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DEPARTMENT OF GEOGRAPHY AND RESOURCE DEVELOPMENT

APPLICATION OF REMOTE SENSING AND GIS TO MASS WASTING SUSCEPTIBILITY MAPPING OF THE AKWAPIM SOUTH DISTRICT.

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL IN GEOGRAPHY AND RESOURCE DEVELOPMENT DEGREE.

NOVEMBER, 2024

DECLARATION

This thesis contains no content that has been acknowledged for the conferral of any other academic qualification in any university or institution. To the utmost of my awareness, this thesis encompasses no content authored or published by any other individual, except where appropriate citations are provided within the text. This thesis is the outcome of investigative efforts carried out by Toklo Emmanuel in the Department of Geography and Resource Development at the University of Ghana.

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DEDICATION

I dedicate this work to my late mother, Madam Mawutor Trorkor, for her crucial role in my educational journey.

ACKNOWLEDGEMENT

My appreciation goes to YEHOWAH (God Almighty), the giver of life and my assistant through this bleak voyage of research. I am profoundly grateful to the individuals whose invaluable support and guidance made this research thesis possible.

First and foremost, I sincerely thank my supervisors, Prof. John Kusimi and Dr. Clement Kwang, for their unwavering dedication, insightful feedback, and boundless patience throughout the research process. Their expertise and mentorship have been instrumental in shaping the direction and quality of this work.

I would also like to express my sincere gratitude to Mr. George Owusu, the skilled cartographer whose expertise in mapping and spatial analysis brought a crucial dimension to this study. His meticulous attention to detail and willingness to share his knowledge enriched the visual representation of the research.

I am forever indebted to my wife and children, whose unwavering support has been my rock. Your encouragement, understanding and belief in me provided the foundation upon which this thesis was built. Your love and encouragement have been my constant motivation, and for that, I am profoundly grateful.

This research journey has been a collective effort, and I am thankful for each person who played a part, no matter how big or small. Together, we have contributed to the advancement of knowledge in this field.

ABSTRACT

This thesis presents a comprehensive study on mass wasting susceptibility mapping in the Akwapim South District of the Eastern Region of Ghana. This study therefore used GIS-based multi-criteria decision analysis to model mass wasting susceptibility of the district by considering factors such as land use/land cover, slope, elevation, geology, soil depth and road distance. The study again investigated the causes, socio-economic and environmental impacts of mass wasting in the district. The study collected data from satellite images, google earth images, digital elevation models and field surveys for the mapping of the prone the prone areas. Factor weights were determined through the Analytical Hierarchy Process (AHP) and the factor class ratings were assigned through logical judgment. Mass susceptibility indices were determined based on a continuous numerical scale developed for this purpose by Saaty (1998) and the pairwise comparison matrix yielded a consistency ratio of 6.4% or 0.064, validating the robustness of the AHP method for this study. High and medium susceptibility zones were found to spread in 67.24 km^2 and 56.03 km2 respectively in the study area while the low susceptible covers about 100.85 km^2 of the total land area of the district. The study again revealed that various mass wasting types occur such as rockfall, rockslide, debris slide, landslide scars and soil creep occurs in the district.

Furthermore, interviews and questionnaires were used to collect data for the social survey. The study unequivocally establishes that high elevation, weak rock formation and human-induced factors, notably poor construction practices and slope excavation for buildings are the principal drivers behind the mass wasting processes in the Akwapim South District, particularly in the Aburi enclave. Also, an in-depth analysis of the socio-economic and environmental impacts arising from mass wasting events in the study area has unearthed critical concerns. The far-reaching impacts encompass property damage, disruption of livelihoods and damage to the environment.

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List of Abbreviation

GIS…………………………….	Geographic Information System
LiDAR………………………….	Light Detection and Ranging
DEM…………………………..	Digital Elevation Model
LSM…………………………….	Landslide Susceptibility Mapping
AHP…………………………….	Analytical Hierarchy Process
WOL…………………………….	Weighted Overlay
MCDM………………………….	Multi-Criteria Decision Making
LULC……………………………..	Land use and Landcover
LZM……………………………..	Landslide zonation maps
WoE…………………………….	Weight of Evidence

CHAPTER ONE

GENERAL INTRODUCTION TO THE STUDY

1.1 Introduction

This chapter gives a general introduction to the entire study. It begins with a background to the study and continues with a problem statement, research aims and objectives, hypothesis, the significance of the study, limitation of the study and finally, the thesis structure.

1.2 Background to the Study

Mass wasting, often referred to as slope failure or landslide, is a geologic process involving the downslope movement of rock, soil, and debris under the influence of gravity (Misawa et al., 2014). Mass wasting activities are more widespread than any other geological event and can occur anywhere in the world (WHO, 2017). They are known to occur in all continents and in the seas and oceans, where they play a key role in the geomorphological evolution of the landscape (Ge et al., 2018). Mass wasting is a natural geological process driven primarily by gravity. The phenomena of mass wasting differ according to their shape, size of the displaced mass, moving mechanisms, velocity and other characteristics (Ali, 2021). A sufficient decrease in shear strength or an increase in shear stress on a hillslope causes mass wasting activities (Omosanya et al., 2022). Slopes become unstable when the shear strength steadily declines to the point of failure due to potential triggers like earthquakes or rainstorms, land degradation, or construction activities (Kariminejad et al., 2022). It is also influenced by various geological, geomorphological and climatic factors such as lithology, slope gradient, soil type, vegetation cover, rainfall patterns, and seismic activity. Geological structures such as faults, joints, and bedding planes can significantly influence the occurrence and extent of mass wasting events and understanding the geological context is fundamental to accurately assessing the susceptibility of an area to mass wasting (Rashid et al., 2017). Similarly, anthopogenic factors such as population growth, deforestation, rapid urbanization, and uncontrolled construction in landslide-prone areas also contribute to a rise in mass wasting fatalities worldwide (Petrucci, 2022).

This phenomenon of mass wasting poses significant hazards to communities, infrastructure and the environment and it represents a severe threat because it causes economic or social losses on private and public properties (Shano et al., 2022). Although mass wasting activities are considered a natural and widespread phenomenon in geological history, humans rarely view landslides in this way because they are quite diverse (Snjezana et al., 2021). Small landslides are frequent along hillslopes, as a result, highways traversing mountaneous areas require yearly block removal from the flanks while larger landslides may impact nearby waterways and have an impact on community activities (Chen et al., 2020).

Livelihood activities are also impacted anytime mass wasting events occur despite significant financial investment and technological advancement made to lessen its effects (Diana et al., 2021). It is not suprising that mass wasting mapping and modelling, landslide hazard assessment, and landslide risk evaluation are increasingly popular among scientists, practitioners and decision makers (Gilham et al., 2019).

Mass wasting susceptibility mapping is a multidisciplinary approach that combines geological, geomorphological, hydrological and geotechnical knowledge to assess and mitigate the risks associated with slope failures (Jones, 2021). By understanding the geological context, employing various methodologies and applying the resulting maps in practical applications, safety and resilience of communities in regions prone to mass wasting events can be enhanced (Malczewski, 1999). A variety of methodologies and techniques are employed in mass wasting susceptibility mapping such as geomorphological mapping, statistical model, mechanical analysis, hydrological and hydrogeological studies, and geotechnical investigations (Snjezana et al., 2021). Geomorphological mapping involves the analysis of landforms, surface features, and their spatial relationships to identify areas susceptible to mass wasting (Stanley et al., 2020). Detailed field surveys and remote sensing data are commonly used in this approach. Statistical Models on the other hand use statistical relationships between known mass wasting events and a range of potential controlling factors (e.g., slope angle, lithology, vegetation cover to predict susceptibility across a landscape (Konopinski, 2021). Mechanical analysis involves the assessment of the mechanical stability of slopes based on factors such as shear strength, pore pressure, and slope angle while hydrological and hydrogeological studies have to deal with understanding how water interacts with slopes as increased water content can significantly influence the likelihood of mass wasting events (Jones, 2021). Finally, geotechnical investigations involve laboratory and in-situ testing of soil and rock properties to assess their stability and susceptibility to mass wasting.

Geographic information systems (GIS) and remote sensing are commonly used for the analysis of landslide intrinsic and triggering factors (Chen, 2022). GIS enables the integration of various geospatial datasets necessary for mass wasting susceptibility studies, including topography, geological data, land cover, and rainfall patterns (Tyagi et al., 2022). GIS enables the overlay and analysis of these datasets, allowing the identification of areas vulnerable to landslides based on their spatial relationships and patterns (Kakavas & Nikolakopoulos, 2021). GIS serves as a decision support system by providing a visual representation of spatial data and analysis of results (Berhane et al., 2020). It allows stakeholders, including researchers, planners, and policymakers, to visualize mass wasting susceptibility maps, identify high-risk areas, and make informed decisions regarding land use planning, infrastructure development, and disaster mitigation strategies (Mahler et al., 2012). Mass wasting studies can also benefit from data from remote sensing techniques like satellite images and aerial photography (Raghuvanshi et al., 2014). These methods are capable of gathering detailed data on geological properties, vegetation cover, and terrain characteristics (Yong et al., 2022).

The choice of Akwapim South District as a study area for mass wasting susceptibility studies is justified due to its dense population with a mix of residential, commercial, and institutional developments. Also, the district's diverse geomorphological features, such as steep slopes and hills, towards the Akwapim mountain create conditions that are favourable for mass wasting processes like landslides and rockfall. The presence of such features increases the likelihood of mass wasting events occurring in the region. Also, the geographical and geological setting of the Aburi enclave of the study area is prone to historical mass wasting events due to the presence of weak rock layers, slope instability and intense rainfall (Ghana Institution of Geoscientists, 2019). Studying a location with a history of mass wasting activities provides valuable insights into the factors that contribute to mass wasting occurrence and aids in the development of effective mitigation strategies (Mertens et al., 2016).

1.3 Problem Statement

Every country in the world, wealthy or poor, has landslide-prone zones therefore technical experts and authorities are worried about the potential locations of mass wasting processes during intense earthquakes or periods of high precipitation (ICL, 2021). According to recent research from World Health Organization, (2022), landslides impacted an estimated 4.8 million individuals globally between 1998 and 2017 and resulted in more than 18,000 fatalities. It is therefore crucial to understand the science behind mass wasting processes, including why they happen, what causes them, the geology involved and where they are most likely to occur (Ali, 2021). In light of this, studies into mass wasting investigation such as susceptibility mapping and landslide risk mitigation, are widely conducted among scientists, engineers, and policymakers as they serve as a crucial platform for lowering the danger of mass wasting disasters as noted by Sendai Landslide Partnerships for global improvement of understanding of landslide recognition and mapping (2021). However, a study conducted by Petrucci (2022) indicated that some global mass wasting susceptibility studies were conducted in uninhabited areas and landslides occurring in uninhabited regions lack direct implications for human life.

In Africa, disasters have occurred more frequently during the past 15 years according to the United Nations International Plan for Disaster Reduction. Throughout the continent over the last ten years, mass wasting-related disasters have claimed more than 4000 lives (Berhane et al., 2020). Many densely populated settlements with poor living conditions, which are common in many developing countries pose a great danger because in these areas, inadequate measures for prevention and control, as well as poor human settlement patterns, lead to many deaths from landslides (Petrucci, 2022). However, several mass wasting susceptibility studies in Africa (Ajake et al., 2022; Mekonnen et al., 2022; Mertens et al., 2016; Nwankwoala, 2019; Shano et al., 2022) could not achieve the desired accuracy in their mapping of the prone areas because of limited availability and quality of data such as published landslide inventories (Snjezana et al., 2021). Hence, there are still gaps in the modelling and mapping of potential areas of mass wasting hazards on the continent at the local and regional levels.

In Ghana, mass wasting activities have been present since the 1930s (Adu-Boahen et al., 2020). As reported by Graphic Online, on October 28, 2019, Aburi Mountain experienced frequent landslides from 2010 to 2019, prompting the Roads and Transport Committee of Parliament to call for the urgent demolition of buildings along the mountains as a solution to persistent mass wasting activities that caused flooding and forced 559 residents to flee after four hours of rain (Bokpe and Aziamor-Mensah, 2021). The Akuapem South is prone to serious mass wasting processes with consequences to life and ecosystem stability. However, there is little knowledge as regarding the predominant triggers of these processes, it is further unclear the types of mass wasting that is predominant in these areas. There have been various perceptions about the causes of mass wasting especially landslides and rock fall, yet, the districts continues to be noted for its booming commercial trade in construction stones such as shist, quartzite and marbles, among others. In the opinion of many scientists and geomorphologist, the plausible causes of mass wasting in the area purported to be rockfall may likely to be misconstrued

Efforts to map mass wasting disaster vulnerabilities and directions for land use are critical issues considered by the Ghana Institution of Geoscientists for the suitability of the dynamic development of sustainable natural and human conditions in the country. However, the problem of mass wasting activities in Ghana is compounded by a lack of accurate and up-to-date mapping of the vulnerability of different areas to mass wasting. Also, most mass wasting studies in Ghana, for example, Adu-Boahen et al. (2020) and Ayitey (1991) concentrated on the magnitude, distribution, impact, and potential corrective actions of slope failures neglecting mapping and forecasting potential areas of mass wasting attacks. Therefore, there remains a critical research gap concerning mass wasting susceptibility mapping in hilly areas in the country of which Akwapim South district remains one critical area. Addressing these research gaps in zoning Akwapim South District based on the level of vulnerability to mass wasting will not only contribute to the advancement of scientific knowledge in the field but also provide valuable information for policymakers and local authorities to develop effectively and targeted landslide risk management strategies to safeguard lives and infrastructure in the region. Furthermore, the rapid urbanization and human activities in the study area have significantly affected the stability of slopes and contributed to mass wasting events. Encroachment on hillslopes, improper land-use planning, and construction practices have exacerbated mass wasting susceptibility. Therefore, investigating the interplay between human interventions and mass wasting occurrences can provide critical insights for disaster mitigation and urban development planning. Using multi-class spatial datasets, this study aims to identify places in the Akwapim South District that are vulnerable to catastrophic mass wasting activities. This information will be important for forecasting future landslides and reducing risks and damages

1.4 Research Objectives

The main objective of this study is to conduct a mass wasting susceptibility investigation in Akwapim South District. Specifically, to:

1. Identify and map the key mass wasting activities occurring in the Akwapim South District
2. Identify the perceived causes of mass wasting by the residents in the Akwapim South District
3. Map mass wasting susceptible zones in the Akwapim South District using GIS
4. Examine the socio-economic and environmental impacts of mass wasting in the Akwapim South district.

1.5 Research Questions

1. What are the types and locations of mass wasting activities in the Akwapim South District?
2. What are the major causes of mass wasting in the Akwapim South District?
3. Which areas in the Akwapim South District are susceptible to potential mass wasting occurrence?

4. What are some socio-economic and environmental impacts of mass wasting activities in the Akwapim south district?

1.6 Hypothesis Statement

H0: Level of awareness among residents regarding the occurrence of mass wasting in the Akwapim South District is not influenced by their educational level or gender.

Ha: Level of awareness among residents regarding the occurence of mass wasting in the Akwapim South District is influenced by their educational level or gender.

1.7 Significance of the Study

Conducting mass wasting susceptibility research, as well as socio-economic and environmental impact analysis, is essential for fostering a safer, more resilient and sustainable community or district. Mass wasting susceptibility research provides scientific evidence for the development of policies and regulations related to land-use planning and environmental protection such as formulating zoning laws that prevent construction in hazardous areas, thereby ensuring the safety of residents (Diana et al., 2021). Identifying areas with a high susceptibility to mass wasting helps in implementing effective risk reduction and mitigation strategies. This information allows local authorities and communities to take appropriate measures, such as building retaining structures, stabilizing slopes, or avoiding construction in high-risk zones, to minimize the potential impact of landslides on human lives and infrastructure (Neamat & Karimi, 2020). Furthermore, understanding areas most vulnerable to mass wasting enables better disaster preparedness and response planning. It allows for the establishment of early warning systems and emergency evacuation protocols, which can save lives and reduce injuries during landslide events (Snjezana et al., 2021). Also, mass wasting can cause severe environmental damage, including soil erosion, habitat destruction, and alteration of watercourses. By identifying vulnerable areas, conservation efforts can be focused on preserving these regions, preventing deforestation, and implementing erosion control measures to maintain the ecosystem's integrity (SAM, 2017). The research also aids in guiding infrastructure development and planning processes. Avoiding construction in landslide-prone areas reduces the risk of property damage and infrastructure loss, saving substantial costs associated with reconstruction and repair. Mass wasting events can result in the displacement of communities and the destruction of agricultural land, impacting livelihoods and economies (Ikhsan et al., 2020). Studying the socio-economic aspects helps in understanding the potential consequences on local communities, and it facilitates the implementation of appropriate socio-economic support and recovery programs (Sarker et al., 2019). Finally, accurate knowledge of mass wasting susceptibility allows insurance companies to assess and determine appropriate premiums for areas at higher risk (Mertens et al., 2016).

1.9 Organization of Study

This research is organized into five (5) sections. The first chapter introduces the topic in general, followed by the problem statement, research questions and study objectives. Additionally, it addresses the importance of the study, and its limitations, and provides an outline of subsequent chapters. Chapter two delves into the existing literature concerning mass wasting concepts, the causes, socio-economic and environmental impacts of mass wasting, the utilization of remote sensing and GIS for mass wasting investigations, and methods for mapping mass wasting susceptibility. Chapter three focuses on the study area and outlines the research materials and methods employed. The initial part of this chapter describes the physical and anthropogenic characteristics of the study area, while the second section thoroughly explains the research methodology. Chapter four presents the findings, data analysis, and discussions. It also visually represents some results through images, tables, and charts. Finally, chapter five offers a summary of the key findings, along with conclusions and recommendations derived from the study.

CHAPTER TWO

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Introduction

This chapter comprises of two parts - a review of related literature and an explanation of the conceptual and theoretical frameworks adopted for the study. The first part reviews the literature on several themes including the concept of mass wasting, causes of mass wasting, the socio-economic and environmental impacts of mass wasting, GIS and remote sensing for mass wasting investigation, landslide causative parameters, and methods of mass wasting susceptibility mapping. The second part solely focuses on conceptual and theoretical frameworks

2.2 Dynamics of Mass Wasting Processes

The character of mass wasting is defined by the topography, gravity, and geological features of the terrain (Ali, 2021). Mass wasting occurs when rocks and soil move downward due to gravity, usually in the form of a sloping section of land moving as a mass with fixed boundaries (Dias et al., 2021). This process can happen suddenly or gradually and is primarily caused by the mvement of surface materials on the earth (Melissa, 2019). The speed of mass wasting is a critical factor in determining its impact on people, as rapid events can occur without warning and leave individuals with little time to react. In emergency management, the quickness of mass wasting can limit the time available to anticipate and respond effectively, leaving less time for the activation of warning systems and emergency procedures such as road closures and evacuations (Shrestha, 2022). Terrain that is typically susceptible to mass wasting includes existing landslide areas, top or base of slopes, minor drainage hollows, old fill slopes, and steep cut slopes while areas that are generally safe from mass wasting include hard, non-jointed bedrock, flat areas away from slopes and steep riverbanks, and top or along the nose of ridges(Chen, 2022). The slope gradient, consolidation, and water are the primary factors that determine the type and rate of mass wasting on the earth's surface (Ali, 2021). Areas with steeper slopes with sediments or fractured and poorly cemented rocks are more likely to experience mass wasting. Additionally, water-saturated materials may lose cohesion and flow easily (Chen, 2022).

Mass wasting activities go through three distinct stages, which include the pre-failure stage, failure stage, and post-failure stages (Blondel et al., 2022). The pre-failure stage covers the period leading up to the actual landslide event, and it involves several processes and conditions that contribute to the eventual failure. Geological factors play a vital role in this stage. For instance, the type of rock and its weathering characteristics can significantly influence the susceptibility to mass wasting. Weak, poorly consolidated rocks are more prone to failure than well-compacted ones (Hungr et al., 2014). Weathering processes such as chemical, physical, and biological factors gradually weaken materials, making them more vulnerable to failure. Chemical weathering, such as dissolution and oxidation, can alter the mineral composition of rocks, reducing their cohesion. Physical weathering induced by factors like freeze-thaw cycles enlarges fractures and reduces the rock's structural integrity (Cruden & Varnes, 1996). The level of saturation and pore pressure within the soil or rock mass is another crucial factor in the pre-failure stage. Increased water content raises pore pressure, reducing the effective stress and shear strength of the material. This, in turn, makes it more susceptible to failure (Vorogushyn et al., 2018). Factors such as rainfall, snowmelt, or human activities like irrigation, slope excavation, etc. can contribute to the saturation of the slope. Furthermore, the presence or absence of vegetation can significantly influence the stability of a slope. The root systems of plants bind soil particles together, increasing cohesion and reducing erosion (Eilertsen et al., 2011). Construction activities which involve excavation and modification of natural slopes can disrupt the equilibrium of the slope and weaken its stability, making it more prone to landslides or slope failures (Ali, 2021). Also, during construction, vegetation is often removed, resulting in reduced slope stability and increased susceptibility to erosion and landslides. Construction of roads and houses in hilly areas can also alter natural drainage patterns by installing drainage systems, modifying natural watercourses, or creating impervious surfaces such as roads and pavements (Abedin et al., 2020)

The failure stage marks the point at which the combined factors lead to a critical reduction in the shear strength of the material (Bøckmann & Vartdal, 2014). This reduction can occur suddenly due to a triggering event, such as an earthquake or rapid rainfall, or gradually as a result of long-term processes (Varnes, 1978). At this point, the material reaches its critical angle of repose, leading to movement. The type of mass wasting event that occurs is dependent on various factors, including slope angle, material type, and moisture content. Common types include rockfalls, debris flows, and earth flows. Each type has distinct characteristics and mechanisms of movement (Wieczorek & Glade, 2007). The dynamics of movement during the failure stage are complex and can vary widely. Factors such as frictional resistance, pore pressure and topographical features influence the velocity and extent of movement. Rapid, catastrophic events like debris flows are characterized by high velocities and extensive damage, while slower-moving earth flows may exhibit progressive movement over time (Hungr et al., 2014). Following the failure, the post-failure stage involves the deposition and redistribution of material. This can lead to the formation of new landforms, such as alluvial fans or talus slopes. The characteristics of the deposited material, including grain size, sorting, and compaction, are influenced by factors such as flow velocity and duration (Crozier, 2010)

The reactivation stage in mass wasting refers to the re-initiation of movement in a previously stable or dormant mass of earth material. This stage can be continuous or occasional (Melissa, 2019). Reactivation can occur due to various triggers such as increased water saturation, earthquakes, changes in slope angle, or other destabilizing factors. In some cases, reactivation can be continuous. For instance, if a slope is constantly subjected to erosional forces like water flow or if it is inherently unstable due to geological factors, the movement may be ongoing over an extended period. This is commonly observed in certain types of landslides, such as slow-moving earthflows (Montrasio et al., 2011). On the other hand, reactivation can also be occasional (Ali, 2021). This occurs when a slope experiences a period of stability followed by a sudden or intermittent event that triggers renewed movement. For example, a heavy rainstorm after a prolonged dry period can lead to a sudden reactivation of mass wasting activities.

The potential destructiveness of landslides is primarily determined by their speed, with some mass wasting events reaching catastrophic velocities of several meters per second (Snjezana et al., 2021). There are seven categories of mass wasting based on velocity, including fall, slide, flow, topple, spread, creep, and complex types (Melissa, 2019). Gravity, mechanical weathering, and the presence of interstitial water heavily influence falls, such as rockfall and debris fall, in steep slopes below bedrock scarps in upland areas (Melissa, 2019). Falls can occur due to basal erosion, undercutting, loss of internal strength due to weathering, or mechanical break-up by temperature variations or high water pressures (Zhang et al., 2020). Another type of mass wasting is toppled, which involves the forward rotation out of the slope of a mass of soil or rock about a point or axis below the centre of gravity of the displaced mass. However, depending on factors such as the rock type, the geometry of the rock mass, and the extent of the discontinuities, the rock mass may remain in this position for an extended period or fall away down-slope due to further weakening or undercutting (Ali, 2021). Topples can range from slow to rapid, with some accelerating throughout the movement. On the other hand, sliding occurs when masses of material move along defined surfaces of rupture known as slip or shear surfaces, and may break up as they move away from the initial rupture point and it involves the extension of a cohesive rock or soil mass combined with a general subsidence of the fractured mass into softer underlying material, often resulting from liquefaction or flow of the softer material, and usually occurring on gentle slopes or flat terrain (Ali, 2021). The primary movement in spreads is a lateral extension of the underlying weak material due to shearing or tensional fractures and may be caused by liquefaction or plastic flow. Rapid ground motion, such as an earthquake, can trigger the failure that usually causes spreads, but they can also be artificially induced (Zhao et al., 2022). In contrast, flow describes a constant motion without the preservation of closely spaced shear surfaces (Das S., 2023). The velocity distribution in the mass resembles that of a viscous liquid, and the lower boundary of the displaced mass may either be a surface with significant differential movement or a thick zone of distributed shear. The transition from slides to flows depends on the water content, mobility, and movement evolution (Lin et al., 2021). Although flows can occur in bedrock, they are typically slow and only take place in areas with high relief. Flows in unconsolidated materials are much more evident, with various types of flows including rock flow, earth flows, debris flow, mudflow, spontaneous liquefaction, and solifluction (Ali, 2021). Complex mass wasting involves more than one movement mechanism, with different types of movement occurring simultaneously or changing as the landslide progresses. Slides can transform into flows in the lower parts of the slope, and materials in a complex landslide can be classified into rock, debris, and earth (Melissa, 2019). In reality, there is a continuum of mass movements from falls through slides to flows (Ullah et al., 2022).

2.3 Socio-Economic And Environmental Impacts Of Mass Wasting

The economic and social effects of landslides and other ground collapses continue to spiral out of control as the population increases and civilization advances (Nwankwoala, 2019). Thousands of lives and properties have been lost due to landslides throughout the world. Climate change, urban pressure, underdevelopment, poverty, and a lack of preparedness are rapidly turning mass wasting-related dangers into catastrophic events that pose a serious threat to human life and hurt the economy (Sarker et al., 2019). Indirect costs from landslides include loss of tax revenue, business interruptions, decreased property prices and productivity, and legal damages (Snjezana et al., 2021). Direct costs include harm to society's infrastructure and built environment (Abedin et al., 2020). In a similar vein, indirect costs typically exceed direct costs, and governments and organizations in the impacted towns bear the brunt of the economic loss (Senanayake et al., 2022). Landslides with significant mortality tolls are generally a result of failures in risk governance, poverty reduction, environmental protection, land use and the execution of building rules (Muchlis et al., 2021). In addition to their physical effects, mass wasting can have detrimental socio-economic effects on people, communities, and even nations. Thousands of lives have been lost as a result of mass wasting-related disasters globally and it has a lasting influence on the families and communities affected including death, displacement, trauma, and psychological effects (Petrucci, 2022). Mass wasting can happen suddenly, and those who are caught up in it might not be able to escape. For instance, it is estimated that 2.2 billion people in China were affected by numerous disasters, and Haiti, one of the world's most vulnerable countries, saw about 230,675 people pass away in a landslide incident and also a landslide in Sierra Leone in August 2017 destroyed homes and killed over 1,000 people (Alam & Ray-Bennett, 2021; Sarker et al., 2019). More than 200 people perished in a landslide that happened in the Chamoli area of India's Uttarakhand in January

2021(The Indian Express, 2021). Similarly, 43 people lost their lives and millions of dollars were damaged in the Oso region of Washington State, United States, in a landslide in March 2014. (BBC News, 2014). Mass wasting also frequently leaves those who were forced from their houses homeless and forced to restart their lives. For example, one side of the communities in Buanchor, Agwagune and Ukpe-Alege in Nigeria, had materials such as rock, water, trees, etc. submerging them during a landslide, resulting in the displacement of many families and many of them needed to re-establish and re-integrate into social systems, such as residential homes and schools (Ajake et al., 2022).

Mass wasting can inflict serious economic consequences, including reduced income, loss of assets, and increased destitution (Rahman et al., 2022). Landslides can sometimes impede market access for sellers by disrupting communication channels and rendering roads impassable, thus making it challenging for them to sell their goods on time or at a fair price. This can lead to a decline in income, a decrease in living standards, and an increase in poverty (Wadhawan et al., 2020 According to a study conducted in the Rwenzori region, landslides have had a significant impact on farmers in the past 15 years. This has affected over 20% of households in the selected villages, resulting in a loss of agricultural revenue for those affected by landslides. Similarly, a separate study conducted in the Nepalese village of Ghumthang found that 92% of residents relied on agriculture as their primary source of income, which decreased to 74% after a landslide destroyed their agricultural land. The study further revealed that 92% of residents had lost their agricultural land, 12% had lost animals, 32% had lost crops, and 52% had lost their homes and other infrastructure due to landslides. It can also deposit large volumes of sediment and debris on roads, blocking them and hindering travel. Debris flows, in particular, can transport a mixture of water, rock, soil, and vegetation, causing significant to the environment. Landslides have a variety of socio-economic effects on rental properties, including business loss, property loss, restoration costs, and decreased property value (Rahman et al., 2022). Mass wasting related property damage repair expenditures can have a major socio-economic impact especially if the cost is high, some people and communities may not have the financial means to make the necessary repairs and this may result in a decrease in property value and a decrease in economic activity (Diana et al., 2021).

Another serious socio-economic implication of landslides includes trauma and psychological effects (Mertens et al., 2016b; Nwankwoala, 2019). Landslides' consequences on human life have the potential to result in psychological damage that lasts a lifetime. Anxiety, fear, despair, and post-traumatic stress disorder can occur in landslide survivors (PTSD) (Diana et al., 2021). Mass wasting can have psychological impacts that affect people's capacity to work, earn a living, and participate in social activities, which can have further negative effects on the economy (Petrucci, 2022).

Mass wasting can also cause serious damage to the environment (Abdo, 2022). One of the primary environmental impacts of mass wasting is the alteration of landforms and topography. Landslides can reshape entire landscapes, creating new landforms and altering drainage patterns (Nguyen et al., 2022). This can lead to changes in water flow, increased erosion, and the loss of fertile soil. The disruption of natural drainage systems can also result in the formation of stagnant water bodies, increasing the risk of waterborne diseases and affecting aquatic ecosystems (Huggel et al., 2022). Mass wasting events can have severe consequences for biodiversity (Muchlis et al., 2021). Vegetation is often uprooted or buried, leading to habitat destruction and loss of plant and animal species. The removal of vegetation also increases the vulnerability of slopes to erosion, further exacerbating the environmental impacts (Ali, 2021). The sediment and debris generated by landslides can smother aquatic habitats, impacting fish populations and other aquatic organisms

(Senanayake et al., 2022). Moreover, mass wasting can trigger secondary hazards such as floods and tsunamis. Large landslides into bodies of water can displace large volumes of water, causing destructive waves that inundate coastal areas (Omosanya et al., 2022). The resulting flooding can cause significant damage to infrastructure, including buildings, roads, and utilities, and result in the loss of human lives (Abedin et al., 2020).

2.4 Mass wasting susceptibility mapping

The major instrument for sustainable regional planning is the mass wasting susceptibility zonation map, which also makes landslide hazard management and mitigation easier (Tyagi et al., 2022) Mass wasting susceptibility is defined as the probability of a spatial terrain triggering mass wasting events over a set of geo-environmental conditions (Zhao et al., 2022). The prediction techniques are based on the popular assumption that the past and the present landslide locations are the keys to the future (Ivanik et al., 2022). In other words, slope failures are determined by a given set of controlling factors, and future slope failures are expected to occur under the same conditions (Abdo, 2022). Mass wasting susceptibility maps show the geographic distribution of the area into zones with different potential mass wasting-related danger levels by classifying the terrain into low, moderate, high and very high susceptible zones and it constitutes the basis for sound land use planning and development for engineering applications ((Islam et al., 2022); Ivanik et al., 2022). By assessing different influencing characteristics, such as geological variables, geomorphic factors, land-use and land-cover factors, etc., landslide susceptibility maps can be drawn to detect future hazardous zones (Islam et al., 2022).

However, data availability and quality, resolution and scale, climate change and impacts are some challenges affecting the reliability of mass wasting susceptibility maps (Ciampalini et al., 2016). Obtaining high-resolution data, especially in remote or inaccessible areas, remains a challenge.

Additionally, data accuracy and consistency are crucial for reliable susceptibility assessments. Also, determining the appropriate scale for susceptibility mapping is essential. Large-scale assessments may overlook localized hazards, while small-scale mapping might not capture regional trends effectively. Furthermore, climate change-induced variations in precipitation patterns and temperatures can alter mass wasting susceptibility. Integrating climate projections into susceptibility models is imperative for accurate assessments (Ciampalini et al., 2016).

2.5 Procedures involved in mass wasting susceptibility mapping

The initial phase in the process of mapping susceptibility to mass wasting entails the comprehensive gathering of relevant data from a diverse array of sources. These data encompass a spectrum of factors, including but not limited to geological, geomorphological, hydrological, climatic, and anthropogenic elements. The inclusion of high-resolution digital elevation models (DEMs), satellite imagery, and historical records of landslides constitutes indispensable components within this data aggregation endeavour. Numerous scholarly investigations have underscored the pivotal significance of possessing precise and current data to enhance the dependability of the outcomes derived from susceptibility mapping (Smith et al., 2014; Chen et al., 2018). After the compilation of data, the ensuing step entails the execution of a thorough factor analysis aimed at the identification of those variables that exert a noteworthy influence on the incidents of mass wasting. Parameters like the steepness of slopes, orientation, lithological composition, land cover classification, intensity of rainfall, and proximity to geological faults have emerged as pivotal determinants in the realm of landslide susceptibility assessments (Lee et al., 2016; Khan et al., 2019). The selection of factors hinges upon the specific attributes characterizing the area under scrutiny and the availability of requisite data resources.

Geospatial techniques, particularly the employment of Geographic Information Systems (GIS), represent a prevalent methodology in the sphere of susceptibility mapping for mass wasting events. GIS serves as a robust platform for undertaking spatial analyses, the amalgamation of diverse strata of data, and the formulation of susceptibility models. An assortment of GIS-based models, including the Analytical Hierarchy Process (AHP), Weight of Evidence (WoE), and Logistic Regression (LR), have been deployed for the assessment of susceptibility levels (Pourghasemi et al., 2015; Althuwaynee et al., 2017). It bears emphasizing that the trustworthiness of susceptibility maps for mass wasting is contingent upon the thorough validation and precise evaluation of their accuracy. These maps undergo validation through comparison with inventories of landslides or meticulous field surveys. Various statistical metrics, such as the Receiver Operating Characteristic (ROC) curves, the area under the curve (AUC), and success rate curves, find application in gauging the fidelity of the models (Pradhan, 2013; Saha et al., 2021).

2.6 Remote Sensing and GIS for Mass Masting Investigation

Landslides are a significant geological threat that endangers both lives and property (Rahman et al., 2022). To assess and mitigate this hazard, landslide susceptibility mapping (LSM) is a crucial method. However, the conventional LSM approach relies on fieldwork and expertise, resulting in high costs and time consumption. (Yamusa et al., 2022). Furthermore, during the past 20 years, the variety of landslide studies produced each year has increased as a result of the growing popularity of GIS technology and remote sensing as a tool for studying landslide susceptibility (Wang. et al., 2020). The accessibility of digital data, especially remote sensing data, and the creation of new models, including machine learning models, may have contributed to this growth in landslide mapping (Miele et al., 2022). The fact that more researchers have conducted GIS-based landslide susceptibility mapping studies and are interested in landslides is likely a result of their satisfaction with GIS and remote sensing data (Aksha et al., 2020). Worldwide research has shown that Remote sensing and GIS methods can produce accurate and dependable mass wasting susceptibility maps that are enhanced by combining data from several sources, including DEM, remote sensing photos, and thematic maps (Khadka et al., 2018). Using sensors on planes or satellites, remote sensing technology collects data over great distances (Ivanik et al., 2022).

The benefit of remote sensing is the ability to collect multispectral and multitemporal data over a wide area, allowing one to characterise the terrain, geology, vegetation, and land use of any region of the earth's surface (Kariminejad et al., 2022). LSM has made use of a variety of remote sensing data sources, including optical, radar, and LiDAR GIS technology to collect, control, examine, and present geographic data (Monge et al., 2022). It offers a platform for combining different types of data and may produce maps that show the geographical linkages and patterns of the data (Sam & Bhardwaj, 2022). Recent research has improved LSM accuracy and effectiveness using RS and GIS approaches. In the Sumber catchment area of Indonesia, a study by Saro-Lee (2019) used satellite imagery, DEM, and thematic maps to construct a landslide susceptibility map. The findings showed that by combining data from various sources, RS and GIS approaches can increase the accuracy of LSM. A landslide susceptibility map in the Srinagar-Rudraprayag region of India was produced by Meghanadh et al (2022) using optical and radar remote sensing data. According to the study, radar data can offer useful details about the geology and soil moisture content, which can increase the accuracy of LSM. In addition, the study found that combining optical and radar data can increase LSM accuracy in comparison to using just one data source. LiDAR data were used in a study by (Lee et al., 2004) to produce a map of landslide susceptibility in the Upper Sandusky watershed, Ohio, USA. According to the study, LSM accuracy can be increased by using LiDAR data to provide accurate information about topography and land features. The study also put forward the idea that LiDAR data may be utilized to analyse the landslide susceptibility of dangerous or inaccessible places, which can be difficult to assess using traditional fieldwork techniques. In the Kullu Valley of India, a study by Arora et al. (2019) used GIS and machine learning algorithms to build a map of landslide risk. According to the study, high-precision LSM results can be obtained using machine learning techniques like random forest and support vector machine. The study also showed that a quick and affordable method for LSM may be achieved by combining machine learning algorithms with GIS approaches.

2.7 Description and processing of mass wasting causative factors for susceptibility mapping

When undertaking GIS-based landslide susceptibility mapping, various researchers took into account a variety of factors influencing mass wasting (Kariminejad et al., 2022). This mass wasting parameter data is made up of natural factors and human factors (Rotaru et al., 2017). Natural factors such as geological, hydrological, anthropogenic, topography, seismicity and climate factors are considered (Muchlis et al., 2021). Six categories, that is topographic, hydrology, transportation, geology, soil, forest, and land use—could be used to classify the causes. Elevation, slope, aspect, curvature, relief, and geomorphology were all topographic considerations and normally Digital Elevation Models (DEMs) are used to extract these parameters (Nguyen et al., 2022). Distance from roads and rails as well as their density are transportation-related considerations (Lv et al., 2022). Lithology, distance from faults and lineaments, the density of faults and lineaments, bedding, and foliation are common geological factors (Achour & Pourghasemi, 2020). Lastly, scholars have looked at both land use and land cover within the context of land use (Singh et al., 2017).

By incorporating data from remote sensing, geospatial analysis and geological surveys, researchers can develop accurate mass wasting susceptibility maps for effective hazard assessment and mitigation. In describing these factors, elevation is a fundamental factor in mass wasting susceptibility mapping. Higher elevations often indicate steeper slopes and more unstable terrain. Studies have shown that landslides are more likely to occur at higher elevations due to the combination of slope gradient, geology, and soil properties (Varnes, 1978). Elevation data can be derived from digital elevation models (DEMs) obtained through remote sensing techniques, such as Light Detection and Ranging (LiDAR) or satellite imagery. Slope angle is another critical parameter for landslide susceptibility mapping. Steeper slopes are more prone to instability and failure. Several studies have shown a positive correlation between slope angle and landslide occurrence (Ohlmacher & Davis, 2003). Slope data can be derived from DEMs and processed to categorize different slope classes for susceptibility analysis. Furthermore, soil properties including soil type, cohesion, and internal friction angle, significantly influence landslide occurrence. Different soil types have varying shear strengths, affecting the stability of slopes. Cohesive soils, such as clays, are prone to landslides due to their low permeability and high water-holding capacity. Studies by Montgomery & Dietrich, (1994) have emphasized the importance of soil properties in landslide susceptibility mapping. Land Use/Land Cover on the other hand plays a crucial role in determining landslide susceptibility. Urbanisation, deforestation, and changes in vegetation cover can alter the stability of slopes. Studies have indicated that areas with dense vegetation cover, such as forests, are less susceptible to landslides compared to areas with sparse or no vegetation (Westen et al., 2003). LULC data can be obtained from satellite imagery or aerial photographs and classified into different categories for analysis. Rainfall also has a significant power to trigger mass wasting, particularly in areas with steep slopes and high-intensity rainfall events. Studies by Guzzetti et al. (2008) have shown a strong correlation between rainfall and landslide occurrence. Rainfall data can be obtained from rain gauges or weather stations and analysed to identify rainfall thresholds for landslide initiation. In addition, geological factors, such as rock type, weathering, and structural characteristics, influence the susceptibility of slopes to landslides. Different rock types exhibit varying degrees of resistance to erosion and failure. Geological maps, geological surveys, and borehole data provide valuable information for landslide susceptibility assessment (Hungr et al., 2014). Roads and transportation infrastructure can also impact landslide susceptibility. Cut slopes, embankments, and construction activities associated with roads can destabilize slopes and increase landslide risk. Studies by Crozier (1999) have shown that areas in proximity to roads are more susceptible to landslides. Road network data can be obtained from transportation departments and used for spatial analysis. When choosing and combining these factors, there isn't a standard code available because of ssdifferent geo-environmental elements that can combine to cause landslides. In his opinion, bedrock geology, geomorphology, soil characteristics, LULC, and hydrological conditions are crucial elements that should be considered when developing landslide susceptibility mapping. Depending on the local climatic conditions, every element affects landslides differently and these variables, along with their combinations, differ depending on the terrain conditions in each location (Huggel et al., 2022).

2.8 Method of mass wasting susceptibility mapping

Mapping mass wasting occurrence is a difficult task because each location has a different topography and climate (Page & Sandrasekaran, 2020). Several techniques are suggested for ranking the danger levels of the terrain while determining slope instability factors (Tyagi et al., 2022). Guidelines for landslide susceptibility mapping have been proposed by some scientific organizations to use standard terminology and assist practitioners in their studies (Mekonnen et al., 2022). According to Meghanadh et al (2022), the approaches used vary from region to region and even within a single region.

According to Tyagi et al. (2022), there are three types of methods for generating landslide maps: qualitative, semi-quantitative, and quantitative. Qualitative approaches involve expert judgement and non-numeric data to create multiple thematic data layers that account for landslide incidents (Raghuvanshi et al., 2014). Geomorphic analysis and inventory analysis are the two primary qualitative methodologies (Tyagi et al., 2022). While qualitative methods can be useful in some situations, their limitations make them less suitable for mass wasting susceptibility mapping when compared to quantitative methods, which are based on data and can provide more objective and consistent results (Canavesi et al., 2020). Expert opinion is the basis of qualitative approaches and is subject to researcher biases and experiences, which can result in inconsistent estimates of landslide susceptibility (Das S., 2023). Also, relying on limited information such as historical landslide incidents or expert knowledge may not provide a comprehensive picture of a region's susceptibility to landslides (Neamat & Karimi, 2020). Qualitative methods are often used in small areas, which may not be representative of the larger region (Wang & Li, 2017). Validating qualitative approaches can be challenging as there is no unbiased norm to compare them to, making it difficult to determine their accuracy.

Methods that combine both qualitative and quantitative techniques are called semi-quantitative methods. This method is used to determine the weights and ratings of factors and their classes in the mapping of mass wasting (Neamat & Karimi, 2020). These techniques analyse data from previous landslides, expert knowledge, or both to reach a judgement (Canavesi et al., 2020). Compared to fully quantitative procedures, semi-quantitative methods are easier to use and require less information and resources (Tyagi et al., 2022). This increases their usability for a wider range of users, including those with less advanced technical knowledge. Moreover, semi-quantitative methods can be applied at a range of scales, from local to regional, and in both urban and rural contexts (Saaty., 2000). Expert knowledge and judgment can be included using semi-quantitative techniques, which can enhance the results' relevance and interpretability (Ullah et al., 2022). In the last three decades, the three semi-quantitative Multi-Criteria Decision Techniques (MCDM) that have seen the most widespread application are weighted overlay, analytical hierarchy process (AHP), and fuzzy logic (Tyagi et al., 2022).

The analytical hierarchy process (AHP), a multi-criteria decision-making methodology that permits weighting many aspects that lead to landslides, stands out among the other methods. It is one of the most popular methods for landslide susceptibility mapping (Reichenbach et al., 2018). AHP is the most widely used technique for decomposing complex decisions into a hierarchy of straightforward patterns that can be assessed subjectively as developed by Saaty in 1980 (Singh et al., 2019). Thus, subjectivity is eliminated and each option is given a numerical ranking using a scale. By comparing the factors pair-wise, it aids decision-makers in determining the relative importance of various elements (Banerjee et al., 2018). For applying AHP, Saaty (1990) provided a step-by-step process.. Most researchers use their own expert opinion to obtain class boundaries because there are also no general rules to group such continuous data automatically (Wang & Li, 2017). AHP can be employed for medium-scale LSM successfully when several landslide-causing elements are taken into account. AHP can be used successfully for medium-scale LSM where various landslide causative factors are considered as alternatives (Tyagi et al., 2022). Other LSM techniques such as Weighted OverLay technique (Chen et al., 2021), the Frequency ratio method (Berhane et al., 2020), the Information Value (IV) method and the Support Vector Machine(Aditian et al., 2018), Logistic Regression and a Random Forest (Hong et al., 2017)were all compared with the AHP method and the comparison revealed that the AHP method provided a more complete representation of the genuine distribution of landslide susceptibility (Tyagi et al., 2022). Using numerous topographical and geological features that cause landslides, the AHP approach is ideal for creating LSZ maps using Geographical Information System (GIS) software (Reichenbach et al., 2018). The AHP's capacity to determine the uniformity of produced weights is an appealing feature and the calculated eigenvalues are used to assess the consistency of the defined matrix (Tyagi et al., 2022). The AHP model utilizes the consistency ratio (CR) as a metric to determine if matrix judgments were randomly generated (Saaty, 1977, 1980, 1994). The formula used to calculate the CR is CR = (CR/RI), where RI is the average consistency index based on the matrix order established by Saaty (1977) and CI is the consistency index. The consistency index is expressed as CI = (λmax - n) / (n - 1), where n is the matrix's order, and max is the greatest eigenvalue, both of which are determined from the matrix. The CR, which ranges from 0 to 1, compares the consistency index to the random index of the matrix. A CR value of 0.1 or less indicates an acceptable level of consistency (Malczewski, 1999), while a CR value greater than 0.1 indicates that the matrix's judgment needs revision due to inconsistent factor ratings.

According to a study by Zhao et al. (2022), a quantitative method can also be used to predict the occurrence of mass wasting by employing statistical representations like probability of landslide occurrence and landslide inventory to generate numerical estimates of the probability of landslides in a region. Based on the presumption that landslide-causing factors and actual landslides are evenly distributed throughout an area, these approaches determine the likelihood of landslides (Tyagi et al., 2022). The quantitative method can determine the weighting and ranking of criteria for landslide susceptibility maps objectively (Meghanadh et al., 2022). In other words, quantitative approaches assess landslide occurrence and affecting elements using mathematical analysis and the creation of a probability statistical model by using statistical and deterministic techniques (Kariminejad et al., 2022). Frequency ratio, weight of evidence, evidential belief function, information value artificial neural networks, support vector machines, decision trees, etc. are some of the quantitative techniques employed in mass wasting susceptibility mapping (Tyagi et al., 2022). However, Large volumes of data, especially precise topographic and geological data, are needed for quantitative approaches, and their collection can be costly and time-consuming (Achour & Pourghasemi, 2020). Moreover, statistical models are frequently used by quantitative methods to forecast landslide risk (Corominas & Moya, 2008). These models are subject to assumptions and constraints, and the quality and amount of the available data may have an impact on their correctness (Steger & Kofler, 2019). Quantitative methods frequently concentrate on physical and environmental variables, such as terrain and geology, and may fail to take into account human factors that can increase the vulnerability to landslides, such as land use, deforestation, and urbanization (Wu et al., 2022). Although quantitative methods can offer insightful information about landslide susceptibility, the complexity and variety of landslide processes, which may not be fully captured by statistical models, limits the accuracy of these methods (Das, 2023).

2.9 Theoretical Perspective

This study utilized causative factor theory, theoretical framework of Environmental Impact Assessment (EIA) and Social Impact Assessment (SIA) to explain the causes, and socio-economic and environmental impacts of mass wasting in the study area.

2.10.1 Causative Factor Theory

The basis of contemporary social science investigation is rooted in the fundamental principle of causation, also known as the causal theory of explanation. This theoretical framework is an invaluable tool for understanding the complex events that shape our world. Essentially, the theory suggests that events are not random incidents, but rather the result of underlying causes or factors that steer the course of these events. This section explores the complexities of this theory, tracing its origins back to the renowned philosopher Carl Hempel and his deductive-nomological model of explanation. Within this model, an explanation is broken down into two key components: the overarching principle or law, which outlines the relationship between cause and effect, and the initial conditions, which identify the specific circumstances under which the cause exerts its influence. Through the formulation of the deductive-nomological model, Hempel crystallized the essence of explanation, transforming it from a nebulous concept into a structured framework. This model, characterized by its dual components, offers a lucid blueprint for unravelling the intricate web of cause and effect. The general law, acting as the cornerstone, furnishes us with the fundamental principle that underpins the causal relationship. Simultaneously, the initial conditions furnish the context within which this relationship materializes, delineating the specific circumstances that catalyse the causal chain.

For researchers navigating the intricate terrain of the social sciences, the application of causative factor theory necessitates a methodical and rigorous approach. This systematic journey comprises a series of interlocking steps, each one indispensable in its own right. Beginning with the identification of the phenomenon under scrutiny, researchers proceed to formulate hypotheses that serve as the compass guiding their exploration. Subsequently, the arduous task of pinpointing causative factors ensues, culminating in the meticulous collection of data. This reservoir of information, once amassed, undergoes rigorous analysis, enabling researchers to distil meaningful insights. Finally, armed with this arsenal of knowledge, conclusions are drawn, offering a comprehensive elucidation of the underlying causes that steer events in the social sciences.

2.10.2 Theoretical framework of Environmental Impact Assessment (EIA) and Social Impact Assessment (SIA)

The theoretical framework of environmental impact assessments (EIA) and social impact assessments (SIA) can be utilized to explain the socio-economic and environmental impacts of mass wasting. To systematically evaluate and analyse the effects of a variety of activities, including disasters like mass wasting, these frameworks are frequently used in environmental and socio-economic research. The study needs to identify the precise type of mass wasting event (such as landslides, mudslides, or rockfalls) and its distinctive characteristics (such as magnitude, location, and frequency) to examine the socio-economic and environmental effects. The framework can be used to predict the magnitude, regional extent, duration, and severity of mass wasting events to assess the direct and indirect environmental impacts. This may include soil erosion, loss of vegetation, sedimentation in water bodies, potential damage to infrastructure, habitat destruction, and impacts on local ecosystems. Also, to assess the socio-economic impacts, there is a need to identify and map the communities and individuals potentially impacted by mass wasting events. Examine the direct and indirect socio-economic consequences. This may include damage to infrastructure, loss of livelihoods, displacement of communities, and the financial burden on affected individuals and governments. By applying the EIA and SIA frameworks to mass wasting in the Akwapim South District, one can systematically analyse the potential socio-economic and environmental impacts of this phenomenon. This approach ensures that decision-makers have access to well-informed, evidence-based assessments to guide their actions in mitigating and managing the impacts of mass wasting in the region.

2.11 Conceptual Framework

In the context of mass wasting susceptibility studies, the causative factor theory which was propounded by H. R Munro was used. Munro developed this theory to explain the underlying causes of mental illnesses and disorders, particularly in the context of psychogenic (mind-related) factors. The theory proposed that various factors, both internal (psychological) and external (social and environmental), contribute to the development and progression of mental illnesses. The theory was also used by Simon (1969), Sen (1999) and Diamond (1997) in their various works. In the context of mass wasting susceptibility mapping, it provides a theoretical framework for understanding the complex interplay of geological, environmental, and human factors that contribute to landslide susceptibility. By considering these factors in mass wasting susceptibility studies, researchers and planners can make informed decisions to reduce the risks associated with mass wasting. According to this theory, mass wasting processes are not random events but are instead the result of multiple interacting factors. The causative factor theory provides the link between the identified factors and their impacts. By analysing the spatial distribution of mass wasting processes and the corresponding susceptibility maps, it is possible to understand the relationships between specific causative factors and the occurrence and magnitude of landslides. This knowledge can then be used to inform decision-making processes, such as land-use planning and hazard mitigation strategies. The causative factors of mass wasting can be broadly categorized into three main groups: predisposing factors, triggering factors, and contributing factors.

Predisposing factors refer to the characteristics of an area or slope that make it more susceptible to mass wasting. These factors include geological conditions, such as the type of soil or rock present, the slope angle and steepness, the presence of weak or fractured materials, and the presence of groundwater. Additionally, human activities such as deforestation, excavation, or improper land use can also contribute to the predisposition of an area to landslides. Triggering factors are the immediate events or conditions that initiate mass wasting. These factors can include intense rainfall or snowmelt, seismic activity (earthquakes), rapid snowmelt or glacier retreat, volcanic eruptions, or changes in groundwater levels. These triggers increase the stress on slopes, weaken the stability of the materials, and initiate the movement of the landslide mass. The Contributing factors are variables that may not directly trigger a landslide but play a role in its occurrence or magnitude. They can include human-induced changes in land use patterns, such as urbanization, inappropriate construction practices, or inadequate slope stabilization measures. Contributing factors can exacerbate the predisposition of an area to landslides and increase the likelihood and severity of slope failures.

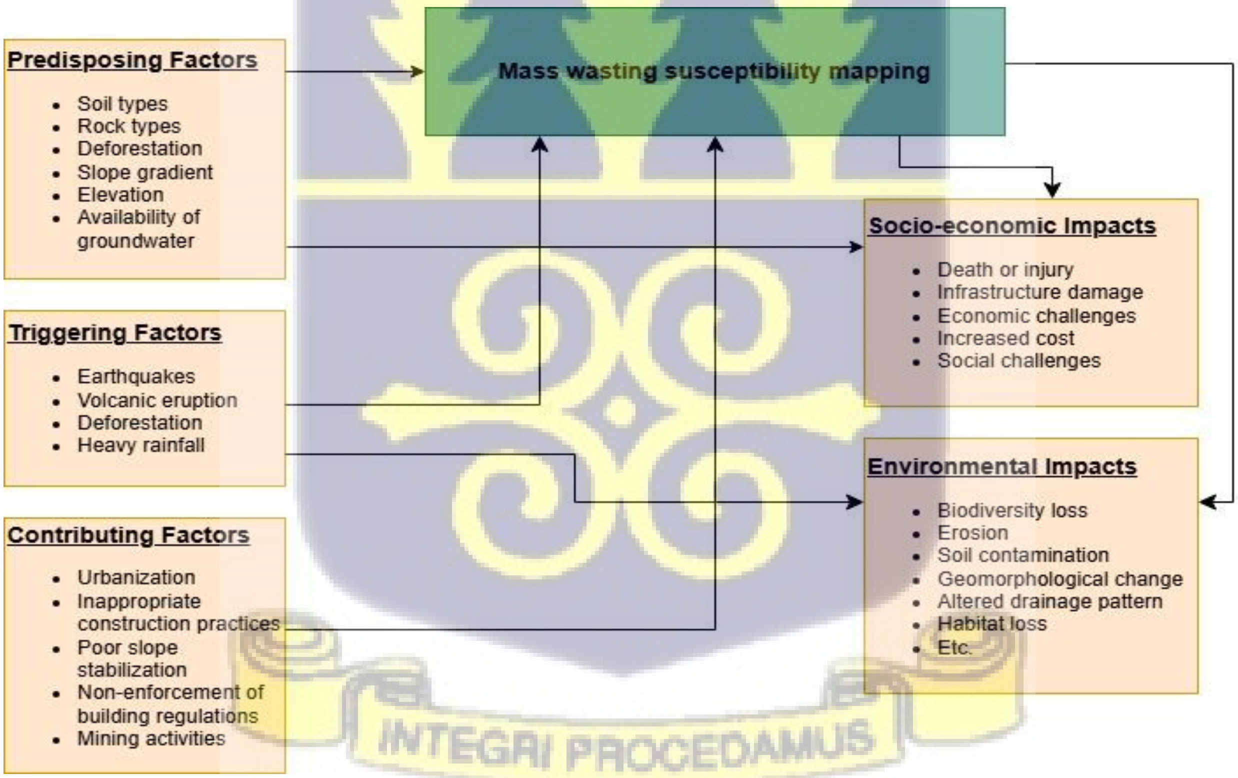

Figure 1: Conceptual framework showing the relationship between the causative factors, socio-economic and environmental impacts of mass wasting modified from causative factor theory, EIA and SIA frameworks

Source: Author (2023)

2.12 Chapter Summary

To conduct the research, the study thoroughly examined the relevant literature and the theoretical framework chosen for the inquiry. The chapter was divided into two parts. The first part of the literature review focused on diverse topics such as types of mass wasting, causes, and socio-economic impacts, as well as the use of GIS and remote sensing for investigating mass wasting, and methods for mass wasting susceptibility modelling. The second part of the review focused on the theoretical and conceptual framework, which was based on the causative factor framework, environmental impacts assessment framework and social impact framework. These frameworks studied the interrelationships among causes, socio-economic and environmental impacts, and the strategy for mapping susceptibility.

CHAPTER THREE

STUDY AREA AND RESEARCH METHODOLOGY

3.1 Introduction

This chapter is made up of two sections. The first section dealt with the description of the research area's biophysical settings. The second part of the chapter also covers the methodological approaches of the study.

3.2 Study area

3. 2.1 Location

The Akwapim South District covers a land area of approximately 224.13 square kilometers and is situated in the southwestern part of Ghana's Eastern Region between latitudes 5.45˚N and 5.58˚N and longitudes 0.0˚W (Ghana Statistical Service, 2014). The district is situated approximately 30 kilometres northeast of the capital city, Accra. It is bordered to the west by the Nsawam-Adoagyiri Municipality, to the south-east the Kpone-Katamanso District, to the south by the Ga East District and to the North-East by the Akwapim North Municipality (Ghana Statistical Service, 2014).

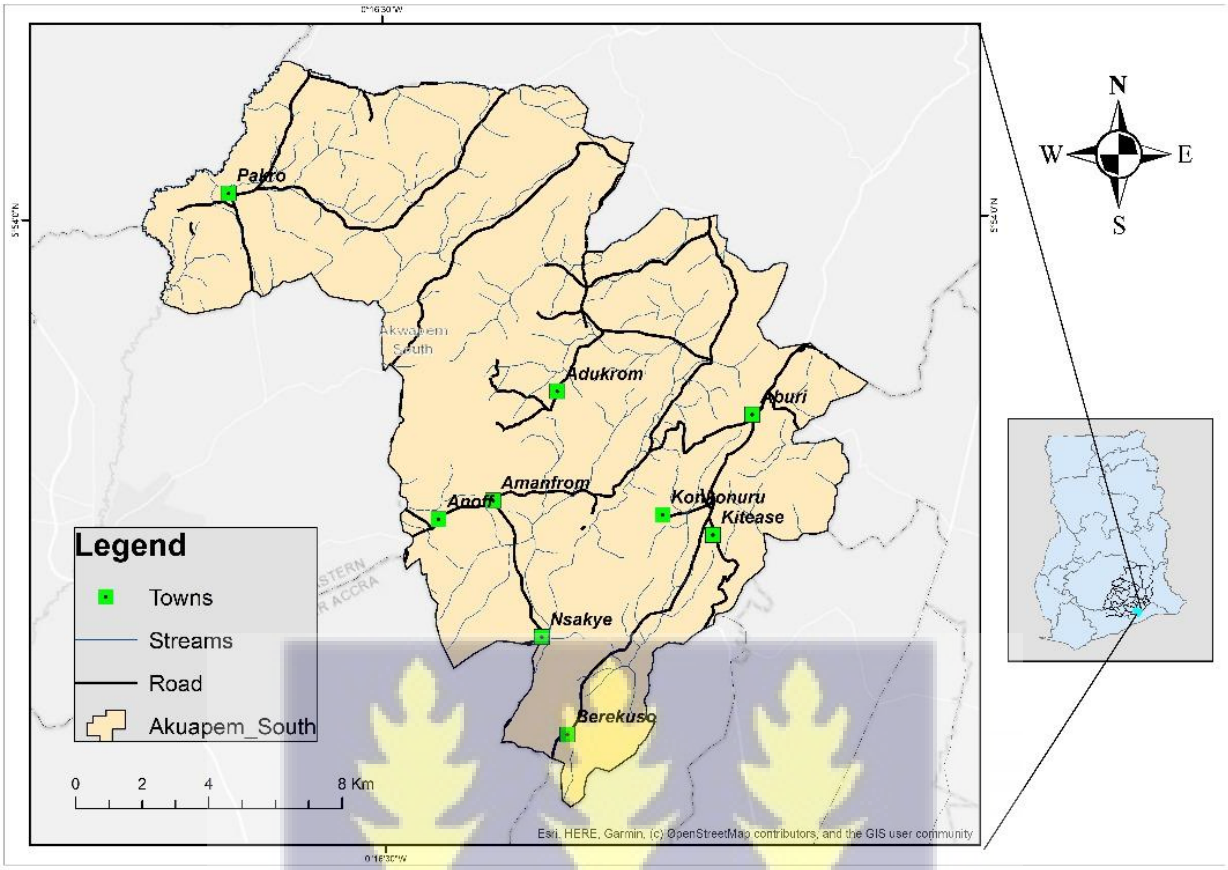

Figure 2: Study area map showing selected towns in Akuapem South District

Source: Authors construct

3.2.2 Geology

The geological history of Akwapim South District is a testament to millions of years of dynamic processes that have shaped the region. The rocks that form the foundation of the district date back to the Precambrian era, which spans from about 4.6 billion to 541 million years ago (Dickson and Benneh (1988). During this period, intense tectonic activities, including mountain-building processes, volcanic eruptions, and sediment deposition, laid the groundwork for the diverse rock formations (Ghana Institution of Geoscientists, 2019). Geologically, the district is situated on the Akwapim Fault, which runs parallel to the eastern coast of Ghana (Bokpe & Aziamor-Mensah, 2021). This fault line is a part of the larger West Africa Transform Margin, where the African Plate and the South American Plate meet. The district's geology is mainly sedimentary rocks metamorphosed to quartzites, schist, shale and philate, forming the Akwapim – Togo ranges (Samuel, 2015). The Precambrian rocks like quartzite, phyllite, and schist. Quartzite, being more resistant to weathering, may slow down erosion, while phyllite and schist are more prone to weathering and decomposition, contributing to unstable slopes. The presence of fault lines and jointed rocks in the region can weaken the earth’s crust, providing pathways for water infiltration. This weakens the underlying material, increasing the likelihood of landslides. The weathering of rocks in the district produces thick residual soils, particularly laterites. These soils can retain water and become saturated, reducing their cohesion and leading to slope failures.

3.2.3 Vegetation

The study area is generally made up of forest, scrub and grassland (Dickson and Benneh, 1988) but presently much degraded. At the time, the forest covers about 90 percent of the district (Dickson and Benneh, 1988). Most of the plants shed their leaves between November and March. The shrublands occur mostly in the western peripheries and the north. Towards the Aburi hills, there are dense clusters of small trees and shrubs. Tall trees tower over the landscape, creating a vibrant green canopy that provides shade and shelter to a diverse array of flora and fauna. The forests are home to various plant species, including mahogany, teak, ebony, and a variety of medicinal plants. Aburi Botanical Gardens, a popular tourist attraction, showcases this rich botanical diversity. The combination of abundant rainfall, fertile soils, and favourable temperatures in Aburi supports various agricultural activities. The district faces significant deforestation due to agricultural expansion, charcoal production, and urbanization. The removal of trees and other vegetation weakens slope stability, making it easier for mass wasting to occur, especially during heavy rains.

3.2.4 Topography

The defining feature of the Akwapim South District is its undulating terrain characterized by a series of hills and ridges. Notable hills include Aburi Hill, which stands as one of the highest points in the district, rising to an elevation of approximately more than 370 meters above sea level (Samuel, 2015). Adjacent to Aburi Hill, a network of ridges extends throughout the district, creating a mosaic of elevated landforms. These ridges play a crucial role in determining drainage patterns and the distribution of settlements within the district (Bokpe & Aziamor-Mensah, 2021). The relief of the district is generally categorized into two main zones, thus the Akwapim-Togo Ranges and the Accra Plains (Ghana Statistical Service, 2014). These elevations provide breathtaking scenic views of the surrounding landscape. Steep slopes and deep valleys are common in the area, resulting in the formation of numerous streams and small rivers that drain the region. Nestled between the hills and ridges are fertile valleys and lowlands that offer ideal conditions for agriculture. These areas, characterized by well-drained soils and ample water sources, are vital for the cultivation of various crops, including cocoa, which is a staple of the district's economy. While the majority of the district is marked by its undulating terrain, there are pockets of flatlands, particularly in the southern regions (Bokpe & Aziamor-Mensah, 2021). These areas often serve as the sites for urban development and infrastructure projects, providing a stark contrast to the hilly landscapes that dominate the district. The Akwapim-Togo ranges feature steep slopes, which inherently promote mass wasting. The gravitational pull is stronger on steeper slopes, causing soil and rock to move downslope more easily. The hilly terrain in the district often results in poor drainage and water accumulation at slope bases. This saturation weakens slope materials, contributing to landslides and slumping.

3.2.5 Climate

The district lies within the semi-equatorial climatic region, and experiences two rainfall seasons in a year, with average rainfall between 125cm and 200cm (Dickson and Benneh,1988).The heaviest rainfall occurs between June and August, contributing to the vibrant greenery and lush vegetation that Aburi is known for. Temperatures in Aburi remain relatively stable throughout the year, with average highs ranging from 28 to 32 degrees Celsius and average lows ranging from 18 to 23 degrees Celsius (64 to 73 degrees Fahrenheit). Humidity levels are generally high due to the proximity to the coast, providing a favourable environment for the growth of rainforests and agricultural activities.

3.2.6 Agriculture

More than 33% of the workforce is involved in agricultural activities, primarily focused on crop cultivation (Ghana Statistical Service, 2014). This district stands as a prominent supplier of pineapples, mangoes, and citrus fruits nationally. The majority of agricultural yields find their way to international markets. In addition, there are smallholders tending to staple crops, alongside a limited number of entrepreneurs engaged in commercial farming. Essential foodstuffs like maize, cassava, plantains, and various vegetables are cultivated, while the livestock spectrum encompasses poultry, sheep, goats, pigs, and cattle, as well as unconventional species like grass cutters.

3.3 MATERIALS AND METHODS

3.4 Philosophical consideration

This research on mass wasting susceptibility studies is grounded in a pragmatism philosophical point of view. Pragmatism, as proposed by William James and Charles S. Peirce in the 1870s and 1880s, emphasizes the significance of empirical evidence and experiential learning. It emphasizes practical consequences, empirical evidence, and the utility of knowledge in solving real-world problems. It places importance on the relevance and applicability of ideas and theories to actual situations. In the context of the research project on mass wasting susceptibility studies, pragmatism provides a suitable philosophical underpinning that aligns with the objectives of the study. Pragmatism encourages the researcher to focus on practical solutions to real problems. By investigating the causes of mass wasting, the researcher seeks to understand the underlying factors contributing to this phenomenon. Pragmatism emphasizes the need to gather empirical evidence to support theories and hypotheses, which is crucial in identifying the most practical and effective measures to mitigate mass wasting. James (1980), argued that theories and concepts are only meaningful if they have tangible consequences. Therefore, in this research project, the identification and analysis of the causes of mass wasting would lead to actionable recommendations for hazard mitigation and prevention strategies. Pragmatism also emphasizes the importance of practical outcomes and utility in knowledge acquisition. In the context of susceptibility mapping for mass wasting, pragmatism encourages the researcher to develop methods and models that can be used in real-world applications. This involves using sempirical data and field observations to create accurate and reliable susceptibility maps that can aid in hazard assessment and decision-making processes. As Sanders (1845) emphasized, the meaning of an idea lies in its practical consequences. Therefore, the susceptibility mapping carried out in this research project must provide meaningful insights and actionable information to stakeholders, local communities and policymakers for effective planning and risk reduction strategies. Dewey, (1898) again argued that knowledge is not separate from experience and action; it is intertwined with it. Therefore, this research project considered the experiences and perspectives of those affected by mass wasting, and the findings should lead to tangible improvements in policy-making, land-use planning, and disaster response measures. Pragmatism values the application of knowledge to improve the human condition and address practical issues. In the case of identifying the socio-economic and environmental impacts of mass wasting, the research went beyond theoretical understanding and assessed the real-world consequences on communities, economies, and ecosystems

3.5 Research design

The research design utilized in this study is based on the case study approach. This approach involves analysis of a specific event, phenomenon, or situation to gain a deeper understanding of the root causes, processes, and outcomes (David, 2014). When conducting studies on mass-wasting susceptibility, this method can be used to examine the various factors that contribute to the occurrence and severity of mass wasting processes in a particular area. This involves gathering data from multiple sources, such as geological, topographical, meteorological, and socio-economic data, to develop a comprehensive understanding of the factors that influence landslide susceptibility (Zhao et al., 2023).

3.6 Research Strategy

A mixed-method research strategy was adopted to undertake this study. Mixed methods research is a research strategy that combines both qualitative and quantitative data collection and analysis techniques to investigate a research problem (Lavrakas, 2013). In the context of mass wasting susceptibility study, the qualitative method uses semi-structured interviews to collect data on the socio-economic and environmental impacts of mass wasting leading to more comprehensive and effective solutions for managing landslide risk. The quantitative method dealt with the analysis of geospatial data from remotely sensed data to analyse causative factors and also to map mass wasting-prone zones.

3.7 Data Sources

The data for this study was collected from both primary and secondary sources to strengthen the rationality of the study and for better and more comprehensive analysis. Primary data was collected through interviews and questionnaires to obtain information on the causes, socio-economic and environmental impacts of mass wasting in the study area. Secondary data was also obtained from remotely sensed data such as Google Earth Explorer images and satellite images on some of the causative factors such as slope, elevation, soil, distance from road and LULC. The main source of the satellite images for the analysis of the causative factors is from the USGS website.

3.8 Social Survey

Semi-structured interviews and questionnaires were employed to solicit information from respondents over 30 years of age on the causes, socio-economic and environmental impacts of mass wasting. The reason for interviewing residents over 30 years of age is to enable them to talk more about historical mass wasting events that occurred in the past.

3. 9 Sampling Techniques

3.9.1. Target Population

The target population for this study comprises communities that are found in the high and medium susceptible zones in the district. These areas were purposively chosen because conditions in these areas can trigger mass-wasting activities and there is also historical mass wasting records in the chosen communities. Communities of interest in the district include Aburi, Kitase, Pakro, Berekuso, Pokrom and Adukrom (Table 2).

3.9.2 Sample size determination and sampling technique

For this study a semi-structured interview was conducted for sixty (60) individuals using purposive sampling from the six different local communities. The respondents were selected based on their willingness to take part in the interview. The interviewees included 24 property owners (4 from each community) who are landlords, offering insights into how phenomena like mass wasting impact their properties and how construction practices contribute to the issue of mass wasting in the communities. In addition, 24 farmers (4 from each community) as well as 5 drivers were also interviewed. The drivers who use the Aburi to Ayi-Mensah Road were selected due to the frequent occurrence of mass wasting events along that stretch of road. Some key personalities such as the Akwapim South District Chief Executive, a representative from the National Disaster Management Organisation (NADMO) and the Akwapim South district planning officer were also interviewed.

Table 1: Stakeholders and number of interviews conducted.

Key informant	**Number interviewed**
District chief executive	1
District planning officer	1
NADMO officer	1
Landlords	24
Farmers	24
Drivers	9
Total	**60**

The second sampling technique involves stratified sampling whereby the six communities (Aburi, Kitase, Pokro, Pokrom, Berekuso and Adukrom) form the stratum from which the respondents were selected to answer the questionnaire. To ensure a fair and accurate representation of all six communities, the 2010 Population and Housing Census (PHC) figures for adults who were above twenty (30) years of age was used to calculate the sample size using Krejcie & Morgan formula..

Table 2: Adult population sizes of the selected communities based 2010 PHC

Community	**Adult Population**
Aburi	3365
Kitase	860
Berekuso	655
Adukrom	1903
Pokrom	915
Pakro	1091
Total	**8789**

The sample size (n), $n = \frac{N.Z^2.p.(1-p)}{e^{2}\cdot(N-1)+Z^2.p.(1-p)}$

Where: N= population size (8789)

Z = Z- score (1.96 for 95% confidence level)

P =Estimated proportion of of the population (0.5)

e = margin of error (precision level: 0.05)

at 5% precision level, the sample size is calculated as:

$$n = \frac{8789.(1.96)^2.0.5.(1-0.5)}{(0.05)^2(8789-1)+(1.96)^2.0.5.(1-0.5)}$$

$$n = \frac{8435.35}{22.93} = 368.11$$

$$n = 368.11$$

Rounding up to the nearest whole number, the sample size for the study is 368 people.

Furthermore, to determine the sample size from each community based on their population sizes, a proportional allocation method was applied. The formula for proportional allocation is

$$\frac{\text{Population of community}}{\text{Total population}} \text{ x sample size}$$

Based on this ormula, the sample size of each community is calculated as illustrated in Table 3.

Table 3: Number of adult respondents from the selected communities

Community	Adult population of towns	Sample size
Aburi	3365	141
Kitase	860	36
Berekuso	655	27
Adukrom	1903	80
Pokrom	915	38
Pakro	1091	46

A simple random technique was employed to select respondents in each community based on their willingness to participate in the survey. Once participants agreed to take part, data was collected survey a survey instrument (questionnaire) and interviews. However, out of the 368 questionnaires administered, only 300 were recovered for processing because some of the respondents failed to answer the questionnaire.

3.10 Data Analysis

After data collection, the responses from the questionnaire were coded and entered into the Statistical Package for Social Sciences (SPSS) version 23 software using syntax editor tool and the results were represented in tables and graphs for easy analysis. Also, to test whether the gender and educational background of the residents have a relationship with the knowledge of residents on the occurrence of mass wasting in the respective communities, a chi-square test of independence was employed to test the people's awareness of the occurrence of mass wasting in the selected communities. Appropriate descriptive and inferential statistics were used to analyse the causes, socio-economic factors, and environmental impacts of mass wasting in the Akwapim South district. Also, interview results were transcribed and interpreted by looking for trends and connections between different responses and were used to support other findings.

3.11 Susceptibility mapping

The causative factors considered for the susceptibility analysis included land use and land cover, elevation, geology, soil, slope and distance from road. The thematic layers for the causative factors were prepared from different data sources such as satellite and Google Earth images. Thematic layers were combined by assigning factor weights derived through the AHP method to produce the mass wasting susceptibility map in a GIS environment

3.12 Identification and mapping of mass wasting types in the study area

This study focuses on the verification and mapping of mass wasting types in the Akwapim South District, using two approaches that included fieldwork and remote sensing techniques. The first phase involved a comprehensive field survey of the study area, aimed at identifying types and locations of mass wasting activities occurring on the ground. Differentiating the various types of mass wasting activities was central to characterizing the nature of material displacement. To achieve this, a series of field visits were conducted to ascertain the movement types and the materials involved. Each mass wasting event's GPS coordinates were recorded and subsequently mapped using Geographic Information Systems (GIS). The second phase of the study made use of high-resolution Google Earth images to identify mass wasting events that were found in inaccessible areas of the study area due to the rugged nature of the terrain. The boundaries of the mass wasting events were then digitized rasterized and mapped.

3.13 Identification of mass wasting causative factors

The causative factors of mass wasting in the study area were also investigated through a two-phase approach. The initial phase encompassed on-site observations during field surveys. This approach provided an in-depth understanding of the physical conditions and features of the study area. By examining the terrain, geological formations, vegetation cover and other relevant elements, visible indicators and potential triggers of mass wasting phenomena were identified. The second phase of the study employed a dual methodology, comprising questionnaires and semi-structured interviews. The questionnaire was carefully designed to address specific aspects concerning the causes of mass wasting, ensuring comprehensive coverage of potential factors. To maintain consistency and facilitate a structured approach to data collection, a predetermined checklist was employed. This checklist served as a guide for participants, offering a comprehensive list of potential causative factors for mass wasting. By adhering to this framework, the study ensured that all relevant aspects were considered and addressed, enhancing the robustness and reliability of the collected data.

3.14 Processing of mass wasting causative factors

The factors that were used to produce the mass wasting susceptibility map of the study area include elevation, slope, soil, land use and land cover, geology and distance from the road. These six causative factors constitute the primary criteria for mass wasting susceptibility mapping in the Akwapim South District and were subdivided into appropriate subgroups for analysis. Each class within these parameters was analysed to ascertain its connection to mass wasting susceptibility in the study area. Consequently, a weightage value is assigned to each class, reflecting its susceptibility to mass wasting. Lower weightage indicates a minor influence on mass wasting occurrence, while higher weightage signifies a more significant impact. The allocation of weightage values for different categories within a criterion is determined based on their presumed or anticipated role in triggering landslides as observed from the field and also classifications made by other researchers in the field of mass wasting susceptibility studies. Finally, each of the thematic maps was overlayed onto the mass-wasting inventory map one after the other to assess the contribution of each of the factors to mass-wasting events on the ground. Based on the overlay analysis, each of the causative factors was given weight in a pairwise comparison matrix where they were integrated and evaluated using the AHP method within a GIS environment. The following paragraphs present a description and analysis of factors that were used to evaluate the mass wasting susceptibility in the study area.

3.15 Land- use and land -cover

Land-use and land-cover (LULC) map was prepared by utilizing a 2021 Landsat 8 OLI image with 30×30m resolution. The image was calibrated into reflectance measure and visually analyzed for cloud cover. The 2021 Landsat 8 image is the best because this study is interested in analysing recent changes in LULC in assessing the current susceptibility of mass wasting. Further, supervised classification was performed using ENVI 5.3 software which classified the image. The LULC classes that were identified include forest, woodland, scrub and grassland, farmland and barren land /settlement (Fig: 6). Barren land/settlement is considered to be the most susceptible class to mass wasting occurrence therefore it is considered to have very high importance with a rank equal to 5. Further, farmland and scrub/grassland were also given a rank of 4 and 3 respectively. Woodland and forest contribute very little to mass wasting and were given ranks of 2 and 1 respectively (Table 2). The LULC map generated was then overlaid onto the mass wasting location map to ascertain the connection between LULC and occurrence of mass wasting in the district.

3.16 Elevation

Elevation was prepared from the Digital Elevation Model (DEM) using LIDAR data with 90m resolution at a scale of 1: 4000 acquired USGS website. The highest point in the study area is beyond 400m above sea level therefore elevation data was sub-divided into five classes ranging from 0- 100m, 100- 200m, 200m -300m, 300-400m and 400m and above (Figthe: 10). Elevation greater than 400m was given the rank of 5 because it is very susceptible to mass wasting. Also, elevation between 300-400m was given a rank of 4, while 1 was given as the lowest rank for elevation below 100m (Table 2). The generated map was also overlayed onto the mass-wasting location map to find the relationship between mapped mass-wasting events and the elevation in the area.

3.17 Slope

Slope data was processed from the Digital Elevation Model. The slope in the study area was reclassified into five classes (0-15°, 15- 30°, 30- 45°, 45- 60° and above 60°) as illustrated in Fig. 11. The slope angle was ranked in order of importance by the use of (1 to 5) respectively (Table 2).

3.18 Distance from Road.

The road data was derived from Google Earth images by digitising and rasterizing major road in the study area by the use of Euclidean distance tool and also to find the straight distances and the closeness of prone zones along the roads (Fig: 7). This Euclidean distance was further reclassified into five distances (0-50m, 100-200mm, 200-300m,300-400m and above 400m) and was ranked in order of importance by the use of (1 to 5) respectively (Table 2).

3.19 Geology

To develop the thematic map for geology, geology data of the study area was acquired from the Ghana Geological Service to prepare the geology map of the study area. The various rock formations were then used to map the study area based on their level of susceptibility to mass wasting (Fig:8). From the map, Granitoid gneiss, Quartzite, Mica, Amphibolite and Sandstones were identified as the main geological units in the district. Granitoid gneiss, Quartzite and Mica were given the rank of 1,2 and 3 respectively due to their resistance to weathering. However, Amphibolite and Sandstone were ranked 4 and 5 respectively due to their weak nature.

3.20 Soil

Soil data was obtained from hyperspectral soil data downloaded from the USGS site. The data was processed and analysed to extract the soil depth. Using appropriate models, the soil depth was estimated to range from less than 3m to about 9m. This was reclassified into 5 classes (< 3m, 3-5m, 5-7m, 7-9m, and above 9m). A soil depth of less than 3m was considered to be highly susceptible to mass wasting and therefore given the rank of 5 because a soil depth of less than 3 meters limits the ability of the soil to resist the forces that cause mass wasting, making it highly susceptible to slope failure and erosion (Mekonnen et al., 2022). However, soil depth of 9m and above was ranked 1, which is a very low susceptible area.

Table 4: Ranking of factor sub-classes.

Causative factor	Factor class	Rank	Importance concerning potential mass wasting
Geology	Granitoid gneiss	1	Very low
	Quartzite	2	Low
	Mica	3	Medium
	Amphibolite	4	high
	Sandstone	5	Very high
Land use & and land cover	Forest	1	Very low
	Woodland	2	Low

	Scrub/ grassland	3	Medium
	Farmland	4	High
	Barren land/ settlement	5	Very high
Slope	0-15° (fair slope)	1	Very low
	15° - 30° moderate slope	2	Low
	30° - 45°	3	Medium
	45° - 60°	4	High
	Above 60°	5	Very high
Soil	9m- 11m	1	Very low
	7m-9m	2	Low
	5m- 7m	3	Medium
	3m – 5m	4	High
	< 3m	5	Very high
Road distance	Above 400 meters	1	Very low
	200-300 meters	2	Low
	100- 200 meters	3	Medium
	50 – 100 meters	4	High
	0-50 meters	5	Very high
Elevation	0 m-100 meters	1	Very low
	100m-200 meters	2	Low
	200m-300 meters	3	Medium
	300m- 400 meters	4	High
	400m-500 meters	5	Very high

3. 21 Mass wasting susceptibility mapping

The GIS-based AHP technique was applied to evaluate the mass wasting susceptibility zonation in the study area. To derive the susceptibility map using the AHP, the causative factors were arranged in a hierarchic order according to their importance in causing mass wasting. Numerical values were assigned according to their subjective relevance using a pair-wise comparison matrix with scores to determine the relative import studyance of each factor according to Saaty's (2000) scale of preference between two parameters in AHP (Table 5).

Table 5: Nine-point importance scale

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	Equal	Moderately	Strongly	Very Strongly	Extremely
Less important						Very important		
The rest of the values								
Intermediaries			(2468)			Preference made halfway		

Source: Saaty (2000)

Also, to calculate the Consistency Ratio (CR) for the pairwise matrix the following formula was used: CR = (CI/RI), where RI is the average of the resulting consistency index and CI is the consistency index. The Consistency Index which is a measure used to evaluate the consistency of the judgments provided by a decision-maker when comparing different options or criteria was expressed as $CI = (\lambda max - n) / (n - 1)$, where λmax is the largest or principal eigenvalue of the matrix and n is the order of the matrix. To calculate the weights of each factor, the geometric mean value of each factor was divided by the sum of all geometric mean values of the matrix.

The final mass wasting susceptibility map was constructed using the AHP method in a GIS environment by applying the following equation: $LSM_{AHP} = ((\text{slope degree} \times W_{AHP}) + (\text{elevation} \times W_{AHP}) + (\text{road distance} \times W_{AHP}) + (\text{lulc} \times W_{AHP}) + (\text{geology} \times W_{AHP}) + (\text{soil} \times W_{AHP}))$ where W_{AHP} is the weightage for each landslide conditioning factor. The pixel values obtained were then classified into 3 classes (low, medium and high) based on natural break to determine the class intervals in the landslide susceptibility map using GIS software.

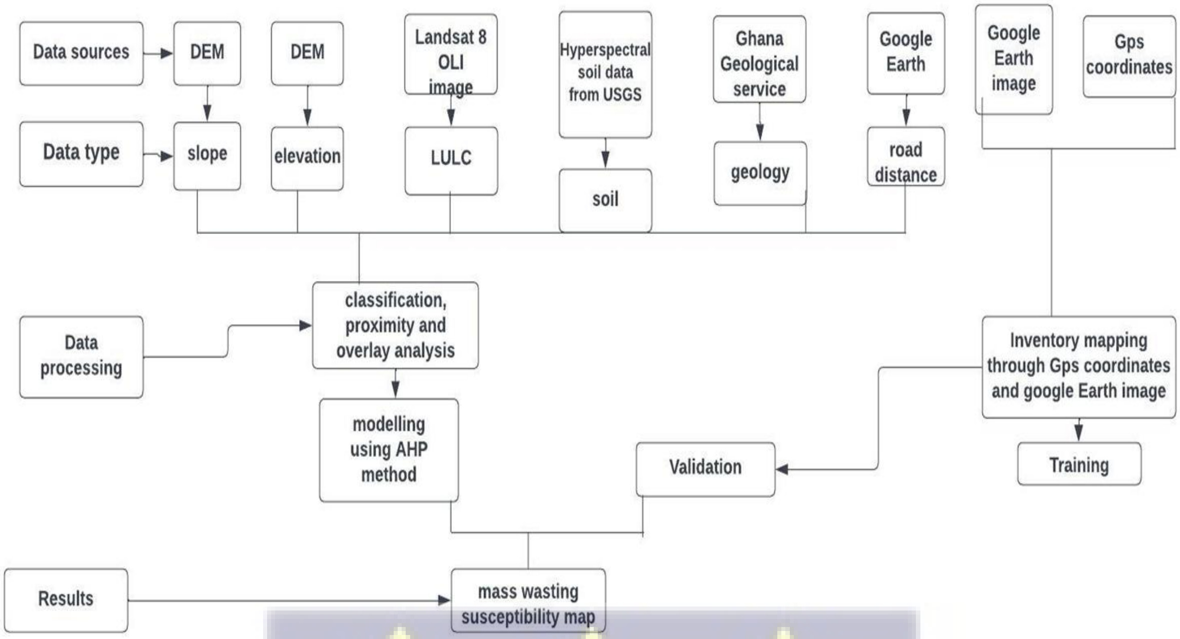

Figure 3:Schematic diagram of workflow

Source: Authors construct

3. 22 Summary

This chapter's initial section was devoted to a thorough review of the relevant literature, which will aid in a deeper understanding of the study as a whole. The subsequent section covered the data collection techniques used under the following headings: the research design and strategy, data sources, sampling technique, sample size, analysis of quantitative and qualitative data and finally susceptibility mapping process.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The first part of this chapter is a report on the analysis of the types and locations of mass wasting events in the Akwapim South District, thematic maps for the various causative factors and the mass wasting susceptibility analysis of the district. It is followed by the presentation of the results of questionnaires administered to respondents. Results from interview of stakeholders were also presented.

4.2 Identification and mapping of mass wasting types in the study area

About 31 mass-wasting events were identified and mapped (Fig: 4). Various mass wasting types occur in different parts of the district. They include rockslides, rockfall, landslide scars, earth flow and soil creeps. Figure 4 shows that most of the mass wasting events take place in the Aburi enclave, where the terrain is high, coupled with weak geology. Adukrom areas, which are also highlands, also experience mass wasting events. However, there is less evidence of such activities in the northern and north-western parts of the district, where the topography is generally low. Figure 4 shows that the most common types of mass wasting activities occurring in the study area are rockfall, rockslide and debris slide. The rockslides and the rockfalls mostly occurred along the dual carriageway linking Aburi and Ayi-Mensah, this is portrayed in Plate 5. However, debris slide mostly occurs in areas where the hill or the slope is cut for construction activities. The mass wasting activities in the district mostly occur between 150m and 400m above sea level. The scars from landslides along the Peduase road are also conspicuous along the slope as illustrated in Plate

3. There are also signs of soil creeping in the form of tilting of trees, poles and road barricades along the Peduase road. As illustrated in Plate 2, most of the mass wasting events that result in debris slides, occurred as a result of cutting of slope for construction purposes in the study, especially in the Aburi enclave.

Table 6: Mass wasting types, their frequencies and areas they predominate

Mass wasting type	**Frequency**	**Area predominate**
Rockfall	6	Along Aburi and Ayi-Mensah double carriage road
Rockslide	16	Very common in the Aburi enclave particularly along Aburi-Ayi-Mensah double carriage road.
Debris slide	5	It very common in the Aburi township and Peduse valley where slopes are excavated for construction activities
Landslide scars	5	Along the Peduase road
Soil creep	4	Bareland areas in the Aburi, Adukrom and the Peduase valley where the land is exposed as result of construction activities

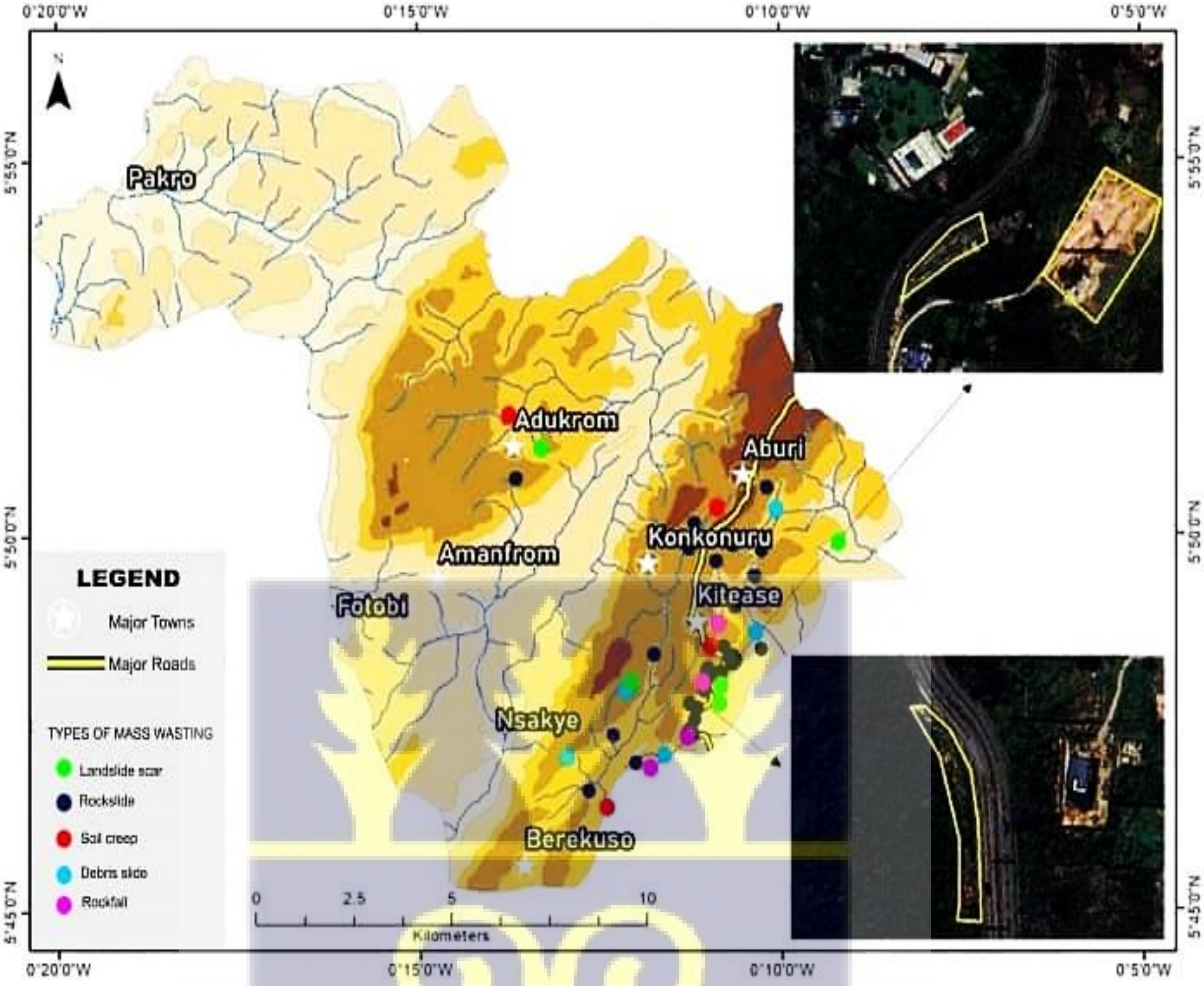

Figure 4: Mass wasting types in the Akwapim South District
Source: Field survey

Plate 1: Rockslides along the Aburi to Ayi- Mensah dual carriage road
Source: Field survey

Plate 2: Debris slide as a result of slope excavation in Aburi

Source: Field survey

Plate 3: Scars from landslides along the Peduase road

Source: Field photo

4.3 Thematic maps for the causative factors

Below is the analysis of the various thematic factor layers used in the mass wasting susceptibility mapping:

4.3.1 Land Use and Land Cover

The primary land use and land cover (LULC) types identified in the study area are forest, woodland, scrub and grasslands, farmlands, and barehand/settlement (Fig: 7). As represented in Table 6, forest and woodland covered vast areas in the study area, covering about 100.6sq. km. Scrub and grassland also covers extensive portions of the study area, occupying 99.06 sq.km. There are also farmlards that covered 16.58sq.km of the land area of the district. Settlements and bareland areas in the district are limited and they covered only 12.99 sq. km.

Table 7: LULC classes and land area covered

LULC classes	Land area covered	Percentage of land covered
Forest	68.58 sq.km	30.6
Woodland	26.90sq.km	12
Scrub and Grassland	99.06 sq.km	44.2
Farmlands	16.58 sq.km	7.4
Settlements/ barelands	12.99sq.km	5 .8

Figure 7 further shows that forest cover in the study area is primarily found in high-elevation areas and low-lying areas. Interestingly, most of the pre-existing mass wasting events are located away from forest cover. Settlements and bare land areas are also scattered throughout the district, particularly in the western and southeastern enclaves. There are also pockets of farmland scattered throughout the district, with the most significant concentration being around the Pakro enclave. The location of mass wasting events on the map indicates that some of them occurred near settlements and bare land areas within the settlements where human activities are common as shown in the field photos.

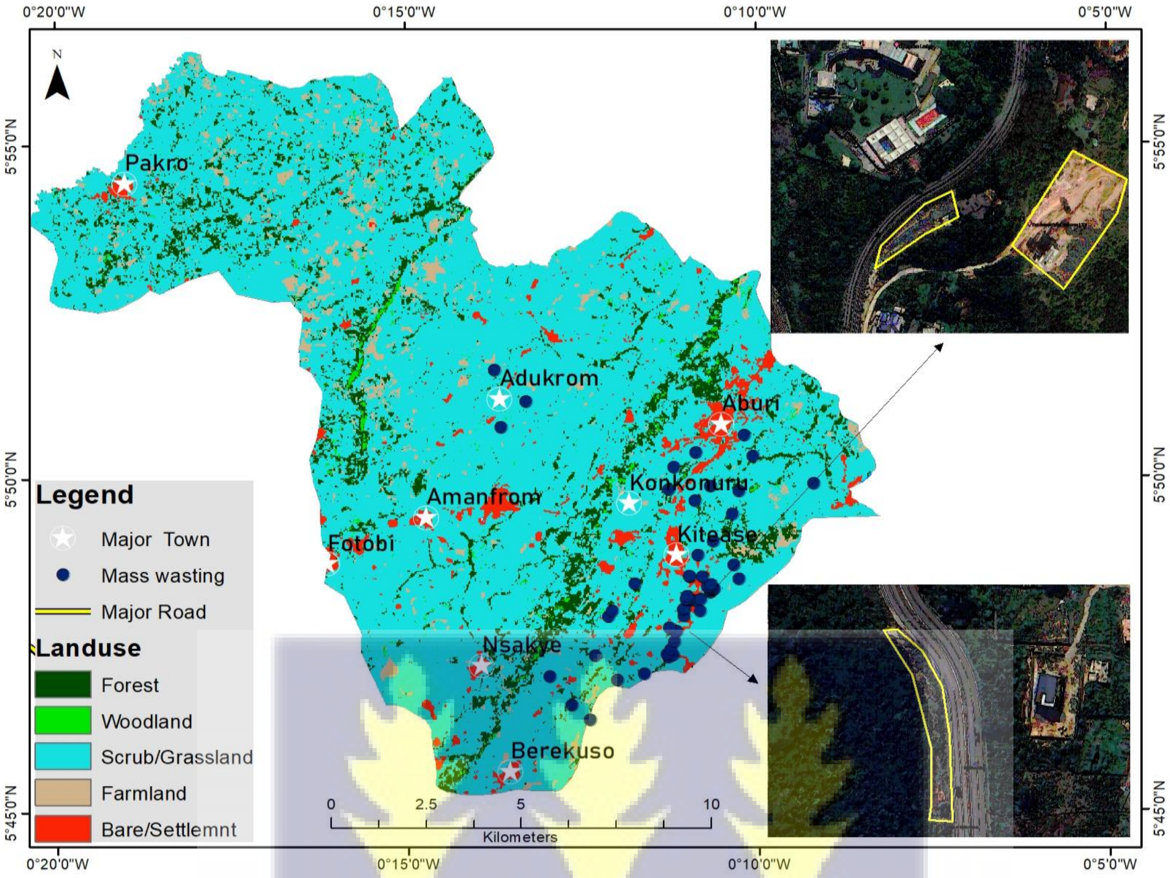

Figure 5: Land use & Landcover map of Akwapim South District.

4.3.2 Road Distance

Analysis from Figure 7 shows the distribution of road networks in the study area. From the map, buffer zones were created along the major roads from 50m to 400m. The closer an area is to the roads, the higher the possibility of mass wasting occurrence. As presented in Figure4, mass wasting activities are spotted along the Aburi- Ayi- Mensah dual carriage road in the Aburi enclave. The presence of mass wasting activities along that major road supports the importance of road distance as an important factor in modelling mass wasting susceptibility of the study area.

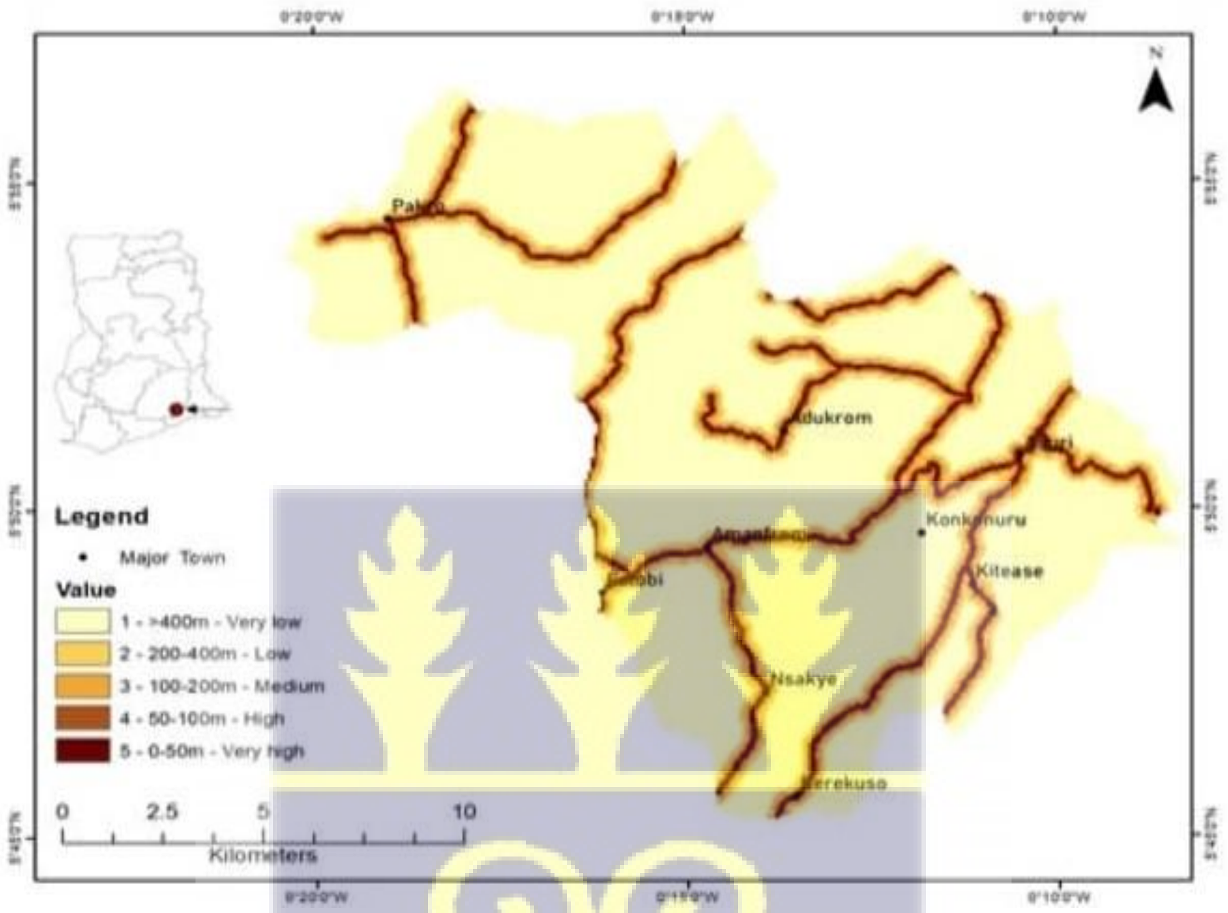

Figure 6: Proximity to road map

4. 3.3 Geology

The geological formation of the study area as illustrated in Figure 8, shows the different geological makeup of the district. These include granitoid gneiss, mica, quartzite, amphibolite and sandstone. As illustrated in the geology map in Fig. 8, most of the pre-existing mass wasting events are mainly found in areas covered by weak sandstones and the amphibolite and they are mainly found around the Aburi and the Adukrom areas. From Pakro, extending to the Fotobi recorded some minimal movements of debris on the ground partly due to the solid geological formation that is made up of granitoid gneiss and quartzite.

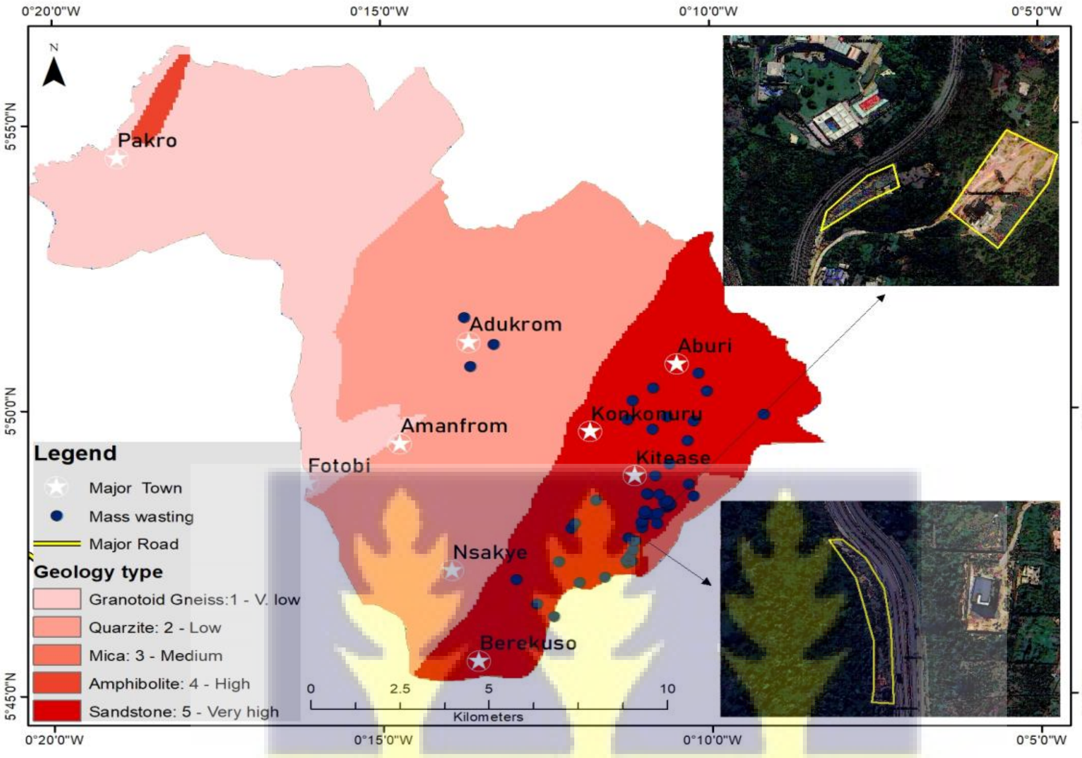

Figure 7:Geology map of Akwapim south district.

4.3.4 Soil Layer

Figure 8, shows the various level of soil depth in the study area. Adukrom areas fall into areas with shallow depth, thus soil depth of less than 3m. Aburi areas have deep soil depth that ranges from 7m to over 9m. It can seen that soil depth plays a small role in the occurrence of mass wasting in the Aburi enclave as mass wasting activities are spotted in areas with deep soil. This suggests that other soil properties such as soil type etc. contribute significantly in the formation of mass wasting activities in the area.

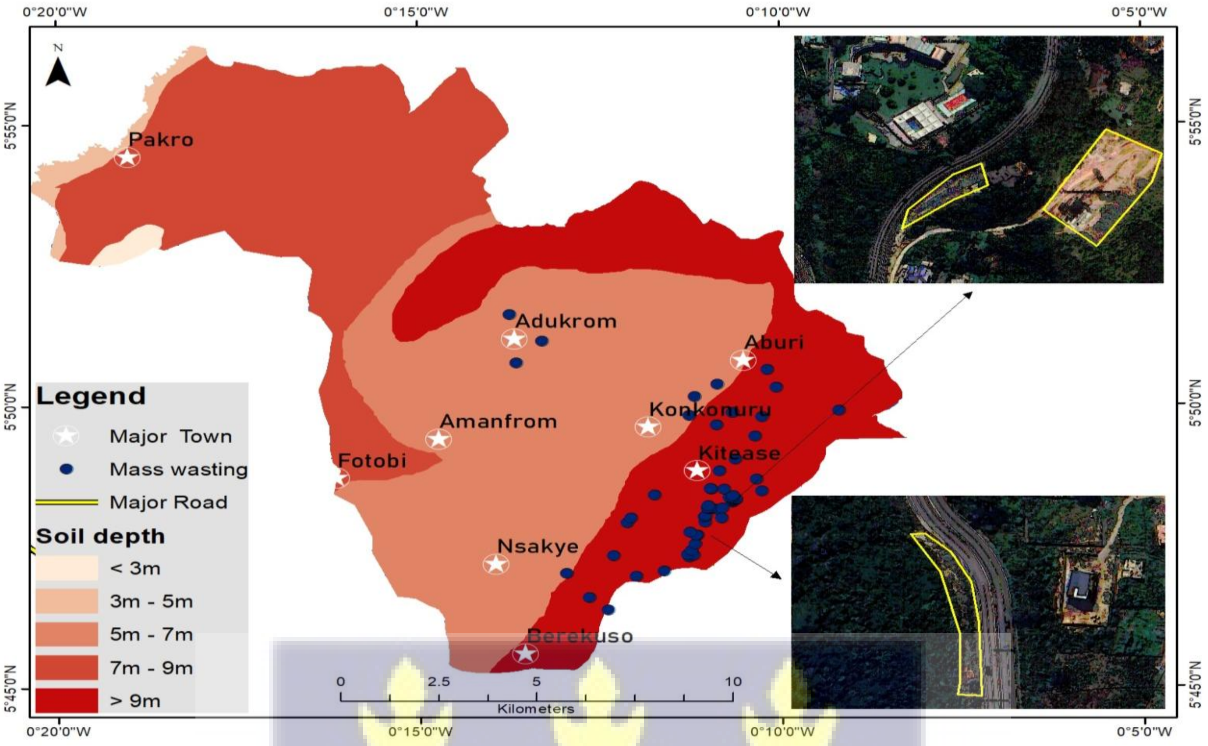

Figure 8:Soil depth map of Akwapim south

4.3.5 Elevation Layer

The study area has diverse range of topography and landscapes, each with a unique impact on its elevation. In Akwapim South, elevation varies widely, from low-lying coastal plains that sit at a height of 200 meters and below but increases sharply exceeding 400 meters above sea level as one moves inland and towards the mountains. As illustrated in Figure 9, high-elevation areas account for approximately 90% of all mapped mass-wasting events in the study area. Regions such as the Aburi enclave and Adukrom areas are situated in high-elevation areas, ranging from 300 meters and above. Conversely, low-lying areas are predominantly situated in the northern section of the district, lying below the 200-meter mark. Upon mapping pre-existing mass wasting events against the elevation map, it became evident that such events occur mostly within an elevation range of 300-400 meters.

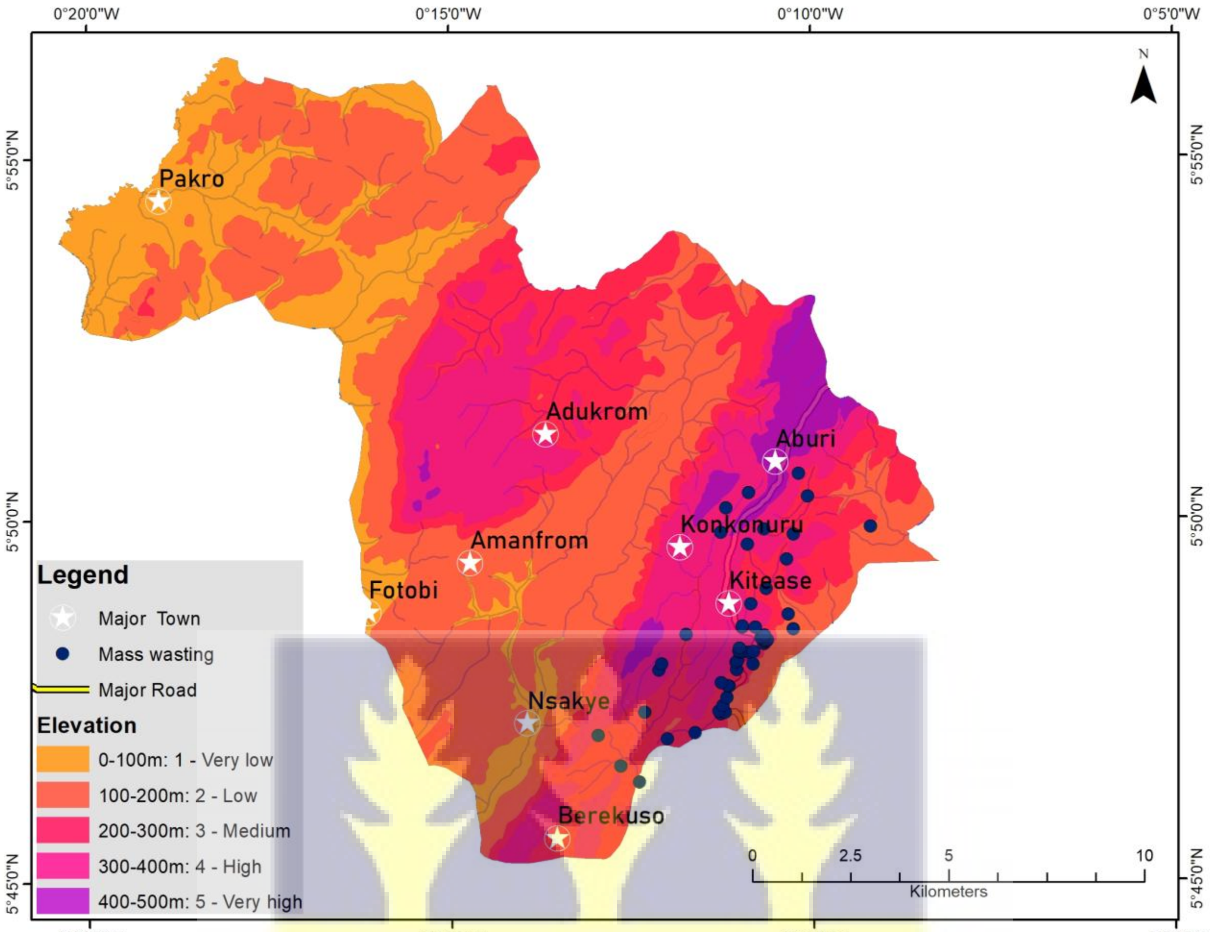

Figure 9:Elevation map of Akwapim South District

4.3.6 Slope Layer

The terrain of the study area consists of steep slopes which increases the vulnerability to landslides. Analysis of the slope in the study area indicates that the steepness of the slope increases towards the Aburi mountains, with slope angles extending from 30° to over 60° in hilly areas. However, in low-lying areas, elevation ranges from 15° to about 30°. As displayed in Figure 11, the majority of the mapped mass wasting events in the district, especially in the Aburi enclave are found along slope angles between 30° and 60°.

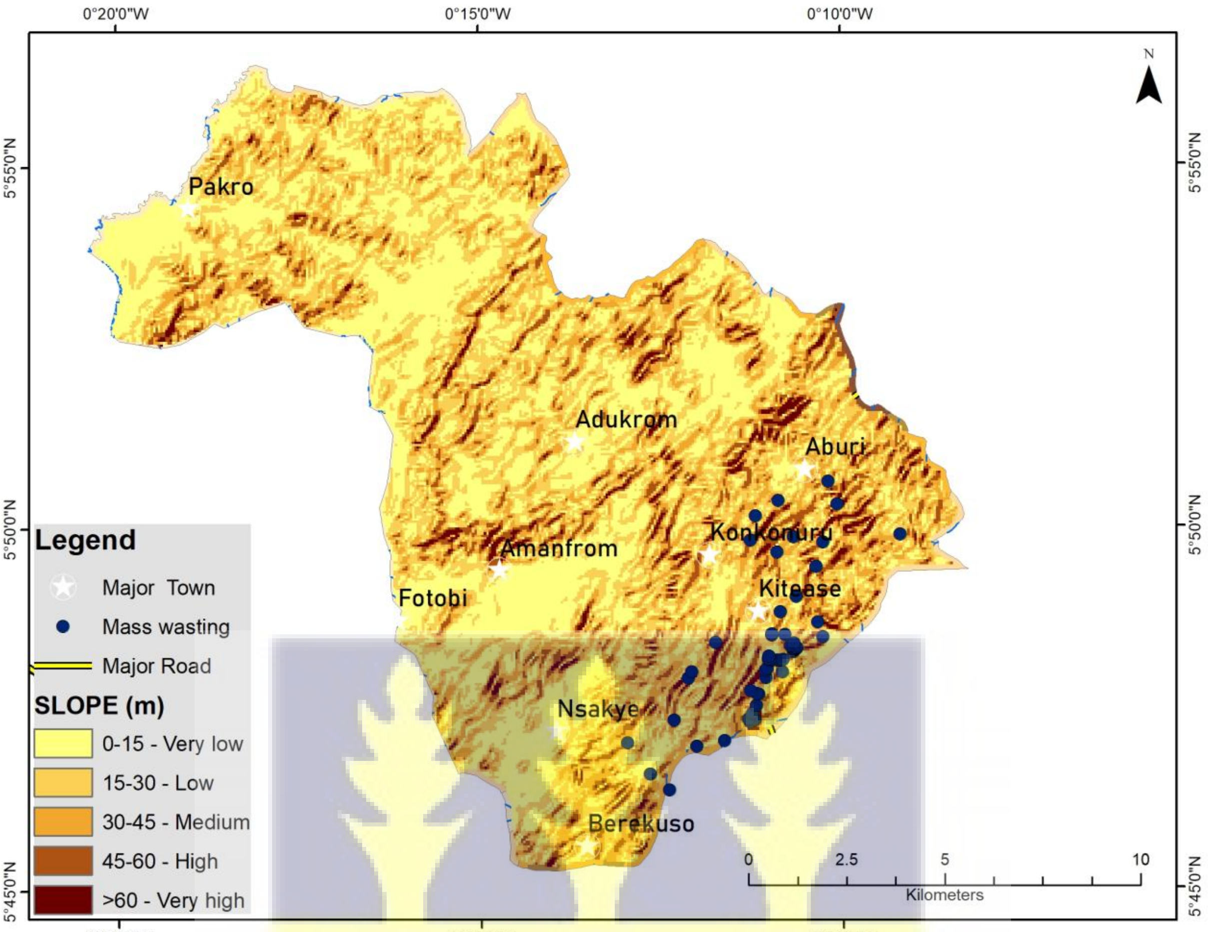

Figure 10: Slope map of Akwapim South District

4.4 Mass masting susceptibility mapping

The mass wasting susceptibility map as illustrated in Fig: 11, is based on the pairwise matrix constructed for the causative factors in Table 8. The Consistency Ratio (CR) of the matrix is 6.4% or 0.064. In this case, the consistency ratio is lower than the threshold of 10% or 0.1, which implies that the judgments in the pairwise matrix are highly consistent and reliable. This is generally considered very good, and decision-makers can have confidence in the relative importance values assigned to the elements in the matrix.

Table 8:Pair-wise comparison of factor layers and weight

Factor	Elevation	Geology	LULC	Slope	Road distance	Soil depth	weight	Consistency Ratio (CR)
Elevation	1						36.0% or 0.36	6.4% or 0.064
Geology	0.33	1					25.0% or 0.25	
LULC	1.00	0.5	1				20.9% or 0.209	
Slope	0.25	0.33	0.50	1			10.4% or 0.104	
Road distance	0.14	0.14	0.14	0.50	1		4.3% or 0.043	
Soil depth	0.12	0.17	0.25	0.17	0.50	1	3.4% or 0.034	

Based on the results of the susceptibility map, distinct zones of vulnerability have been identified throughout the study area. As indicated in Table 9, the area with the greatest susceptibility covers roughly 67.24 square kilometres of land within the district, which sp ans a total of 224.13 square kilometres. This high susceptibility zone represents about 30% of the entire land area of the district. The medium susceptible zone covers 56.03 km^2, which represents 25% of the land area of the study area. Lastly, the low susceptible zone covers 100.85 km^2, accounting for 45% of the land area.

Table 9: Land area covered by the various mass wasting susceptible zone

Zone	**Land area covered**	**Per centage**
High	67.24 km^2	30%
Medium	56.03 km^2	25%
Low	100.85 km^2	45%

Furthermore, as illustrated in Figure 12, areas that lie in the highly susceptible zones include the whole of the Aburi enclave, except for a few w locations. There are also pockets of highly susceptible zones in the Adukrom areas. All the susceptible areas are found along the Akwapim – Togo ranges with steep slopes and high elevation. Then high susceptible areas cover about 30% of the total land area of the study area. As indicated in the map, about 99% of all the pre-existing mass wasting events are found in the high susceptible areas. The medium susceptible areas, on the other hand, are scattered all over the district, especially in areas that have, scrub and grassland and farmlands. The medium areas mostly occupy areas where the rocks are not weathered and where the slopes are moderately gentle such as the valley areas around Adukrom. Medium susceptible areas are highly concentrated in Adukrom areas. The medium susceptible areas occupy about 25% of the land area of the district. It is worth noting that some of the pre-existing mass wasting events are found in the medium susceptible area, around Adukrom. However, the majority of the land area in the district, about 45%b falls within low susceptible zones. A large part of the northern section and south-western areas of the map, fall within the low susceptible zones. About 60% of the areas covered by the low susceptible zones are areas covered by granitoid and quartzite rock formations. Areas lying in the low susceptible areas are found below 300m above sea level and are mostly covered with woodlands, scrub and grassland.

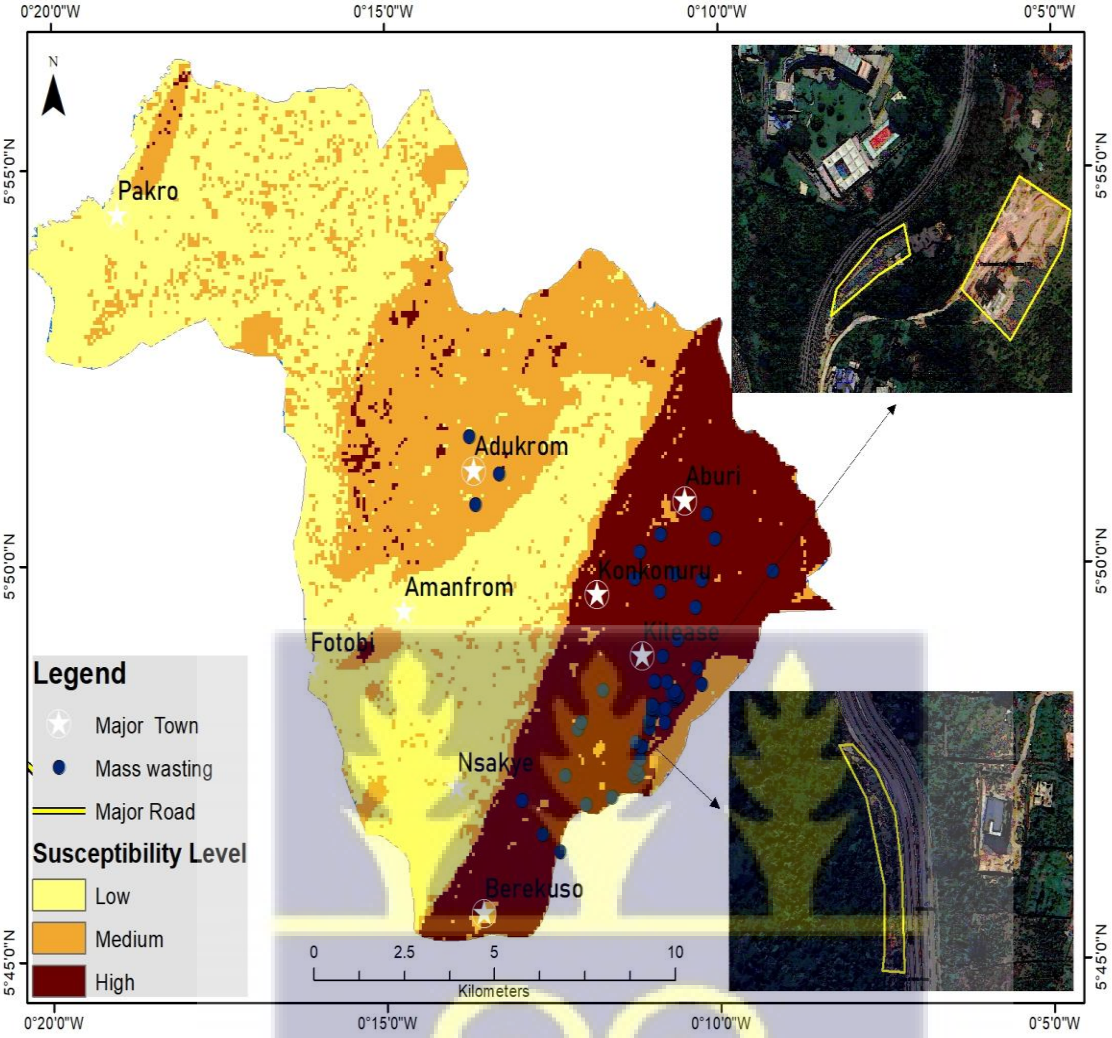

Figure 11:Mass wasting susceptibility map of Akwapim South District

To find the contribution of the various land use and land cover types to the occurrence of mass wasting in the district, the LULC m ap was overlayed onto the final susceptibility map as shown in Figure 12. It has been observed that in the high susceptible areas, there are bare lands and farmlands. Also, forest cover is located at the margin of the high susceptible zone which is located on the hills. The medium susceptible areas are also made up of isolated woodlands, and bare lands. Finally, the low susceptible areas are mainly covered by forest, scrub and grassland, woodlands and farmlands.

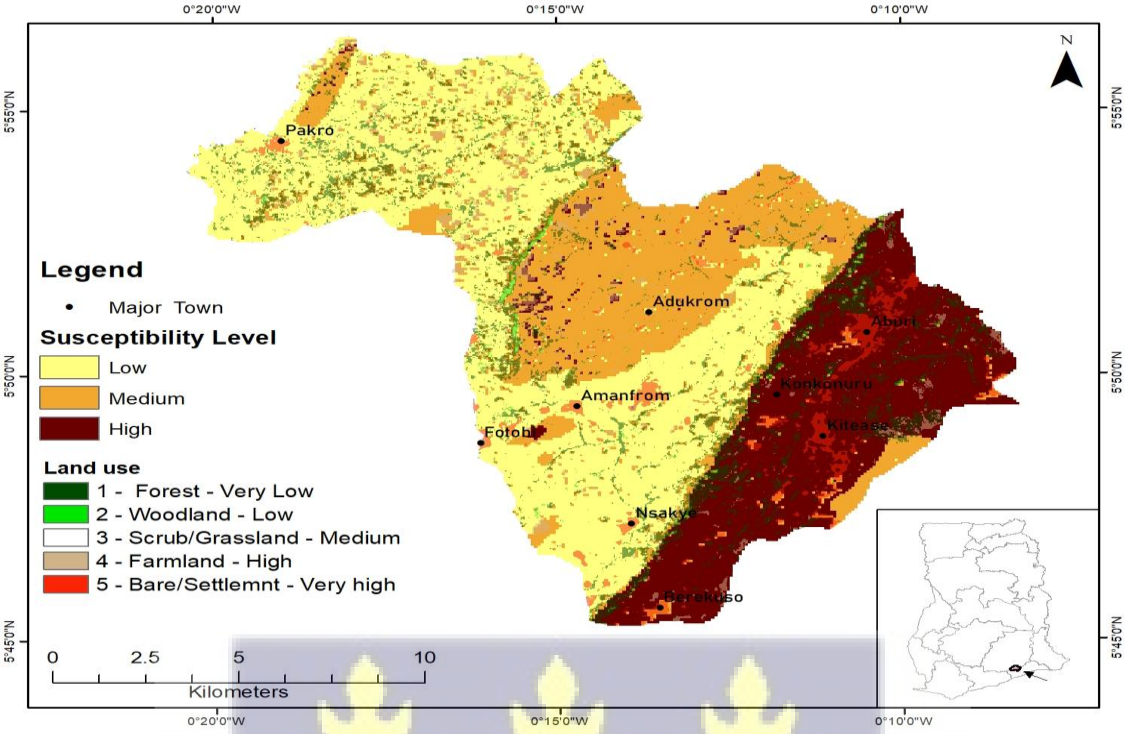

Figure 12:Overlay of LULC on the mass wasting susceptibility map

4.5 Causes, Socio-Economic and Environmental Impacts

4.6 Socio-Demographic Characteristics of Respondents

The socio-demographic characteristics of respondents solicited include age, sex, level of education and number of years they lived in the Study area. According to the data presented in Table 10, the results indicate a higher level of male participation in the survey compared to females. In terms of statistical representation, men accounted for 61% of the participants, while women made up of 39%. Regarding the distribution of age groups, the findings demonstrate that 13% of respondents fell within 30-40 age range, 27% were between 41 and 50, 50% were aged 51- 60 and 10% were above 61 years. Furthermore, the analysis of education levels revealed that among the respondents, 12% had no formal education background. Those with education backgrounds include basic education (17%), secondary school (50.3%) and tertiary education (20.7%). From

Table 10 below, 13.3% of the participants had lived in Aburi for 5-20 years. The result also shows that 26.6% of the respondents had resided in Aburi for 21-30 years, while 60% had a longer residency period of 31-45 years.

Table 10::Socio-demographic characteristics of respondents

Variable		Number of respondents	Percentage
Age	30- 40	39	13
	41- 50	81	27
	51-60	150	50
	Above 61	30	10
Sex	Male	183	61
	Female	117	39
Education	None	37	12
	Basic Education	50	17
	SHS/Middle Sch	151	50.3
	Tertiary	62	20.7
Duration	5-20	40	13.3
	21-30	80	26.6
	31-45	180	60

Source: Fieldwork, 2023

4.7 Causes of Mass Wasting

Figure 14 represents the perceived causes of mass wasting in the Akwapim South district. Poor construction practices are a major contributing factors, representing 30%. Urbanization is a significant contributing factor, representing 20% of the total causes. Geological factor such as weak and fractured rocks plays a significant role in mass wasting, contributing to 22% of the total causes in the study area. Rainfall also represents 12% of the total causes of mass wasting in the study area. According to the figure, 8% of the general causes of mass wasting come from deforestation. Steepness of slopes also influence the stability of the land but as a factor, it has a relatively minor impact, contributing to 5% of the total causes. The "others" category includes various additional factors contributing to mass wasting that are not explicitly mentioned in the given list and they account for 5% of the total causes. Human-induced factors (Deforestation, Poor construction, and Urbanization) contribute to 58% of the causes of mass wasting in the study area. While natural factors (Geological and Slope steepness) contribute to 27% of the causes. climate-related factor (Heavy rainfall) contributes to 12% of the total causes.

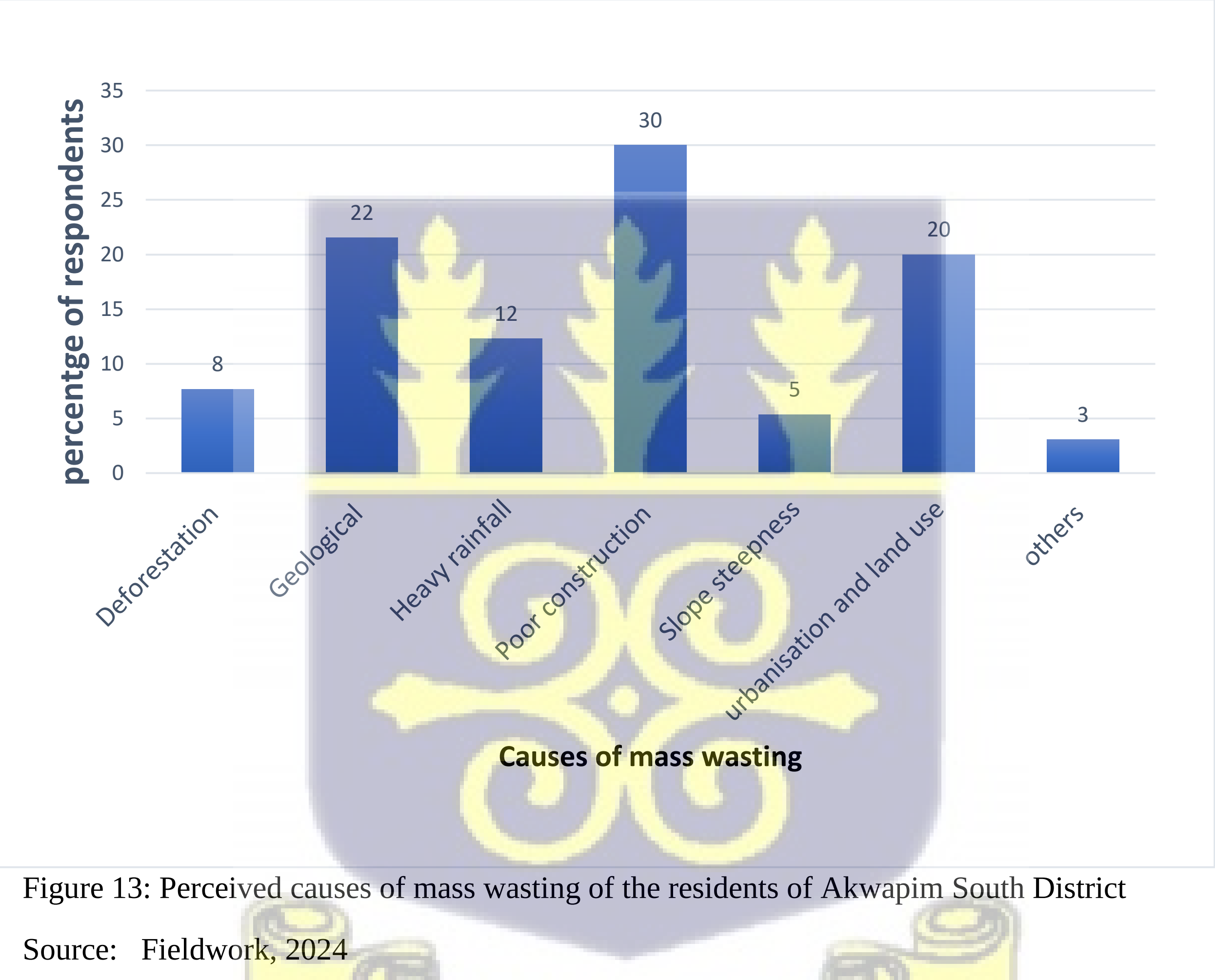

Figure 13: Perceived causes of mass wasting of the residents of Akwapim South District

Source: Fieldwork, 2024

Plate 4: Slope cutting for building in Aburi

Source: Field survey

4.8. Socio- Economic Impact

Damage to infrastructure is the most significant perceived impact of mass wasting in the study area accounting for 28.9% of the impacts. This includes damage to roads, buildings, bridges, or other essential facilities. Also, property damage is the second most impact perceived impact of mass wasting in the district, representing 25% of the impacts. Also, mass wasting events caused psychological trauma and it accounts for approximately 10.6% of the perceived impacts, emphasizing the mental health impact on individuals and communities. This claim was strongly supported by drivers who ply Aburi to Ayi- Mensah Road where mass wasting activities occur frequently. About 9% of respondents also complain about interruptions in essential services, such as water, electricity, or communication networks in the community. Around 8% of the perceived impacts were on displacement of people from their homes due to the mass wasting event and it indicates the extent to which people's lives were disrupted. Economic losses such as reduced agriculture productivity, high cost of repairs incurred on damaged properties, represents 5% of the impacts and it reflect the negative impact on businesses and livelihoods in the area. There were miscellaneous impacts reported by 3.3% of respondents, which were not categorized explicitly in the given information. The data collected and illustrated in Table 11, indicated that there were deaths that resulted activities of mass wating in the district. This represents 1.6 % of the perceived impact of mass wasting in the district.

Table 11:Socio-Economic impacts of mass wasting

Variables	Number of respondents	Percentage (%)
Loss of lives	4	1.6
Damage to infrastructure	87	28.9
Damage to property	75	25
Displacement of residents	50	16.6
Psychological trauma	32	10.6
Interruption of essential services	27	9
Economic losses	15	5
Others	10	3.3

Source: Fieldwork, 2024

4.9. Environmental Impacts

From Figure 14, soil erosion and loss of vegetation are the two most significant environmental impacts of mass wasting in the study area accounting for 24% and 42% respectively. Habitat destruction (12%) and burial of land/soil (13%) are relatively high individual impacts in the study area and this idicates how mass wasting has contributed to the loss of biophysical identity of the area. The degradation of water quality is a lesser biophysical consequence of mass wasting activities in the study area and it represents 4% of the impacts. From the mass wasting location map (Fig.5), it can be observed that some of the mass wasting incidents occurred in the drainage basin of some streams in the district, especially around the Aburi enclave. Other impacts mentioned by the respondents represent 5%.

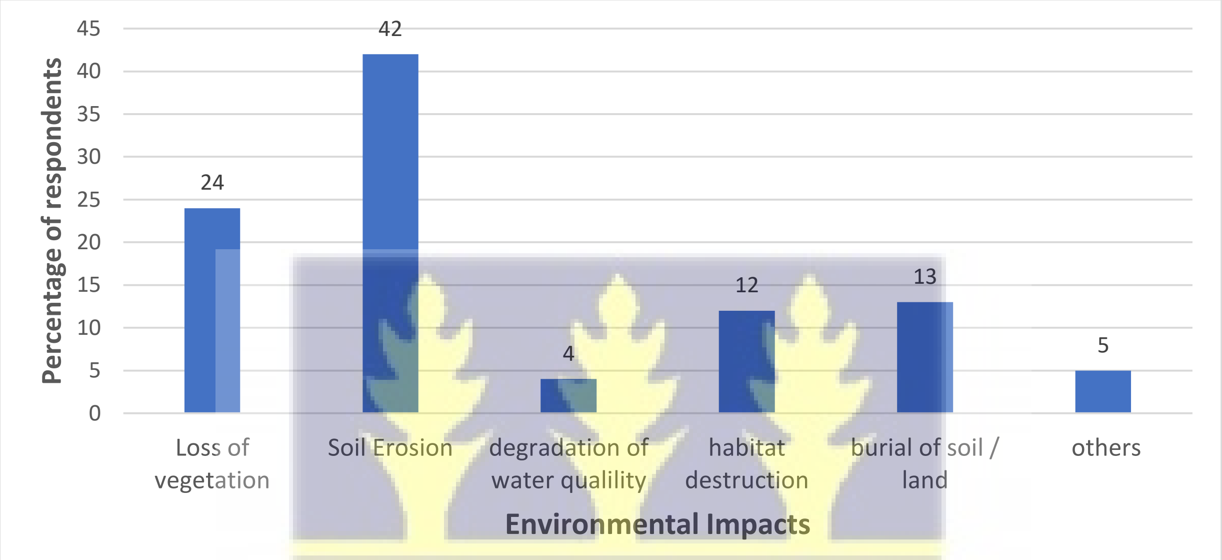

Figure 14:Environmental impacts of mass wasting

Source: Field work

4.10 Awareness of Mass Wasting occurrence

The respondents were asked to choose from a scale of 1-3, their level of awareness of mass wasting in the communities. The data suggests that a significant portion of the community (61.1%) has some level of awareness about mass wasting occurrence, indicating they are highly aware . However, it is important to note that there is still a considerable portion over 38.9% of the repondents that are somewhat aware or not aware at all about the occurrence of mass wasting in the district (Table 12)

Table 12:Awareness of the potential impact of mass wasting

Level of Awareness	**Number of respondents**	**Percentage (%)**
Highly Aware	217	72.4
Somewhat Aware	71	23.6
Not aware at all	12	4

Source: Fieldwork, 2024

Scale: 1= Not Aware at all, 2= Somewhat Aware, 3=Highly Aware

4.11 Hypothesis Testing

The chi- square results as illustrated in Table 13 and Table 14 shows that the p-values are greater than 0.05, suggesting that there is not enough evidence to reject the null hypothesis of no association between the variables. The results showed that educational background and gender have no association with the knowledge of mass wasting activities in the district.

Table 13:Relationship between sex and awareness of mass wasting.

		Awareness level			
		Highly Aware	Somewhat Aware	Not aware at all	Total
Sex	Male	85.3	68.6	21.2	175.2.0
	Female	62.0	49.9	13.2	125.1
Total		147.0	118.5	34.4	300

χ^2=2.004; df= 1; p=0.367

Table 14: Relationship between Education and Awareness

		Aware			
		Highly Aware	Somewhat Aware	Not aware at all	Total
Education	None	16.8	21.9	12.9	51.6
	Basic Education	31.7	26.9	13.7	77.3
	SHS/Middle school	35.2	29.8	15.1	84.1
	Tertiary	43.6	36.4	17.0	87
Total		127.3	115.0	58.7	300

χ^2=8.534; df= 6; p=0.202

4.12 Discussion of Result

The Akwapim South District, situated in the Eastern Region of Ghana, is characterized by diverse topography, which influences the occurrence of mass wasting. Aburi enclave, one of the prominent areas in the district, has been particularly susceptible to mass wasting, posing significant threats to the community, infrastructure and the environment.

The results of this study revealed that mass wasting processes in the Akwapim South District, particularly in the Aburi enclave, exhibit various types of movements and failure characteristics. Rockslides, rockfalls and debris slide are the predominant and more severe types of mass-wasting activities occurring in the district as emphasized by Kusimi (2020) in an interview with Ghana Web on February 12, 2020. The main highway connecting Aburi to Ayi Mensah is particularly susceptible to rock falls, rock slides and landslide scars, caused by poor engineering work during the construction of the dual carriage road (Ghana Insttitution of Geoscientists, 2019). These events are observed on steep slopes with rock formations prone to fracture and displacement. Landslides and soil creep are also common occurrences along the Peduase range and the Adukrom areas. Along the Peduase road, there are visible scars from landslides and signs of soil creep, which can be observed through the tilting of trees, poles, and road barricades. The rapid movement of rocks and other debris led to severe impacts on both infrastructure and land. These slope failures in the study area especially in the Aburi enclave are typically induced by poor construction, weathering, or seismic activity, as highlighted by the Ghana Institution of Geoscientists (2019). Heavy rainfall and prolonged saturation of the slope act as triggers of debris slides, especially in areas with poor construction activities and inadequate vegetation cover as noted by (Miele et al., 2022; Montrasio et al., 2011). Understanding the diverse types and characteristics of mass wasting events in the Akwapim South District is crucial for evaluating the region's susceptibility to landslides. This knowledge plays a pivotal role in disaster preparedness efforts, land-use planning, and the implementation of appropriate mitigation measures to protect lives and property.

Also, the mass wasting susceptibility mapping that was conducted in the Akwapim South District shows that there are high, medium and low susceptible zones. After analysing Fig:11 and Table 9, it is clear that 30% (67.24 km2) of the study area is classified as high susceptibility zones, 25% (56.03 km2 as medium susceptibility zones and 45% (100.85km2) as low susceptibility zones. The southern parts of the study area, particularly around the hilly areas of the Aburi enclave, are of high susceptibility zones due to steep slopes and high elevations coupled with weak sandstone formations with visible fractures. These areas have sedimentary rocks, making them moderately susceptible to mass wasting events (Ghana Institution of Geoscientists, (2019). The steep slopes in these high susceptible zones increases the likelihood of mass wasting events. Almost 99% of the mapped mass wasting events have occurred in these high susceptible zones, emphasizing the need to pay attention to these areas. The medium susceptibility zones scattered throughout the study area, with more concentrations in the south-eastern part of the study area especially around Adukrom. These zones are found in areas with scrub and grassland, bare land, farmland cover and areas with isolated woodlands. The medium susceptible zones are generally underlain by less weathered rocks, which provide a degree of stability compared to the highly susceptible zones. The geological composition of the Adukrom areas is primarily comprised of amphibolite and mica rocks, which are somewhat weak. The medium susceptible zones are characterized by moderately gentle slopes. These topographic conditions reduce the likelihood of mass-wasting events, as gravitational forces are less pronounced. Although the incidence of mass wasting events in medium susceptible areas is lower compared to high susceptible zones, some previous mass wasting events have been recorded in the Adukrom area. This suggests that there are localized factors that also play a role in mass wasting susceptibility.

Furthermore, low susceptible zones cover a large portion of the district and are concentrated mainly in the north, north-western and south-western parts of the district. The low susceptible zones are mainly located in areas of low elevation and gentle slopes. It also consists mainly of granitoid and quartzite rock formations. These formations are more resistant to weathering and erosion, providing a stable foundation against mass wasting events (Korup et al., 2022). Granitoid gneiss is a metamorphic rock composed primarily of minerals such as quartz, feldspar and mica. It is generally resistant to weathering and erosion due to its hard and durable nature. Quartzite, on the other hand, is a metamorphic rock primarily made up of quartz grains, often derived from sandstone. It is highly resistant to weathering and erosion, making it one of the most durable rock types. Areas falling within the low susceptible zones are generally situated below 200 meters above sea level and are covered with woodlands, scrub, and grassland. These land cover characteristics contribute to reduced susceptibility to mass wasting, as vegetation stabilizes the slopes and reduces erosional forces (Westen et al., 2018).

Also, the results of this study have provided compelling insights on the causes of mass wasting in the district. The susceptibility analysis revealed that high elevation, weak geology and land use/land cover emerged as the most important factors that promote slope failure in the study area. This finding aligns with the observed mass wasting occurrences that are mainly found in elevated areas, particularly around the Aburi enclave where the rock strata exhibit weakness. The Ghana Institution of Geoscientists' report on unregulated human activities such as slope excavation, further highlights the critical need for regulatory measures and awareness campaigns. The study further revealed that elevation is a significant factor in the occurrence of mass wasting in the district. This finding emphasizes that variations in elevation play a crucial role in mass wasting susceptibility and this finding is supported by the absence of mass wasting events in low-lying areas, indicating the potential link between elevated enclaves, increased gravitational potential energy and heightened instability. The association of steep slopes or cliffs with higher elevations further amplifies the risk as noted by Hansen et al. (2013). Geological formations in the district also emerged as a formidable factor. This is attributed to the intrinsic characteristics of the geological formations in the district, such as weak, weathered and fractured rock layers that contribute to increased instability as reported by Samuel, (2015). The composition and structure of bedrock also play a pivotal role in permeability and drainage properties, influencing the potential for mass wasting events (Charles et al., 2017). Also, the heightened seismic activity around the Aburi mountains further compounds this risk as noted by the Ghana Institution of Geoscientists (2019).

Land use/land cover (LULC) is another significant factor that underscores the impact of human activities like deforestation, urbanization, agriculture, and substandard construction practices, increasing the mass wasting susceptibility of the district, especially around Aburi. The findings of the study as presented in Figure 14, show that the primary causes of mass wasting in Akwapim South District have been attributed to poor construction practices, urbanization and changes in land use. These factors point to the fact that the development and alterations in how land is utilized in the study area contribute to mass wasting occurrences. Urbanization often involves extensive modifications to the land, such as constructing buildings, roads and infrastructure (Malehmir et al., 2016). Also, removal of vegetation cover through anthropogenic and landslide events is another potent catalyst for surface runoff and soil erosion, further escalating the potential for mass wasting events as noted by Mind'je et al. (2020). Vegetation plays a crucial role in slope stabilization by absorbing rainfall, reinforcing soil structure, and preventing erosion (Sancho et al., 2015). Without sufficient vegetation, slopes become more susceptible to mass wasting events. Furthermore, is worth noting that heavy rainfall also aids slope failures in the area. Intense or prolonged rainfall saturates the soil, increasing its weight and reducing its stability, leading to landslides, debris flows, or other forms of mass wasting. There was an incident of mass wasting in Aburi on October 28, 2019, after four hours of heavy rainfall (Ghana Web, 2019). This is a clear evidence of climatic influence on mass wasting in the Aburi enclave. Steep slopes are more prone to slope failure, particularly when combined with other contributing factors like heavy rainfall or weak soil. Overall, this study highlights the nuanced interplay of different factors that influence mass wasting susceptibility. These insights are invaluable in formulating targeted mitigation strategies and informing land use policies.

Mass wasting activities also has significant socio-economic impacts on communities and the environment in the study area. Understanding these impacts is crucial for devising effective mitigation and management strategies. Analysis of findings as presented in Table 11, shows that lives were lost due to mass wasting in the Akwapim south district. As reported by Bokpe & Aziamor-Mensah (2021) in October 6, 2010, a landslide occurred during a heavy downpour at Adukrom-Yensi in the Akwapim south district that killed three people and destroyed many properties. It is therefore important to address the potential risks associated with mass wasting events in the district. Damage to infrastructure has the highest perceived impacts. This poses a high degree of danger as it results in the disruption of vital services, transportation, and communication networks (Nwankwoala, 2019). For example, Bokpe & Aziamor- Mensah, (2021) noted that on June 20, 2010, a heavy downpour triggered a landslide on the Peduase-water works road, a stretch of the Ayi-Mensah-Aburi dual carriageway in the study area, blocking part of the road. Property damage is another significant socio-economic impact reported in the study area. It indicates the destruction or impairment of buildings, houses, and other structures. While it may not directly endanger lives, it can have severe economic and emotional consequences for the affected individuals and communities (Ajake et al., 2022). Displacement of residents is another portion of the socio-economic impacts that affect people in the Akwapim South District. A portion of the population in the district has been forced to leave their homes due to the mass wasting events. Displacement can be dangerous as it disrupts people's lives, leads to social instability, and poses challenges in terms of finding shelter and meeting basic needs and it is in line with a report by (Sasaki et al., 2016). Bokpe & Aziamor-Mensah (2021) indicated that heavy rainfall caused mass wasting in Aburi on 28 October 2019, and it led to the displacement of about 559 people in the area. Psychological trauma also highlights the psychological impact on individuals and communities affected by mass wasting events especially those who were displaced from their homes and those drivers who ply Aburi to Ayi- Mensah dual carriageway. While it may not have immediate physical dangers, psychological trauma can have long-lasting effects on mental health and well-being (Nwankwoala, 2019). Also, economic losses represent the economic impact of mass wasting events in the study area. These include loss of livelihoods, reduced economic activities, increased costs for recovery and repair, reduced agricultural production etc. in the affected communities. Long-term economic losses have far-reaching consequences for the affected region as noted by (Mertens et al., 2016).

The Akwapim South District, a charming region surrounded by stunning mountains, is currently facing mass wasting occurrences. As illustrated in Figure 15, mass wasting brings about a host of environmental issues for the affected communities. The disappearance of vegetation upsets the fragile equilibrium of the ecosystem in the study area. Also habitat destruction as a results removal of vegetation casts a long shadow over the district's biodiversity. The activities associated with mass wasting dismantle habitats, displacing wildlife and disrupting crucial ecological processes. This upheaval precipitates the decline and potential extinction of plant and animal species, heralding a loss that resonates through the enclave's natural heritage. This disappearance results in diminished animal habitats, intensified soil erosion, and a noticeable effect on the local biodiversity, as outlined by Sam (2017). The effects of this loss ripple throughout the intricate network of life in this enclave. Soil erosion and scarification of the landscape are also other environmental impact that left a mark on the terrain. Mass wasting events, such as slope failures and landslides, peel away layers of soil, unveiling the bedrock beneath and leaving indelible scars on the once-pristine landscape (Melissa, 2019). This transformation alters the natural geomorphology and compromises the aesthetic appeal of the region. The burial of fertile soil, a notable consequence that is induced by mass wasting, engulfs extensive areas of arable land, severing the lifeline of agricultural potential in the affected areas (Seeber et al., 2007). Land scarcity resulting from mass wasting is hurting local agricultural activities and putting the region's food security and economic stability at risk. Additionally, the degradation of water quality is another environmental challenge caused by mass wasting in the area. Streams that flow through the district from the rugged mountains are less affected by sediments and pollutants introduced by mass wasting (SAM, 2017). This degradation, in turn, jeopardizes drinking water sources and overall water availability, amplifying the toll on the enclave's inhabitants.

Finally, the chi-square test results in Tables 13 & 14, present a noteworthy insight into the relationship between education level, gender, and awareness of the occurrence of mass wasting within the study area's population. Surprisingly, the findings suggest that there exists no statistically significant association among these variables. This intriguing discovery prompts a deeper exploration into the underlying factors that contributed to the awareness of the occurrence of mass wasting among the residents. In this context, societal shifts, dynamic communication landscapes and the burgeoning influence of digital media have emerged as pivotal elements that reshape the dissemination of awareness across diverse demographics (Weber & Hsee, 1998). The traditional notion that awareness of disaster risk is inherently linked to gender roles is transforming. With societal changes, men and women now have comparable access to information and exhibit similar levels of awareness. This paradigm shift challenges the conventional assumption that awareness levels are distinct based on gender. The evolving dynamics of information accessibility, spurred by the digital revolution, further blur the lines. Individuals across all genders now have equal opportunities to engage with awareness campaigns and media outlets. Education, though influential, represents just one facet of the multifaceted landscape that shapes awareness levels. Cultural background, personal interests, and exposure to a diverse array of media outlets are all formidable contributors to an individual's level of awareness (Watson et al., 2017). In the digital age, accessibility to information has transcended the boundaries of education levels. Even those with lower educational attainment now have the means to access content aimed at raising awareness through various online platforms. This democratization of information has profound implications for the dynamics of awareness within the study area's population.

19 Summary

This chapter focused on a discussion of results and findings from the study conducted. GIS and Remote sensing tools were used to analyse the types, causative factors and zoning of the study area into different levels of susceptibility to mass wasting in the study area. Also, views of key informants and other residents in the study area were collated on the causes, s socio-economic and environmental impacts of mass wasting. The results and findings were analysed and illustrated using tables, charts, pictures and maps. From the results, hilly terrain with unregulated human activities are susceptible to mass wasting especially the Aburi enclave. Also, the socio-economic impact of mass wasting in the Akwapim South District were investigated as well as the havoc of mass wasting in the environment of the study area. The next chapter presented the summary, conclusion, and recommendation of the whole thesis.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Introduction

The research findings that were revealed during the survey are summarized in this chapter. The research objectives were addressed, the key findings were compiled, and conclusions were drawn. It included recommendations made for authorities and community members to follow in addressing the risk of landslides both now and in the future.

5.2 Summary

This study embarked on an extensive investigation into mass wasting susceptibility mapping in the Akwapim South District. Through a comprehensive analysis of geological, topographical, and anthropogenic factors, the research has provided invaluable insights into the dynamics and vulnerabilities of mass wasting processes within the study area. The study revealled that rockfall and rockslide constitute the predominant mass wasting processes occurring in the Akwapim South District, particularly in the Aburi enclave. Other mass wasting types such as landslide, debris fall, slope scars and soil creep are also present in the study area, especially in the Aburi enclave. These findings align with previous research conducted in similar geological contexts, reinforcing the significance of topographical, geological and human-induced factors in shaping the landscape's susceptibility to mass wasting events. The identification of these processes as the most prevalent serves as a vital baseline for subsequent analyses. The study also classified the district into three levels of susceptibility to mass wasting events. Areas around Adukrom are classified as medium susceptible zones, while the Aburi enclave falls into the high susceptible zone. A salient discovery is the concentrated occurrence of mass wasting processes within the Aburi enclave. This enclave stands out as the epicentre of heightened susceptibility, with a confluence of geological features and anthropogenic activities exacerbating the risks. The intricate interplay of geological attributes, such as high elevation and weathered rock formations, with anthropogenic influences, including poor construction practices and extensive slope excavation, underscores the vulnerability of this region.

The study unequivocally establishes that high elevation, weak rock formation and human-induced factors, notably poor construction practices and slope excavation are the principal drivers behind the mass wasting processes in the Akwapim South District, particularly in the Aburi enclave. This revelation holds paramount significance for policymakers, urban planners, and local communities alike. It underscores the urgent need for comprehensive regulatory frameworks and construction guidelines that account for geological vulnerabilities, thereby mitigating the potential for future mass wasting events.

An in-depth analysis of the socio-economic and environmental impacts arising from mass wasting events in the study area has unearthed critical concerns. The far-reaching ramifications encompass property damage, disruption of livelihoods and potential loss of life. Furthermore, the environmental repercussions extend beyond the immediate affected areas, with long-term consequences for ecosystem stability and resilience. These findings highlight the imperative of proactive mitigation measures, emphasizing the intersectionality of geological hazards with socio-economic and environmental dimensions.

The culmination of this research effort is the creation of a susceptibility map, which vividly illustrates the vulnerability of the Aburi enclave to mass wasting events. This cartographic representation serves as a powerful tool for decision-makers, enabling them to formulate targeted strategies for risk reduction and disaster preparedness. The delineation of high susceptibility areas empowers stakeholders to allocate resources efficiently, channelling efforts towards the most vulnerable regions.

The study also assessed the awareness of the occurrence of mass wasting among residents. A significant portion demonstrated a high or moderate level of awareness, influenced by previous incidents, education, media coverage, and proximity to hazard zones. However, some individuals had limited knowledge about mass wasting processes in the study area, indicating the need for improved awareness campaigns, educational programs, and media coverage.

5.3 Conclusion

This thesis represents a comprehensive and meticulous examination of mass wasting susceptibility within the Akwapim South District, with a specific focus on the Aburi enclave. Through a multifaceted approach encompassing geological, topographical, and anthropogenic factors, this study has illuminated the intricate interplay of these elements in influencing susceptibility patterns. The concentration of mass wasting processes observed in the Aburi enclave, attributed in part to human activities, serves as a stark reminder of the pressing need for proactive intervention. The implications of these findings extend beyond the academic realm, emphasizing the practical urgency of implementing measures to mitigate the risks associated with mass wasting in this region. By leveraging a combination of geospatial tools and rigorous field surveys, this study succeeded in delineating susceptibility zones for mass wasting events across the Akwapim South District. Notably, it was determined that the Aburi enclave is particularly prone to such occurrences. This nuanced understanding of susceptibility distribution is invaluable for the formulation of targeted intervention strategies. Furthermore, the research brought to light that a substantial portion of the district's land area is not predisposed to mass wasting events. This insight provides a basis for prioritizing resources and efforts towards areas where they are most urgently needed, thereby maximizing the effectiveness of intervention initiatives. Natural factors, including weak geological formations, unregulated human activities, and high elevations, emerged as prominent drivers of mass wasting within the district. This reinforces the critical importance of considering the underlying geological and topographical characteristics in susceptibility assessments and subsequent mitigation efforts. Beyond the physical manifestations, it is imperative to acknowledge the profound socio-economic and environmental repercussions brought by mass wasting events in the study area. These impacts reverberate through the very fabric of the community, affecting livelihoods and altering the biophysical identity of the region. Recognizing and addressing these broader implications is crucial for ensuring the long-term resilience and well-being of the affected communities.

5.4 Recommendations

Given the identified drivers of mass wasting processes, particularly in the high susceptible zone of the Aburi enclave, there is a pressing need for the development and implementation of comprehensive regulatory frameworks and construction guidelines. These should specifically address geological vulnerabilities, incorporating measures to mitigate risks associated with high elevation, weak rock formation, poor construction practices and extensive slope excavation. Government and urban planners should collaborate to establish and enforce guidelines that prioritize sustainable land use practices, construction standards, and slope management to reduce the potential for future mass wasting events.

The research highlights the intricate interplay of geological attributes with anthropogenic influences, emphasizing the vulnerability of the Aburi enclave. Urban planning in the Akwapim South District should integrate geological considerations, especially in high susceptible zones. This includes careful land-use planning, zoning regulations and infrastructure development that account for geological features to minimize the impact of mass wasting events. Collaboration between geologists, urban planners, and construction professionals is essential to create resilient and sustainable communities.

Given the socio-economic and environmental impacts of mass wasting events, including property damage, disruption of livelihoods, and potential loss of life, it is imperative to establish early warning systems and emergency preparedness protocols. Local authorities should invest in monitoring technologies and systems that can detect precursors to mass wasting events. Simultaneously, community members should be trained on emergency response procedures and evacuation plans. Establishing a communication network for timely dissemination of alerts and information during potential mass wasting events is crucial in reducing the severity of their impact.

Local authorities such as the Municipal Assembly, chiefs and opinion leaders should spearhead reforestation and other appropriate vegetation restoration initiatives on slopes and hillsides. This strategic intervention serves a dual purpose: reinforcing soil stability and reducing erosion. The proliferation of vegetation enhances the overall resilience of the landscape, providing a natural defence against mass wasting hazards.

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APPENDIX ONE

QUESTIONNAIRE

UNIVERSITY OF GHANA DEPARTMENT OF GEOGRAPHY AND RESOURCE DEVELOPMENT

I am an MPhil student at the Dept of Geography & Resource Development, University of Ghana. This questionnaire is part of an MPhil thesis research on the topic "Application of remote sensing and GIS to mass wasting susceptibility mapping of the Akwapim South District". Respondents are assured that their replies will be kept anonymous and that this study is just for academic purposes. The objective of this inquiry is to learn more about the socio-economic and environmental effects of mass waste in Aburi as well as its causes. Please provide the best information and experience you have while responding to the following questions.

Background information of respondents.

Age: 20- 30 [ ] 30 – 40 [ ] 40 – 50 [ ] 60 and above [ ]

Sex: Male [ ] Female [ ]

Level of education: None [ ] Basic education [] Secondary/ Middle school [ ] Tertiary [ ]

Duration of stay: 5- 20 [] 21- 30 [] 31- 40 [] 41 and above []

Causes of mass wasting

1. Are you a resident of Aburi, Ghana?

a) Yes

b) No

2. Which part of Aburi do you reside in? ……………………………………….

3. How long have you been living in Aburi?

4. a) Have you personally witnessed or experienced mass wasting events in Aburi?

a) Yes

b) No

b) Which part does it occur?

……………………………………….

If the answer to Question 4 is "No," please skip to Question 10.

5. Are you a victim of mass wasting?

6. If yes, how were you affected?

7. How frequently do mass wasting events occur in Aburi?

a) Very frequently

b) Frequently

c) Occasionally

d) Rarely e) Never

8. Which locality do they normally occur?

9. What do you believe are the main causes of mass wasting in Aburi? (Select all that apply)

a) Heavy rainfall

b) Deforestation

c) Slope steepness

d) Poor construction practices

e) Urbanization and land-use changes

f) Geological factors

g) Other (please specify): ________________

Socio-economic impacts

10. How do mass wasting events affect the local community in Aburi? (Select all that apply)

a) Loss of lives

b) Damage to infrastructure (roads, utility lines etc.)

c) Damage to property (buildings, vehicles etc.)

e) Displacement of residents

d) psychological trauma

e) Interruption of essential services (water, electricity, etc.)

f) Economic losses

g) Other (please specify): ________________

Environmental impacts

11. How does mass wasting impact the environment in Aburi? (Select all that apply)

a) Soil erosion/scarification of landscape

b) Loss of vegetation

c) Degradation of water quality

d) Habitat destruction

e) Reduced agricultural productivity

f) Burial of soil/ land

f) Other (please specify): __________________

12. Are there any long-term environmental consequences resulting from mass wasting events in Aburi? Please describe.

Mitigation strategies

13. What measures do you think should be taken to mitigate the impacts of mass wasting in Aburi?

14. Are there any existing initiatives or programs in Aburi aimed at preventing or reducing mass wasting events? If yes, please provide details.

15. On a scale of 1- 3, indicate your awareness level of the causes and potential impacts of mass wasting. [1] [2] [3]

3= Very aware, 2 = Somewhat aware, 1= Not aware at all

16. Are there any additional comments or information you would like to share regarding mass wasting in Aburi?

APPENDIX TWO

INTERVIEW AND DISCUSSION GUIDES

Causes, Socio-economic and Environmental Impacts of Mass Wasting in Aburi

Farmers and landlords interview guide.

1. How long have you been involved in agriculture/land management in this area?

………………………………………………………………………………………..

2. Are you familiar with the term "mass wasting"? yes or no

3. Have you observed any instances of mass wasting in Aburi or its vicinity? If yes, please describe the events. ………………………………………………………………………..

…………………………………………………………………………………

4. Where do they normally occur?

………………………………………………………………..

5. Are you a victim of mass wasting processes? Yes or no

6. If yes, how does it affect you

……………………………………………………………………..

7. How has mass wasting affected your farming activities or land use practices?

………………………………………………………………………………..

8. Have you experienced any crop losses or damage to buildings due to mass wasting? If yes, please explain. ………………………………………………………………………

………………………………………………………………………………………..

9. How has mass wasting affected your income or livelihood as a farmer/landlord?

…………………………………………………………………………………………..

10. Are there any additional socio-economic consequences you have noticed in the community due to mass wasting?..

……………………………………………………………………………………….

11. In your opinion, how has mass wasting affected the local environment in Aburi? b. Have you witnessed changes in soil fertility or erosion patterns resulting from mass wasting?

……………………………………………………………………………………….

……………………………………………………………………………………..

12. Have there been any impacts on water sources, such as rivers or streams, as a result of mass wasting?

13. What are your expectations for the future in terms of mass wasting and its impacts on agriculture and land management in Aburi?

……………………………………………………………………………………………………

14. What are some major causes of mass wasting in your area?

…………………………………………………………………………………

15. How can this be managed?

………………………………………………………………………………………………

Interview guide for major stakeholders (DCE, Municipal planning officer NADMO coordinator and the Assemblymen)

1. Is mass wasting a major environmental problem in the district?

…………………………………………………………………………………………..

2. Where are the major localities of mass wasting?

…………………………………………………………………………………………………..

3. How frequently does mass wasting occur in the area, and what are the primary types of mass wasting events observed?..

4. What are the main geological and environmental factors that contribute to mass wasting in Aburi? …………………………………………………………………………………….

……………………………………………………………………………………………..

5. Are there any human activities that exacerbate or contribute to mass wasting in the area?

…………………………………………………………………………………………….

6. Have there been any significant disruptions to transportation, housing, or economic activities due to mass wasting events?

……………………………………………………………………………………………….

7. What are the major effects/ setbacks of mass wasting processes when they do occur?

…………………………………………………………………………………………………….

8. What early warning systems or monitoring mechanisms are in place to detect and respond to potential mass wasting incidents?

……………………………………………………………………………………………………..

9. How does the Aburi community collaborate with other relevant agencies, such as NADMO, to coordinate disaster response efforts?

……………………………………………………………………………………………………

10. Are there any long-term strategies to improve land-use planning and infrastructure development to minimize the vulnerability to mass wasting?

…………………………………………………………………………………………………

11. What measures have been taken to control this hazard?

…………………………………………………………………………………………………