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FLOOD RISKS ASSESSMENT IN KIKULETWA CATCHMENT USING GIS AND REMOTE SENSING.

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A Dissertation Submitted to the Department of Geospatial Science and Technology in Partial Fulfillment of the Requirements for the Award of Science in Geoinformatics (Bsc.GI) of Ardhi University

CERTIFICATION

The undersigned certify that they have read and hereby recommend for the acceptance by Ardhi University dissertation titled "**Flood risks assessment and management in Kikuletwa Catchment"**, partial fulfillment of the requirements for the award of Bachelor of Science in Geomatics of the Ardhi University.

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Dr. Dorothea Deus

(Supervisor)

Date…………………………....

DECLARATION AND COPYRIGHT

I, **Lawrent, George C**, hereby declare that, the contents of this dissertation re the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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22718/T.2019

(Candidate)

Date…………………………………………

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DEDICATION

I dedicate this dissertation to my family, my father Mr. Cyprian Laurent, my beloved mother Mecktrida George, my sisters and brothers for their support, love and encouragement in financial and academic support to ensure am mentally stable.

ABSTRACT

The frequency and intensity of flood events have been increasing globally, posing significant threats to communities and infrastructure. Kikuletwa catchment is one of the most vulnerable areas to flood hazards, and none of the previous studies have tried to map flood prone area. Despite the fact that flood prone areas identification and mapping is crucial task to support decision-makers in management of flood risks.

This study aims to identify and map flood prone in Kikuletwa catchment, using the integration of Geographic Information System, Remote Sensing, multi-criteria decision-making method with analytical hierarchy process. Flood controlling factors such as elevation, slope, distance from rivers, annual rainfall, drainage density, topographic wetness index, land cover, Normalized Difference Vegetation Index, soil type, and curvature were weighted and overlaid together to achieve the objective of the study.

The final flood risk map generated by the weight overlay was found to be consistent with the historical flood events in the study area. The result shows that about many parts of Arusha and Hai districts are high susceptibility to flooding, and most parts are of the study area has moderate and low susceptibility to flooding. The mountainous parts of the study area dominated by high elevation and steep slope that are very low susceptible to flood. The downstream areas are the one most potential to flood risks. High drainage density, topographic wetness index, and cropland land use were found to be more susceptible areas to flood hazards.

This dissertation has succeeded to identify the flood risk prone areas at Kikuletwa using GIS and Remote sensing. Based on the method and findings of this dissertation, I recommend other researchers to use different method such as Boosted Regression Tree for assessing the flood risk prone areas since AHP has bias since the assigning of the weights to criteria is based on personal feelings.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
CI	Consistency Index
CSV	Comma Separated Values
CR	Consistency Ratio
CU	Curvature
CW	Criteria Weight
CWS	Criteria Weight Sum
DD	Drainage Density
DEM	Digital Elevation Model
DTR	Distance to river
EL	Elevation
FFSM	Flash flood susceptibility maps
FRA	Flood Risk Assessment
GEE	Google Earth Engine
GIS	Geographic Information System
LiDAR	Light Detection and Ranging
LU	Land Use
MCDM	Mult-Criteria Decision Making
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
PP	Pre-processing
RD	River Distance
RF	Rain Fall
RFM	Rapid Flood Model
RI	Random Index
SA	Slope Aspect
ST	Soil Type

TIFF	Tagged Image File Format
TMA	Tanzania Meteorological Authority
TWI	Topographic Water Index
USGSS	United State Geological Survey
WRD	Waterway and River distance

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND.

Flood is the natural hazard that is potentially dangerous phenomena occurring on earth at a given time. It can cause damage to both natural environment and man-made features such as buildings and roads. (Dawod, Mirza & Al-Ghamdi 2012) indicated that flood disasters can cause substantial economic cost and also bring pathogens into urban environments causing micro-bial development and diseases. (Bathrellos, and Gaki-Papanastassiou (2014) described that flood hazard caused by climatic change can cause morphological changes in land forms and disrupt human activities. (Ashmawy, 1994; Pradhan, & Al Fadail, 2016;) said that heavy rainfall influences the increase in volume of runoff and enhance flash flood in downstream areas.

Flash floods are the result of heavy precipitation more than drainage capacity saturation value, causing massive amount runoff water along the drainage network and leading high discharge rate at the basin outlet (Gaber & Buchroithner, 2009). Nowadays, flash flood problems dramatically increase due to various factors such as land use/landcover changes, urbanization activities along flash flood prone areas, poor standard infrastructures and high-density house hold (Munich Reinsurance,2002; Pelling, 2003). Serious control measure and prevention are needed so as to minimize the effects and damages cause by flood. Early warnings and emergencies responses are urgently needed solution as to government and flood management agencies can minimize the damage (Feng & Wang, 2011).

Flash flood susceptibility maps (FFSMs) provide information on the spatial distribution of flood-prone areas. They are crucial tools for planners, developers, decision makers, and environmental managers to help in selecting favorable locations for future land use development (Abdulwahid & Pradhan, et al.,2016).

Remote sensing and GIS have become one of the long-time tools for efficiently and effectively interpreting, monitoring and analyzing different types of hazards including flood. Mapping of the flood prone areas is one of the crucial methods for flood risk assessment. GIS environment provides potential tools for integrating, visualization and handling of the diverse spatial dataset (Billa et al.,2006; Pradhan & Youssef, 2011).

There are various approaches including heuristic, statistical, and deterministic that are applied in natural hazard assessment and land use suitability analysis (Ayalew & Yamagishi et, al (2005). Heuristic is AHP method that is considered as the multiple decision-making method and was developed by Saaty (1977). AHP method uses both qualitative and quantitative factors for ranking and evaluating alternative scenario so as to select the best solution for a problem (Saaty, 1990, 2004). Different researchers have used and proved that AHP is the good method to provide accurate and reliable prediction of flood (Bathrellos et al., 2016).By predicting the occurrence of flood potential areas, it will be easy to assess and manage the risks caused by flood.

Newly studies show that the percentage of global population at risk from flooding has risen by almost a quarter since the year 2000 (Matt McGrath). By the year 2030, millions will experience more flooding due to climate change and demographic change. Flood are considered as the most destructive of all-natural disasters because they are the common cause of deaths and results into many damages (Miller, 1997). Flood of rivers and streams is the most frequent type recorded around the globe, most often stemming from long periods of rain. River floods affects the largest area on land and destroy more lives and property than any other form of flooding (International Federal of Red Cross and Red Crescent Societies, 1999).

Then there is a great need to assess and manage the risks due to flooding, especially Flooding of rivers and streams. Flood risks assessment is the process of identifying, evaluating and managing the risks associated with floods. It involves the analysis of the likelihood and potential consequences of floods and developing strategies to reduce the impact on people, property and the environment. The assessment typically involves the following steps; identification of flood hazards, vulnerability assessment, risk analysis, risk management and monitoring and review (Karamat et al 2016*)*. This research aims at assessing the flood risk prone areas at Kikuletwa river since none of previous studies has tried to map flood prone areas at Kikuletwa.

1.2 DESCRIPTION OF THE STUDY PROBLEM

Extreme rainfall events lead to dramatic damage to human life and properties most seriously by contributing to urban flooding (Lindholm, 2008). However, flood events along rivers are frequently happening. These flood events bring destruction of properties and loss of life. Most rivers are affected by climate change that they receive much rainfall more than their ability to hold water leading to high rate of discharges at the outlet. Kikuletwa river is one of the rivers that is affected by flood leading to risks such as loss of life to humans, destruction of properties.

One of the flood cases happened at Kikuletwa is that reported on 25th April 2020 where about 50 houses were destroyed. Different researches done shows the flood effects at Kikuletwa catchment. However, none of them has identified the flood risk prone areas, so the aim of this research is to assess the flood risks by mapping flood prone areas at Kikuletwa Catchment.

Figure 1.1 *Flood in Kikuletwa river (the citizen)*

1.3 STUDY AREA

The Kikuletwa catchment is one of the sub-catchments of the Pangani River Basin located in Eastern Africa. The catchment covers a total area of 6,077 km2. Rainfall within the catchment is bi-modal, with long rains from March to June and short rains from November to December. The catchment hydrological year starts from 1st October to 30th September the following year.

The catchment has five tributaries: Nduruma, Themi, Usa-Kikuletwa, Sanya-Kware, Kikafu - Karanga rivers, whereby three of the tributaries (Nduruma, Themi, and Usa-Kikuletwa rivers) have recently turned ephemeral due to increased water consumption (Komakech, 2013). The water resources of the Kikuletwa catchment are characterized by the occurrence of springs originating along the slopes of Mt. Meru and Mt. Kilimanjaro. The largest springs are Chemka, Rundugai and Kware springs, providing 90 % of the water during the dry season. Kikuletwa river is one of the two large rivers discharging into Nyumba ya Mungu Dam (PBWO/IUCN, 2006) located at latitude 3°19’S to 3°54’ and longitude 36°30’ to 36°49’E . The primary water uses in the catchment are agriculture by small-scale farmers practicing supplementary and full-scale irrigation on the slopes of Mt Meru and Mt Kilimanjaro, mining, domestic water uses for the main cities (Arusha and Moshi), large scale commercial farms, tourist facilities and pastoralists. Increased population has led small scale farmers to expand their lands and irrigation systems, hence using more water for irrigation to supplement rainfall (Komakech and van der Zaag, 2013). As a result, some sections of the main Kikuletwa River have changed from perennial to ephemeral rivers (Komakech, 2013). Figure1.2 show the Location map of Kikuletwa Catchment.

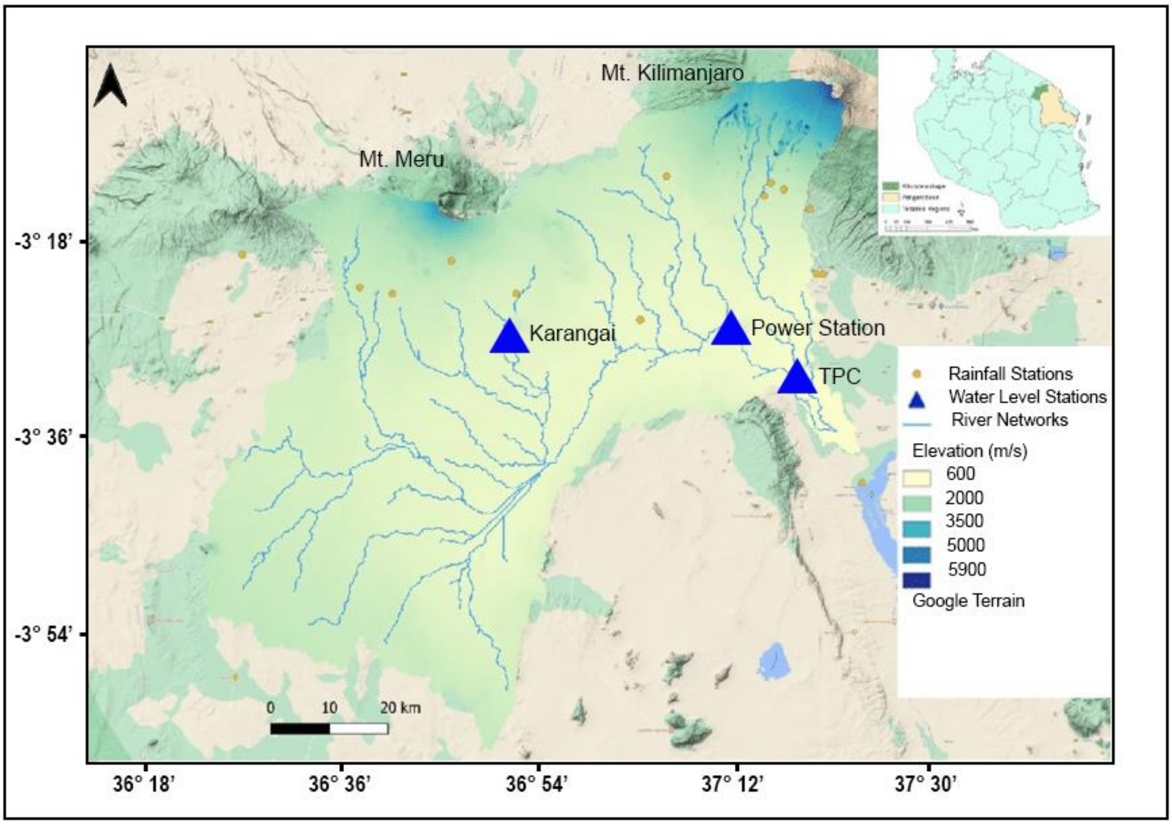

Figure1.2 *Location map of the study area*

1.4 OBJECTIVES

1.4.1 Main Objectives

The main objective of this study is to assess flood risks prone areas at Kikuletwa river using GIS and Remote Sensing.

1.4.2 Specific Objectives

i. Identification of criteria to be used in assessment of flood risks
ii. Assessment of the flood risks by considering criteria identified
iii. Mapping of flood prone areas

1.5 RESEARCH QUESTIONS

The following are questions that will guide in doing the research;

i. What are the criteria to be used in assessment of flood risks?
ii. What are the areas that are mostly affected by flood?
iii. Are vulnerable flood areas, correct?

1.6 SIGNIFICANCE OF THE STUDY

The following are the reasons why this project is so important to be conducted and what will contribute in a particular field;

i. The assessment of risk associated with floods is one of the important steps in managing it.
ii. By identifying areas that are vulnerable to flooding both community and the government can better prepare and protect themselves from impacts of flooding, including damage of properties and infrastructure and death of people.
iii. It helps in creating a platform for land use planning in flood prone areas.
iv. It helps in mitigation and emergency management planning so as to reduce the impact that maybe caused by flood.

Therefore, mapping flood prone areas is an important component of a comprehensive flood risk management strategy and plays an important role in helping the communities to become more resilient to the impact of flooding.

1.7 BENEFICIARIES

There are many people who can benefit from this research including; society, government, environmental agencies, planners and decision makers and scientists and other researchers;

i. Society and Government

Both the government and society may benefit from this research through the information provide by maps that will help in making effective decisions. The government may take some measures like construction of infrastructures such as culverts that will minimize the impact of flood in the area. Then society may use the maps to identify the flood prone areas and evacuate from these areas in order to avoid the loss of life and properties.

ii. Planners and Decision makers

By identifying the flood prone areas, it will be easy for decision makers and planners to identify the flood prone areas and determine what activities should be done it also will provide a better understanding of the potential flood risks associated with flood so as to inform them about how to mitigate those risks through the implementation of flood control measures or the development of emergency response plans

iii. Scientist and Researchers

Scientists and researchers may use the method used in this research to assess the flood risks in other area of their interest and this will increase number researches about flooding. Also, researchers and scientists will use the results from this method to compare them with the results from other method so as to come up with the best method that will contribute in obtaining best and accurate results.

1.8 DISSERTATION ORGANIZATION

This research is organized in five chapters where these chapters explain about different concepts, methods that were executed in this research, results obtained and discussion of these results from different stages of the research.

Chapter 1 covers the background of the research, including the study area where the research will be covering, research problem to be solved, main and specific objective, significance of the research, beneficiaries as well as scope and limitation.

Chapter 2 will be covering the literature review including concepts about floods and different methods for mapping floods. In this chapter is where definition of all the key words explained.

Chapter 3 covers all the procedure and methods that were used in execution of the research as well as whole data used in the research.

Chapter 4 provides the results obtained when performing different processes and methods so as to meet the main objective of the research.

Chapter 5 provide the conclusion basing on the objectives which were to be attained and the final output obtained and also this chapter provides the recommendations on the final products may be utilized basing on the challenges.

CHAPTER TWO
LITERATURE REVIEW

2.1 OVERVIEW

Flood risk assessment plays a crucial role in mitigating the potential damages caused by floods. In recent years, Geographic Information Systems (GIS) and Remote Sensing have emerged as valuable tools for analyzing and predicting flood hazards. This literature review aims to provide an overview of the existing research related to flood risk assessment using GIS and Remote Sensing, with a focus on the specific case study of Kikuletwa River. This chapter will be covering the concepts about floods and different methods for mapping floods. In this chapter is where definition of all the key words explained. This chapter consists of various sections such as section 2.2 talking about flood, the key points about flood such as causes, impacts types and others. Section 2.3 explains about Flood in rivers, section 2.4 explains about DEM, section 2.5 explains about GIS and RS in flood risk assessment, section 2.6 explains about Multicriteria Decision Making and section 2.7 explain about AHP also there is section 2.8. Flood Risk Assessment Criteria and the last section 2.9 explain about Criteria Reclassification.

2.2 FLOOD

Floods are natural disasters that occur when there is an overflow of water onto normally dry land. They can be caused by various factors, including heavy rainfall, snowmelt, dam failure, or coastal storms (Forkuo, 2011). Floods can have devastating impacts on human lives, infrastructure, agriculture, and the environment.

Here are some key points about floods (Andrés & Julio, 2020):

i. Causes: Floods can result from intense or prolonged rainfall, where the volume of water exceeds the capacity of the land to absorb it or for rivers and drainage systems to handle it. Additionally, factors such as rapid snowmelt, storms and hurricanes, or dam failures can contribute to flooding.

ii. Types of Floods: There are different types of floods, including river floods, flash floods, urban floods, coastal floods, and groundwater floods. Each type has unique characteristics and causes.

iii. Impact: Floods can cause significant damage and pose risks to human life and infrastructure. They can lead to loss of life, displacement of people, damage to buildings, roads, bridges, and utilities, contamination of water sources, and destruction of crops and livestock. Floods also have long-term impacts on economies and ecosystems.

iv. Flood Risk Assessment: Assessing flood risk is crucial in understanding vulnerable areas and developing effective mitigation strategies. This involves analyzing factors such as topography, hydrology, historical flood data, and land use to determine the likelihood and severity of floods in specific regions.

v. Flood Management and Mitigation: Flood management includes a range of strategies and measures to reduce the impact of floods. These can include constructing flood control infrastructure like levees and floodwalls, implementing floodplain zoning and land-use planning, improving forecasting and early warning systems, promoting flood insurance, and enhancing public awareness and preparedness.

vi. Environmental Importance: Floods also play a role in the natural environment. They replenish water sources, support ecosystems such as wetlands, and contribute to the transportation of sediment, nutrients, and organic matter.

vii. Climate Change: Climate change is expected to impact the frequency and intensity of floods in many regions. Rising global temperatures can lead to more intense rainfall events, increased melting of glaciers and polar ice, and changes in precipitation patterns, all of which can influence flood occurrences.

Flood management and preparedness are crucial for minimizing the impacts of floods on human lives and infrastructure. Governments, communities, and individuals need to work together to implement effective flood control measures, improve early warning systems, and promote resilient infrastructure and land-use practices in flood-prone areas.

2.3 FLOOD IN RIVERS

Certainly, Floods in rivers occur when there is an excessive amount of water flowing in a river channel, causing it to overflow its banks and inundate the surrounding areas (Tsay, 2013). River floods can be particularly destructive due to the large volumes of water involved and the potential for widespread damage (NSSL, 2016). Here is a deeper explanation of the key factors and processes involved in river floods:

i. River Hydrology: River floods are closely related to the hydrological cycle, which involves the movement of water between the atmosphere, land, and oceans. Precipitation, such as rainfall or snowmelt, contributes to the river's water volume.

Factors such as the intensity, duration, and spatial distribution of precipitation determine the potential for flooding.

ii. River Basin Characteristics: The characteristics of the river basin play a crucial role in river floods. Factors such as the size and shape of the basin, the slope of the land, soil type, vegetation cover, and land use patterns all influence the movement and storage of water within the basin. Steep slopes, impermeable surfaces, or areas with poor drainage can increase the risk of flooding.

iii. River Channel Capacity: The capacity of a river channel to carry water is another key factor. It depends on the size, shape, and roughness of the channel. If the volume of water exceeds the channel's capacity, it will overflow and lead to flooding. Factors such as sediment deposition, vegetation growth, or human modifications to the river channel can affect its capacity and exacerbate flooding.

iv. River Discharge: River discharge refers to the volume of water passing through a given point along the river per unit of time. When the discharge exceeds the channel's capacity, it results in flooding (MA , Fan , Zhang, & Ming , 2014). Discharge is influenced by factors such as precipitation, snowmelt, groundwater inputs, and upstream inflows from tributaries.

v. Flood plain: The floodplain is the low-lying area adjacent to a river channel that is prone to flooding. During periods of high river discharge, the excess water spills out onto the floodplain, inundating the surrounding areas. The extent and depth of flooding depend on factors such as the topography of the floodplain, presence of levees or natural barriers, and the volume and velocity of water.

vi. Flood Routing: River floods involve the process of flood routing, which is the movement of water downstream along the river system. As water moves downstream, it can accumulate from tributaries, causing the floodwaters to spread and intensify. The timing and magnitude of peak flows are influenced by factors such as the shape of the river channel, storage capacity in lakes or reservoirs, and the presence of obstacles or constrictions.

vii. Flood plain Management: Managing River floods involves a combination of structural and non-structural measures. Structural measures include the construction of levees, floodwalls, or reservoirs to regulate the flow of water and provide flood protection. Non-structural measures focus on land-use planning, floodplain zoning, early warning systems, and public education to reduce the exposure and vulnerability of communities to floods.

Understanding the complex interactions between precipitation, river characteristics, and the surrounding landscape is crucial for predicting and managing river floods. This knowledge allows for better flood risk assessment, early warning systems, and the development of effective flood management strategies to protect lives and minimize property damage in flood-prone areas.

2.4 DIGITAL ELEVATION MODEL (DEM)

Digital Elevation Models (DEMs) are essential geospatial datasets that play a critical role in flood risk assessment research. DEMs provide information about the elevation of the Earth's surface, allowing researchers to model and analyze the topography of an area. This elevation data is crucial for understanding how water flows across a landscape and can help identify areas at risk of flooding. In the context of flood risk assessment, DEMs provide valuable information for various analyses and modeling techniques (Hadi & Mohammad , 2021). By utilizing DEMs, researchers can derive important parameters such as slope, aspect, curvature and flow accumulation, which are key inputs for flood modeling, mapping and vulnerability assessments.

The slope of the terrain, derived from DEMs, plays a crucial role in determining the speed and direction of surface water flow (Tsay, 2013). Steeper slopes often indicate areas were water flows more rapidly, potentially increasing the risk of flash floods or erosion. By analyzing the slope information derived from DEMs, researchers can identify areas that are prone to rapid water runoff and assess their susceptibility to flooding. Aspect, another important parameter derived from DEMs, refers to the direction in which a slope face. It influences the distribution of solar radiation, which can affect evaporation rates and vegetation growth. By considering aspect in flood risk assessment, researchers can gain insights into how the spatial distribution of water runoff and vegetation patterns may influence flood dynamics.

Additionally, DEMs provide valuable information for hydrological modeling, which is crucial for simulating the behavior of water across a landscape. By incorporating DEMs into hydrological models, researchers can simulate the flow of water through stream networks, identify flood-prone areas, estimate flood inundation extents, and assess the vulnerability of infrastructure and communities to flooding. Furthermore, DEMs are often used in conjunction with other geospatial datasets, such as land cover maps and rainfall data, to enhance flood risk assessments. By integrating DEMs with these datasets, researchers can analyze the relationship between topography, land cover characteristics, and flood vulnerability.

2.5. GIS AND REMOTE SENSING IN FLOOD RISK ASSESSMENT

Geographic Information System and Remote Sensing (GIS) technologies have revolutionized the field of flood risk assessment by enabling the integration of various spatial datasets and analysis techniques (Biswas, Sudhakar , & Desai, 2002). These technologies allow for the identification and mapping of flood-prone areas based on multiple criteria and variables. GIS and remote sensing technologies play a crucial role in flood risk assessment by providing valuable spatial data, analysis tools, and visualization capabilities. Here is an explanation of their role in flood risk assessment (Biswas, Sudhakar , & Desai, 2002):

i. Data Integration: GIS allows for the integration of various spatial datasets, including topographic maps, land use/land cover data, hydrological data, and satellite imagery. Remote sensing data, such as satellite imagery or aerial photographs, provide high-resolution information about the Earth's surface, including flood extent and land cover changes.
ii. Flood Mapping: Remote sensing data is used to create accurate flood extent maps. By analyzing pre- and post-flood imagery, GIS can identify and map flooded areas. This information helps in understanding the spatial extent and severity of flood events.
iii. Elevation Data: Digital Elevation Models (DEMs) derived from remote sensing data, such as LiDAR, provide elevation information that is crucial for flood modeling and mapping. DEMs help identify low-lying areas, flow pathways, and potential floodplains, aiding in the assessment of flood risk.
iv. Hydrological Analysis: GIS enables the integration and analysis of various hydrological data, such as stream networks, rainfall data, soil types, and land cover characteristics. By combining these datasets, GIS can analyze factors such as flow accumulation, drainage patterns, and infiltration rates, which are important for assessing flood risk and understanding hydrological processes.
v. Flood Hazard Mapping: GIS-based analysis combines multiple criteria, such as elevation, slope, proximity to rivers, and land cover, to generate flood hazard maps. These maps identify areas at high risk of flooding, assisting in land-use planning, emergency response, and flood mitigation strategies.
vi. Vulnerability Assessment: GIS allows for the integration of socio-economic data with flood risk data. This helps assess vulnerability by considering factors such as population density, infrastructure, and critical facilities in flood-prone areas. GIS-based

vulnerability assessments aid in identifying areas and populations at higher risk during flood events.

vii. Decision Support Systems: GIS-based decision support systems provide a platform for integrating and analyzing various data layers and models related to flood risk. These systems enable scenario analysis, flood impact assessment, and the evaluation of mitigation measures, supporting informed decision-making and emergency response planning.

viii. Communication and Visualization: GIS provides powerful visualization tools for communicating flood risk information through maps, charts, and graphs. These visual representations enhance understanding among stakeholders, emergency responders, and the general public, facilitating effective communication and collaboration in flood risk management.

The role of GIS and remote sensing in flood risk assessment is widely recognized in scientific literature and has been applied in numerous studies and real-world applications.

2.5.1 Researches done using GIS and Remote Sensing

The following researches has integrated GIS and Remote sensing in solving the flood hazard problem as follows; Ajanaw and Dessalegn Worku (2022). Potential flood-prone area identification and mapping using GIS-based multi-criteria decision-making and analytical hierarchy process in Dega Damot district, northwestern Ethiopia, used the same method to identify the flood prone area in Dega Damot district where he used eleven criteria elevation, slope, flow accumulation, distance from rivers, annual rainfall, drainage density, topographic wetness index, land use and land cover, Normalized Difference Vegetation Index, soil type, and curvature which were weighted and overlaid so as to archive the objective of the study.

Also, (Minyan Duan, et al 2009). Use of Remote Sensing and GIS For Flood Hazard Mapping in Chiang Mai Province, Northern Thailand. Printed by: Chinese Academy of Surveying and Mapping, Beijing 100039, China, used the same methods.

(Nani et al), used the same method where the flood hazard map was generated by using selected hazard factors including land use, topography, slope, and rainfall pattern. The result showed that the Kobe River basin is a flood-prone area, with 77.46% of its land classified as less prone to flooding and 21.41% classified as flood-prone. However, only 21.41% of its land is classified as flood-prone. Only 1.13% of the land is protected from the danger of floods, compared to the whole country.

2.6 MULTI-CRITERIA DECISION MAKING (MCDM)

Multi-Criteria Decision Making (MCDM) is a widely used approach in flood risk assessment, allowing for the incorporation of multiple criteria and their respective weights to determine the overall flood vulnerability of an area. The MCDM method aids in decision-making by considering various factors simultaneously and assigning importance to each criterion based on its relevance to flood risk (Saaty, 1980). Multi-criteria decision making (MCDM) techniques play a significant role in flood risk assessment by incorporating multiple criteria and their respective weights to support decision-making processes. MCDM helps evaluate and rank different flood risk scenarios based on various factors (Saaty, 1980). Here's an explanation of how MCDM is applied in flood risk assessment:

i. Criteria Selection: In flood risk assessment, various criteria are considered, such as flood elevation, slope, soil type of an area, annual rainfall, curvature of an area and other environmental consequences. These criteria are selected based on the specific context and objectives of the assessment.

ii. Criteria Weighting: Assigning weights to the selected criteria is crucial as it reflects their relative importance in the decision-making process. Weighting can be done through expert opinions, stakeholder consultations, or analytical methods such as Analytic Hierarchy Process (AHP) or Analytic Network Process (ANP). AHP is commonly used in flood risk assessment to derive weights by pairwise comparisons of criteria based on their importance.

iii. Criteria Evaluation: Each criterion is assessed for different flood risk scenarios using appropriate data sources, models, and analysis techniques. For example, GIS can be used to analyze flood depth and velocity data, while socio-economic impacts can be evaluated based on demographic and economic data.

iv. Scoring and Aggregation: Scoring methods are applied to each criterion to convert raw data into comparable values or scales, such as assigning numerical scores or ratings. The scores are then aggregated based on the criteria weights to obtain an overall score or ranking for each flood risk scenario.

v. Sensitivity Analysis: Sensitivity analysis is performed to examine the robustness of the results by varying the weights assigned to the criteria or considering different scenarios. This helps understand the impact of changing criteria importance on the final rankings and supports decision-making under uncertainty.

vi. Visualization and Communication: The results of MCDM in flood risk assessment are often visualized through maps, charts, or decision matrices to facilitate understanding and communication. Visual representations help stakeholders and decision-makers grasp the relative importance of criteria and the ranking of flood risk scenarios.
vii. Decision-Making Support: The outcomes of MCDM provide decision-makers with a comprehensive evaluation of flood risk scenarios, considering multiple criteria and their weighted importance. This supports informed decision-making in flood risk management, land-use planning, emergency response, and the prioritization of mitigation measures.

MCDM techniques enhance flood risk assessment by incorporating multiple criteria, providing a systematic approach to evaluate different scenarios, and supporting transparent decision-making processes. The integration of MCDM with GIS and other tools enables a comprehensive analysis of flood risk and aids in developing effective strategies for flood risk reduction

2.7 ANALYTICAL HIERARCHY PROCESS (AHP)

The Analytical Hierarchy Process (AHP) is a systematic approach that facilitates the comparison and prioritization of criteria in MCDM. AHP employs pairwise comparisons and mathematical calculations to derive relative weights for each criterion, thereby establishing their importance in flood risk assessment.

The analytical hierarchy process (AHP) suggested by Saaty (1987) is the most commonly used and effective method in the multi-criteria decision-making (MCDM) process to assign the relative importance of each criterion or factor considered in the study, and many different previous studies (Abdelkarim et al. 2020; Ajibade et al. 2021; Allafta and Opp 2021; Astutik et al. 2021; Aydin and Birincioğlu 2022; Danumah et al. 2016; Das and Gupta 2021; Elsheikh et al. 2015; Karymbalis et al. 2021; Mahmoud and Gan 2018; Ogato et al. 2020) have employed this method to weight each flood-controlling factors and, finally, to identify and map flood-prone areas. The factors employed for flood susceptibility mapping using multi-criteria decision-making were given based on the local physical characteristics of the study area and assessment of previous studies. Assigning relative weights for criteria in the Analytic Hierarchy Process (AHP) involves a step-by-step process. Here is a general procedure to follow as suggested by Saaty (1987);

i. Define the Decision Hierarchy: Identify the main goal or objective of the flood risk assessment and break it down into a hierarchy of criteria. The top-level criterion represents the main objective, and the lower-level criteria represent the sub-criteria that contribute to the overall objective. Ensure that the hierarchy is structured in a logical and meaningful way.
ii. Pairwise Comparisons: Create a pairwise comparison matrix to assess the relative importance of each criterion with respect to the criterion directly above it in the hierarchy. The matrix is square, with the number of rows and columns equal to the number of criteria in the hierarchy. Each element of the matrix represents the relative importance or preference of one criterion over another. Use a scale, typically from 1 to 9, to assign values indicating the strength of preference or importance.
iii. Determine Relative Importance Values: Analyze the pairwise comparison matrix to determine the relative importance values for each criterion. Calculate the geometric mean for each row of the matrix and normalize the values to obtain the relative weights. Normalization involves dividing each value in a row by the sum of all values in that row. The resulting values represent the relative importance or weights of the criteria.
iv. Consistency Check: Assess the consistency of the pairwise comparison matrix to ensure reliable results. Calculate the consistency ratio (CR) by dividing the consistency index (CI) by the random index (RI). The CI is a measure of the matrix's inconsistency, while the RI is a random consistency index derived from the matrix's size. If the CR exceeds a predetermined threshold (e.g., 0.1), the pairwise comparisons may be inconsistent, and revisions should be made.
v. Refine Pairwise Comparisons (if necessary): If the pairwise comparisons are inconsistent ($CR > 0.1$), review and revise the comparisons to improve consistency. Iteratively adjust the values until a consistent set of pairwise comparisons is achieved.
vi. Synthesize Results: Aggregate the relative weights obtained from the pairwise comparisons to obtain the overall weights for each criterion. Multiply the relative weights of each criterion by the weights of its parent criterion, working up the hierarchy until the top-level criterion is reached. The resulting values represent the final relative weights of each criterion.

It's important to note that this is a general outline of the steps involved in assigning relative weights in AHP. The actual implementation may vary based on the specific context of the flood risk assessment and the available software or tools for AHP analysis.

Additionally, expert judgment and stakeholder input may be required throughout the process to ensure a comprehensive and accurate weighting of the criteria.

2.8. FLOOD RISK ASSESSMENT CRITERIA

For the assessment of flood risk at Kikuletwa River, several criteria have been considered. These criteria encompass both natural and human-induced factors that influence the likelihood and severity of flooding. The selected criteria include slope, elevation, topographic wetness index, curvature, drainage density, distance to the river, land cover, NDVI, precipitation and soil. To facilitate the integration of criteria, reclassification into a standardized scale is necessary. In this study, the criteria have been reclassified on a scale of 1 to 5, where 1 represents very low vulnerability, 2 low, 3 moderate, 4 high and 5 represents very high vulnerability. This reclassification allows for the quantitative analysis and comparison of different criteria within the flood risk assessment framework (Andrés & Julio, 2020).

CHAPTER THREE

METHODOLOGIES

3.1 OVERVIEW

This chapter comprises of all data acquisition, procedures and all methods used so as to fulfill all objects of the research and getting the intended outputs. So as to assess the flood risks, we first have to understand that the flood risk is the product of flood hazard and vulnerability. In this case we are going to assess the flood hazard and vulnerability. The chapter has various section including section 3.2 showing all data used their format, resolution and their sources. Another section is section 3.3 explaining about data preprocessing that data are prepared to be ready to use, section 3.4 explaining all flood criteria how they were obtained, section 3.5 explains flood hazard how it was obtained from the criteria used. It includes AHP calculations and tables that were used so as to get the final product. All of the processes are expressed in figure 3.1 Methodological flow chart.

3.2 DATA ACQUISITION

The following table 3.1 showing lists of data acquired so as to make the research successful. Then data acquired were processed so as to obtain the required final output

Table 3. 1 Shows the data used

DATA	FORMAT	RESOLUTION	SOURCE
SRTM_DEM	TIFF	30m	Earth Explorer (USGSS) (http://earthexplorer.sdgs.gov)
RAINFALL DATA	TIFF & CSV	4km	Terr Climate & Tanzania Metrological Authority (TMA)
SOIL	TIFF	-	FAO-UNESCO
ADMINISTRATIVE BOUNDARY	SHAPEFILE	-	DivaGIS (http://www.diva-gis.og)
POPULATION DATA	CSV	-	NBS
LAND COVER, NDVI	RASTER	10m	GEE

3.3 METHODOLOGICAL FLOW CHART.

Chart below show the work plan from the acquisition of data to processing and to output finally

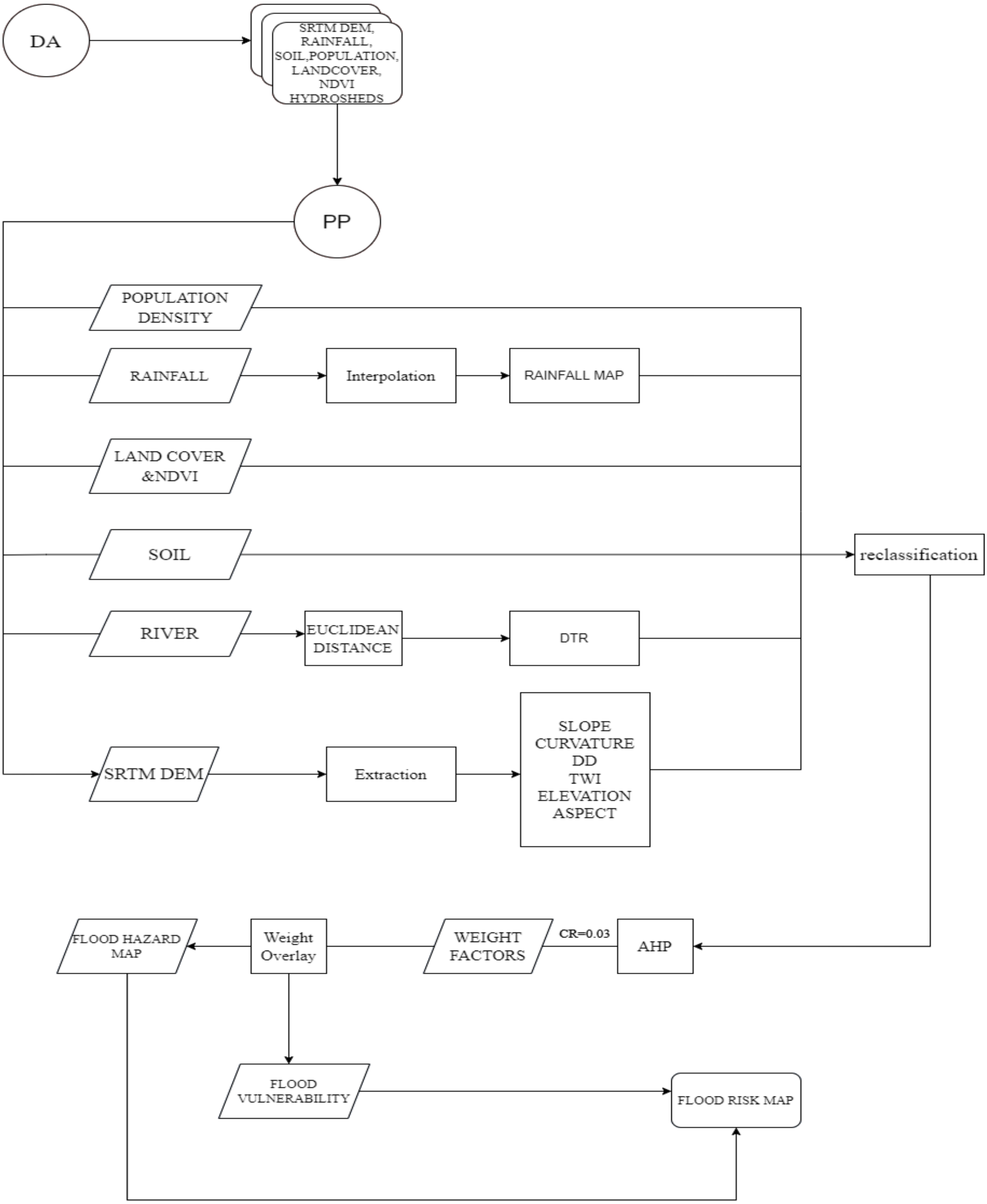

Figure3.1 Methodological flowchart

3.4. PRE-PROCESSING

This is the initial stage when dealing with data collected, it involves data preparation for further processing so as to obtain products free from errors and of good quality (good results). It involves processes such as clipping, preparation of shapefile and reprojection.

3.5 FLOOD INDEXES GENERATION

This was done by first importing the DEM in the software and then the required indexes such as slope, topographic wetness index, curvature, drain density and elevation were obtained. Other variables such as NDVI and Soil type were obtained from Satellite Image and world digital soil map respectively. The rainfall variable and distance to river were obtained, where rainfall was obtained by using IDW interpolation and distance to river was obtained by using hydro river shapefile of the location area.

3.5.1 Slope

The DEM was added in the ArcGIS then from spatial analyst toolbox navigate to surface analysis then slope. The slope dialogue will open and DEM was selected as the input raster. The slope is always calculated by the method known as "3x3 neighborhood" algorithm. This algorithm calculates the slope for each cell in the DEM by fitting a plane to a 3x3 window of neighboring cells and determining the angle of the steepest descent. Also, there are some parameters that have been used including input raster, output measurement units and slope measurement type which are DEM raster and degree respectively. To calculate the slope from a Digital Elevation Model (DEM), you can use the Slope tool. The Slope tool calculates the maximum rate of change in elevation between each cell and its neighbors, resulting in a slope value for each cell in the DEM. Equation 3.1 and 3.2 shows the formula for slope.

Here's the formula to calculate slope:

$$Slope = \frac{Rise}{Run} \qquad \text{………………. (3.1)}$$

Where;

$Rise$ is the change in elevation between cells.

Run is the horizontal distance between cells.

In ArcGIS, the Slope tool uses the following equation to calculate the slope:

$$Slope = \left[A\tan\left\{\sqrt{\left({dz/_{dx}}^{2} + {dz/_{dy}}^{2}\right)}\right\}\right] \times \left[\frac{180}{\pi}\right]$$

Where;

$dz/_{dx}$ is the partial derivative of the elevation surface in the x-direction

(Change in elevation along the x-axis).

$dz/_{dy}$ is the partial derivative of the elevation surface in the y-direction

(Change in elevation along the y-axis).

$A\tan\{\quad\}$ is the arc tangent function.

π (pi) is a mathematical constant representing the ratio of a circle's circumference to its diameter

(Approximately 3.14159).

The Slope tool performs this calculation for each cell in the DEM to generate a slope raster layer. The resulting slope values represent the steepness or gradient of the terrain at each location. This formula assumes that the DEM data is in a consistent coordinate system with elevation values in the same unit of measurement.

3.5.2 Aspect

An aspect map is prepared from the DEM. The aspect is typically calculated using a method known as the "8-direction" or "9-direction" algorithm. This algorithm determines the downslope direction from each cell in the DEM by examining the elevation values of neighboring cells.

3.5.3 Curvature

This follows the same procedures as how you create slope and aspect map but in the spatial analysis, we choose curvature where DEM was an input raster. To calculate curvature from a Digital Elevation Model (DEM), you can use the Curvature tool. The Curvature tool calculates the rate of change in slope or the rate of change in slope aspect for each cell in the DEM. Equation 3.3 shows the formula for curvature.

The formula to calculate curvature is as follows:

$$Curvature = \frac{d^2z}{dx^2} - \frac{d^2z}{dy^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Where;

$\frac{d^2z}{dx^2}$ represents the second derivative of the elevation surface with respect to the x-axis.

$\frac{d^2z}{dy^2}$ represents the second derivative of the elevation surface with respect to the y-axis.

3.5.4 Topographic Wetness Index (TWI)

The topographic wetness index is calculated using slope and flow direction as inputs. Whereby the flow accumulation is obtained after getting the flow direction raster into which flow direction is used as an input while calculating the flow accumulation. Equation 3.4 shows formula for Topographic Wetness Index.

The formula for calculating TWI is expressed as;

$$TWI = \ln \frac{\alpha}{\tan \beta + C} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where;

$\propto$ represents flow accumulation

β represents Slope degree

C represent a constant number equal to 0.001

3.5.5 Drainage Density

Drainage density is a measure of how well-defined and dense a network of streams or rivers is within a given area. It is calculated by dividing the total length of all streams or rivers in a watershed by the total area of the watershed. Equation 3.5 shows formula for Drainage Density.

$$Drainage\ Density = \frac{Total\ Stream\ Length}{Watershed\ Area} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

3.5.6 Normalize Difference Vegetation Index

NDVI (Normalized Difference Vegetation Index) is a commonly used index in remote sensing and GIS to assess vegetation health and density. It quantifies the difference between the reflectance of near infrared (NIR) and red-light bands captured by remote sensing sensors. Equation 3.6 shows the formula for Normalized Difference Vegetation Index.

The formula to calculate NDVI is as follows:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \qquad \text{………………….} (3.6)$$

Where;

NIR is the spectral reflectance in the near-infrared band.

Red is the spectral reflectance in the red band.

By using Google Earth Engine some code was run with regard of the formula above to get the $NDVI$

3.6 FLOOD HAZARDS ON THE STUDY AREA

The flood susceptibility map was obtained by integrating all 10 indicators to flood which were reclassified into the scale of 1 to 5 as 1 represents Very low susceptible, 2 low, 3 moderate, 4 high and 5 very high. By using weight overlay the flood hazard map was obtained. Each flood indicator has its weight that obtained from AHP.

In AHP there are about three steps that are to be followed so as to get the weight for weight overlay. First is by determining the geometric mean, the geometric mean is obtained from the Pairwise Matrix into which each criterion is given an importance. Thomas L. Saaty (1987) provided a scale that can be used to give the importance to each factor the scale ranges from 1 to 9 as shown on the table 3.2. After assigning the scale Geometric mean is found, (Table 3.3) is a pairwise matrix table which shows the scale of importance given to the criteria.

Next, the normalized pairwise comparison matrix table (Table 3.4) was prepared by dividing each value in the column in the pairwise comparison matrix by the sum of the column. In this stage, the weight of each factor was computed (Table3. 4) by dividing the sum of each row in the normalized pairwise comparison matrix table by the number of factors. The weight of each factor needs to be checked if correct. Equation 3.7 shows formula for Consistence of weights.

The following formula was used to check the consistence of the weight obtained.

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad \text{……………….} (3.7)$$

Where;

CI is the consistency index

n is the number of factors

λ_{max} is the highest eigenvalue of the pairwise comparison matrix.

The highest eigenvalue can be calculated to different table, as suggested by Saaty the maximum eigenvalue (λ_{max}) of the comparison matrix was calculated (Table 3.5) by the following procedures:

i. multiplying each value in the column (in the matrix table which is not normalized) by the criteria weight
ii. computing the weighted sum value by adding the values in the rows
iii. calculating the ratio of each weighted sum value to the respective criteria weight, and averaging the ratio of the weighted sum value to the criteria weight.
iv. Finally, the consistency ratio (CR) was computed using the following equation suggested by Saaty (1987) to verify the consistency of the comparison. Equation 3.8 shows formula for Consistence Ratio.

$$CR = \frac{CI}{RI} \qquad \text{………………... (3.8)}$$

Where;

CR is consistency ratio

RI is Random index which varies

CI is consistency Index

RI varies depending on the numbers of factors in the pairwise matrix. The pairwise comparison matrix is said to be consistency if the CR is below 0.10, the CR obtained from our tables was 0.03

Table 3.2 Shows the Saaty scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contributing equally to the object
2	Weak or Slight	Experience and judgment slightly favor one activity over the other
3	Moderate	Experience and judgment strongly favor one activity over the other
4	Moderate plus	
5	Strong importance	An activity is favored very strongly over the other
6	Strong plus	
7	Very strong	An activity is favored very strongly over the other
8	Very, very strong	
9	Extreme Importance	The evidence favoring one activity over the other in the highest

The following is the pairwise matrix that has assigned the value to each criterion and providing the geometric mean.

Table 3.3 Shows the Pairwise Matrix

	AW	Rf	DTR	Soil	Slope	TWI	Dd	NDVI	LC	Cu	El	GM
Rf	9.00	1.00	1.50	1.50	1.29	1.80	2.25	1.50	1.29	2.25	1.13	1.55
DTR	6.00	0.67	1.00	1.00	0.86	1.20	1.50	1.00	0.86	1.50	0.75	1.03
Soil	6.00	0.67	1.00	1.00	0.86	1.20	1.50	1.00	0.86	1.50	0.75	1.03
Slope	7.00	0.78	1.17	1.17	1.00	1.40	1.75	1.17	1.00	1.75	0.88	1.21
TWI	5.00	0.56	0.83	0.83	0.71	1.00	1.25	0.83	0.71	1.25	0.63	0.86
Dd	4.00	0.44	0.67	0.67	0.57	0.80	1.00	0.67	0.57	1.00	0.50	0.69
NDVI	6.00	0.67	1.00	1.00	0.86	1.20	1.50	1.00	0.86	1.50	0.75	1.03
LC	7.00	0.78	1.17	1.17	1.00	1.40	1.75	1.17	1.00	1.75	0.88	1.21
Cu	4.00	0.44	0.67	0.67	0.57	0.80	1.00	0.67	0.57	1.00	0.50	0.69
El	8.00	0.89	1.33	1.33	1.14	1.60	2.00	1.33	1.14	2.00	1.00	1.38
SUM		6.89	10.33	10.33	8.86	12.40	15.50	10.33	8.86	15.50	7.75	10.68

Table 3.4 below shows the Normalized pairwise comparison matrix and calculated weight for each criterion.

Table 3.4 Shows the normalized matrix

	RF	DTR	SO	SL	TWI	DD	NDVI	LC	CU	EL	CRITERIA WEIGHT	%WEIGHT
RF	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	13
DTR	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	10
SO	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	11
SL	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	11
TWI	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	8
DD	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	6
NDVI	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	10
LC	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	11
CU	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	5
EL	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	15
SUM												100

The following table 3.5 shows the calculation of consistency of pairwise comparison (CR=0.03)

Table 3.5 Consistency ratio

CW	0.13	0.1	0.11	0.11	0.08	0.06	0.1	0.11	0.05	0.15		
	RF	DTR	SO	SL	TWI	DD	NDVI	LC	CU	EL	WS	λ
RF	0.13	0.15	0.17	0.14	0.14	0.14	0.15	0.14	0.11	0.17	1.44	11.06
DTR	0.09	0.10	0.11	0.09	0.10	0.09	0.10	0.09	0.08	0.11	0.96	9.59
SO	0.09	0.10	0.11	0.09	0.10	0.09	0.10	0.09	0.08	0.11	0.96	8.72
SL	0.10	0.12	0.13	0.11	0.11	0.11	0.12	0.11	0.09	0.13	1.12	10.17
TWI	0.07	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.06	0.09	0.80	9.99
DD	0.06	0.07	0.07	0.06	0.06	0.06	0.07	0.06	0.05	0.08	0.64	10.65
NDVI	0.09	0.10	0.11	0.09	0.10	0.09	0.10	0.09	0.08	0.11	0.96	9.59
LC	0.10	0.12	0.13	0.11	0.11	0.11	0.12	0.11	0.09	0.13	1.12	10.17
CU	0.06	0.07	0.07	0.06	0.06	0.06	0.07	0.06	0.05	0.08	0.64	12.78
EL	0.12	0.13	0.15	0.13	0.13	0.12	0.13	0.13	0.10	0.15	1.28	8.52
SUM												10.12

After obtaining the criteria weight, weight overlay was performed using ArcGIS so as to obtained the flood hazard output.

3.7 FLOOD RISK MAP

The flood risk map was obtained by weight overlay where the reclassified flood hazard output and factors for flood vulnerability which are distance to road population and land cover were also reclassified and assigned their weight as follows, flood hazard was assigned a weight of 35%, Land Cover 25%, population and Distance to Road were assigned a weight of 20%.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 OVERVIEW

This chapter will present and discuss all the products obtained in different executions so as to accomplish the research. The results to be presented includes all indicators to both flood hazard and vulnerability including slope, aspect, drainage density, elevation, topographic wetness index, distance to river, soil texture type, normalized difference vegetation index, rainfall and Total population, Land Cover, distance to road respectively. Also, this chapter will involve variable importance graphs, flood risk map as well as validation results.

4.2 FLOOD HAZARD INDICATORS

These are tools or measures used to assess the potential risk and like hood of flood in the project area or area of interest. These indicators help in identifying areas that are prone to flooding and provide valuable information for effective flood risk management and planning. The indicators take into account various factors that contribute to the occurrence and severity of flooding. The following are maps of various flood hazard indicators. The flood indicators include the slope, aspect, elevation, drainage density, curvature, topographic wetness index, soil type, Normalize Vegetation Index, Land Cover, distance to river and rainfall.

4.2.1 Elevation

The elevation of the study area ranges from 676 to 5886 meters from the sea level. This shows that it has mountains and some plain surfaces. The map was reclassified again into the scale of 1 to 5. The first class was 676-1138m, it was reclassified as 5 a very highly vulnerable to flood because the area is lower elevated, the second class was 1138-1600m was reclassified as high,1600-2357m it was reclassified as moderate, 2357-3531m was reclassified as low and the last class 3531-5886m was reclassified as very law vulnerable to flood because it is a high elevated area. Generally, the lower elevated areas have a higher probability of flood occurrences compared to higher elevated areas because lower elevated areas have comparatively higher river dis-charge and get flooded faster by the flow of high water. Figure 4.1 show the reclassified elevation map of the study area.

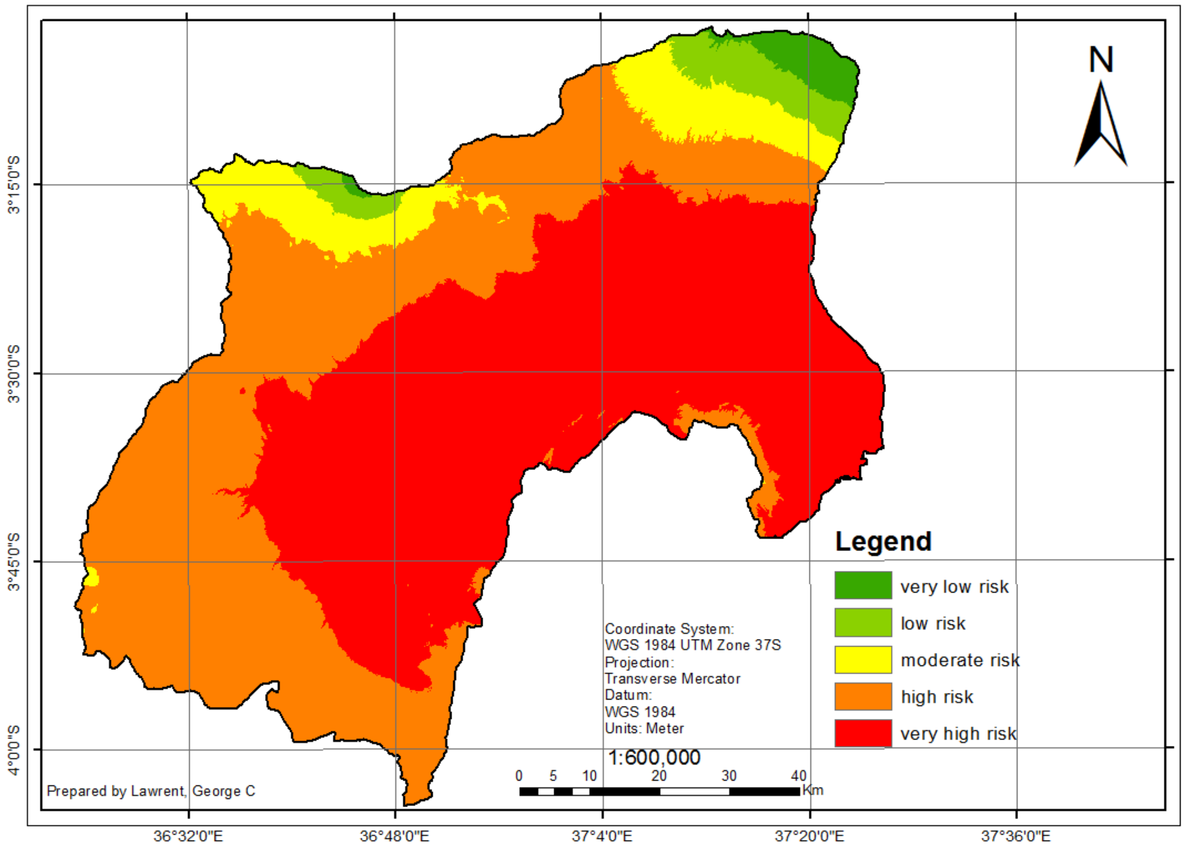

Figure 4.1: Reclassified Elevation Map.

4.2.2. Slope

The nature of the slope distribution that covers the study area ranges from 0 to 81.3694 degrees which is maximum value. The slope of the land controls the velocity of surface water flow. As the slope decreases, the velocity of surface water flow decreases, and the amount of water over the land and the probability of a flood increases. (Astutik et al. 2021; Das and Gupta 2021; Zzaman et al. 2021). Mountain areas generally have steeper slopes that prevent the collection of water, whereas lowlands or flatlands with gentle slopes have a higher probability of flood inundation. The slope of our study area was reclassified into the scale of 1 to 5 as follows, 0-3.8, 3.8-9.6, 9.6-18.2, 18.2-30.6, 30.6-81.4 as very high, high, moderate, low, and very low vulnerable to floods, respectively. Figure 4.2 shows nature of slope distribution of the study area.

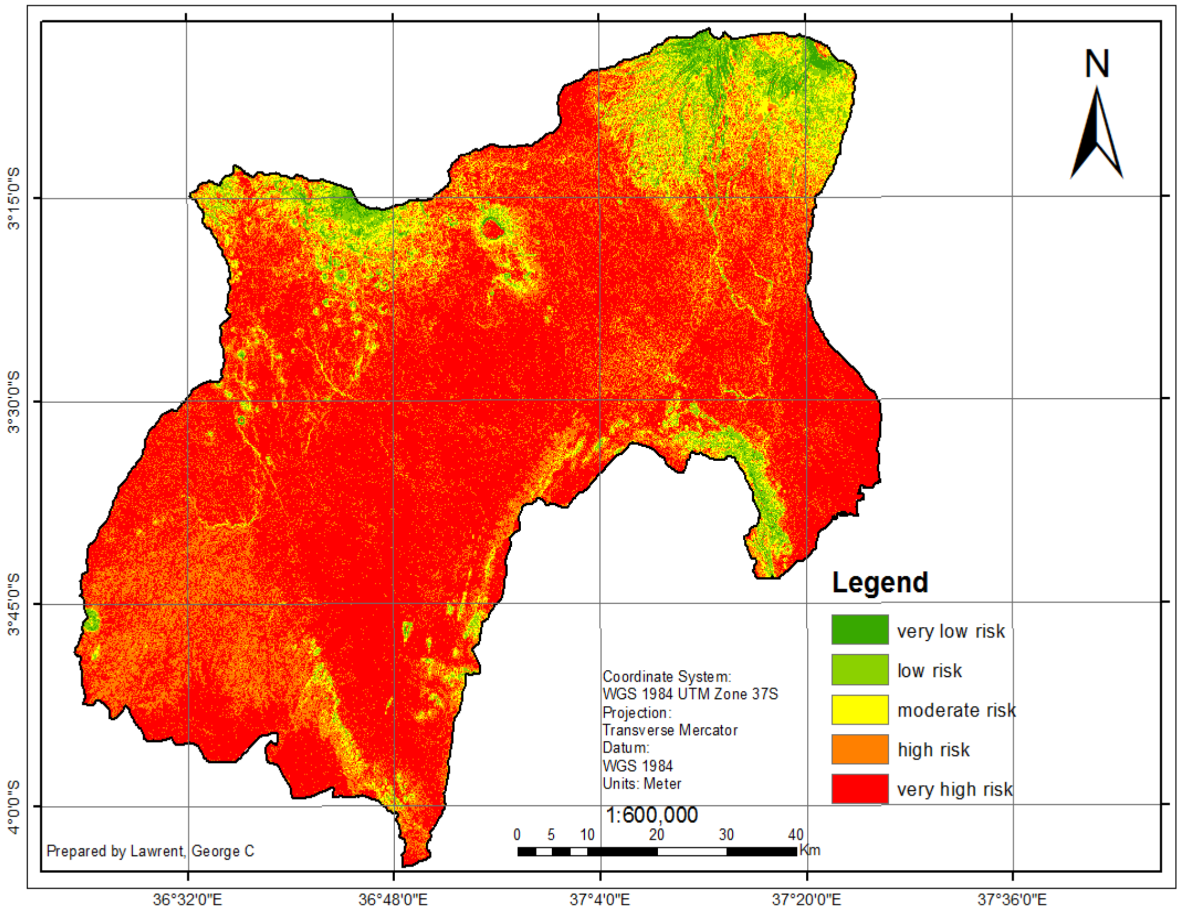

Figure 4.2: Reclassified Slope Map.

4.2.3 Aspect

An aspect map is the representation of the directional orientation or slope aspect of the terrain surface. T provide information about the direction that the slope faces, usually expressed in degrees or as cardinal direction North(N), South(S), East(E), West(W), NE, NW, SE, SW and others. The slope orientation in our study area includes N, S, E, W, NE, NW, SE, SW as well as flat meaning that the slope is not oriented in any direction. Mostly in dams and rivers slope is not oriented in any direction.

4.2.4 Topographic Wetness Index

TWI of the study area ranges from -10 up to 14.3902 showing that areas with high TWI value are likely to be at high susceptible to flood. TWI was reclassified into the scale of 1 to 5 as -10 to -5, -5 to -3, -3 to -1, -1 to 2 and 2 to 14 as very low, low, moderate, high., very high respectively. The TWI is directly proportional to flood risk; the higher the TWI value, the greater the likelihood of flood inundation this is simply because TWI is an index used to quantity the topographical effect on runoff generation and flow accumulation volume at any given place. It depicts the tendency of water to collect at a given spot or travel downhill due to gravitational pressure (Lee and Rezaei 2022). Figure 4.4 shows the reclassified TWI of the study area.

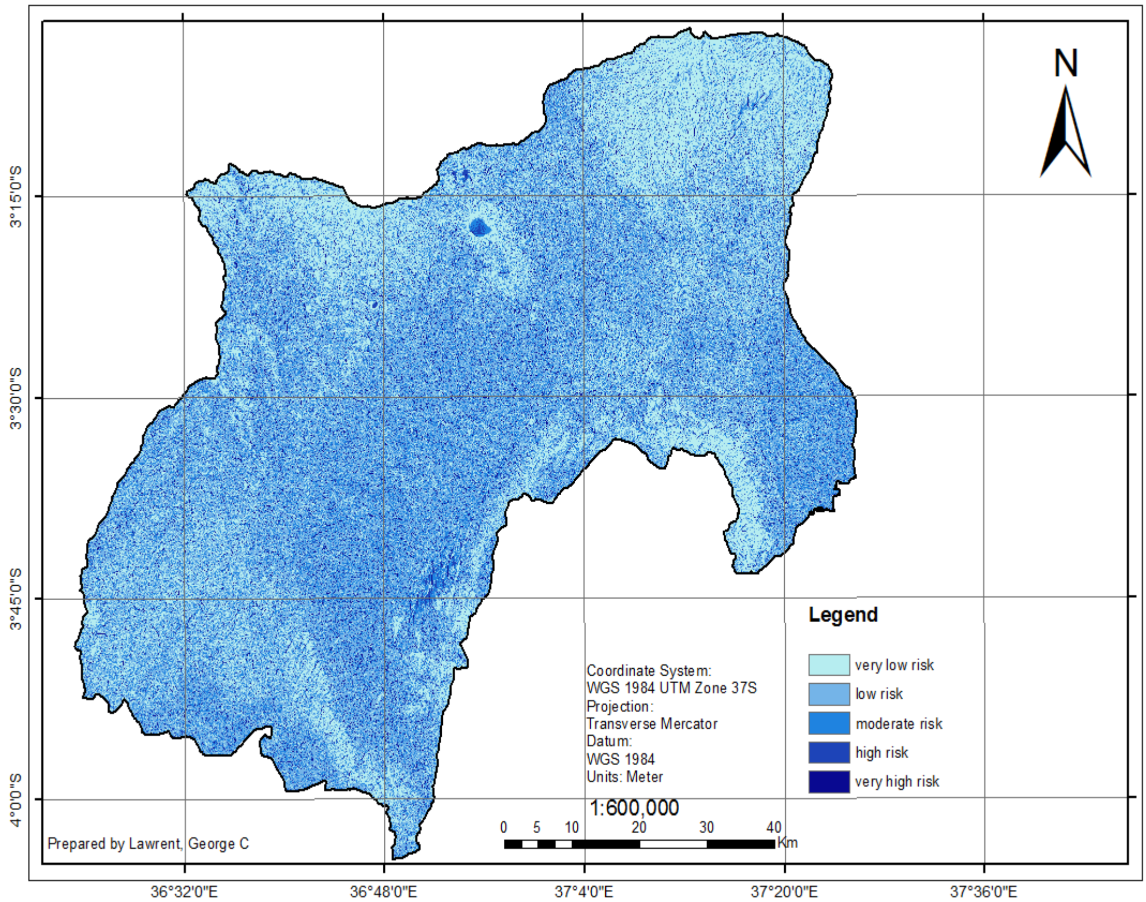

Figure 4. 3 Reclassified Topographic Wetness Index map

4.2.5 Curvature

The curvature values in the study area ranges from -5.3136e+11 the minimum value up to 1.12104e+12. The curvature information obtained from DEM can provide information to flood hazard mapping in the following ways, identifying the river channel location and its extent within a watershed. It becomes possible to delineate the possible main river channel and its distributaries. In the study area, areas with high curvature and meandering channels tend to have broader floodplains, which are prone to inundation during flood events and vice versa. The curvature was also reclassified into scale of 1 to 5. A positive curvature value indicates a convex surface, a negative curvature value indicates a concave surface, and a value close to zero indicates a flat surface, and the flat curvature is very prone to flooding followed by concave and convex. Figure 4.5 shows the reclassified curvature of the study area.

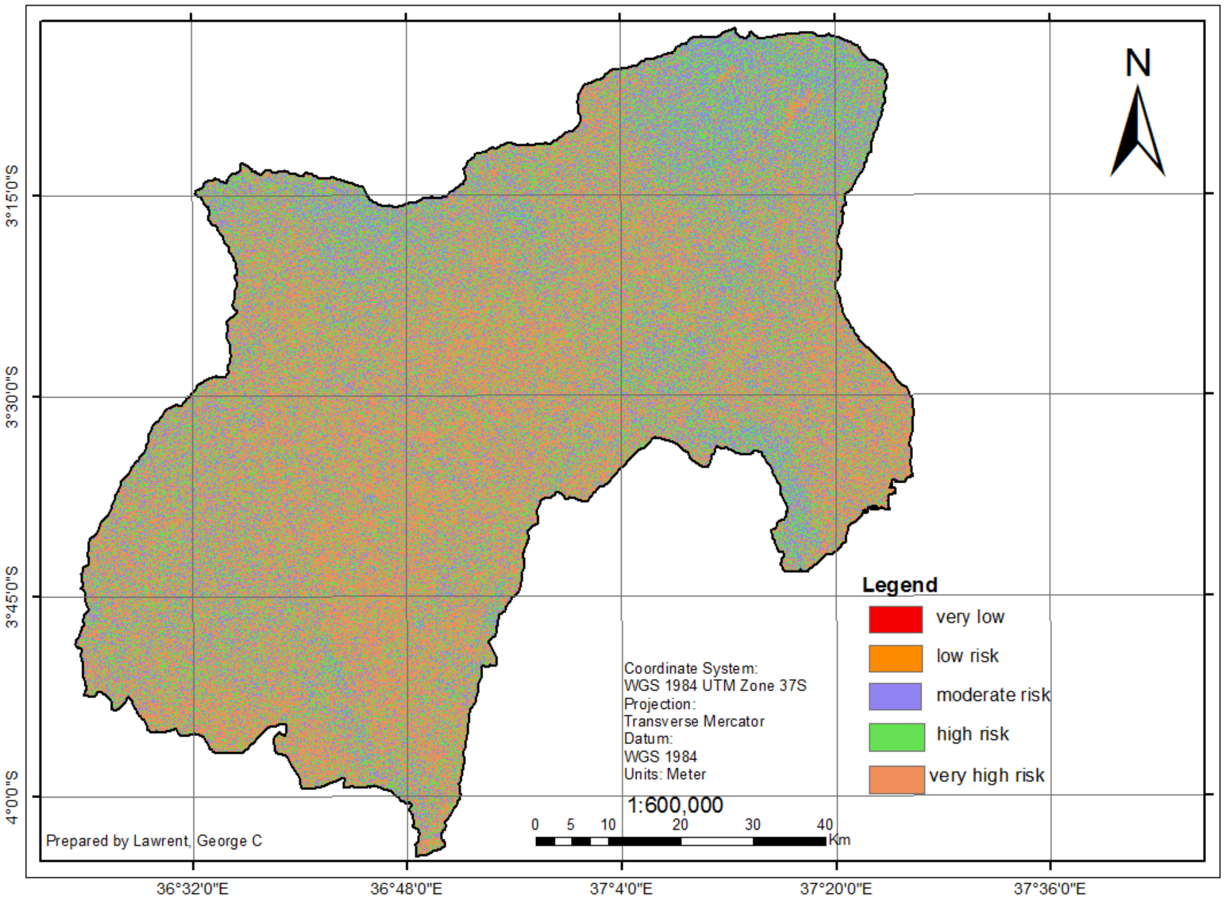

Figure 4.4Reclassified Curvature map.

4.2.6 Drainage Density

The drainage density represents the ratio of the total length of streams within an area to the size of the area (Zzaman et al. 2021). The higher the drainage density, the higher the surface runoff and the higher the probability of flooding. Drainage density was reclassified into the scale of 1 to 5 as follows 7 to 103, 103 to 172, 172 to 239, 239 to 320 and 320 to 496 as very high, high, moderate, low and very low respectively. Figure 4.6 shows the reclassified drainage density map. Figure4.6 shows the reclassified drainage density.

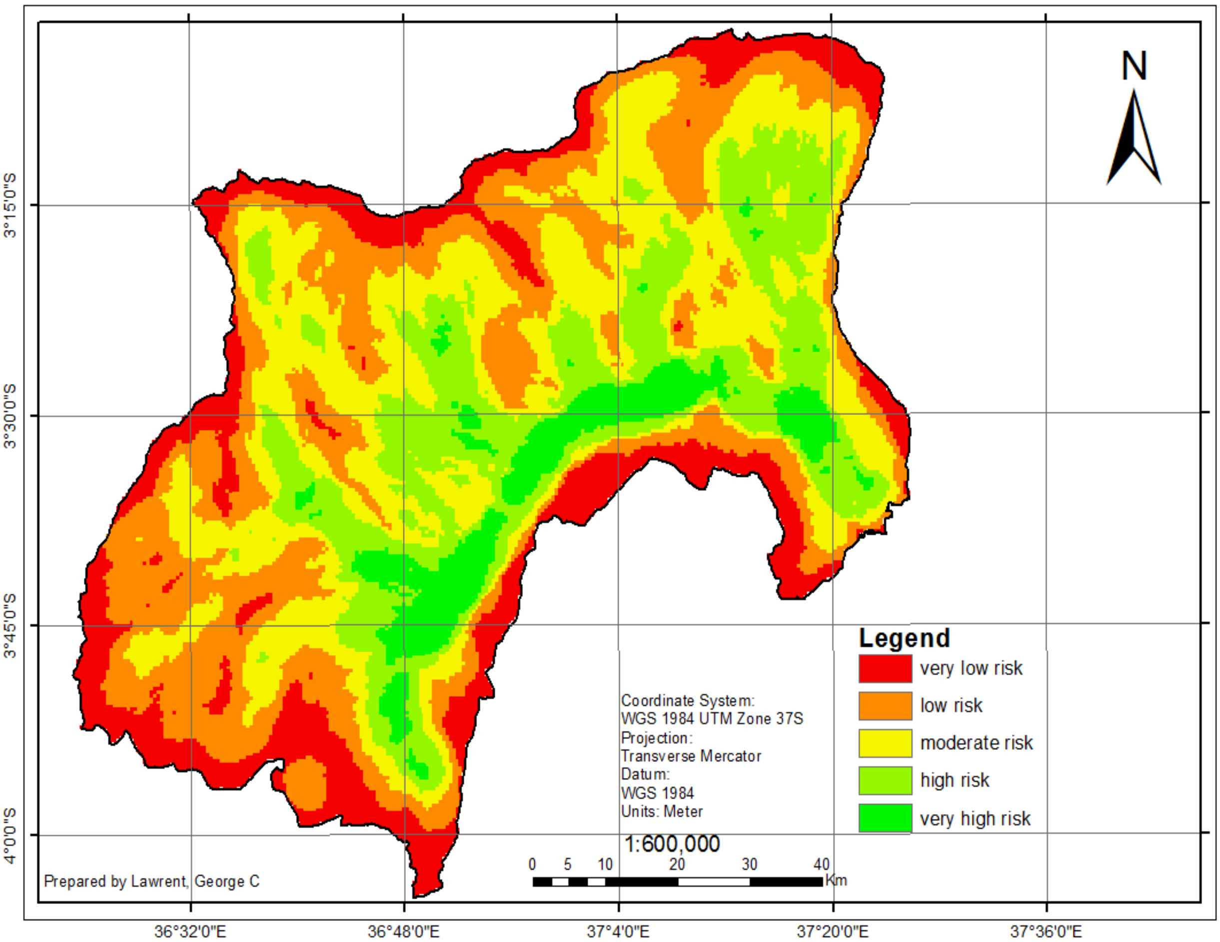

Figure 4.5 Reclassified Drainage Density

4.2.7 Distance to River

Areas that are close to rivers have a higher probability of flood inundation than areas located far away from the rivers since surplus water from the river initially reaches alongside river banks and adjoining lowland areas (Mahmoud and Gan 2018). This is because as the distance increases, the slope and elevation become higher. Area that are closer to river were reclassified as 5 very high susceptible to flood while areas that are too far from the river were classified as very low susceptible to flood. Figure 4.7 shows the reclassified map of distance to river.

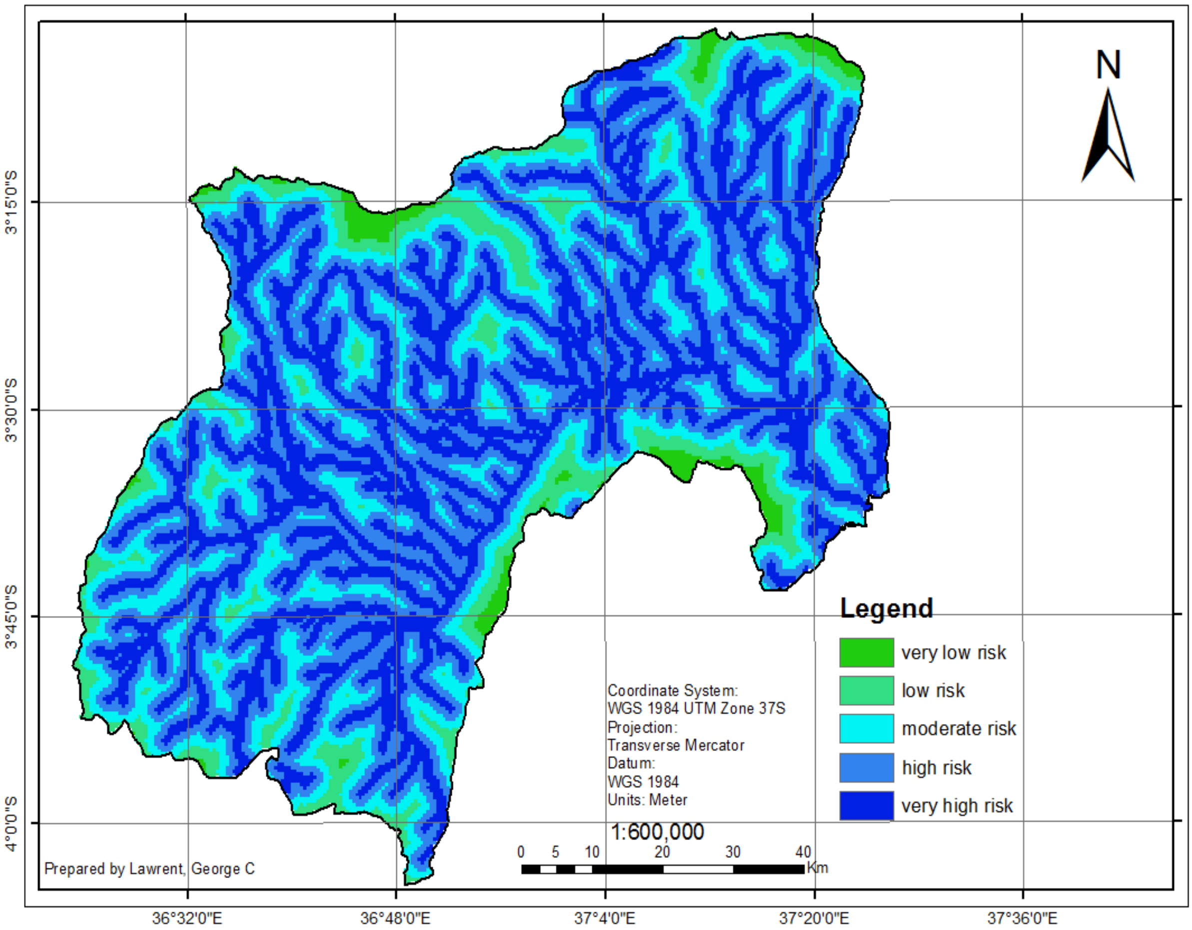

Figure 4.6 Reclassified Distance to river map

4.2.8 Rainfall

This is one of the greatest factors when dealing with flood, no rainfall no flood. I can say rainfall is the key driving factor for flood occurrence. The mean annual rainfall for about 10 years from 2012 to 2022 was obtained. The mean annual rainfall values vary as 32 to 51mm, 51 to 70mm, 70 to 89mm, 89 to 108mm, 108 to 127mm. the values were reclassified into the scale of 1 to 5 as very low, low, moderate, high and very highly vulnerable to flood respectively. Figure 4.8 shows the reclassified rainfall map.

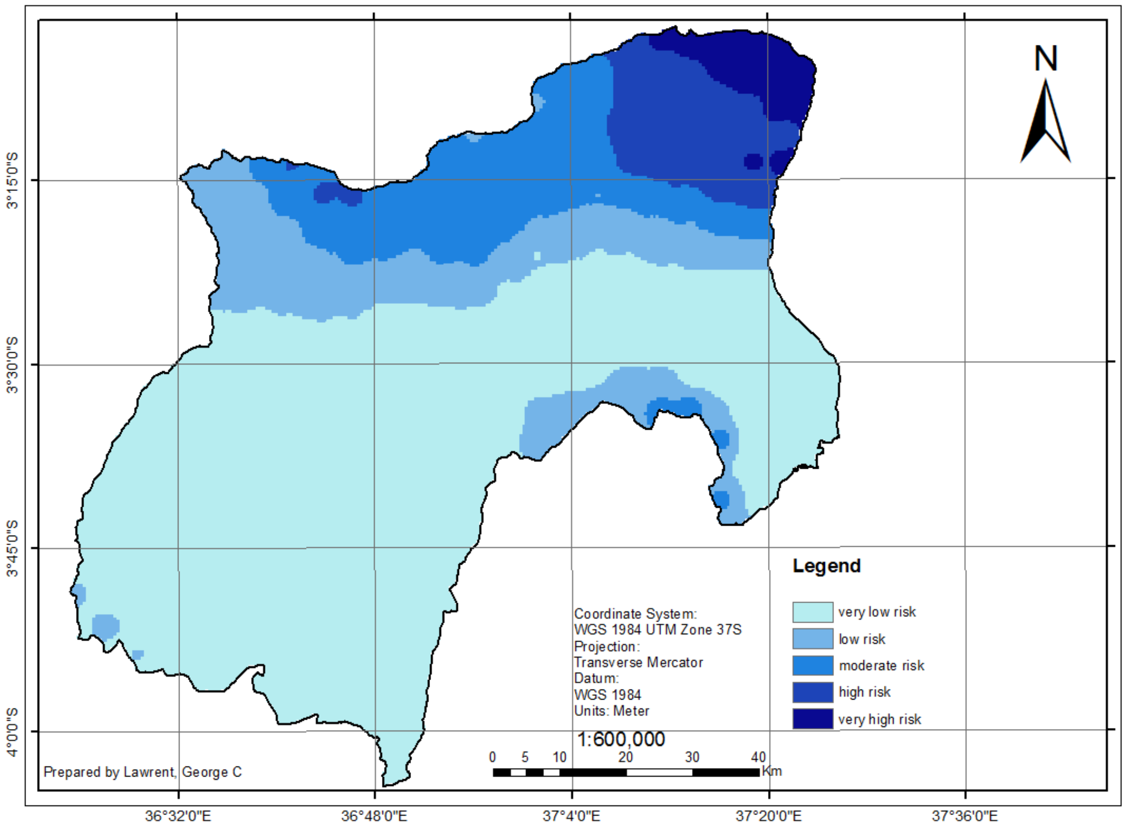

Figure4.7 Reclassified Rainfall map

4.2.9 Land Cover

Land cover is another important factor for flood since the presence of vegetation on land can affect the occurrence of flood. Areas with dense vegetations tends to hinder the flow of water and induces high infiltration. So, these areas are less susceptible to flood. Town areas or areas with residence tend to have high runoff and little infiltration due to impermeable surfaces. Allafta and Opp (2021) considered shrub land, cropland, bare land, urban, and waterbody as very low, low, moderate, high, and very high susceptibility to flooding, respectively. Das and Gupta (2021) categorized waterbody, build-up, agriculture, sparse vegetation, and dense vegetation as very high, high, moderate, low, and very low vulnerability to flooding, respectively. Hagos et al. (2022) also classified built-up areas, farmland, grassland, shrubland, and forestland areas as extremely high, high, moderate, low, and extremely low vulnerability to flooding, respectively. So, as well as in the study area permanent water bodies and built-up area as very high, cropland as high, grassland and bare/spares vegetation as moderate, shrubland as low and tree cover area as very low. Figure 4.9 shows the reclassified Land cover map.

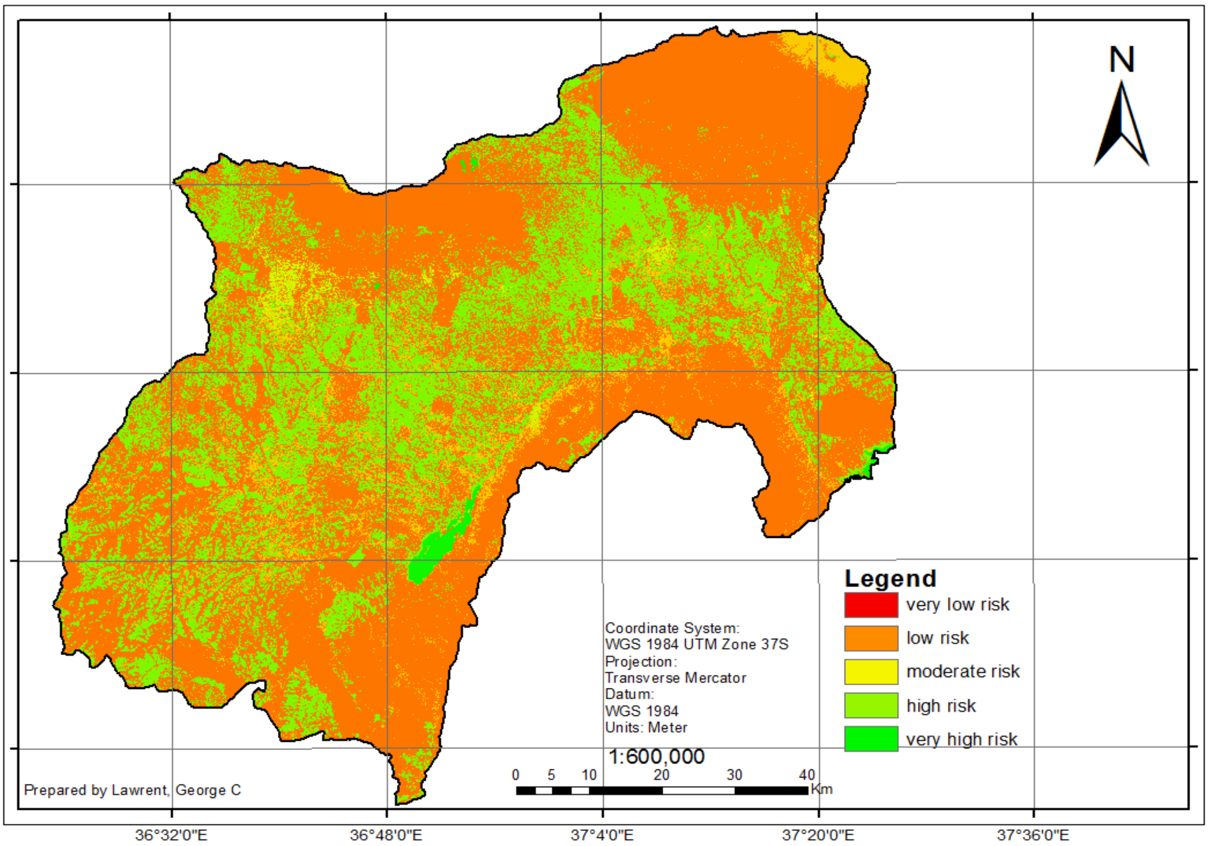

Figure 4.8 Reclassified Land Cover map.

4.2.10 NDVI

Normalize difference vegetation index is another factor to be considered while assessing the flood risks in a given area. It tells about the amount and health of vegetation on the given area. Higher vegetation density decreases the speed of the runoff and flood inundation (Tehrany et al. 2017). This study considered areas with NDVI values from − 0.52 to -0.02, -0.02 to 0.28, 0.28 to 0.42, 0.42 to 0.50, and 0.60 to 0.87 as very high, high, moderate, low and very low susceptible to flooding, respectively. Figure 4.10 shows the reclassified NDVI of the study area

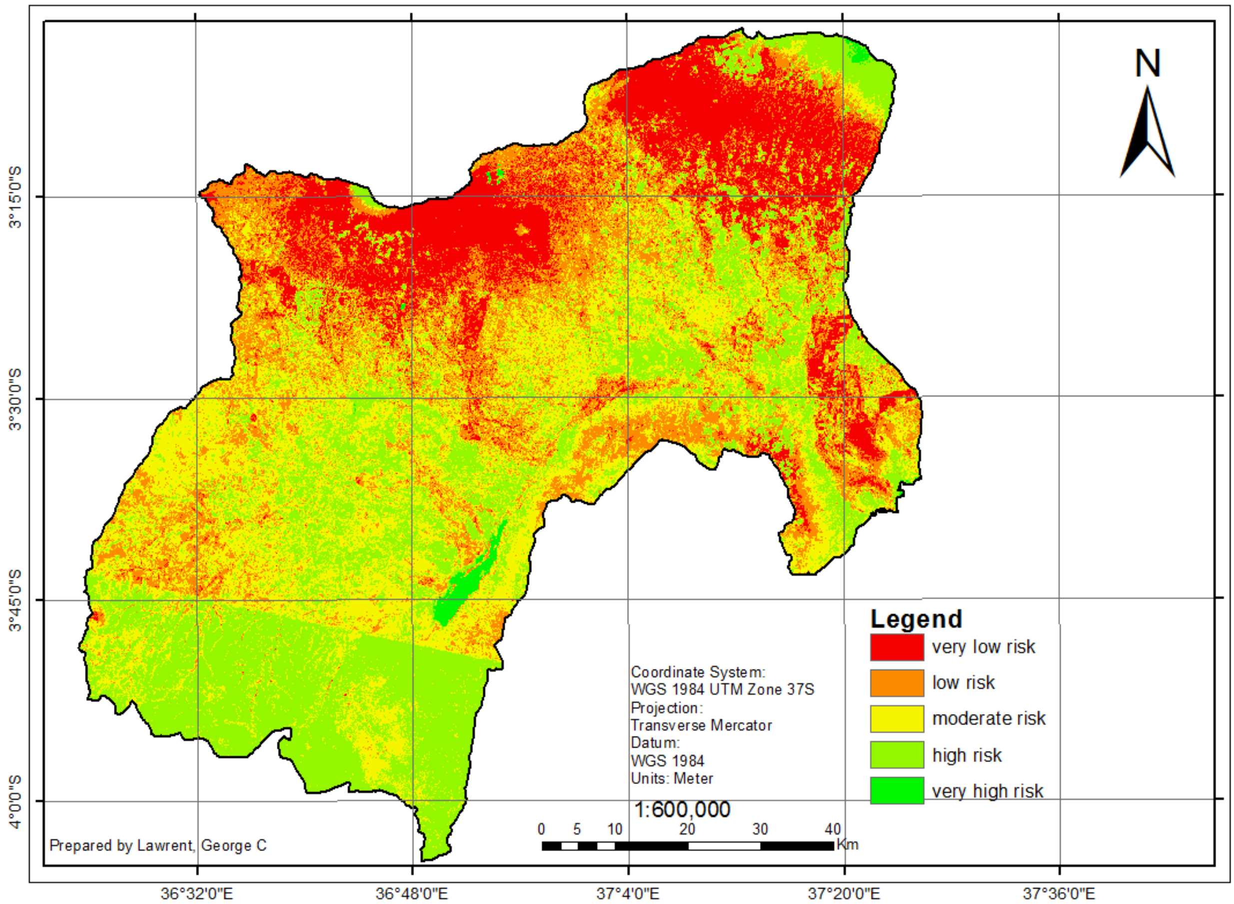

Figure 4.9 Reclassified NDVI

4.3 FLOOD RISK MAP

The flood hazard map of the study area was obtained. The map shows that most areas at the low-lying elevation and near rivers are at high risk to flood and areas of the mountain are at very low risk to flood. Some areas of Arusha and Hai are the one at high risk to flood also most of the Simanjiro area and Moshi rural are at moderate risk to flood compared to others. The flood vulnerable factors population density, land cover and distance to river were reclassified to scale of 1 to 5 as very low, low, moderate, high and very high risk the same to flood hazard it was reclassified to the same scale. This map shows that most parts of Arusha, Hai and both Moshi urban and some parts of Moshi rural are at high risk to flood. On the other hand, areas of Simanjiro, Monduli and Meru are at moderate risk to flood and Rombo areas are at low risk to flood risk.

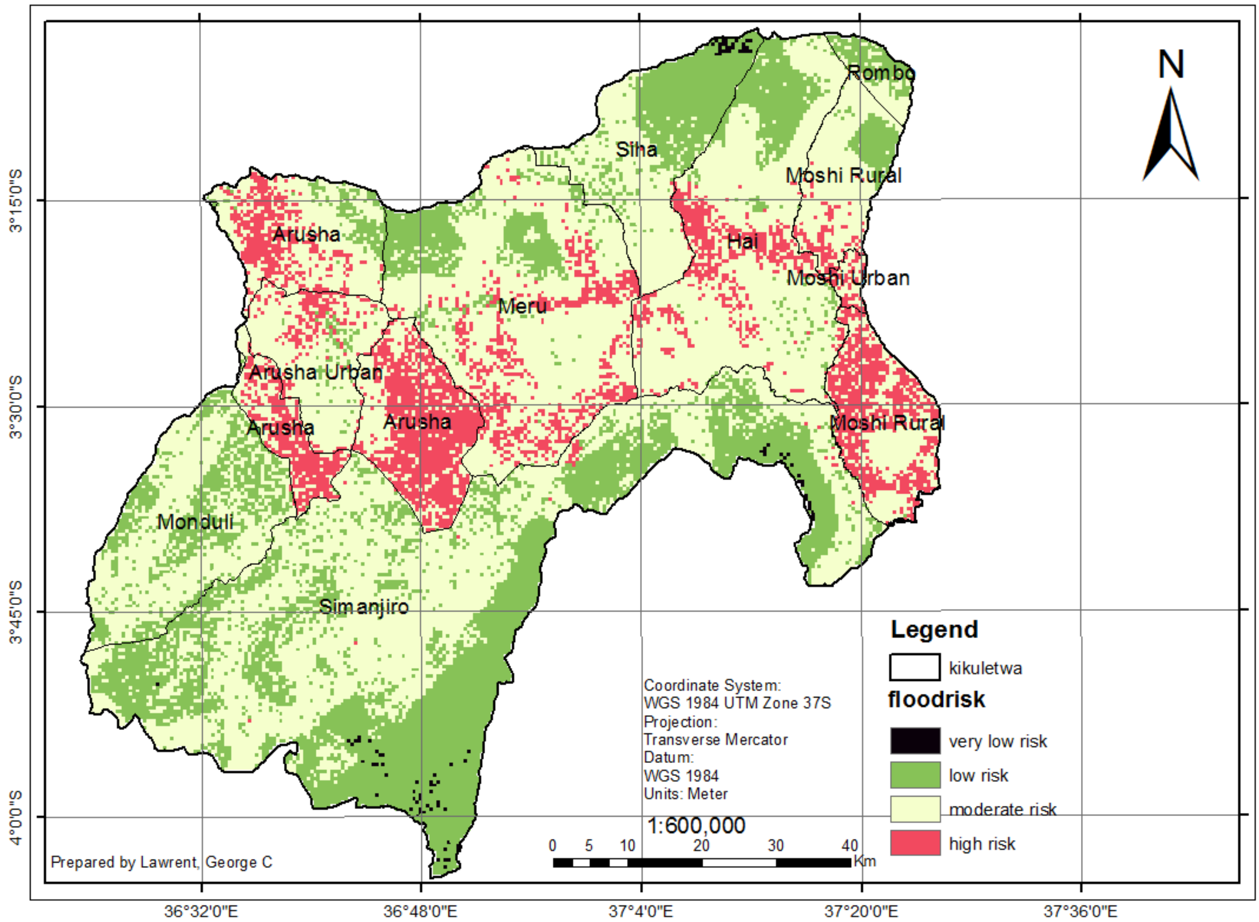

Figure 4.10 Flood risk map

4.4. DISCUSION

The present study focused on conducting a comprehensive flood risk assessment at Kikuletwa River Catchment. The assessment aimed to understand the potential flood hazards and vulnerabilities associated with this river system and provide valuable insights for effective flood management and mitigation strategies in the area. The analysis of hydrological data and topographic information revealed several key findings regarding flood risk at Kikuletwa River. Firstly, the study identified that the river exhibits a high susceptibility to flooding due to its rapid response to rainfall events. The steep slopes surrounding the river and its tributaries contribute to increased surface runoff, which amplifies the flood risk during intense rainfall periods. The downstream areas were found to be particularly prone to flooding, as the river widens and encounters more extensive floodplain areas. The research shows that some parts of Arusha, Hai, Meru, Simanjiro and Moshi Urban that are in a low-lying area are at high risk to flood compared to other areas. Also, Rombo district is at very Low risk to flood. This shows that all low-lying areas close to the river are at high risk to flood.

In addition to hydrological factors, land use patterns and human activities in the vicinity of the river were identified as contributing factors to flood risk at Kikuletwa River. The expansion of agricultural practices near the river, particularly in floodplain areas, has led to increased soil erosion and sedimentation within the river channel. This sedimentation, combined with the natural narrowing of the river in certain sections leading to flood risk during high flow conditions. The conversion of natural wetlands into residential or commercial areas also restricts the natural absorption and storage capacity of the floodplain, further increasing flood vulnerability. The findings of this flood risk assessment have significant implications for flood management and mitigation strategies at Kikuletwa River. The results highlight the need for targeted interventions to reduce flood risk and enhance community resilience in the area. These interventions could include implementing floodplain zoning regulations to limit development in high-risk areas, promoting sustainable land use practices that minimize soil erosion, and improving river channel maintenance to ensure unobstructed flow during flood events. Furthermore, community engagement and awareness programs are essential for fostering a culture of flood preparedness and response. By educating local residents about flood risks, providing early warning systems, and facilitating evacuation plans, the impact of future flood events can be minimized.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this dissertation, we have reviewed and synthesized concepts and techniques of flood hazard and give an overview of recent literature related to mapping flood risk prone areas. Floods are the most common kind of hydro-meteorological disaster on the earth surface. Flooding is the most common of all environmental hazards and it regularly claims over huge number of lives per year and adversely affects around millions of the people world-wide. More than one third of the world's land area is flood prone which affecting around 82 percent of the world population. The only way of tackling this problem is by reducing their impact. Assessing area vulnerable to flood and assessing the risks of flood is one of the biggest steps to minimize the flood impact. By mapping the areas vulnerable to food it's one of the ways to go in reducing the flood impacts.

This research has tried to assess the flood risk prone area at Kikuletwa catchment using technology of Remote sensing and GIS, multi-criteria decision making and AHP. By using these techniques flood risk map was obtained, so the integration of GIS and remote sensing, MCDM and AHP can be used for flood mapping and it can produce better results.

5.2 RECOMMENDATION

Based on the findings and conclusions of this dissertation the following recommendation are proposed;

i. The obtained flood maps can be used in different projects by different stakeholders for mitigation and risk management purpose so as to reduce the impact of flood.
ii. Other methods also could be used to assess the flood risk such as Boosted Regression Trees

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