	56%
Chilobwe	87%	33%

With Ndirande being the oldest high density informal settlement in Blantyre, most participants are more likely aware of it. In addition, Ndirande is notorious for its bustling informal market in which people joke, 'you can build a car from scratch will all parts sourced from Ndirande'. To quote Norwood, (1972).

> "The commercial center of Ndirande is the market..... Until January 1971, this was sited where the tracks leading to Blantyre converged and was the main center of activity for Ndirande. The old market was at a central point extremely convenient for people going to and from the Blantyre city area. This market was entirely unofficial and not recognized by the city authorities."

As illustrated in Figure 19 more than 20 participants identified Ndirande as partially a planned THA. Many residents who own THA-designated plots have built more than one house on their plots; hence, the THA-designated parts of Ndirande and Chilobwe likely closely resemble the informal parts of the settlements. Figure *19* figure also shows that 12 participants expressed that Chilobwe developed as an informal settlement while some still explained that it is partially planned and partially unplanned.

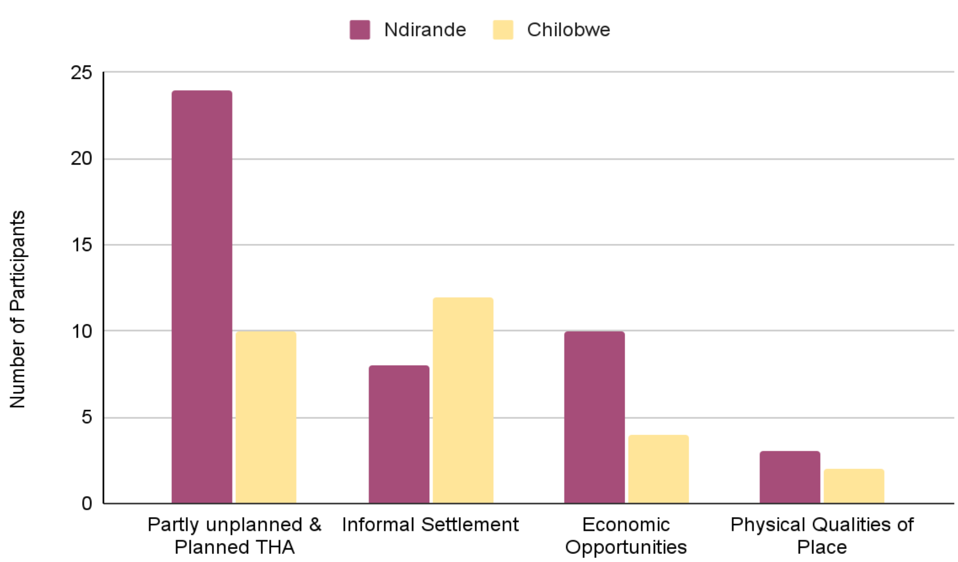

Figure 19. Perspectives of participants on the history of the establishment of Ndirande and Chilobwe as settlements

as illustrated by these quotes from participants:

> "Ndirande firstly developed as an informal settlement for the Malawians who were migrating to Blantyre on a large scale. Due to the colonial government restrictions on land especially for Africans left the Africans with no options but to squatter in the areas such as Ndirande and Bangwe. Ndirande had no proper services suitable for a settlement which put a risk on public health in Blantyre. Ndirande now still is growing as an informal settlement with poor services."

> "Part of Ndirande is planned while the other part is not planned."

> "Chilobwe developed first as a squatter settlement in the 50s. Post independence, the Government created THA plots for low-income urban dwellers."

Respondents were asked to explain the extent to which colonial practices have influenced the spatial development of Ndirande. As illustrated in Table *6* below; 'Proximity to employment' (at white settlers' homes and businesses) was a major reason as to why Africans chose to settle in Ndirande. This is followed by the curfew that was implemented by the colonial government which barred Africans' movement within the city at night. These two factors above are most likely linked to each other since the curfew that was implemented between 6:00 pm and 6:00 am required people that worked in the city to live closer to their place of work.

Table 6. Means and coefficient variations in the level of agreement by participants of the reasons for the location of Ndirande development as an informal settlement and the influence of colonial practices on spatial development (1-10 scale)

	Mean	CV	n
Night curfew limiting mobility	6.0	0.4	72
Outside of city and not subject to planning regulations	5.1	0.6	66
Proximity to employment	6.8	0.4	73

The proximity to employment has the highest perceived influence on spatial development (mean of 6.8). The relative consistency in responses (CV values) suggests that these perceptions are relatively common among the respondents. Participants expressed that the residents settled in Ndirande for economic opportunities i.e. for jobs at Makata. Makata is an industrial zone near Ndirande which harbors several manufacturing industries (e.g. Coca Cola Beverages Ltd, Castel Malawi Brewery who are large employers) Opinions regarding the curfew tend to be more uniform among respondents, there is more diversity in views concerning the influence of location and proximity to employment on their perceptions. Most respondents who responded ‘Other’ expressed that many Africans settled in Ndirande because they had access to cheap land and housing.

Respondents were asked if colonial zoning practices had an enduring effect on infrastructure, exposure to environmental hazards, and adverse health impacts. As illustrated in Figure 20 below, most urban planning participants affirmed that historical colonial practices in Blantyre had affected informal settlement’s exposure to environmental hazards. Many participants across all professions were uncertain. This is likely due to their lack of expansive knowledge of colonial zoning processes, and thus, they could not link environmental hazards as being exacerbated by the history of the urban form. As a former undergraduate urban planning scholar in Malawi, I could only learn more about colonial zoning practices in school. Someone outside the profession might have faced significant challenges to access that knowledge.

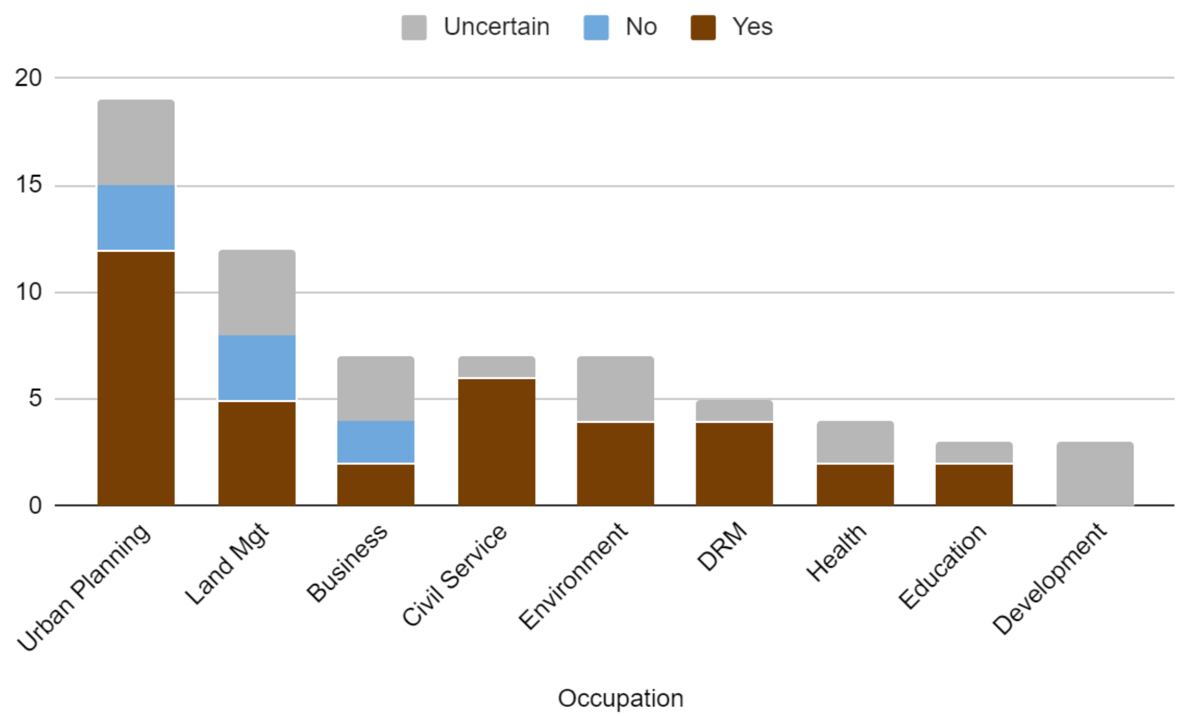

Figure 20. Participant agreement (n=67) by profession to the statement that colonial zoning practices' effect has an enduring effect on current exposure to environmental hazards.

Respondents were asked to rank challenges that disadvantaged communities in informal settlements encounter because of historical housing patterns influenced by colonial urban planning (No. 1 being the most important and No. 5 being the least important). As illustrated below in Table *7* 'poor infrastructure and lack of essential services' had the lowest mean rank of 1.53 out of 5 (std. dev. =0.784,). This indicates that, on average, respondents perceive it as the most important challenge faced by disadvantaged communities influenced by historical housing patterns and suggests that respondents consider poor infrastructure and the lack of essential services as the most pressing issue among the options that were provided. This was followed by 'Disproportionate exposure to environmental hazards and natural disasters' which had a mean score rank of 2.45 out of 5 (standard deviation=0.904), indicating that it is perceived as the second most important challenge on average. Though not ranked as highly as 'poor infrastructure and lack of essential services’, it is still considered significant by respondents.

Table 7. Mean and standard deviation of informants’ perspectives (n=X) on the relative importance of challenges tied to historical housing patterns Shows the average scores of challenges from historical housing patterns influenced by colonial urban planning.

	Mean	Standard Deviation
Poor infrastructure and lack of essential services	1.53	0.784
Disproportionate exposure to environmental hazards and natural disasters	2.45	0.904
Segregation due to socioeconomic status	3.05	1.26
Increased negative health impacts	3.13	0.939

As illustrated in Table 8 below, participants consistently believed there were more prominent physical issues for Chilobwe compared to Ndirande. For Chilobwe, the physical conditions are more consistently mentioned with lower CV values, indicating a lesser variability with ‘poor housing structures’ and ‘high population densities’ as the most mentioned issues, which have a mean of 0.9. Similarly, in Ndirande, these issues were also prevalent, albeit with a higher variability of responses. The most mentioned issues were ‘poor housing structure’ and ‘high population density,’ with a mean of 0.6.

Table 8. Survey respondent perceptions of the presence (0=no mention, 1=mention) of physical conditions in Ndirande and Chilobwe that exacerbate vulnerability. The mean, coefficient of variation (CV) and number of respondents for each physical condition are presented.

	Ndirande			**Chilobwe**		
	Mean	CV	n	Mean	CV	n
Poor housing structures	0.6	0.9	83	0.9	0.4	76
Poor road network	0.5	1.0	83	0.8	0.6	76
Lack of sanitation/stormwater systems	0.5	0.9	83	0.8	0.5	76
High population density	0.6	0.9	83	0.9	0.4	76

Chapter 4: Vulnerability Analysis

This chapter first presents a review of the literature on urban climate vulnerability with a particular focus on marginalized communities. This review is followed by an analysis of how the location of marginalized communities in Blantyre contributes to their vulnerability to flooding. Using both survey findings and geospatial analysis of green cover, soil, and topography, it empirically evaluates the climate, physical, social, and governance contributions to the vulnerabilities of marginalized communities in Blantyre City.

4.1 Climate Vulnerability

Within Malawi, the Southern Region is the most prone to flooding events (Ngongondo et al., 2015; Winsemius et al., 2018). Over half of the most affected districts are in the south, amongst which Blantyre is one of the worst-affected areas (Ngongondo et al., 2015; GoM, 2015). Blantyre's climate has significantly changed over time. Blantyre receives significant quantities of rainfall per annum, with an expected increase in variability of rainfall and storm events (GoM, 2024). The city's average annual precipitation (greater than the national average) increases the likelihood of urban flash flooding (GoM, 2023). From 1961–2015, the urban areas of Blantyre received a maximum mean annual rainfall average of 1140.2 mm, 1000.0 mm, and 834.6 mm from weather stations (Ngongondo et al., 2015).

In this thesis, I examined rainfall trends from 1981 to 2023, focusing on rainfall distribution and amount, and how these factors contribute to the likelihood of flooding and mudslides. To illustrate these findings, Figure 21 below presents the Maximum daily precipitation recorded in Blantyre. The graph effectively demonstrates a fluctuation of highs and lows over the four decades under investigation, with 2022 marking the highest recorded maximum daily precipitation in over the years. The effects of Cyclones Ana and Gombe in 2022 are also apparent, likely intensifying the rainfall in the city.

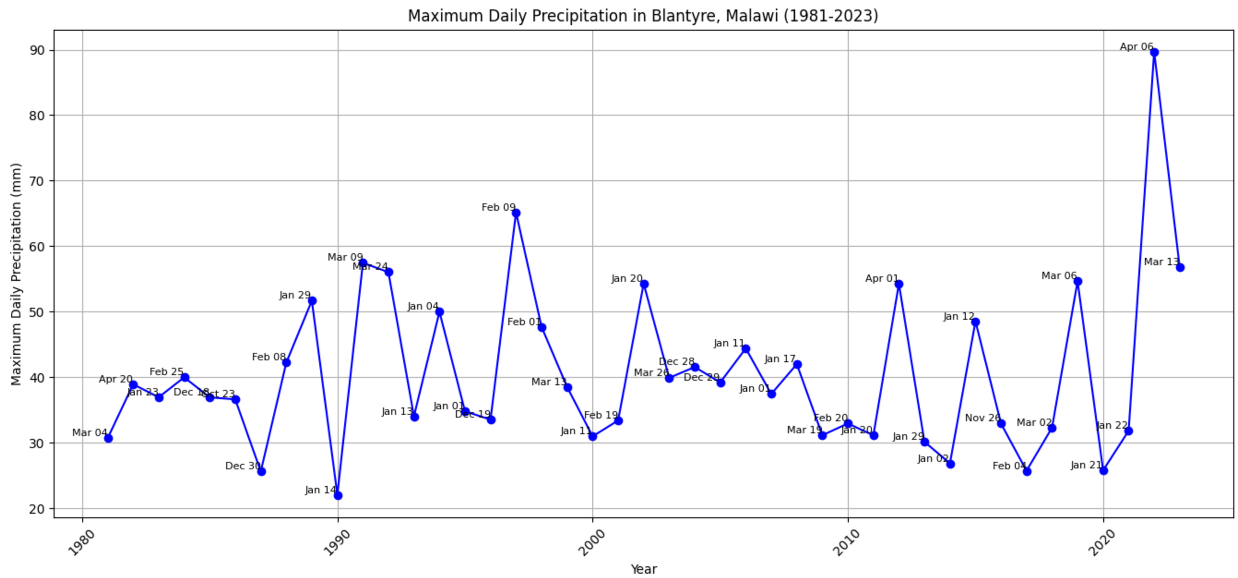

Figure 21. Maximum Daily Precipitation from 1981 – 2023

Table 9

Table 9 **Error! Reference source not found.**below shows extreme rainfall events that contributed to an increased rate of rainfall since 2010.

Table 9. High rainfall events that impacted Malawi since 2010.

Year	**Extreme Rainfall Event**
2012	Cyclone Funso
2015	Tropical Depression
2019	Cyclone Idai
2022	Tropical Storm Ana, Cyclone Gombe
2023	Cyclone Freddy

periodve occurred in thirteen years, their intensity concentrated within a short period of time rather than spread out through the rainy season. The magnitudes of these individual storms have increased (Ngongondo et al., 2015). It's important to note that despite these changes, the total annual rainfall has not shown a significant shift (Ngongondo et al., 2015). Hence too much rainfall in a short period of time increases the risk of landslides and flooding. Figure 21 shows the maximum daily precipitation in Blantyre with dates on when that rainfall was recorded. It is important to note that March 13th as indicated in the graph coincides with when Cyclone Freddy dumped most of the rainfall in Blantyre. The distribution of rainfall during major climate events can play a major role in the distribution of flooding. Figure 22Figure 22 below shows the maximum daily rainfall distribution in Blantyre during the month of March 2023. This effectively shows the distribution of rainfall associated with Cyclone Freddy. Please note the large variation with rainfall almost doubling from the northwest to southeast.

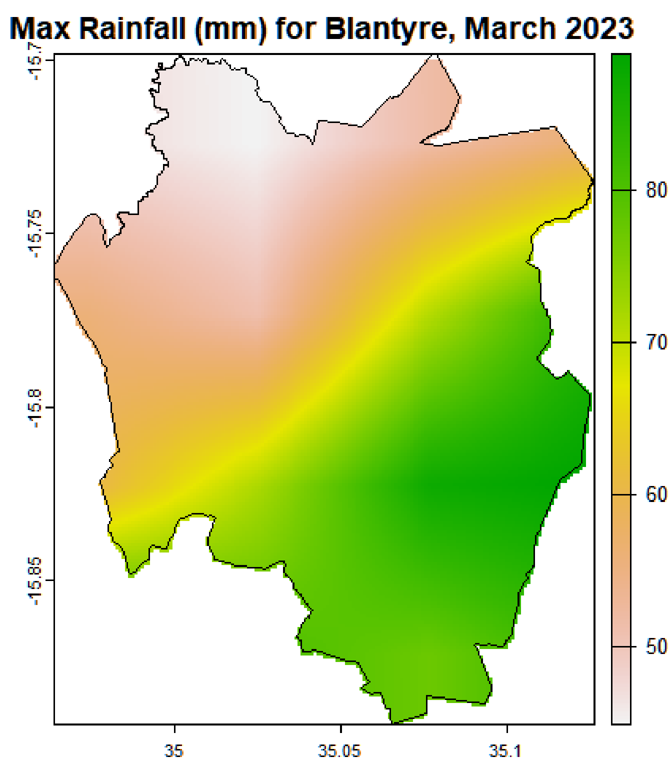

Figure 22. Maximum daily rainfall recorded in March 2023

4.2 Physical Vulnerability

Blantyre’s topography is undulating, interspersed with hills and mountains, and drained by nine river catchments. Blantyre also has flat areas that serve as wetlands and sponge areas with some steep slopes, making the city vulnerable to flash flooding and landslides. Housing in informal settlements in Blantyre is primarily situated in valleys, steep slopes, and unstable ground of the district’s hilly terrain. To quote GoM (2024)

> “Unplanned development on steep slopes increases the risk to those residents but also to the environment (GoM, 2024).”

As Banda (2015) points out, the vulnerability within a community is often associated with the conditions of the built environment that different people live in. In the case of Blantyre, the poor housing infrastructure in these informal settlements exacerbates their vulnerability to flooding. Steep slopes are unsuitable for development. In Blantyre, they are mostly found in existing reserves or dedicated conservation areas, and development on these steep slopes mainly results from encroachment into these areas.

Inspecting the coping capacity of natural elements while analyzing risk posed by natural hazards is crucial to the comprehensiveness of the analysis (Dewan, 2013; UNDP, 1992). The Figure 23 below illustrates the Pressure and Release (PAR) model, which shows that the physical environment is vital when referring to unsafe conditions in a settlement, exacerbating vulnerability. The PAR model suggests that disasters happen with the juxtaposition of hazards with vulnerable people. Vulnerability stem from structural factors, such as the legacies of housing segregation in Blantyre and structural barriers to rural livelihoods in surrounding areas. These structural factors shape dynamic pressures could include rapid population growth and the persistent blind spots in Blantyre City urban planning. From the perspective of the PAR model, disasters like Freddy only occur through confluence of preexisting vulnerabilities and the cyclone.

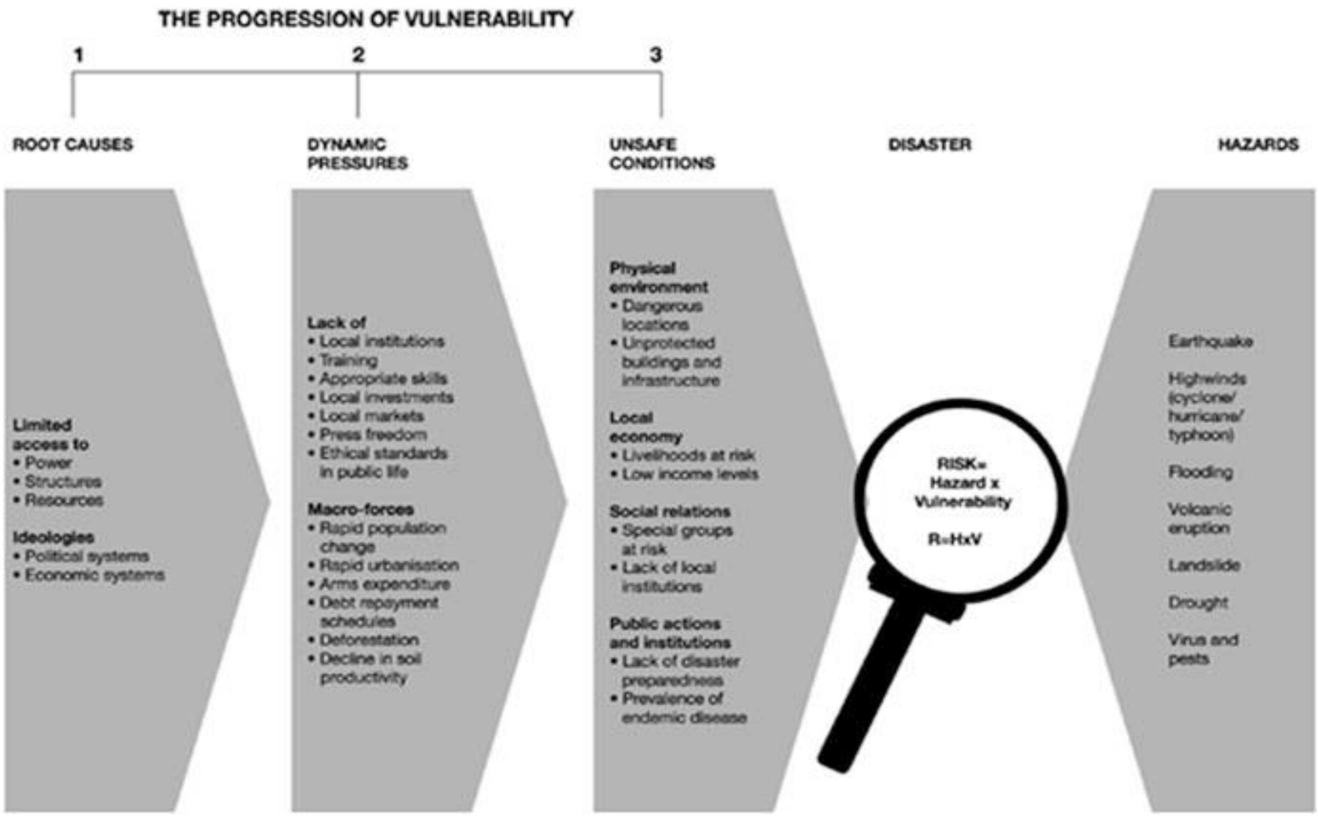

Figure 23. Pressure and release model (PAR) (Adapted from Dewan, 2013; Wisner et al. 2004)

Low-income communities like Ndirande, located in flood-prone areas with low-lying topography or inadequate stormwater drainage systems, are the most physically vulnerable to floods and face increased risks of inundation and damage to infrastructure and property in Blantyre.

> ” Across Ndirande runs the Nasolo River, a sluggish meandering sewer in the dry season where malaria mosquitos incubate, children play, and women do their laundry,” (Bodelier, 2008).

Bodelier calls the Nasolo River a sewer due to its pollution, as stated in the above quote. Partially due to deforestation on Ndirande Hill, the Nasolo changes into a dangerous current in the rainy season, sweeping away chickens, children, bridges, and houses, transforming into a devastating flood (Bodelier, 2008). During Cyclone Freddy, Blantyre City experienced flash floods, which included many mudslides. Freddy dumped six months of rainfall in six days on Malawi and neighboring Mozambique (Chothia & Jegwa, 2023). As of March 14th, 2023, the Department of Disaster Management Affairs (DODMA) reported:

> "21,049 people have been affected, 65 deaths have occurred, and 32 camps have been established. Flash floods from hills with high speeds. Roads damaged; Kabula police bridge affected. Areas that had flash floods require more effort, especially Soche Hill. Some people are still missing."

Biophysical vulnerability is driven by interacting factors, including proximity to low-lying floodplains, interfluves, and cyclonic paths; flood recession agriculture; heavy erosion and siltation; and use of poor-quality building materials (Graham, 2006). Despite the country's history of experiencing similar extreme weather events, such as Tropical Storm Anna in 2022, Malawi has yet to fully adapt to these recurring disasters.

4.3 Social and Governance Vulnerability

When considering human vulnerability to natural hazards, the term 'social vulnerability' has been used to describe vulnerability arising from historical, cultural, socio-economic, and political processes that make people vulnerable (Mwale et al., 2015). Social vulnerability to flooding in Blantyre is exacerbated by social and other stressors that marginalized communities are subjected to. These livelihood conditions that contribute to vulnerability include low income, food insecurity, and a lack of access to health services. These factors reduce the ability of these communities to withstand a flooding event, leaving the communities worse off after flooding.

Variations in flood impacts among households were due to contextual factors, coping strategies, and flood impacts (Banda, 2015).

As shown in the Figure 24 below, the main tarred road runs through the bustling commercial and manufacturing center of Ndirande. A stroll through Ndirande reveals a lively scene, with both sides of the main road teeming with timber sellers, minibus repairers, pubs, take-away food stands, and producers of burglar bars, cooking stoves, and comfortable couches (Bodelier, 2008). This entrepreneurial spirit is a defining characteristic of Ndirande, where many residents are active participants in the informal financial sector. However, their low income and reliance on the informal economy also make them more vulnerable to flooding. When the floods strike, they not only lose their sources of income but also suffer a significant economic setback.

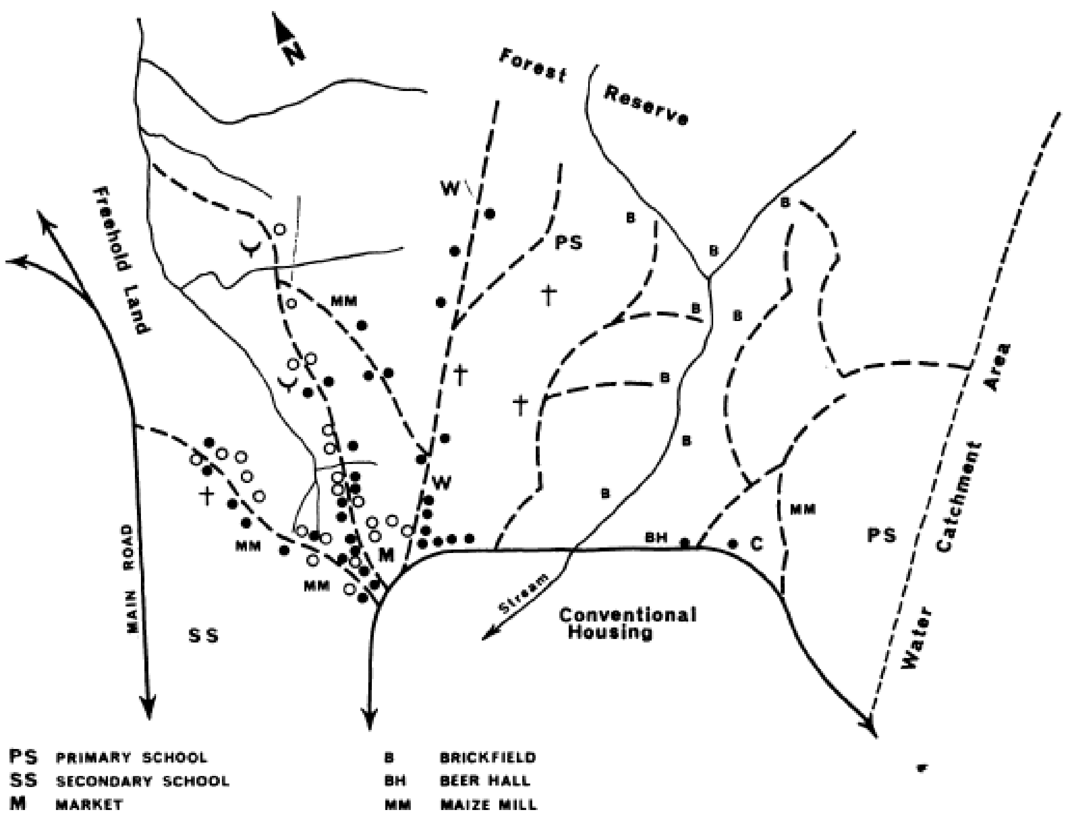

Figure 24. The urban structure of Ndirande (Norwood, 1972)

Social factors such as social networks, community cohesion, and governance structures are keystones in a community's resilience to flooding. Communities with strong social networks and cohesive communities may be better equipped to respond to floods and recover from their impacts. In contrast, those with weak social networks and poor governance structures may need help coordinating and implementing effective flood management strategies. Blantyre relies on extension services to educate its residents on climate and environmental factors. Extension Planning Areas (EPAs) have been demarcated by the Agricultural Development Divisions (ADDs). However, these extension services are insufficient to disseminate climate information. Extension agents are needed to effectively provide vulnerable populations with information about climate and support services needed to support the building of residents' adaptive capacities (Coulibaly et al., 2015).

The City of Blantyre has grown a lot since the country's independence. The 2018 census showed that Blantyre City had a population of 879,000, with 50.13% males and 49.87% females, and the projections indicate that Blantyre City should have a population of about 995,000 in 2022 (GoM, 2023). The number of family members contributes to social capital formation, reducing transaction costs, facilitating information flow, and increasing trust (Coulibaly et al., 2015). The average household size in Malawi is 4.5 members; women head three in ten households (GoM, 2017). A larger family size provides the labor resources needed to perform farm activities and raises the productivity of the factor of production; however, that large family size may have limited financial resources to meet the household obligations, which will negatively impact resilience and recovery from natural hazards (Coulibaly et al., 2015). In the case of Ndirande and the informal settlements in Blantyre, most residents have little or no land for farming due to the high population densities in these areas and the rugged terrain unsuitable for farming. Ndirande's gross population density is between 15 and 24 du/ha (dwelling units per hectare), while Bangwe's is 25 du/ha (GoM, 2024). Both of these densities present high population densities in both settlements. A large family size primarily is associated with a high dependency ratio, which increases vulnerability and impacts the ability of a family's resilience to flooding events.

4.4 Findings: Factors contributing to Flood Vulnerability

In this thesis, I use land cover, topography, and geological conditions (soil type) to analyze the physical exposure of communities of interest to floods in Blantyre City. Blantyre's hilly topography forces people to settle on hillsides which experience more rapid and destructive flooding. Given Blantyre's hilly topography, landslides, which are related to the region's geology, geomorphology, climate, and land use regimes, are a frequent geo hazard that affects the city (GoM, 2024). Tree and vegetation cover helps reduce the speed of runoff by absorbing runoff and slowing down the water flow during heavy rains. Geological conditions, with a focus on soil type, influence the study areas by increasing their vulnerability to flooding. The soil's particle size and composition affect water permeability and retention. Clay soils on a high slope gradient are more susceptible to mudslides since they possess all the mentioned qualities.

4.4.1 Green Cover

The extent of tree cover in Blantyre has been declining steadily over an extended period. Most of the hills, water catchment areas, and riverbanks in Blantyre have been deforested due to over-dependence on wood fuel, use of timber for housing construction, and land clearing for human settlement (UN-HABITAT, 2011). From 2001 to 2022, Blantyre City lost approximately 785.69 acres of tree cover, equivalent to a 22% decrease since 2000 (Global Forest Watch, 2024).

As illustrated in Figure 25 below, built-up land increased significantly from 1994 to 2018. There is a significant loss of cover in the south and southeast of the city, with minimal loss in the North. The general area where Soche and Bangwe Hills are located has lost the most cover. Ndirande Hill does not show a significant cover change, as there wasn't much cover in 1998. However, the extent of built-up land in Ndirande (north central area) has increased significantly. In Bangwe and Ndirande, most areas impacted by mudslides were in watersheds with a high fraction of steep slopes, bare land, and cropland. Extensive deforestation, illegal encroachment, and charcoal production on the nearby hill slopes have heightened the areas' vulnerability to flooding.

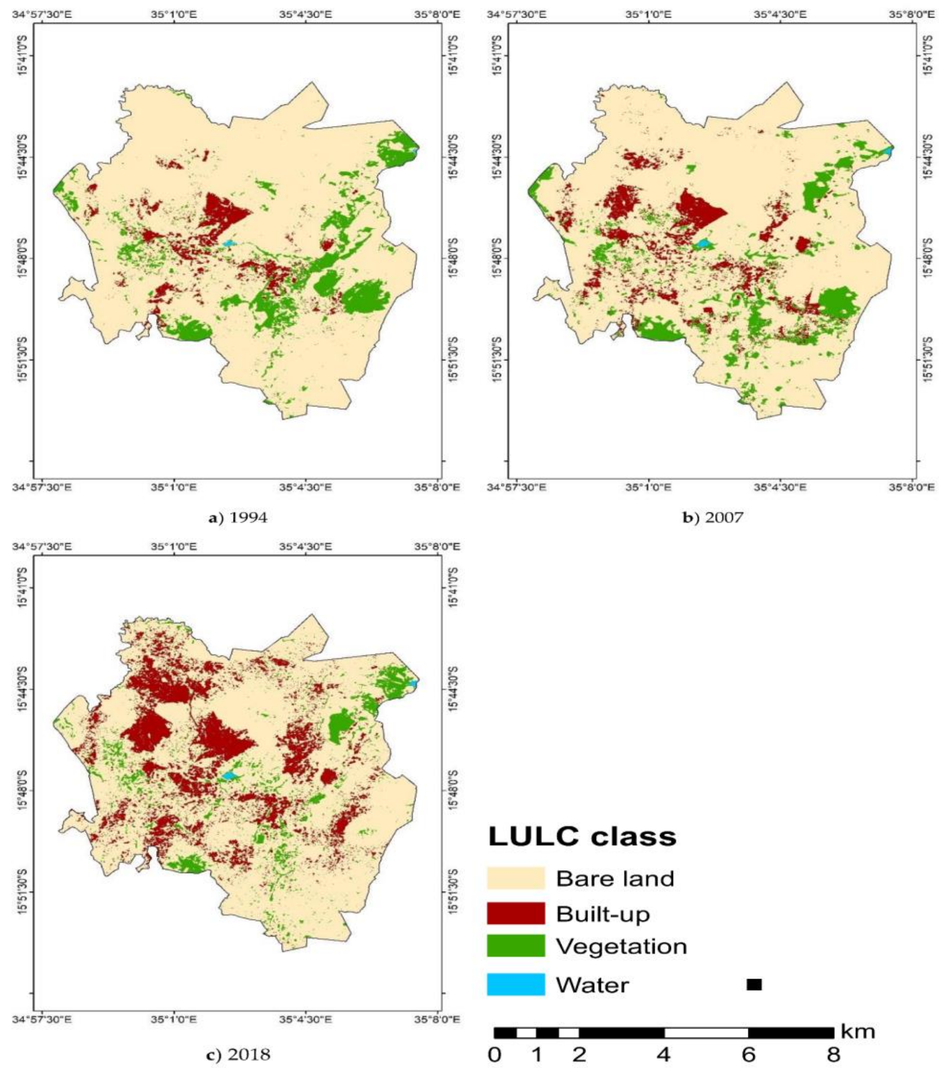

Figure 25. Classified land use/land cover (LULC) maps for Blantyre city in (a) 1994, (b) 2007 and (c) 2018. (Mawenda et al 2020)

Figure *26* below shows the locations of all informal settlements in Blantyre, their proximity to protected areas (forests), and the location of mudslides from Cyclone Freddy. The figure suggests that other areas, not informal settlements, are affected by the mudslides in Blantyre.

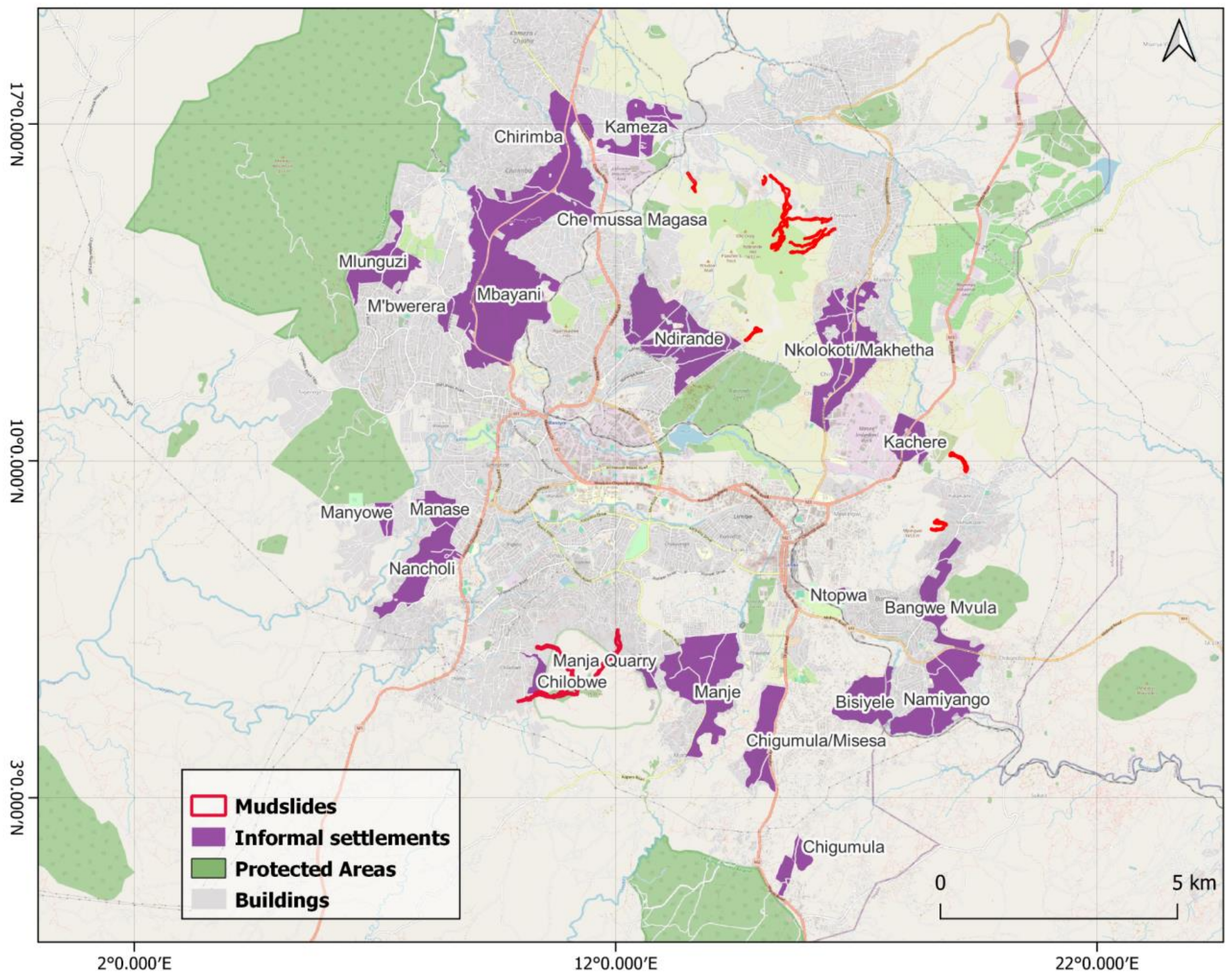

Figure 26. Shows the location of informal settlement and mudslides (After cyclone Freddy)

This is so because the officially recognized informal settlements (the only shapefiles accessible during the overlay process) do not include THA-designated areas. In reality, the informal settlements extend beyond the officially recognized boundaries, well into THA-designated areas where the mudslides were prominent. It is important to note that the communities of interest (Ndirande and Chilobwe) are on the slopes of Ndirande Hill and Soche Hill respectively.

4.4.2 Geological Conditions: Soil Type

The ground surface conditions of Blantyre, including the soil type, soil saturation, and permeability capabilities, contribute to flooding. Blantyre City has three main soil types. Most areas have dark gray or reddish-brown clay loam soil, but areas near rivers and streams have clayey alluvium deposits, while hilly areas consist of sandy soils (Maoulidi 2012; Matope, 2000).

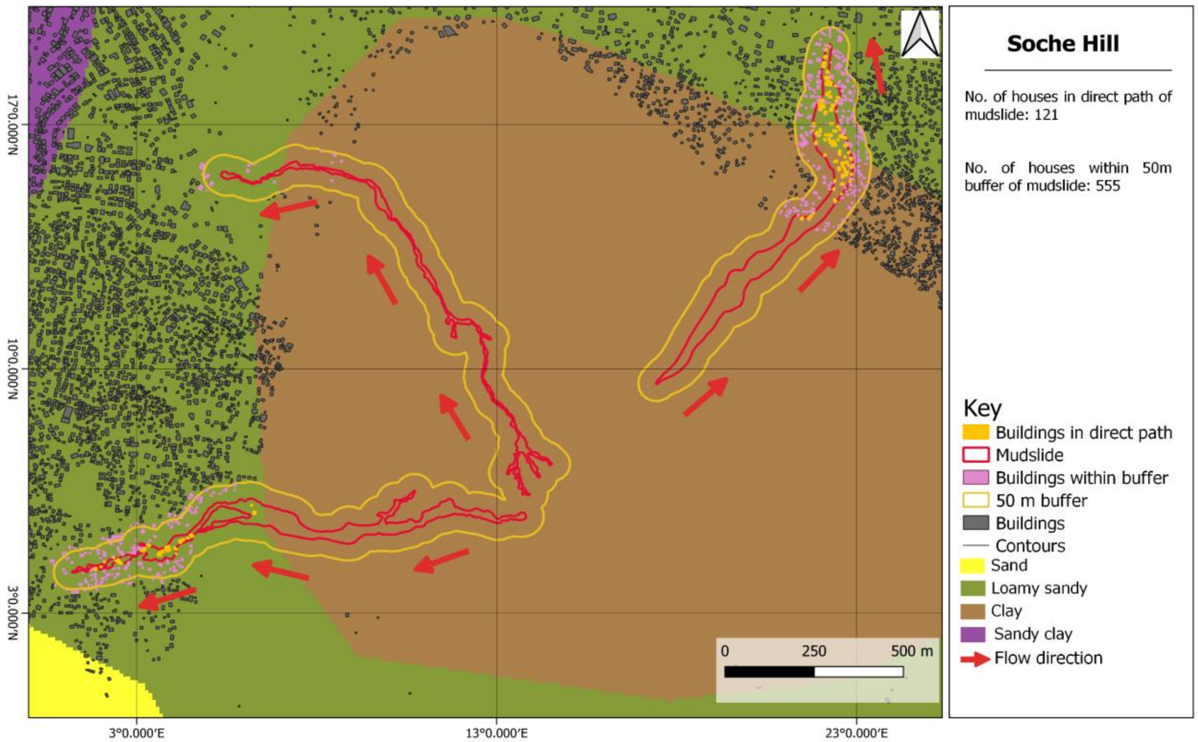

Figure 27. Soche Hill soil-type vulnerability to mudslides

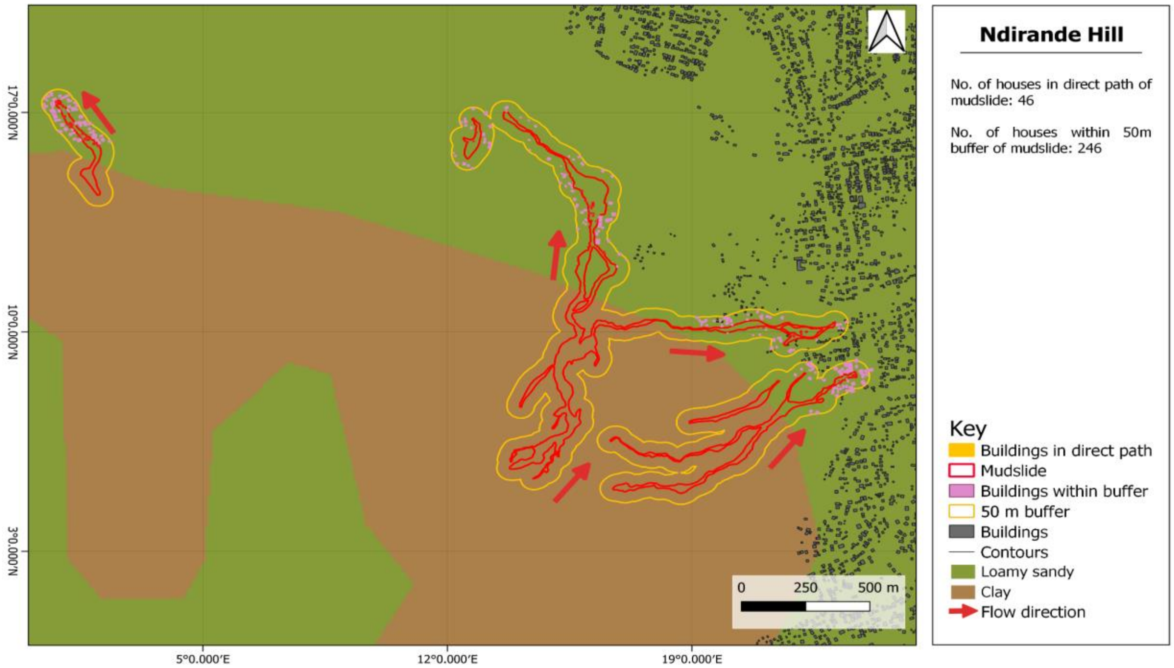

Figure 28. Ndirande North Hill soil-type vulnerability to mudslides

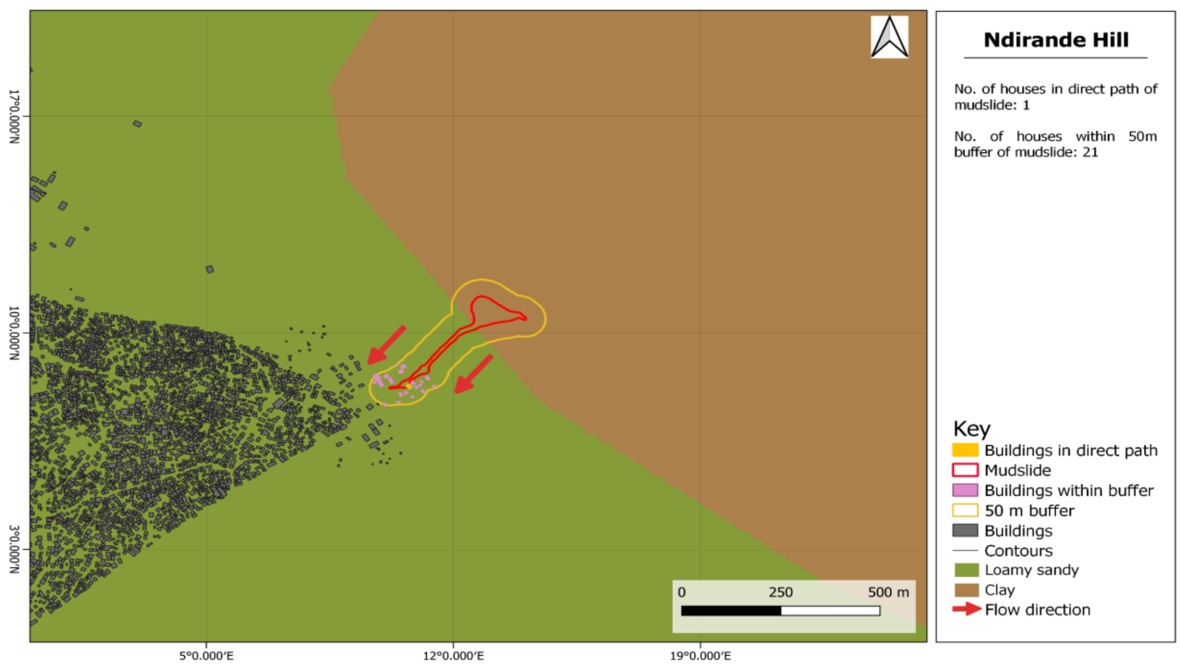

Figure 29. Ndirande South Hill soil-type vulnerability to mudslides

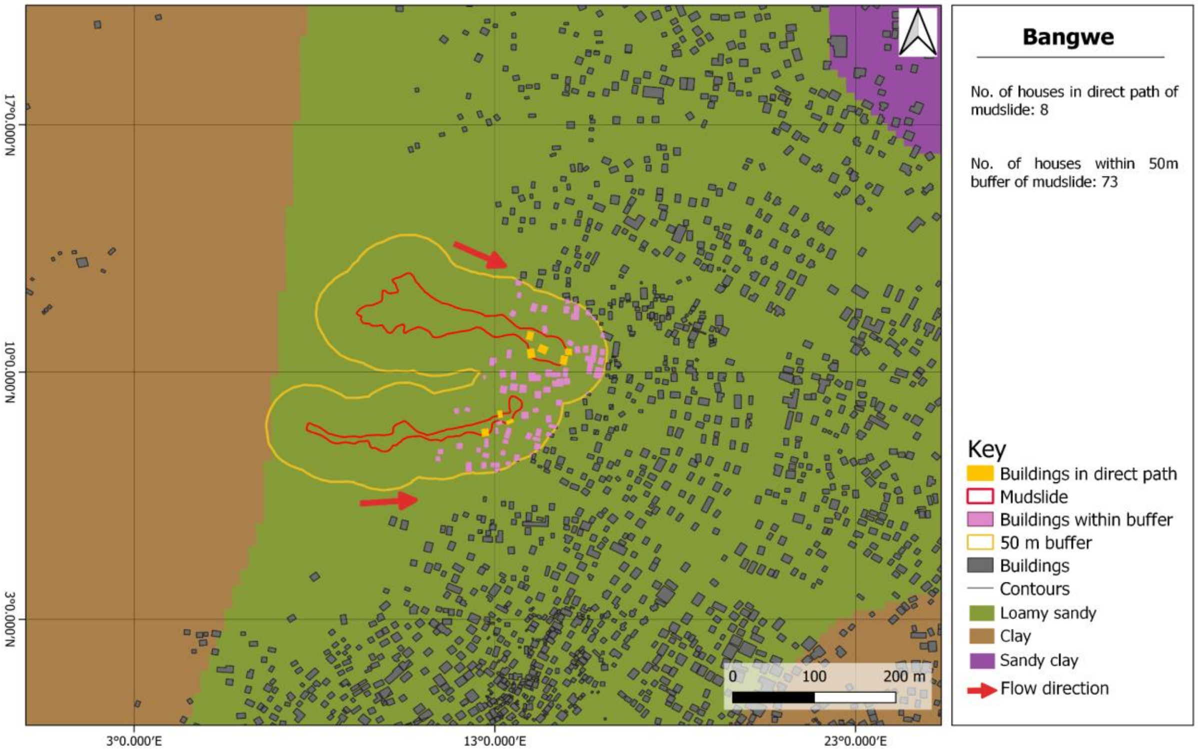

Figure 30. Bangwe Hill soil-type vulnerability to mudslides

Figures 27-30 illustrate Soche, Ndirande, and Bangwe hills, showing that they have clay soil on the slopes and loamy sandy soil at the foot. During Cyclone Freddy, as the mudslides happened, they carried clay soils from the hills and deposited them at the foot of the hills, where Chilobwe Clay soils have a high-water retention. This makes the soil naturally hold much water and become saturated, reducing its stability. While saturated, the clay becomes heavy, forcing it to slide off the slope.

4.4.3 Topography

Aside from settlement characteristics exacerbating vulnerability, Figure 29 below shows Blantyre's rugged terrain. The mountains surrounding the city lie between 800 and 1600 meters above sea level, including Soche (1524 meters), Ndirande (1564 meters), and Bangwe (1510 meters) (GoM, 2024). The physical features of Blantyre's land surface accelerate run-off. With such a high elevation and rugged terrain, many communities have resorted to building on mountain slopes, hence being susceptible to flash floods. As shown in Figure 31Figure *31* below, numerous streams and rivers originate from the highlands and flow onto the flatter ground. The rapid run-off from these highlands leads to sediment transportation, with the sediment eventually being deposited at the foot of the hills. The high-water velocity, a key factor in the formation of gullies, has significantly contributed to the flooding situation.

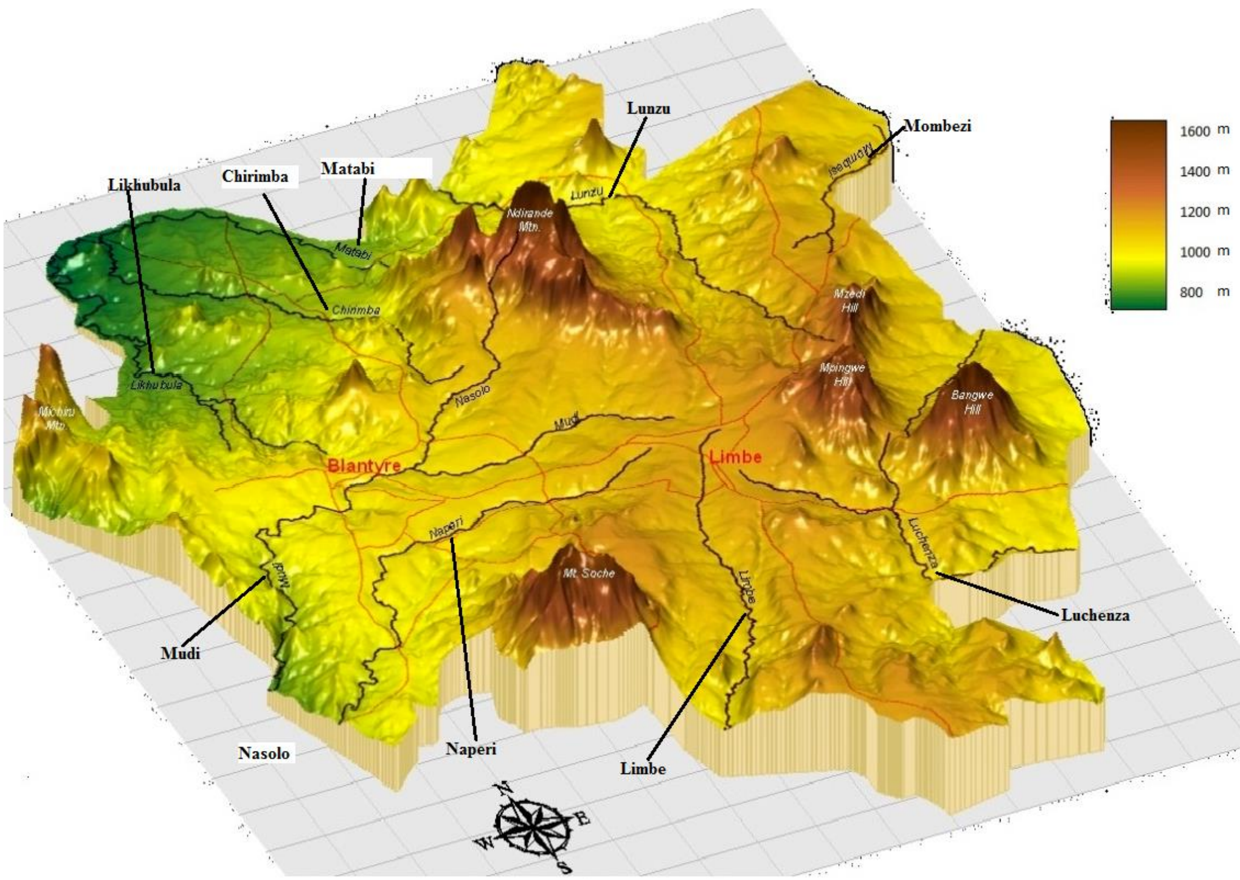

Figure 31. Blantyre topography. Source: Maoulidi 2012; Costly Chanza, BCC (2011)

GIS was used to digitize and map water flow affecting communities of interest during Cyclone Freddy. Figures 32-35 below show slope characteristics and the communities affected by the cyclone. Tight-knit contours depict a steep slope. As illustrated in the images below, mudslides follow steep slopes, with Ndirande and Soche Hill having the steepest slopes where mudslides occurred.

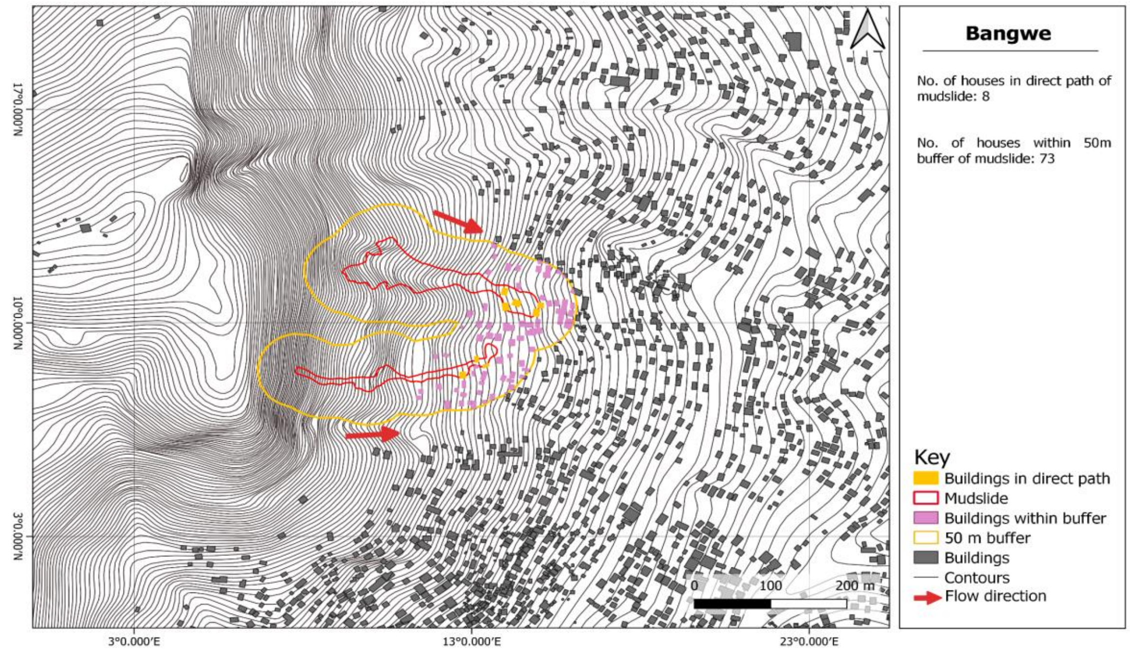

Figure 32. Bangwe Hill slope vulnerability to mudslides

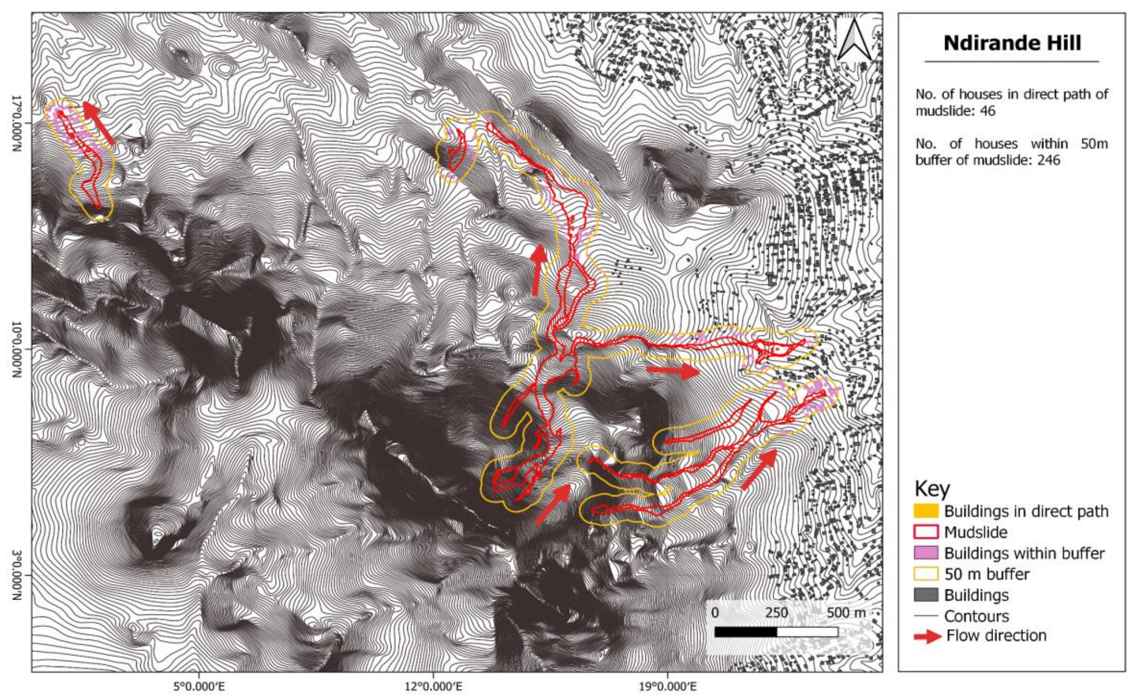

Figure 33. Ndirande Hill North slope vulnerability to mudslides

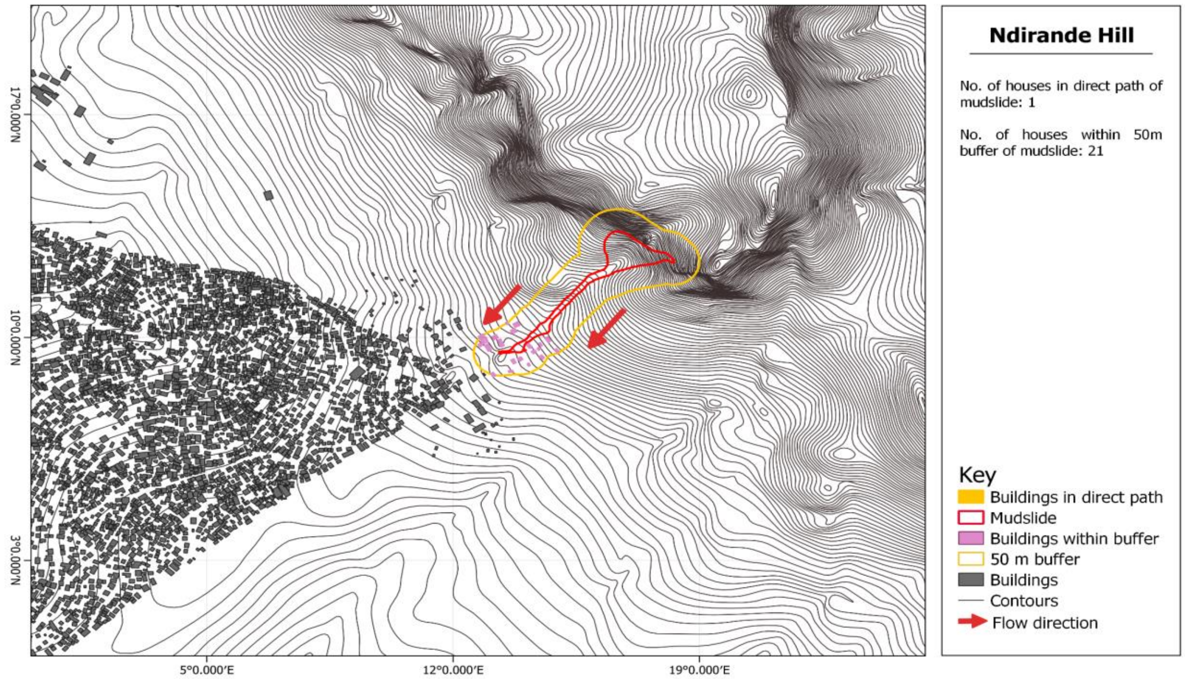

Figure 34. Ndirande Hill South slope vulnerability to mudslides

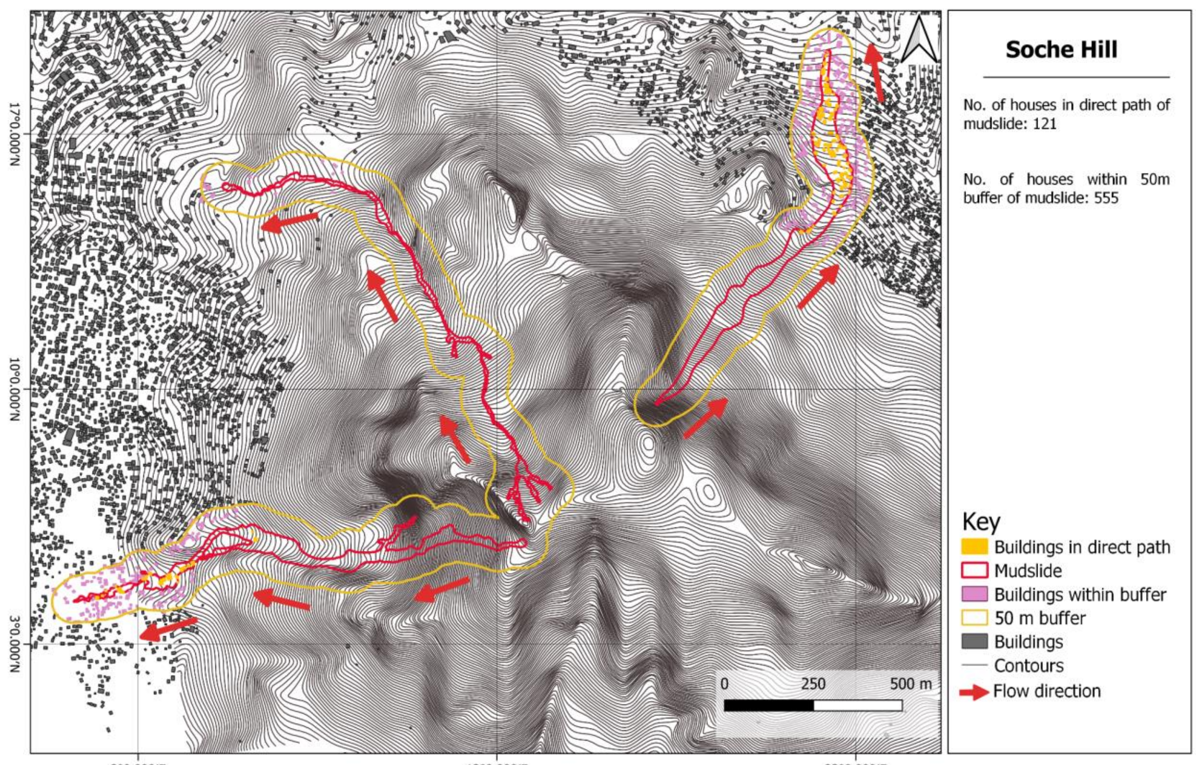

Figure 35. Soche slope vulnerability to mudslides

As depicted in the images above (Figures 33-36), Soche Hill, where the Chilobwe community resides, was the most affected by Cyclone Freddy due to the high density of houses on the hill slopes.

Participants were asked to explain Cyclone Freddy's varying degrees of impact on Ndirande and Chilobwe. Table *10* below shows that Chilobwe tends to have higher average impacts across all categories than Ndirande. However, the variability in these impacts is generally similar between the two locations, except for loss of life and loss of business and employment, where Ndirande shows more variability.

Table 10. Perceptions of participants on extent of impact of Cyclone Freddy (1-10 scale)

	Ndirande			**Chilobwe**		
	Mean	CV	n	Mean	CV	n
Property damage	6.7	0.3	79	8.0	0.3	76
Loss of life	4.3	0.6	75	7.2	0.3	76
Displacement	4.9	0.5	80	7.0	0.4	76
Damage to infrastructure	6.4	0.3	78	7.6	0.3	76
Loss of business and employment	5.4	0.5	78	6.6	0.4	74

To quote one of the participants:

> "In Chilobwe, Cyclone Freddy had the greatest impact due to the high proportion of unauthorized settlements on the high slopes of Soche Hill, almost all of which were washed away. This also had the highest impact on the number of lives lost. In Ndirande, the impact was not as severe, but lives and properties were also lost."

Table 11. Conditions contributing to the vulnerability of residents to floods (0=no mention, 1=mention)

	Ndirande			Chilobwe		
	Mean	**CV**	**n**	**Mean**	**CV**	**n**
Speed and depth of runoff	0.2	1.8	83	0.5	1.0	76
High population density	0.4	1.2	84	0.3	1.7	76
Inadequate flood defenses	0.3	1.5	84	0.4	1.1	76
Limited access to information about risk	0.3	1.6	83	0.3	1.5	76
Poor housing quality	0.4	1.3	84	0.3	1.4	76
Poor drainage systems	0.4	1.3	84	0.4	1.4	76

As illustrated in Table *12* above, Chilobwe was believed to have experienced an elevated level of speed and depth of runoff from nearby elevated areas compared to Ndirande, where vulnerability is due largely to high population density. Participants believed that both Ndirande and Chilobwe have similar levels of housing infrastructure and limited preparedness and access to information about flooding.

4.4.4 Flood Risk

A flood risk map was developed, using slope, soil and vegetation cover data, to showcase areas of high or low risk of flooding or mudslides. Figure 36 below illustrates areas of high, moderate and low risk for flooding. High risk areas can be noted in and surrounding Ndirande, Soche and Bangwe hills with Chilobwe, Ndirande and Bangwe informal settlements falling under the high-risk category. Other informal settlements within Blantyre fall under the moderate to high-risk category. For instance, this includes Kachere in the East, closer to Bangwe, Chirimba, and Kameza on the city's northwest side. Please note that the informal settlement boundaries are likely not representative of the actual boundaries since they do not encompass THAs. While THAs are considered planned development, they are likely just as vulnerable as surrounding informal settlements.

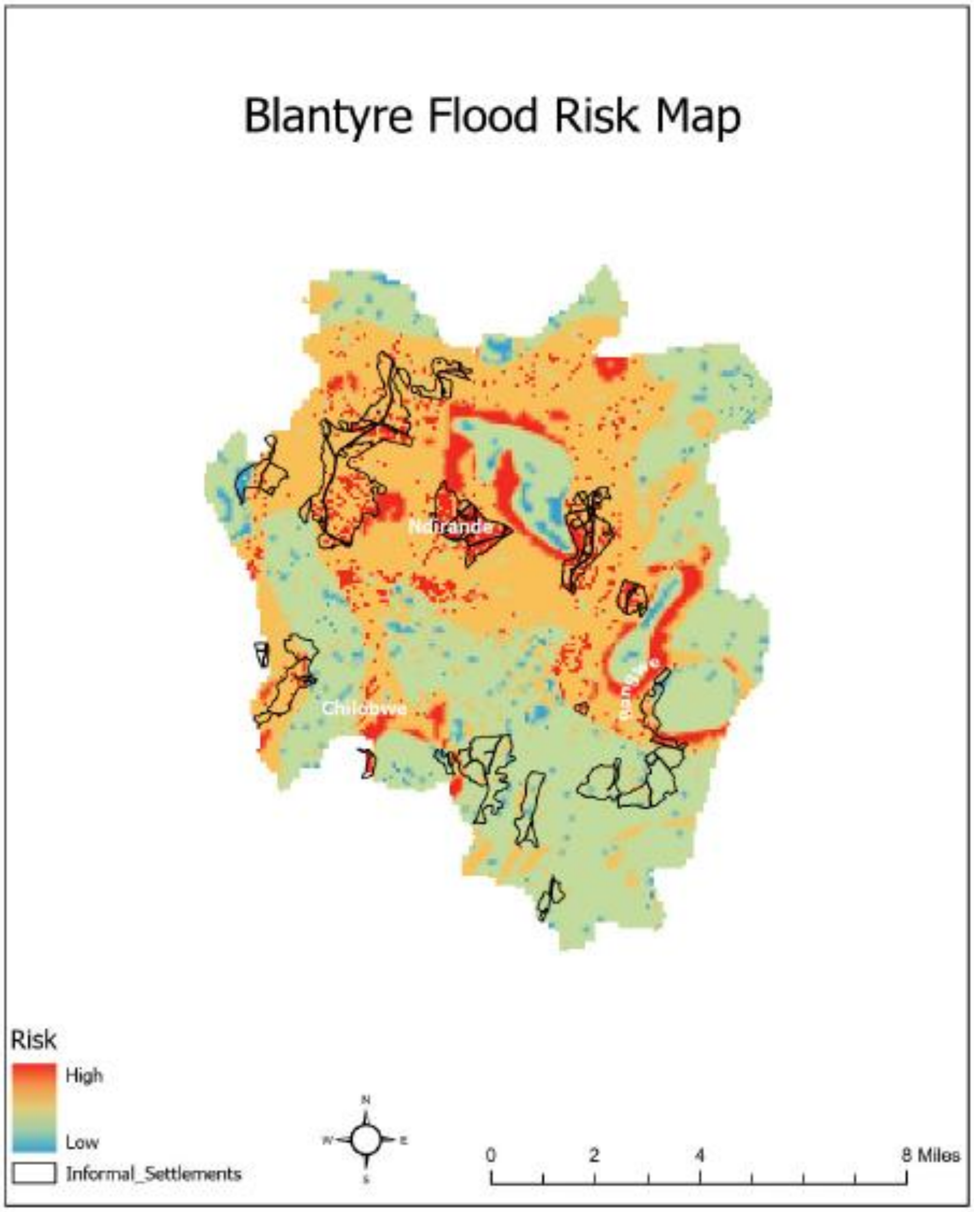

Figure 36. Blantyre Flood risk map with color-coded areas of high to low risk overlayed by the location of informal settlements.

In summary, the reduction of vegetation on the hillsides in the study locations has not only heightened their vulnerability to flooding but also directly impacted the social environment. Exposed terrain amplifies runoff, particularly impacting Chilobwe because of its steep incline.

The clay-rich soil atop the hills is consequently prone to erosion, leading to mudslides. The rugged landscape of Blantyre accelerates runoff, worsening sediment buildup in valleys during flood events.

Chapter 5: Flood Disaster Management and Policy

This chapter addresses the third research question: To what extent do flood management policies and strategies reduce vulnerability for marginalized communities in Blantyre? The study begins by a review of existing DRM efforts and their relevance to marginalized communities' vulnerability. This chapter also critically engages with a recent piece of national legislation: the Disaster Risk Management Bill (2023). The chapter then presents the findings from the survey, which provide a valuable perspective from professionals in the field.

5.1 Existing Policies Related to Disaster Risk Management (DRM)

Malawi's disaster risk management (DRM) policy landscape has been shaped by international frameworks, including the Sendai Framework for Disaster Risk Reduction 2015–2030 and the African Strategies for Disaster Risk Reduction (GoM, 2023). Most frameworks and strategies for DRM in Malawi are developed and implemented at the national level. Mkandawire (et al. 2021) developed a model that traced and brought together the interactions between Blantyre city adaptation legislation and urban climate resilience development over the years. Figure 13 below shows the model developed as a tool for researchers and practitioners in urban planning and climate resilience development domains to coproduce climate resilience mechanisms and solve complex city or urban development problems (Mkandawire et al., 2021). It lists all the frameworks that shape DRM in Malawi. As depicted in Figure 37 below, the authors employed a systems thinking process to develop feedback loops. These loops reveal the interactions climate change researchers can use to gain a comprehensive understanding of the context in which collaborating partners operate right from the start of the learning process.

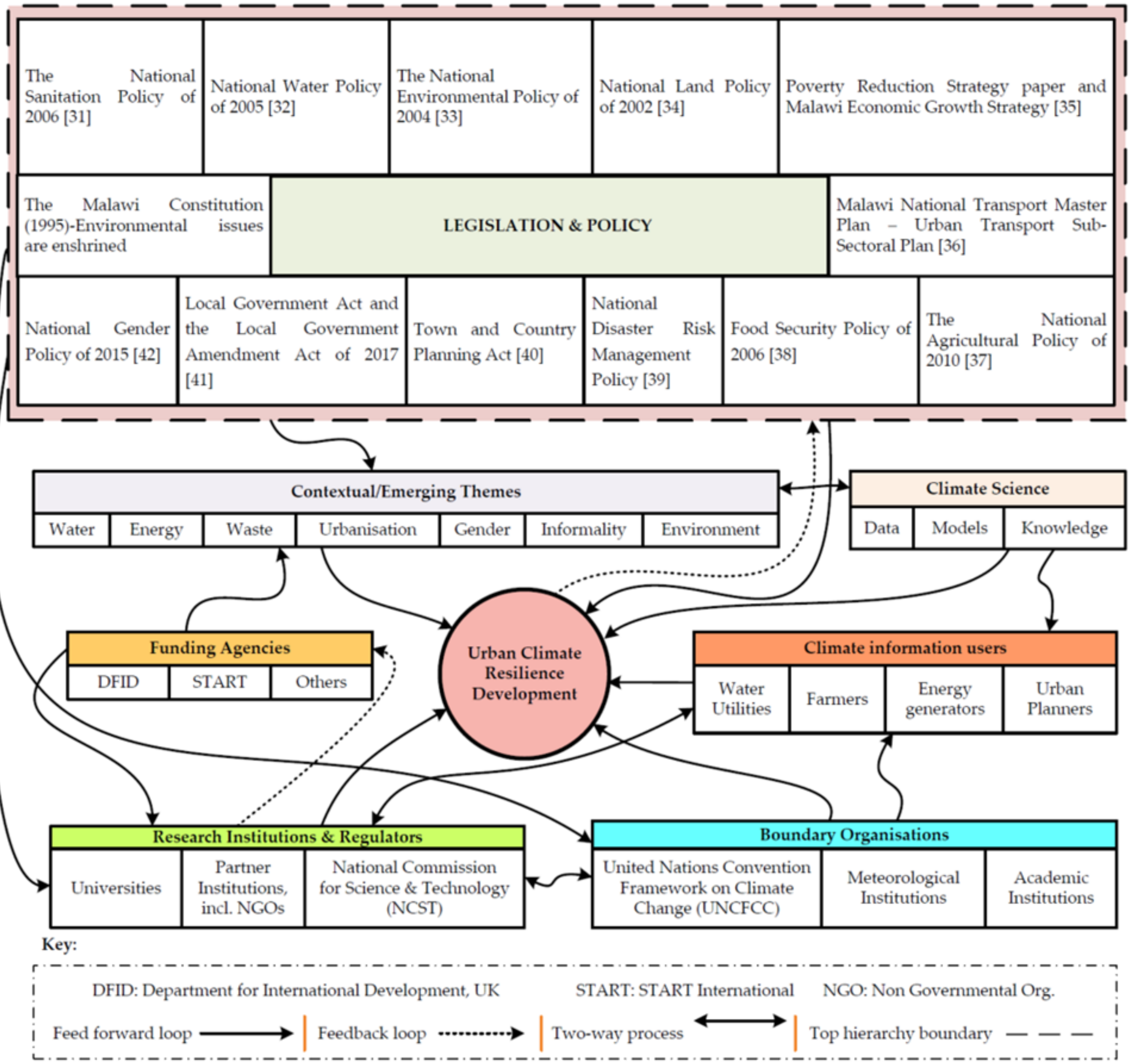

Figure 37. Policies and Strategies related to DRM (Source: Mkandawire et al., 2021)

The model was designed to save time and resources, as stakeholders (i.e., urban planners) would know which climate-resilient decision mechanisms are already being employed and the mode and medium of communication that helps them understand climate information better (Mkandawire et al., 2021).

5.2 Blantyre City's flood management policies and strategies for reducing vulnerability for marginalized communities in Blantyre.

Globally, many countries have embarked on the fight against the impacts of climate change by facilitating strategy development in adaptation and vulnerability management. In Malawi, the National Adaptation Plan of Action (NAPA), an operational tool under the National Environmental Action Plan of 1994 Agenda 21, addresses the country's urgent and immediate adaptation needs. The NAPA aims at (i) identifying a list of priority activities, (ii) formulating priority adaptation options, (iii) building capacity for adapting to longer-term climate change and variability, and (iv) raising public awareness on the urgency to adapt to the adverse effects of extreme weather events (Zuka, 2021: GoM 2006).

However, there have been debatable outcomes after approximately three decades of implementing climate adaptation strategies and plans. The adaptive capacity of Blantyre and Malawi is complex and influenced by a myriad of correlated factors. Low-income communities in Blantyre have the lowest ability to adapt to flooding induced by climate-related phenomena. A study conducted in 2015 shows that among five districts in the southern region, only two (Blantyre and Chikwawa) have the weakest capacities to adapt consistently with expectations as these districts face numerous problems, including food insecurity, high illiteracy rate, poor access to safe water and sanitation, and high prevalence of HIV/AIDS (Coubaly, 2015). Blantyre and Chikwawa face a web of challenges that undermine health, economic stability, and overall resilience, making it difficult for these districts to meet adaptive expectations and improve their conditions.

Real-life lessons from projects helping Malawi adapt to climate change since the 2000s show many mixed feelings and conflicting ideas about dealing with and adapting to climate change. These conflicting views stem from the mismatch between how policymakers frame strategies for climate change adaptation and the actual experiences of the communities undergoing adaptation. (Zuka, 2021). In the existing system, the Malawian government has not facilitated and delivered risk reduction at the local scale, primarily due to a lack of dedicated funding sources (Trogrlić, 2019; Kita, 2014). Hence, disaster risk reduction (DRR) is predominantly led and implemented by non-governmental organizations (NGOs) (Trogrlić, 2019; Trogrlić, 2018)

5.3 Disaster Risk Management Bill (2023)

The 2023 Disaster Risk Management Bill (DRM) was a notable step towards addressing the concerns arising from the mismatch between policymakers and the communities experiencing climate-related disasters. To quote Malawi Save the Children[10] (2023):

> "Parliament, on 12th April 2023, passed the long-awaited Disaster Risk Management Bill which replaces the Disaster Relief Preparedness Act of 1991. The Bill, which would have taken even much longer if it were not for the devastating impact of cyclone Freddy, provides some ray of hope in terms of systematic response to disasters"

The occurrence of Cyclone Freddy pushed the parliament to pass the DRM bill to guide disaster management in the country. Before this, the Disaster Relief Preparedness Act of 1991, which was being used, missed out on some critical aspects of disaster risk management. For instance, the 1991 bill mainly laid out provisions for administrative management during a

[10] Malawi Save the Children, 2023. Malawi Parliament Passes Disaster Risk Management Bill as Country Recounts Impacts of Cyclone Freddy. Save the Children Website: https://malawi.savethechildren.net/news/malawi-parliament-passes-disaster-risk-manage-bill-country-recounts-impacts-cyclone-freddy

disaster and did not adequately address settlement vulnerability, mitigation, and recovery. The 2023 DRM bill expanded on the previous bill by providing for the notable provisions below:

1. Establishment of the National Disaster Risk Management Committee (NDRMC) to be chaired by Secretary to the President and cabinet.
2. The establishment of the Office of the Commissioner for Disasters and a Disaster Risk Management Trust Fund.
3. Those collecting relief on behalf of disaster victims will be required to report to the Office of the Commissioner of Disasters, disclosing the source and providing a detailed account for every item/fund they administer.
4. The government is to declare certain areas ‘High-Risk’ and relocate all people occupying such places as determined by the commissioner, responsible minister, and in consultation with the minister of lands (Save the Children, 2023).

The bill has laid out a policy structure essential for managing disasters. It strongly focuses on establishing DRM structures at the local level and ensuring preparedness through measures such as contingency planning and establishing an early warning system (IFRC, 2023).

5.4 Analysis of the Disaster Risk Management Bill (2023) and its potential for addressing flood risk in Blantyre.

Parliament passed the bill quickly after Cyclone Freddy’s devastating impacts on the country’s southern region. The DRM bill was developed to guide response, recovery, and mitigation efforts before, during, and after a disaster’s occurrence. During the survey, respondents were asked to indicate how familiar they were with aspects of the DRM Bill (2023). The provisions illustrated in Figure 38Figure *38*Figure *38* below are central themes of the bill, which would help boost disaster management efforts in the country and benefit Blantyre City’s informal settlements. It highlights that familiarity with the DRM Bill's aspects are highest in the Planning sector, followed by Civil Service and Land Management. Sectors like education and NGOs, however, are the least familiar with the bill's provisions.

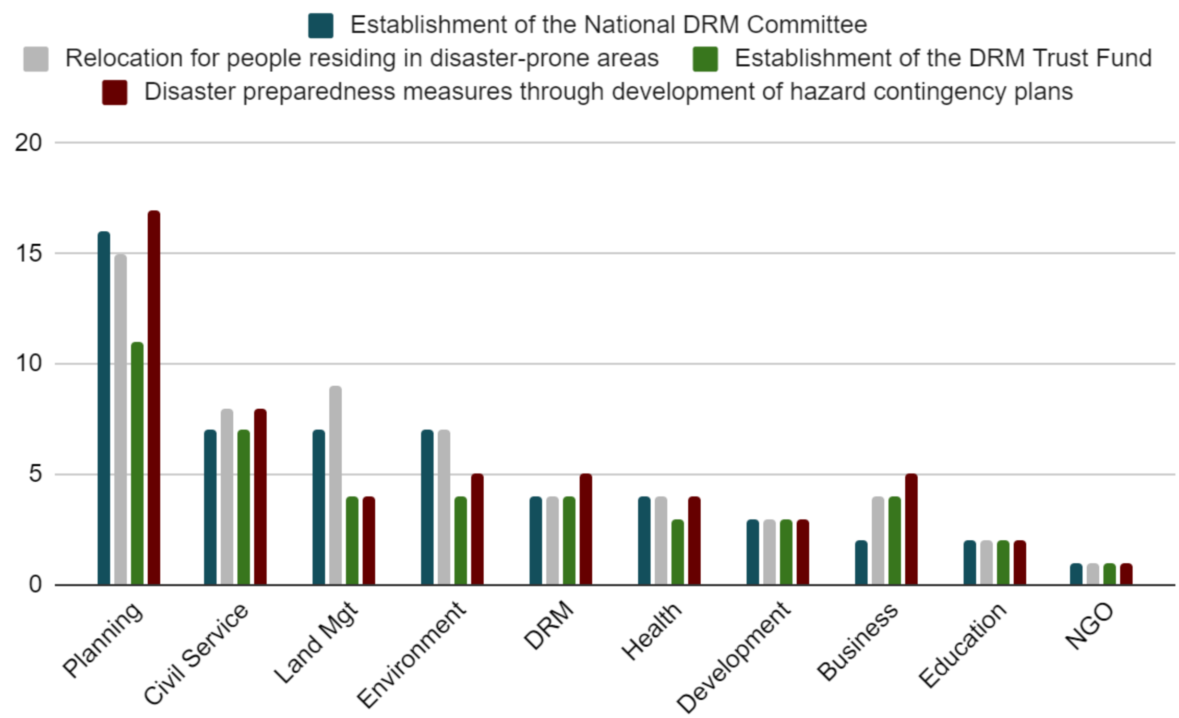

Figure 38. Participants' familiarity with the Disaster Risk Management Bill (2023) as expressed by informants' occupation.

The provision for disaster preparedness measures, for instance, through the development of hazard contingency plans and maintenance of DRM information systems, was much more familiar to the respondents in the planning and land management sectors than in others. This distribution likely reflected the varying degrees of direct involvement or interest in DRM activities across different sectors. The Planning sector, for example, is likely more interested in DRM, hence their higher awareness of its provisions. The differences in familiarity with the

DRM Bill among sectors can likely explain the level of sector participation in or concern for DRM activities. The more a sector is engaged in or concerned with these activities, the more likely it is to be familiar with the DRM Bill. As shown in Figure 39 respondents commonly perceive that the flood management strategies implemented by the Blantyre City Council have had no significant impact on enhancing the resilience of marginalized communities. However, despite the perceptions aggregating in the center (No impact), there is variability in opinions, ranging from significantly worsened to significantly improved, indicating a diverse range of perspectives among respondents.

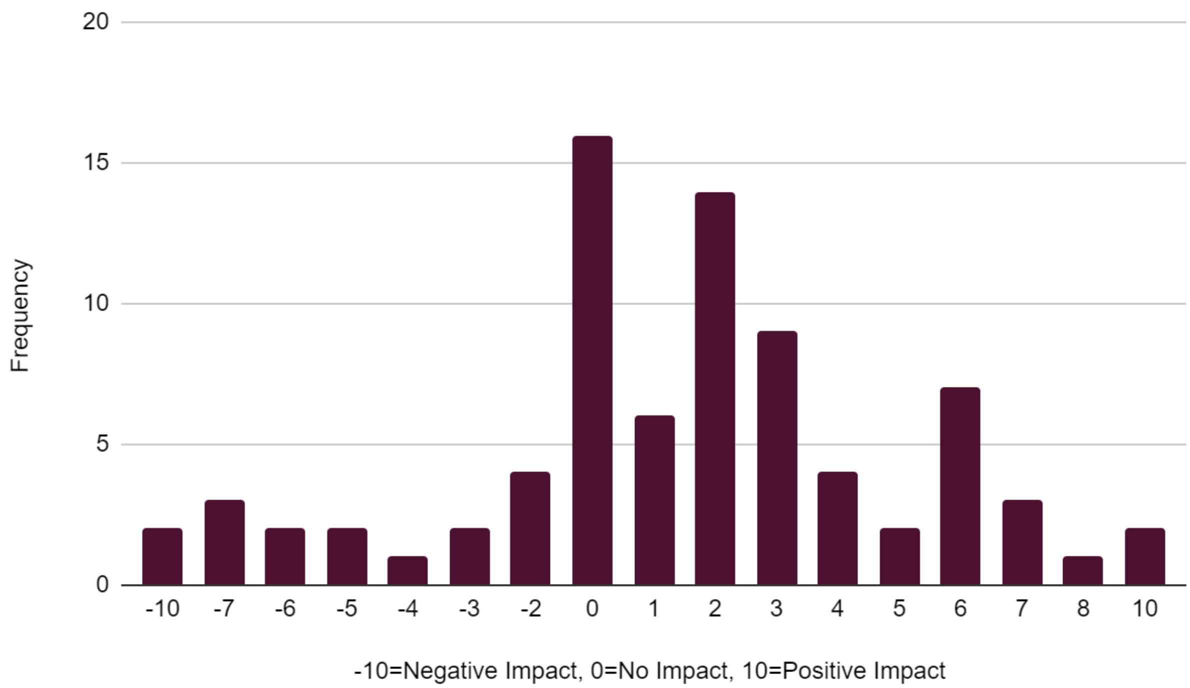

Figure 39. Perceived effectiveness of Blantyre City Council’s flood management strategies for enhancing resilience of marginalized communities (Pre-2023 DRM Bill)

After looking at the perceived effectiveness of policies and strategies before the DRM bill by all participants, the data was further analyzed to look at the differences between perception of the participants that were interviewed either in Lilongwe or Blantyre. Table *12* below shows the mean and coefficient variation of participants' responses. It is important to note that the Blantyre participants hold more negative views about how pre-DRM bill planning strategies had shaped vulnerability in Blantyre.

Table 12. Perceived effectiveness of Blantyre City Council's flood management strategies in enhancing resilience of marginalized communities (Pre-2023 DRM Bill) depending on city location of participants

	n	Mean	CV
Blantyre	22	-0.31	-12.54
Lilongwe	51	2.12	2

I conducted further analysis on both city location and occupational grouping. Table 13 below shows means and std deviation of participants from different professions.

Table 13. Professionals’ perceived effectiveness of Blantyre City Council's flood management strategies in enhancing resilience of marginalized communities (-10 to 10 point scale). Mean, standard deviation and number of survey participants by professional field.

Professional's Field	**Mean**	**Standard Deviation**	**n**
Planning	0.64	2.72	22
Environment	0.21	5.44	14
Civil Service	2.25	3.77	20
Others	2.6	3.54	18
Total	1.46	3.87	74

As illustrated in Table 13, the standard deviation (3.87) suggests participant opinion variability across the scale. The mean response for those based in Blantyre reveals a diverse range of opinions towards the effectiveness of Blantyre City Council’s flood management strategies, with a negative sentiment being the most prevalent. It's noteworthy that in Table *12*, Lilongwe (2.12) has a higher mean than Blantyre (-0.31), indicating a more positive average rating of the flood management strategies. Henceforth, it is possible that the overall perception between Blantyre and Lilongwe perceptions might be influenced by the slightly negative perception of those in Blantyre.

Therefore, the examination of the perceptions between location and professions highlights important points where the slightly negative mean rating from Blantyre participants suggests dissatisfaction of the flood management strategies (pre-DRM bill). This sentiment is particularly notable given that Blantyre is the study area and the city directly impacted by these flood management strategies. The high variation in responses within Blantyre, indicating polarized opinions, suggests the complexity of the issue. While some may see benefits of the strategies, others feel neutral or negatively about them. As illustrated in Table 13, professionals in planning and environment fields, who are likely the most knowledgeable about the technical and practical aspects of flood management, exhibit more neutral to slightly positive perceptions. This implies that those most familiar with the strategies' intricacies and their impact on vulnerability are more critical or skeptical about their effectiveness.

Respondents were asked to share one aspect of the DRM bill that could be improved to reduce vulnerability further. As shown in Figure 40 below, it is important to note that relocation emerged as a widely agreed-upon strategy among respondents for reducing vulnerability. This was particularly emphasized in terms of its enforcement. Other suggestions included preparedness and response, and the need for increased funding availability, but relocation was the most prominent.

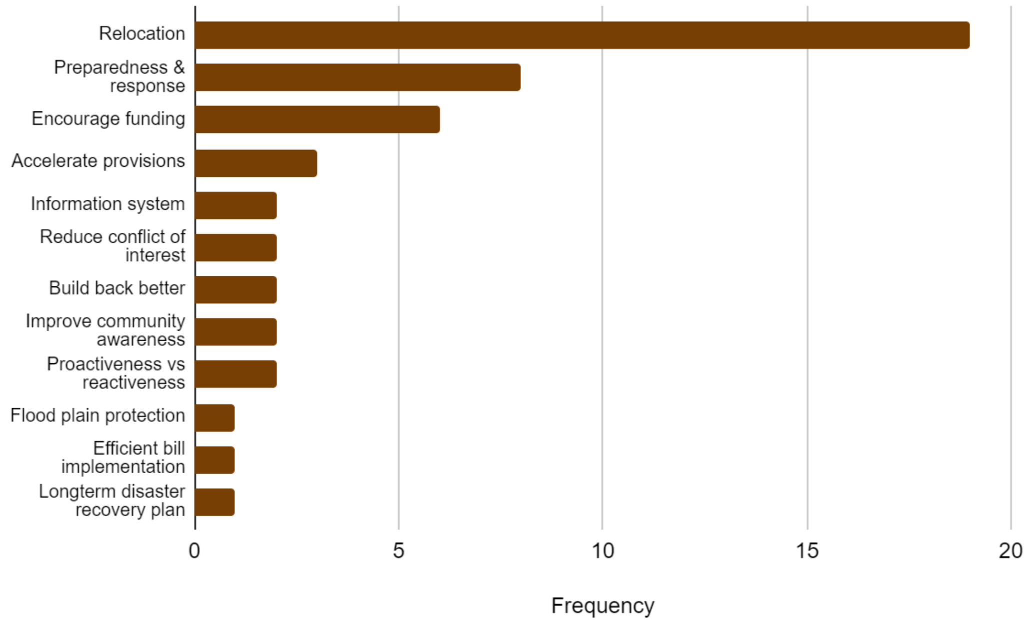

Figure 40. Shows participants' suggestions in improving the DRM Bill (2023)

Participants were also asked to give their recommendations by sharing what they believed were the significant steps Blantyre City Council could take to reduce flooding for marginalized communities. Figure 41 below shows the recommendations participants believed were significant steps needed for Blantyre City Council to mitigate flooding for marginalized communities.

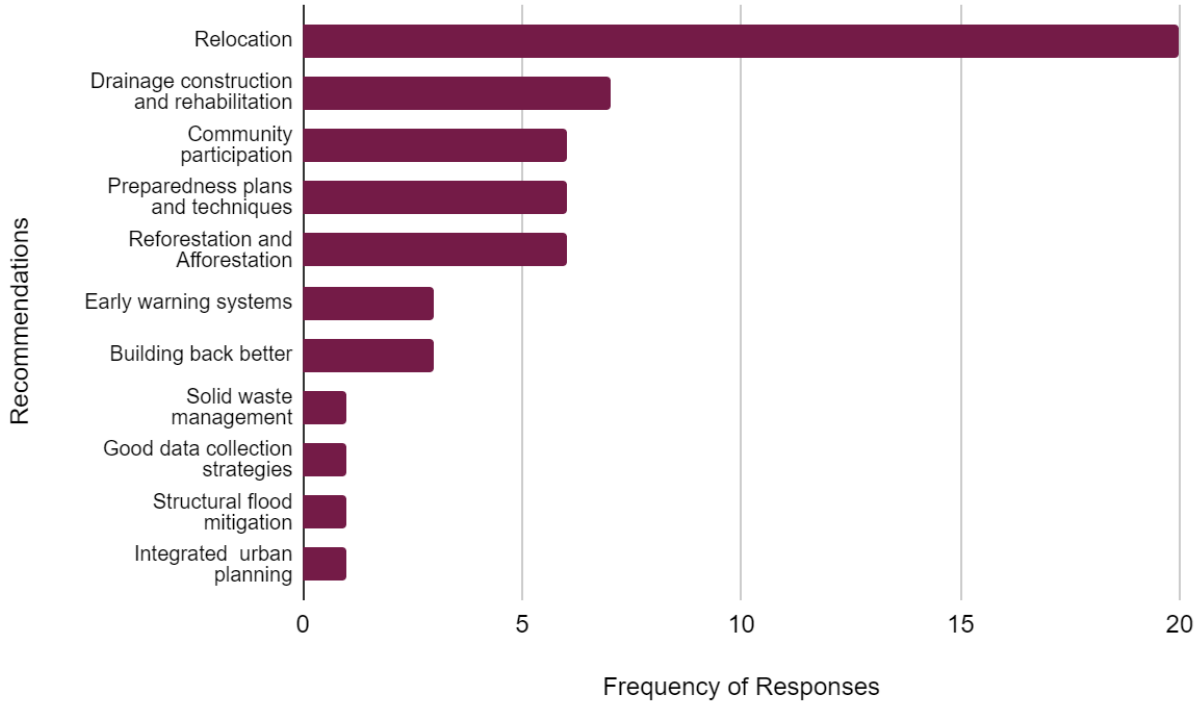

Figure 41. Shows recommendations from participants towards reducing vulnerability for marginalized communities.

Participants believed that enforcing relocation was a major step among the significant steps the Blantyre City Council could take to reduce flooding for marginalized communities. This was coupled with other suggestions, including enforcing sustainable land use laws and policies, drainage construction and rehabilitation, solid waste management, community sensitization and participation, building back better, reforestation and afforestation, structural flood mitigation, integrated urban planning, and early warning systems. Below are quotes from a couple of respondents:

> "Relocate vulnerable people and vegetation replacement in disaster prone areas"

> "One aspect of the Disaster Risk Management (DRM) bill that could be improved to further reduce vulnerability is enhancing community participation and empowerment in disaster preparedness and response efforts. While many DRM bills emphasize government-led initiatives and top-down approaches, greater

> emphasis on grassroots engagement and community-driven strategies could enhance resilience at the local level. By empowering communities to actively participate in identifying risks, developing mitigation measures, and coordinating response efforts, the DRM bill could tap into local knowledge, resources, and capacities. This could lead to more contextually relevant and effective strategies tailored to the specific needs and vulnerabilities of each community, ultimately strengthening resilience, and reducing vulnerability to disasters."

> "The most important thing to reduce flooding for marginalized communities is River canalization and community sensitization on solid waste management. Communities unnecessarily damp their solid waste into the nearby stream thereby narrowing it hence pausing threat to the surrounding communities to floods."

The Blantyre Urban Profile (UN-Habitat, 2011) pointed out that no local-level legislation supported urban disaster risks. Since then, there hasn't been any local-level disaster risk management plan or legislation. Any recovery work has been ad hoc and reactionary. It was also highlighted that fragmented building regulations and by-laws fail to fully address proper building codes to guide the design and construction of buildings, hence increasing vulnerability (UN-Habitat, 2011). Fast-forward to date, and no local-level disaster risk management plan exists.

Chapter 6: Discussion and Conclusion

6.1 Marginalized Communities Spatial Arrangement's Reflection of Colonial Urban Planning

Informal settlements in Blantyre City continue to expand. The spatial arrangement of certain informal settlements, particularly the oldest ones, reflects the zoning and planning regulations implemented during Malawi's colonial era. These informal settlements house marginalized communities that are vulnerable to climate-induced disasters. The information gathered with the survey supported by Blantyre's flood map suggests that the location of informal settlements, outside Blantyre's central business district (CBD) and mostly in hazard-prone areas, reflects colonial urban planning policies.

Racially segregated planning, applied during the colonial period, introduced poor zoning and planning methods that have been carried over into the present. The Physical Planning Act (2016) has maintained most of the provisions of the Town and Country Planning Act (1988) while introducing a few changes, i.e., clarifying what role chiefs play in land distribution. Henceforth, planning regulations that emerged during the colonial period, i.e., the development of hierarchical development plans that require the provision of residential zones depending on population density, have been maintained. This pattern of segregation has persisted, with wealthier people and political elites occupying the previously owned white areas while most of Blantyre's population live in informal settlements.

Poor planning creates a risk that increases vulnerability (Richmond, 2018). Literature explains and reflects these findings.

> "The city (Blantyre) that witnessed independence still retained many of the features that had shaped the character of the colonial town" (McCracken, 1998).

These city planning techniques, which originated during the colonial period, were either ad hoc or adopted from the British Town Planning Act. The Blantyre colonial city plan was incidental because it began with the first white settlers who laid the first roads for access.

Having emerged as informal settlements, the colonial government turned parts of Ndirande and Chilobwe into THA's, meaning that new high-density plots were made available for purchase by the Malawi Housing Corporation (MHC) with the bare provision of essential services. For instance, as of 2011, about 46% of informal settlement dwellers accessed water through kiosks, 11% had piped water at home, 13% walked long distances to access piped water, and the remaining 30% acquired their water from other unspecified sources (UN-HABITAT, 2011; NSO, 2008). In contrast, 80 percent of residents of formal settlements had access to piped water (UN-HABITAT, 2011; Vazquez, 2009). The influx of poor people into Blantyre prompted the colonial government to experiment with a scheme to facilitate access to cheap, affordable housing with basic urban amenities. Informal settlements arose in the periphery of the city and in hazard-prone spaces due to the colonial government's segregative tendencies, as it regarded the Africans as a health risk. Colonial planning was used to separate white settlers from Africans by creating barriers to accessing the urban space. To quote Bizzaro (2023, p.95):

> "Unless Africans were employed as servants, they were not allowed to settle within the township boundary and so a huge village rose up at the foot of Ndirande Mountain, which to this day is Blantyre's high-density suburb. The reason for this segregation was not only racist, it was believed that while Africans did not suffer from malaria as badly as Europeans did, the parasite was in their blood and with them living in the vicinity it could be more easily transmitted to Europeans who had no immunity to it."

Ndirande developed initially as an unplanned settlement and later it was converted into a Traditional Housing Area (THA). Therefore, there is a part of Ndirande that is informal and a part of it is formal. In the THA designated areas of the settlement, the government provided a plot of land, an access road or path and a paying water supply no more than 1000 ft from the plot

(Norwood, 1973). This translates to residents not being provided with housing loans, core houses and individual water supplies in which residents resort to using polluted water from nearby streams (Norwood, 1973).

Efforts to restructure urban planning directives in the country post-independence did not change the public health ordinances that have existed since colonial times. These Traditional Housing Areas (THAs), which still exist, coerce what I call ‘rural conditions’ in urban spaces. By rural conditions, I refer to the way remote village structures are enforced in Malawi. Villages in rural areas are communal in nature in that they are not supplied with government-owned utilities and infrastructure. Residents rely on streams, wells, and boreholes for water. The land is managed by local chiefs. There is no public wastewater system, and at most, villages will only have one main access road, which is mostly untarred.

Rural conditions function well in rural areas as those spaces are governed by chiefs who follow customary practices to distribute and manage land for residential purposes. However, in an urban setting, such forms of governance in THAs are detrimental to settlement success. As observed in the survey results, both Ndirande and Chilobwe are now considered as partially planned and partially unplanned. The planned parts of those settlements are THAs which have at the very least, minimal services. to quote Norwood (1972).

> “Authority generally finds itself in a quandary about Ndirande. Ndirande should not be there at all. The whole place is an illegal development. It is considered, and not without good reason, that to provide roads, water supply, better sanitation, a refuse collection service, etc. would only cause an increased rate of squatting. The city bylaws and town planning control are not designed to deal with the place.”

In most THAs and unplanned settlements, most houses are semi-permanent or traditional, with an increase in more permanent structures recently (Majawa, 2009). There is a great mix of uses in these areas, with poor accessibility and some houses only having footpaths for access

(Majawa, 2009). The building regulations for low-income housing (THAs) were maintained under the Public Health Act of 1965 (Cap 34:01) which solidifies the public health colonial rationalization of urban space and its hidden fears (Manda, 2019; Home, 2014). Since the Public Health Act was not included in the laws being examined or changed in 2016, there's a possibility that regulations governing low-income housing construction could remain biased or discriminatory, possibly rooted in colonial-era laws, even after supposed reforms in planning laws take place (Manda, 2019).

Most cities in Malawi have singled out land use planning in urban areas as a regulatory framework that ironically has proved futile resulting in increased vulnerability to disasters (Gondwe et al., 2017).

6.2 Spatial Dynamics of Marginalized Communities vulnerability in Flood Prone Blantyre

Marginalized communities are the most at risk from disasters (Graham, 2006). This risk is amplified by the exposure to physical hazards and the living conditions in their residential areas. In my case study of Ndirande and Chilobwe settlements; the existing urban fabric, green cover, and slope play an important role in increasing vulnerability to flooding. Apart from Ndirande and Chilobwe, I also looked at Bangwe briefly as it was also another informal settlement in Blantyre that was affected by Cyclone Freddy.

I noted that in all three settlements, there has been a significant loss of green cover over time. Significant loss was noted on Bangwe and Soche hills which are in proximity to Bangwe and Chilobwe settlements respectively. There was a lower rate of loss on Ndirande Hill since it was the earliest settlement for Africans in the city and has been bare the longest. In 1949, Ndirande was substantially wooded with indigenous trees (Norwood, 1972). Ndirande had a forest reserve that had been established by the colonial government to preserve indigenous flora and fauna and to protect the quality of water at Mudi dam (Riley, 2021; Ng'ong'ola 1990). High deforestation and land clearing for farming and dwelling construction have increased the area's susceptibility to flooding. Restrictive zoning practices that confined Africans to informal settlements and made the more livable areas inaccessible to Africans, continued to contribute to rapid post-colonial population growth. The population in informal settlements continued to grow as people with low incomes could not afford to live elsewhere. Henceforth, rapid post-colonial population growth has caused land degradation and increased physical exposure to flooding. In the 1990s, rapidly rising poverty, increased population density combined with reduced state capacity to prevent deforestation meant the reserve was rapidly deforested (Riley, 2021). Cyclone Freddy mudslides highly affected community members whose houses were at the foot of the areas with bare lands. High deforestation and land clearing for farming and dwelling construction has increased the susceptibility of the area to flooding.

Poor housing structures and poor public infrastructure in these informal settlements mean that when extreme weather events happen, they are more than likely to cause devastating damage.

6.3 Flood Management Policies' Impact on Vulnerability in Blantyre City

Colonial planning policies and strategies have impacted the spatial layout of settlements in Blantyre. Like Malawi, many developing countries have preserved the regulatory frameworks they inherited from their colonial past (Graham, 2006). Studies have shown that environmental risks facing local communities in developing countries today have been historically shaped by unequal distribution of opportunities and power (Zuka, 2021; Mandala, 1990; Mulwafu, 2010). The implementation of the Town and Planning Act of 1947 during colonial rule, which was imported from Britain, is an example of such a scenario. The Act was revised and reinstated in 1988 but was not adapted to address current local environmental conditions. Colonial and post-colonial economic reorganization ignored local environmental management practices and set in motion environmentally degrading pathways.

The 2023 Disaster Risk Management Bill (DRM) marked a significant advancement in bridging the gap between policymakers and communities affected by climate-related disasters. It introduced vital measures such as establishing a DRM Committee, a national DRM trust fund, and a provision for the National Department of Planning to identify high-risk areas. However, it is essential to acknowledge that this legislation overlooks marginalized communities' vulnerability in disaster-prone regions. Mainly, densely populated neighborhoods facing flood risks must be adequately addressed, revealing a notable limitation.

The DRM bill provides for the declaration of specific areas as ‘High-risk' and the relocation of people in hazard-prone areas. However, this provision is lacking because it does not incorporate the need to address marginalized communities who are vulnerable when disaster strikes their areas. Marginalized communities are more likely vulnerable because these communities are unprepared for disasters and have difficulty recovering. Relocation as a mitigation strategy brings other concerns that need to be addressed for it to be effective. For instance, during relocation, there is a need for well-serviced land (provided with access roads, water, sanitary services, and power) to be supplied for resettled households. Long-term sustainability of resettled communities requires, among others, productive livelihoods, building community cohesion, provision of employment opportunities, and easy access to infrastructure and social services (Kita, 2016; Keraminiyage & Piyatadsananon, 2013; Usamah & Hyaden, 2012).

Therefore, while the DRM bill represents progress, there remains a crucial need for further attention to the needs of marginalized communities to ensure comprehensive disaster risk management.

6.4 Limitations

The development of a flood risk index faced several challenges including:

- ➔ Securing clear satellite imagery for digitizing the flow paths was challenging. The only clear satellite imagery accessible for use was from March 2023. Cloud cover heavily impacted visibility.
- ➔ The first route was to use Synthetic Aperture Radar (SAR) data to map flood water. However, this was futile as Blantyre mostly experienced mudslides hence there wasn't any still water to be mapped.
- ➔ Carrying out flood risk analysis without proper access to layers needed turned out to be challenging in order to finalize the project in a timely manner. I had to rely on Clinton to source most of the layers and some layers would not easily be in sync with the boundaries.

During survey administration. The team faced the following challenges:

- ➔ Other potential participants were busy during data collection as they were preparing for tropical storm Filipo, which was forecasted to affect southern Malawi. Therefore, they were not available to participate in the survey.
- ➔ Key potential respondents in academia were on recess during the survey administration period therefore they could not be reached to participate in the survey.

6.5 Recommendations

Blantyre's city planners can contribute to reducing the vulnerability of marginalized communities to flooding by taking proactive measures to improve the built environment and infrastructure in these areas. The Blantyre City Council (BCC) would need to develop a comprehensive flood risk management plan that prioritizes vulnerable communities' needs, such as providing safe shelters, constructing flood barriers, and improving drainage systems.

Marginalized communities need more access to information about flood risks and mitigation strategies. Sharing information on climate-resilient decision mechanisms already being deployed is essential. Social media can also be a supplemental communication method to disburse early warning information as it is a good source of disaster-related data (Kalonde et al., 2023). Documenting real-world experiences during disasters can be a good source of information for disaster management programs (Kalonde et al., 2023). For instance, with Cyclone Freddy, it was observed that in Malawi, information about damages related to disasters and response measures taken was widely shared through social media platforms, especially WhatsApp, Twitter, and Facebook (Kalonde et al., 2023).

However, social and economic inequalities in these communities may be challenging for city planners to address, affecting the development of flood risk management plans. For instance, most of the residents of informal settlements in Ndirande and Chilobwe are renters working odd jobs in the city and do not own the land they reside on. If residents are not successfully relocated, building flood-resistant infrastructure like storm barriers or drainage is challenging due to the settlements' high population densities.

The new Blantyre Urban Structure Plan, which is being developed, is an opportunity to address the vulnerability of marginalized communities.

People do not lightly decide to settle on land which they know to be vulnerable to land-slip or flooding (Graham, 2006). If there is nowhere else for low-income people to go, however, they will settle on dangerous sites. Thus, planning authorities should minimize the need to settle in dangerous places by proactively providing alternative sites into which prospective informal settlers can be directed. For this, areas should be designated, planned, and provided with at least some infrastructure, and settlement should be as simple as possible. If such alternative sites exist, it would then be reasonable to ban settlement in hazard-prone areas that need to be designated, to keep such areas under frequent surveillance, and to implement eviction measures against those who break the ban (Graham, 2006). A well-functioning land allocation system, in which there is good information and clarity of title, and a regulatory environment in which low-income households can afford to build, are prerequisites for housing development which is sustainable and reduces vulnerability (Graham, 2006)

6.6 Conclusion

Historical planning policies and processes have contributed to the urban fabric in Blantyre City, Malawi. Vulnerable communities in Traditional Housing Areas (THAs) and informal settlements are unequally exposed to climate-induced disasters like floods in Blantyre, Malawi. This study's findings underscore the imperative for holistic approaches to disaster risk management that address the root causes of vulnerability, including historical injustices and socio-economic disparities. Urban planning policies must prioritize the needs of marginalized communities and incorporate participatory approaches to ensure the resilience of informal settlements in the face of climate-induced hazards. By bridging the gap between research and practice, this study offers actionable insights for policymakers, urban planners, and practitioners striving to build more inclusive and resilient cities in Malawi and beyond.

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Appendices

Appendix A: Survey Questionnaire

Spatial Risk and Flood Vulnerability in Blantyre, Malawi

Start of Block: Introduction

Q0 **Why are we contacting you?**
Patricia Fraley at the University of Wisconsin-Madison USA is writing a thesis on 'Exploring the Relationship between Marginalized Communities' Spatial Distribution and Susceptibility to Flooding in Blantyre, Malawi.' We therefore invite you to participate in this survey. This thesis project seeks to collect data through this survey administered to a sample of adults aged between 18 - 70 across different job professions related to disaster management in Malawi. The survey will ask questions related to spatial inequity, flood vulnerability and Tropical Cyclone Freddy's impact on Blantyre city.

What is the purpose of the study?
This research project seeks to understand the spatial organization of disadvantaged communities in flood-prone areas of Blantyre and how it amplifies their susceptibility to flooding. Additionally, it investigates the role of historical planning practices in shaping the current vulnerability of these communities. The survey aims to uncover the effectiveness of Blantyre City's flood management policies and strategies in mitigating vulnerability for these disadvantaged communities.

What should you expect?
Policy recommendations will be informed by the survey findings, guiding efforts in flood mitigation and recovery strategies. Participation in this survey is entirely voluntary. You can skip any survey questions that you do not want to answer. Even if you start the survey, you are not required to complete it. You can stop at any time. All your answers will be confidential, and they will not be shared with anyone outside the research team. The survey will take about 20-30 minutes for you to complete.

How can you find out more:

Don't hesitate to contact Patricia Fraley at +1 608 236-3882 (pfraley@wisc.edu) or her advisors Asli Gocmen (+1 734 904-2762, gocmen@wisc.edu) or Matthew Turner (+1608 852-5675, mturner2@wisc.edu) with questions about this survey. Feel free to ask the field assistants any questions you may have. The field assistants contact details are: Patrick Chisamba at +265992902185 (patrickpeace12neba@gmail.com) and Catherine Mkandawire at +265888275529 (catherinemkandawire15@gmail.com). These phone numbers are also available through WhatsApp.

In addition, if you have any questions about this survey, feel free to also reach out to:

Secretariat, National Committee on Research in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw

Do you consent to participate in this survey?

○ I consent (1)

○ I do NOT consent (2)

Skip To: End of Survey If Why are we contacting you? Patricia Fraley at the University of Wisconsin-Madison USA is writing... != I consent

End of Block: Introduction

Start of Block: Communities' Spatial Arrangement and its Relationship to Colonial Planning

Q1 How familiar are you with Blantyre City?

○ Not at all familiar (1)

○ A little familiar (3)

○ Familiar (6)

○ Very Familiar (7)

Skip To: End of Block If How familiar are you with Blantyre City? = Not at all familiar

Page Break

Q2 How familiar are you with Ndirande?

○ Not at all familiar (1)

○ A little familiar (2)

○ Familiar (3)

○ Very familiar (4)

Skip To: Q7 If How familiar are you with Ndirande? = Not at all familiar

Page Break

Q3 Are you aware of how Ndirande as a settlement developed?

◯ Yes (4)

◯ No (5)

◯ I am not sure (7)

Page Break

Display This Question:

If Are you aware of how Ndirande as a settlement developed? = Yes

Q4 Please elaborate on how Ndirande developed as a settlement.

____

Page Break

Q5 In your opinion, to what extent have colonial practices influenced the locational (spatial) development of Ndirande?

0=No influence | 5=Moderate Influence | 10=High influence

0 1 2 3 4 5 6 7 8 9 10

Curfew which barred Africans' movement within the city at night ()	
The area being outside of the city and therefore not subject to by-law and town planning control ()	
Proximity due to employment at white settlers' homes and businesses ()	
Other ()	

Page Break

Q6 To the best of your knowledge, to what degree has Ndirande been impacted by Cyclone Freddy in the following areas?

No effect at all = 0 Highest Effect = 10

	0	1	2	3	4	5	6	7	8	9	10
Property Damage ()											
Loss of life ()											
Displacement ()											
Damage to infrastructure ()											
Loss of businesses and employment ()											
Other ()											

Page Break

Q7 How familiar are you with Chilobwe?

○ Not at all familiar (1)

○ A little familiar (2)

○ Familiar (3)

○ Very familiar (4)

Skip To: End of Block If How familiar are you with Chilobwe? = Not at all familiar

Page Break

Q8 Are you aware of how Chilobwe as a settlement developed?

- Yes (4)
- No (5)
- I am not sure (7)

Page Break

Display This Question:

If Are you aware of how Chilobwe as a settlement developed? = Yes

Q9 Please elaborate on how Chilobwe developed as a settlement.

____

Page Break

Q10 To the best of your knowledge, to what degree has Chilobwe been impacted by Cyclone Freddy in the following areas?

No effect at all = 0 Highest Effect = 10

	0 1 2 3 4 5 6 7 8 9 10
Property Damage ()	
Loss of life ()	
Displacement ()	
Damage to infrastructure ()	
Loss of businesses and employment ()	
Other ()	

Q11 Which characteristics are present in the communities below? (Check all that apply)

	Poor housing structures (1)	Poor road network (2)	Lack of public sanitary infrastructure i.e sewage system, stormwater drainage system (3)	High population density (4)
Chilobwe (1)	☐	☐	☐	☐
Ndirande (2)	☐	☐	☐	☐

Q12 Have colonial zoning practices mentioned in the previous question had an enduring effect on infrastructure, exposure to environmental hazards and negative health impacts?

○ Yes (1)

○ No (2)

○ Not sure (3)

Skip To: End of Block If Have colonial zoning practices mentioned in the previous question had an enduring effect on infra... != Yes

Q13 Please rank the following challenges that disadvantaged communities, such as Ndirande, encounter because of historical housing patterns influenced by colonial urban planning (No. 1 being the most important)

______ Poor infrastructure and lack of essential services (4)
______ Disproportionate exposure to environmental hazards and natural disasters (5)
______ Segregation due to socio-economic status (6)
______ Increased negative health impacts (7)
______ Other (8)

Q14 Kindly elaborate on the varying degrees of impact Cyclone Freddy has had on both Ndirande and Chilobwe.

____

Q15 In your opinion, has any of the following contributed to the vulnerability of these disadvantaged communities to floods?

	Chilobwe (1)	Ndirande (2)
Speed and depth of runoff from nearby elevated areas (1)	▢	▢
High population density (6)	▢	▢
Inadequate flood defenses (7)	▢	▢
Limited access to information on flood risk and preparedness (8)	▢	▢
Poor Housing quality (9)	▢	▢
Poorly constructed drainage systems (10)	▢	▢

End of Block: Communities' Spatial Arrangement and its Relationship to Colonial Planning

---

Start of Block: Flood Management Policies and Strategies

Q16 Which organization do you work for?

○ Blantyre City Council (1)

○ Civil Society/NGO (2)

○ Department of Disaster Management Affairs (DODMA) (3)

○ Department of Physical Planning (4)

○ District Council (5)

○ Environmental Affairs Department (14)

○ Malawi Housing Corporation (6)

○ Ministry of Lands (7)

○ Ministry of Resources and Climate Change (8)

○ Ministry of Health (10)

Q17 Are you familiar with these aspects of the Disaster Risk Management (DRM) Bill (2023)

▢ Establishment of the National Disaster Risk Management Committee (2)

▢ Provision for relocation for people residing in disaster-prone areas (4)

▢ Establishment of the Disaster Risk Management Trust Fund (5)

▢ Provision for disaster preparedness measures through development of hazard contingency plans and maintenance of DRM information systems (6)

Q18 To what extent do you believe Blantyre City's flood management strategies were successful in improving the resilience of marginalized communities to flooding before the 2023 DRM bill?

	-10	-8	-6	-4	-2	0	2	4	6	8	10
-10=Made it significantly worse, 0=Did not effect, 10=Significantly improved ()											

Q19 State one aspect of the DRM bill that you think could be improved to further reduce vulnerability.

____

Q20 If Blantyre City Council could take one significant step to reduce flooding for marginalized communities, what do you believe this step should be?

____

End of Block: Flood Management Policies and Strategies

Start of Block: Demography

Q21 What is your age?

- ◯ 18 - 30 years old (1)
- ◯ 31 - 45 years old (2)
- ◯ 46 - 60 years old (3)
- ◯ Over 60 years old (4)

Q22 What is your gender?

- ◯ Male (1)
- ◯ Female (2)
- ◯ Prefer not to say (3)

Q23 What is your occupation?

____

End of Block: Demography

Appendix B: R Script for Flood Risk Map

This R Script was coded by Clinton Nkolokosa during classification of layers for flood risk map.

```
#install required packages

#install.packages("rnaturalearth")

#install.packages("elevatr")


#import required libraries

#remotes::install_version("cli", version = "3.6.1")


library(sf)

library(units)

library(sp)

library(dplyr)

library(terra)

library(rnaturalearth)

library(elevatr)

library(tidyverse)

library(chirps)

library(raster)

library(viridis)
```

```
#load BT district areas polygon shapefile
mw <- st_read("C:/QGIS/mwi_admbnda_adm2_nso_20181016.shp")
st_crs(mw)
plot(st_geometry(mw))
bt <- mw|>
  dplyr::filter(mw$ADM2_EN == "Blantyre City") |>
  dplyr::select(ADM2_EN, geometry)


#=============================================================
===========
# load elevation data
bt
mapview::mapview(bt)
plot(bt)


elev <- get_elev_raster(locations = bt, z = 9, clip = "locations")


terra::plot(rast(elev), plg = list(title = "Elevation (m)"))
plot(st_geometry(bt), add = TRUE)


# Calculate the slope in degrees
slope <- terrain(elev, opt='slope', unit='degrees')
slope
```

```
# Plot the slope layer

plot(slope, main="Slope (degrees)")


#=============================================

# Classification of slope degree as adopted from
https://geographyfieldwork.com/SlopeSteepnessIndex.htm


# Define the reclassification matrix

# Each row represents a range with the format: from, to, becomes

# # all values >= 0 and <= 0.39 become 1, etc.

reclass_matrix <- matrix(c(

  0.01, 1.1, 1,

  1.12, 8.50, 2,

  8.50, 40.0, 3

), ncol = 3, byrow = TRUE)


reclass_matrix


# Reclassify the slope raster

slope_reclass <- raster::reclassify(slope, rcl=reclass_matrix)

slope_reclass


# Plot the reclassified slope raster

plot(slope_reclass, main="Reclassified Slope")
```

```
mapview::mapview(slope_reclass)


writeRaster(slope_reclass, "reclassified_slope.tif")


#=========================================================================
===========
# download CHIRPS data
dates <- c("2023-03-01","2023-03-31")


# input SpatVector and return raster
v <- vect(bt)
r3 <- get_chirps(v, dates, server = "CHC", as.raster = TRUE)
r3
r3$`chirps-v2.0.2023.03.24`
plot(r3)


# Get min and max values for each layer in the raster stack
minmax_values <- minmax(r3)


# Convert to a data frame for better readability
minmax_df <- data.frame(Date = names(r3),
                        Min = minmax_values[1,],
                        Max = minmax_values[2,])
minmax_df
```

```
# Save the r3 raster
writeRaster(r3, "BT_rainfall.tif")
here::here()


# calculate max rainfall
max_rainfall <- max(r3)
max_rainfall
plot(max_rainfall)

# Calculate the mean layer
mean_rainfall <- mean(r3)
mean_rainfall
plot(mean_rainfall)

# Convert the SpatRaster to a Raster object
mean_rainfall <- raster(mean_rainfall)
mean_rainfall

max_rainfall <- raster(max_rainfall)
max_rainfall
```

```
plot(mean_rainfall)

plot(max_rainfall)


# Convert the SpatRaster to a RasterLayer object (if needed)

mean_rainfall <- terra::rast(mean_rainfall)

max_rainfall <- terra::rast(max_rainfall)


# Reproject to UTM (assuming UTM Zone 36S for Blantyre, Malawi)

mean_rainfall_utm <- terra::project(mean_rainfall, "EPSG:32736")  # EPSG code for UTM Zone 36S

max_rainfall_utm <- terra::project(max_rainfall, "EPSG:32736")


# Define the new resolution in meters

new_resolution <- 100  #100 meter resolution


# Check the new resolution

print(terra::res(mean_rainfall_utm))

terra::res(max_rainfall_utm)


# Define the desired resolution in meters

desired_resolution <- 100


# Calculate the factor by which to increase resolution

current_resolution <- mean(terra::res(mean_rainfall_utm))
```

```
factor <- round(current_resolution / desired_resolution)
factor

current_resolution2 <- mean(terra::res(max_rainfall_utm))
factor2 <- round(current_resolution2 / desired_resolution)

# Increase the resolution using disagg
mean_rainfall_resampled <- terra::disagg(mean_rainfall_utm,
                                         fact = factor,
                                         method = "bilinear")

max_rainfall_resampled <- terra::disagg(max_rainfall_utm,
                                        fact = factor2,
                                        method = "bilinear")

# Reproject back to the original CRS (if needed)
mean_rainfall_resampled_ll <- terra::project(mean_rainfall_resampled,
                                             crs(mean_rainfall))

max_rainfall_resampled_ll <- terra::project(max_rainfall_resampled,
                                            crs(max_rainfall))

# Plot the resampled raster
```

```
plot(mean_rainfall_resampled_ll)
plot(bt, add =TRUE)

plot(max_rainfall_resampled_ll)
plot(bt, add =TRUE)


# Convert bt to SpatVector if needed
bt_vect <- vect(bt)

# Crop the resampled raster to the extent of Blantyre City boundary
mean_rainfall_cropped <- terra::crop(mean_rainfall_resampled_ll, bt_vect)
max_rainfall_cropped <- terra::crop(max_rainfall_resampled_ll, bt_vect)

# Mask the cropped raster with the Blantyre City boundary
mean_rainfall_masked <- terra::mask(mean_rainfall_cropped, bt_vect)
max_rainfall_masked <- terra::mask(max_rainfall_cropped, bt_vect)

# Plot the masked raster and Blantyre City boundary
plot(mean_rainfall_masked, main = "Mean Rainfall (mm) for Blantyre, March 2023")
plot(bt_vect, add = TRUE)

plot(max_rainfall_masked, main = "Max Rainfall (mm) for Blantyre, March 2023")
```

```
plot(bt_vect, add =TRUE)


# Define a blue color palette

blue_palette <- colorRampPalette(c("white", "lightblue", "blue", "blue3"))


# Plot the masked raster with the blue color palette

plot(mean_rainfall_masked, col = blue_palette(100),

     main = "Mean Rainfall March 2023 (Blantyre)")


# Add the Blantyre City boundary on top

plot(bt_vect, add = TRUE, border = "red", lwd = 2)


# Save the masked raster

terra::writeRaster(mean_rainfall_masked,

                   "mean_rainfall_march_2023_blantyre_resampled.tif")


mean_rainfall_masked


# reclassify based on this rainfall classiifcation scheme:

# https://www.nchm.gov.bt/attachment/ckfinder/userfiles/files/Rainfall%20intensity%20classification.pdf

# Define the reclassification matrix

rainfall_reclass_matrix <- matrix(c(
```

```
  0, 0, 1,        # No rain
  11, 30, 2,      # Moderate rain
  30, Inf, 3     # Heavy to extreme rain
), ncol = 3, byrow = TRUE)


# Reclassify the raster
max_rainfall_reclass <- classify(max_rainfall_masked, rainfall_reclass_matrix)


# Check the reclassified raster
print(max_rainfall_reclass)
plot(max_rainfall_reclass, main = "Reclassified maximum Rainfall")


writeRaster(max_rainfall_reclass, "max_rainfall_reclassified.tif")
#=============================================================================


# load 2022-23 NDVI layer obtained from GEE,
# available here https://drive.google.com/file/d/1PTQpvAoFwXBpwq-LPPIpirFaP39BJ1bV/view?usp=drive_link


ndvi <- raster("C:/R/BT mudslides/BT_mudslides/NDVI_BT.tif")
ndvi


plot(ndvi)
```

```
# Define a suitable color palette for NDVI

ndvi_colors <- colorRampPalette(c("red", "yellow", "green2"))


# Plot the NDVI raster with the viridis color palette

plot(ndvi, col = ndvi_colors(100), main = "NDVI 2022-23 Blantyre City",

    xlab = "Longitude", ylab = "Latitude")


# Add a color legend

plot(ndvi, legend.only = TRUE, col = ndvi_colors(100),

    legend.args = list(text = 'NDVI', side = 3, line = 1))


# NDVI classification scheme. See
https://ipad.fas.usda.gov/cropexplorer/Definitions/spotveg.htm

# Define the reclassification matrix

reclass_matrix <- matrix(c(-Inf, 0.1, 1,

                           0.1, 0.50, 2,

                           0.50,1.0 , 3),

                         ncol = 3,

                         byrow = TRUE)

reclass_matrix


# Reclassify the NDVI raster into three classes

ndvi_reclass <- reclassify(ndvi, reclass_matrix)
```

```
# Plot the reclassified raster

plot(ndvi_reclass,

     main = "Reclassified NDVI Map",

     xlab = "Longitude",

     ylab = "Latitude")


# Add a color legend

plot(ndvi_reclass,

     legend.only = TRUE,

     main = "NDVI Classes",

     col = c("red", "yellow", "green"),

     at = c(1, 2, 3),

     legend.width = 2,

     legend.shrink = 0.7)


writeRaster(ndvi_reclass, "ndvi_reclassified.tif")




#===============================================================
===========

# Soil data


soil <- st_read("C:/Users/clint/Downloads/Soil Types/5c6e2c35-d274-48b5-9ef9-
aaf5bbdb586d/mw_soils.shp")
```

```
soil

plot(soil)


# Ensure both shapefiles use the same CRS

bt <- st_transform(bt, crs = st_crs(soil))


# Clip the soil data using the Blantyre City boundary

soil_clipped <- st_intersection(soil, bt)

soil_clipped

names(soil_clipped)

soil_clipped$SURFACE_TE

soil_clipped$SUBSURFAC_

plot(soil_clipped[9])

plot(soil_clipped[6])

plot(soil_clipped[22])

terra::plot(soil_clipped[12])


# Reclassify the soil types based on the LANDFORM field

soil_clipped$class <- dplyr::case_when(

  soil_clipped$LANDFORM == "footslopes" ~ 3,

  soil_clipped$LANDFORM %in% c("uplands", "uplands with inselbergs", "dissected uplands")
~ 2,

  TRUE ~ 1)
```

```
soil_clipped$class

# Define the raster extent and resolution
raster_extent <- st_bbox(bt)  # Get the bounding box of the Blantyre City shapefile
resolution <- 0.0001 # Define an appropriate resolution for your data

# Create an empty raster with the same extent and resolution
raster_template <- rast(xmin = raster_extent["xmin"], xmax = raster_extent["xmax"],
                        ymin = raster_extent["ymin"], ymax = raster_extent["ymax"],
                        resolution = resolution)

# Rasterize the soil_clipped shapefile using the class field
soil_raster <- rasterize(soil_clipped,
                         raster_template,
                         field = "class",
                         fun = "max")

# Plot the raster
terra::plot(soil_raster, main = "Reclassified soil, Blantyre City")

# Save the raster to a file
terra::writeRaster(soil_raster, "reclassified_soil_bt.tif")
```

```
#==========================================================================
==========

# Create Rainfall-induced Mudslide susceptibility index


# Check the extent, resolution, and CRS of each raster
terra::ext(max_rainfall_reclass)
terra::res(max_rainfall_reclass)
terra::crs(max_rainfall_reclass)
terra::ext(slope_reclass)
terra::res(slope_reclass)
terra::crs(slope_reclass)
terra::ext(ndvi_spatraster)
terra::res(ndvi_spatraster)
terra::crs(ndvi_spatraster)
terra::ext(soil_raster)
terra::res(soil_raster)
terra::crs(soil_raster)


# Check object types
class(slope_reclass)
class(max_rainfall_reclass)


slope_reclass <- terra::rast(slope_reclass)
slope_reclass
```

```
# Resample rasters to the same extent and resolution as max_rainfall_reclass
slope_resampled <- terra::resample(slope_reclass, max_rainfall_reclass)
slope_resampled
ndvi_resampled <- terra::resample(ndvi_spatraster, max_rainfall_reclass)
ndvi_resampled
soil_resampled <- terra::resample(soil_raster, max_rainfall_reclass)
soil_resampled

max_rainfall_reclass

# save final layers
# Function to save resampled raster
save_resampled <- function(resampled_list, folder_path) {
  # Create the folder if it doesn't exist
  if (!dir.exists(folder_path)) {
    dir.create(folder_path)
  }

  # Iterate over each resampled raster in the list
  for (i in seq_along(resampled_list)) {
    # Extract raster name
    raster_name <- names(resampled_list)[i]
```

```
    # Build the file path
    file_path <- file.path(folder_path, paste0(raster_name, ".tif"))
    # Save the raster
    writeRaster(resampled_list[[i]], filename=file_path, overwrite=TRUE)
  }
}

resampled_list <- list(
  slope_resampled = slope_resampled,
  ndvi_resampled = ndvi_resampled,
  soil_resampled = soil_resampled,
  max_rainfall_reclass = max_rainfall_reclass
)

# Specify the folder path
folder_path <- "C:/R/BT mudslides/BT_mudslides/Final_layers"

# Call the function to save resampled rasters
save_resampled(resampled_list, folder_path)
```