# ANALYZING THE MORPHOLOGICAL CHANGES OF RIVIRIVI RIVER'S CHANNEL, ITS CAUSES AND IMPACTS: A CASE STUDY OF MANYONGA VILLAGE, T/A NKAYA IN BALAKA DISTRICT.

PRINCE BAKUWA DRM/012/19

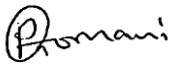
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ABSTRACT

The morphology or physical form of a river plays a vital role in shaping the surrounding environment and impacting the lives of communities residing along its banks. This study examines the morphological changes occurring in the Rivirivi River, with a specific focus on Manyonga Village located in Traditional Authority Nkaya, Balaka District. The primary objectives are to analyze the extent and patterns of these morphological changes, identify the underlying causes driving these changes, and assess the impacts on the local community.

The research employs a remote sensing approach, utilizing satellite imagery spanning multiple decades (1993, 2008, and 2023) to quantify changes in the river's course, erosion patterns, and accretion areas, thereby detecting shifts in the river's path. Additionally, changes in land use/cover and linear regression and Pearson correlation coefficient (r) analyses were conducted on precipitation and discharge data to determine the influencing factors and impacts of the Rivirivi River's changes.

The results indicate that an area of 794.361392 square meters of Manyonga Village has been eroded, representing 0.26% of the total eroded area. The total eroded area is 288,448.64 square meters, accounting for 76.16% of the study area. Accretion or the deposition of sediments, has occurred over an area of 75,573.63 square meters, making up 19.95% of the study area, while 14,703.74 square meters (3.88%) remained unchanged.

The study contributes to a comprehensive understanding of the dynamic nature of the Rivirivi River and its implications for the Manyonga Village community. The findings provide insights into the interplay between natural processes, anthropogenic activities, and climate variability, informing sustainable river management strategies and enhancing resilience in riparian communities.

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ACRONYMS/ABBREVIATIONS

| | |
|---|---|
| DCCMS | Department of Climate Change and Meteorological Services |
| DEM | Digital Elevation Model |
| DNs | Digital Numbers |
| DWS | Department of Water Resources |
| GIS | Geographic Information System |
| LiDAR | Light Detection and Ranging |
| LULC | Land Use and Land Cover |
| RS | Remote Sensing |
| SDGs | Sustainable Development Goals |
| T/A | Traditional Authority |
| USGS | United States Geological Survey |

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# 1.0. INTRODUCTION

## 1.1. Background

Researchers studying river engineering pay close attention to major geomorphological occurrences such as river bank erosion, accretion, and lateral channel migration all over the world (Ibitoye, 2021). Around the world, the habitat of a flood plain was fairly prevalent. Bank erosion results directly from channel displacement. There was a noticeable quick rate of river bank line movement in the world. The morphology of land use is being highlighted by river bank erosion or channel change. Although bank erosion and lateral shifting of river channels in flood plain areas are natural occurrences, human involvement has made them appear less natural. The migration of a river channel typically occurs within a corridor or region, which can be problematic for local residents. As a result of river channel migration and erosion, several individuals had lost their homes, farmland, infrastructure, or livelihoods. The difference in migration rate was a result of a short-term interaction between the rates of cut bank erosion and point bar sediment buildup. The resistance of the banks affects how far the river channel shifts laterally. Anthropogenic actions or natural occurrences can speed up migration. For instance, the rate of migration may be accelerated by clearing vegetation from a flood plain. Because of quick and widespread human intervention in natural processes, the majority of them were semi-natural. Many of them exhibit a shift in the channel's spatial and temporal position. A significant characteristic of lateral channel migration was the erosion of floodplain rock along one bank and uncommonly heavy sedimentation along the other bank (Sarkar et al., 2018).

12 major rivers in Africa are Nile (6,600 km), Congo (4,700 km), Niger (4,184 km), Zambezi (3,540 km), Ubangi-uele (2,270 km), Kasai (2,153 km), Orange (2,092 km), Shebelle (1,820 km), Lualaba (1,800 km), the Kwago (1,770 km), Limpopo (1,750 km) and Okavango (1,700 km)(Matthews, 2022). These rivers were shifting their course due to various factors.

The Niger River's lower section had major spatial changes that affected the local governments of Ajaokuta and Ofu, and in 2020 Ibitoye M. conducted study to assess the channel morphological properties of the river using remote sensing methods. As the primary source of fresh water for the majority of Egypt's people, the Nile River was essential to the country. Using RS and GIS, the study was carried out to examine the morphological changes of the river from the Aswan high dam to the delta Barrages (Egypt) (Negm et al., 2018). Mark Trigg carried out research in 2020 to measure geomorphological changes on the Congo River using remote sensing and navigational charts from a century earlier. These studies all revealed that rivers are changing their courses as a result of sedimentation and the deposition of sediment in meander.

In Malawi, Shire River rises in Samama and runs 400 km south and southeast to its confluence with the Zambezi River in Ziu Ziu, Mozambique. There are upper, middle, and lower sectors of the Shire River Basin, which covers an area of around 18,945 $km^2$ (Mijoni & Izadkhah, 2009). Ground water discharge analysis and characterization, flood management, evaluating land use changes and its impacts on hydrological regime and other related researches are what had been conducted throughout the shire catchment.

Rivirivi originates from Kirk Ranges in Ntcheu district and passes through the western center and southern east part of Balaka district. It drains water in Shire River (Kambuku et al., 2018). The Rivirivi River is a crucial source of water for Manyonga Village, supporting other socioeconomic activities as well as agriculture. Recent observations, however, point to physical modifications in the river's channel, including erosion, sedimentation, and course variations. The lives of the local community may be impacted by these changes, which could result in greater flooding, soil erosion, and changing land use patterns. To guide successful land use planning and resource management methods, a thorough analysis of these morphological changes and their effects was conducted.

## 1.2. Problem Statement

There are various reasons for the shifting of the river channels that are observed throughout Malawi. Many different communities are being impacted by these natural events. There had not been enough research on studies about river morphology in Malawi in terms of course shifting, which makes it difficult for policy makers and other institutions involved in disaster risk management to identify disaster risks and make wise decisions about how to reduce those risks and impacts they might cause. In 2014, Chimtengo et al, conducted a research on analyzing changes in water availability to assess environmental water requirements in the Rivirivi River basin, Southern Malawi which mainly focused on comparing the existing human uses of this river basin with the environmental water needs and highlights the effects of land use and water abstraction techniques on the flow regime.

One of the rivers that is changing its path is the Rivirivi River due to a number of circumstances. The river is rerouting towards Manyonga village, T/A Nkaya in the Balaka district, endangering lives, their properties, and degrading the environment as a whole.

## 1.3. Main Objective

To analyze the spatial morphological changes of Rivirivi River channel, its causes and impacts in Manyonga village, TA Nkaya, Balaka district.

## 1.4. Specific Objectives

- To analyze the spatial morphological changes of Rivirivi River from 1993 to 2023.
- To determine the influencing factors for Rivirivi river morphological changes.
- To assess the impacts of Rivirivi River's morphological changes on land use.

## 1.5. Research Question

- What spatial morphological changes have occurred in Rivirivi River in Manyonga village from 1993 to 2023?
- What causal factors are triggering channel shifting in Rivirivi River?
- What are the impacts of Rivirivi River's morphological changes on land use?

## 1.6. Significance of Study

The study on the morphological changes of rivers in Malawi is significant and it supports a number of the SDGs, the Sendai Framework (2015-2030), Malawi Vision 2063, and the Malawi Disaster Risk Management Policy (2015). This paper supports the Sustainable goal number 11 and 13 which focuses on the sustainable cities and Climate Change respectively. These goals were achieved through understanding the disaster risks which is the priority number 1 for Sendai Framework and these assisted to build an inclusively prosperous and independent nation as a goal in Malawi Vision 2063. This paper also underscores mainstreaming disaster risk management into sustainable and reducing or avoiding underlying risk as priority number 1 and 5 for Disaster Risk Management policy (2015). This study acted as the cornerstone for the methodical and technological approaches that guide the river morphology investigations in Malawi. Involving the local communities under peril gained could have benefited from this research to understand better the causes of the disaster risk they are exposed to. The Malawian government has benefited from this study in sense that it has made the government aware of the effects that river morphology has to the local population especially in Manyonga village, T/A Nkaya in Balaka district. This study was important for a variety of researchers, including those who study the environment and agriculture, because it shed light on how human activities and natural processes affected river channels and the land use, as well as how changes in river channels affected agricultural practices in rural areas. This may be important for crop management and initiatives for conserving soil and the catchments.

# 2.0. LITERATURE REVIEW

## 2.1. Introduction to River morphology

A stream flow forms from the collection of rainwater moving down hills. A channel is the area through which a stream travels. A waterway and the water that flows through it are together referred to as rivers. A drainage basin is the space from which a waterway receives its water supply. A water divide separates drainage basins. The main stream and numerous tributaries make up a river system. It might be challenging to identify the main stream in situations where numerous tributaries have a comparable length and flow. A river system's layout is called a drainage pattern. Through channel dynamics, a river creates a variety of landforms. Erosion, transport, and sedimentation are the three primary channel processes or fluvial processes (Kuiper, 1965). Valleys made up of channels and slopes are formed when erosion dominates in a drainage basin's upper reach area. Sediment load refers to the materials a channel transports to its lower reaches. Sediment load production is primarily caused by weathering of the rocks that make up slopes. An alluvial plain is created by depositing sediment and they exhibit three fundamental channel patterns which are straight, meandering, and braided. The patterns and forms of a river's channels are used to explain its morphology, which is influenced by things like discharge, the materials in the riverbed, the depth and width of the channel, and the slope and velocity of the water on its surface. These elements interact with one another rather than being completely independent (Chang, 2008).

## 2.2. Channel processes

### 2.2.1. Erosion

Two processes happen when water is running which are corrosion and erosion. Erosion is a hydraulic process that is fueled by the force of moving water. Running water transports gravel, which cleans the channel and flushes debris from the riverbed. A canal gets wider and deeper due to erosion known as lateral erosion and deepening erosion, respectively. A canyon forms when erosion that is deepening takes control. Rocks in streams disintegrate due to chemical reactions. Corrosion is the name of this phenomenon. An iconic example

of a karst landform formed mostly by corrosion is calcareous limestone (Chang, 2008). In addition to stream water, weathering also plays a role in the formation of deep valleys. Long-term weathering of the rocks that make up slopes has resulted in the formation of rock wastes, including other fine materials, as well as rock fragments. Gravity and the torrential rain that is falling on the slopes cause the weathered materials to fall into the valley floor. These processes cause the valley to extend downstream and the upper slopes to retreat. Running water scour and transport the weathered materials deposited in a valley bottom to its lower reaches (Benjamin, 2023).

### 2.2.2. Transportation

A river's capacity to convey sediment load increases with water velocity. The three processes for moving sediment load are suspension, traction, and corrosion. Stream water corrodes rocks by this process, bringing them invisibly into solution. Without coming into contact with the river bed, such fine materials as clay, silt, fine sand, and materials lighter than water are transported in the water or on the water's surface. Suspended loads are the items carried during this process, which is referred to as suspension. Stream water becomes turbid due to suspended loads. Sand jumps or bounds on a riverbed, while larger-diameter gravel slides or rolls. These actions are referred to as traction. Bed load is the term for the sediment load that traction carries (Aniebone & Umeuduji, 2019).

### 2.2.3. Sedimentation

A flood brought on by prolonged rain transports a significant amount of bed load from the mountains to the plain. The capacity to move a bed load is suddenly diminished when a flood flows from the mountains to a plain. An alluvial plain is created by the orderly deposition of bed load particles. In an alluvial plain's upper reaches, a gravel-filled alluvial fan develops. Alluvial fans have surfaces that resemble cone segments. Concave radial and cross-sectional profiles are present as one moves toward the lower reach. Fine debris and sand make up the delta that is growing close to a river mouth. Fluvial and marine processes combine to produce the shape of a delta. There is a good chance that an arcuate delta will

occur if neither of these two processes is better than the other. This shape represents a delta's mature condition. A "bird foot delta" forms when a large sediment load enters a quiet bay. When river silt is moved by powerful coastal currents and waves, a cuspate delta with numerous lines of sand bar may develop. In the space between an alluvial fan and a delta, a flood plain made up of back swamps and natural levees is present. Sand and silt form the foundation of a natural levee. Back swamps have clayey deposits that are lower and wetter than those found in natural levees. An alluvial fan has braided channels that are connected to one another. The channels on an alluvial fan frequently change their directions when a significant flood flows down from mountains, and the new channel is maintained until the next flood. Groundwater is the only source of water for the former channel, which has been abandoned. On floodplains and deltas, the abandoned river's lower stretches can still be seen (Gurnell et al., 2012).

### 2.2.4. River Braiding

River braiding, sometimes referred to as braided rivers or Anabranching Rivers, is a particular kind of river morphology that has numerous interwoven channels. Often dividing and merging, these channels form an intricate web of watercourses that resemble "braids." River braiding is generally seen in areas with specific environmental and topographical characteristics. The following are important characteristics and elements related to river braiding (Zhang et al., 2015):

Sediment Load: In regions where rivers are heavily loaded with silt, river braiding is common. The coarse components in this silt, such as sand and gravel, are easily carried by the river's flow.

Low Gradient: The gradient or slope of braided rivers is usually modest. The river can deposit silt on the gradual slope, forming bars and islands in the channel. Variable Discharge: In areas where there are seasonal variations in precipitation and snowmelt, the water flow in braided rivers can fluctuate greatly. The channels might entwine more when there is strong flow, and they might split when there is low flow.

Bar Formation: There are bars and islands composed of deposited sediment that are characteristic of braided rivers. The water divides into several channels as a result of these bars acting as obstacles inside the river.

Dynamic and Ever-Changing: The process of braiding rivers is dynamic. Over time, channels may split, merge, or change, resulting in a very variable river system.

Braided River Ecosystems: Because the channels and islands provide a diversity of habitats, these river systems frequently support distinct and varied ecosystems. They might be crucial for aquatic and animal species.

Human Impact: The natural processes of braided rivers can be changed by human activities including agriculture, urbanization, and dam construction, which can have an impact on the flow dynamics and sediment transport of these rivers. The opposite of river braiding, channelization, can occasionally result from these consequences.

The management of water resources, flood control, and ecological preservation may all be impacted by river braiding, which is a natural geomorphic process that can be modified by human activity. Successful management and conservation of these distinctive and dynamic ecosystems depend on an understanding of the traits and behavior of braided rivers.

## 2.3. Controls of River Morphology

Numerous natural and man-made variables affect river morphology, or the form and shape of a river channel. It is crucial to comprehend the factors that govern river shape in order to manage rivers, reduce erosion, and maintain ecosystems. These are a few of the main factors influencing river morphology (Friend, 1993):

Geology and Geomorphology: The bedrock and sediment types that make up a region's underlying geology have a big impact on how a river looks. The form of a channel is influenced by the rate of erosion of different types of rock.

Climate and Precipitation: A watershed's rainfall and snowmelt distribution have an impact on river flow and sediment transport, which in turn form the river channel.

Tectonics: Tectonic forces have the ability to raise or lower land, which has an impact on a region's general topography and base level. River form and gradient may be affected by this.

Sediment Supply and Grain Size: The kind and amount of silt that a river carries affects the features of the channel. High sediment Load Rivers can flow in meandering or braided patterns.

Erosion and Sediment Transport: The gradient, discharge, and channel roughness of a river all affect flow velocity, which in turn affects the erosional forces acting on it. The channel of the river is shaped in part by the sediment that it can carry.

Human Activities: The shape of rivers can be dramatically changed by human activities including channelization, dam construction, and urbanization. Reduced habitat variety, increased erosion, and straighter waterways are all possible outcomes of these operations.

Vegetation: The stabilizing effects of riparian plants lessen erosion along riverbanks. It affects channel dynamics as well as the movement of sediment. Meandering can be encouraged when there is greenery.

Base Level: What a river can erode to is called base level. River shape and profiles can be changed by modifications to the base level, such as rising or falling sea levels or the building of dams.

Channel Width and Depth: River discharge, sediment load, and slope all have an impact on the width and depth of the water. Deeper, wider rivers have diverse channel features and have the capacity to carry more silt than smaller rivers.

Local Geomorphological Features: Certain geological or geomorphological features, such as terraces, bedrock outcrops, and alluvial fans, can affect the morphology of rivers in certain locations.

Historical and Anthropogenic Changes: A river's present shape may be permanently impacted by its past evolution, including previous land use and technical changes.

Climate Change: Climate change-related changes in temperature and precipitation patterns can have an impact on river flows and may result in changes to the morphology of rivers.

Ecological Interactions: River shape can be impacted by the existence of riparian and aquatic ecosystems. Diversity of habitats and channel stability can be enhanced by vegetation in particular.

For river management, conservation, and restoration projects, it is crucial to comprehend how these controls interact. Sustaining the natural dynamics of rivers while balancing human requirements and environmental preservation is the goal of effective river management systems.

## 2.4. River Morphology Assessment Techniques

Assessing the physical properties and processes that generate and impact the form and function of river systems is done through the use of river morphology evaluation methodologies. The methods encompass gathering and examining information about several facets of river morphology, such as channel configuration, sediment movement, flow characteristics, and vegetation trends.

### Field Surveys and Measurements:

This is one of the techniques that uses the following as explained by Guy and Norman, 1970:

Cross-sectional surveys: This involves the measuring river channel geometry at numerous places, including width, depth, and bank slope.

Longitudinal profiles: Surveying the river's longitudinal profile to assess slope, bed characteristics, and elevation variations at different locations of the river.

Sediment sampling: It requires gathering and analyzing sediment samples (e.g., bed material, suspended sediment) to better understand sediment properties, transport rates and erosion/deposition patterns.

Flow measurements: Measuring water velocity, discharge, and stage at various sites to better understand flow dynamics and hydraulics.

Vegetation surveys: Determine the type, distribution, and density of riparian and in-stream vegetation that can affect channel morphology and stability.

Remote Sensing and GIS Analysis:

This was underscored by Shi et al., 2022.

Aerial photography and satellite imagery: This involves analyzing high-resolution images to map channel patterns, identify morphological traits, and track changes over time.

LiDAR data: LiDAR-derived DEMs are used to study channel topography, floodplain features, and terrain characteristics.

GIS tools: It includes integrating field data, remote sensing data, and other spatial information into GIS platforms to enable spatial analysis, mapping, and modeling of river morphology.

Hydraulic and Sediment Transport Modeling (Belletti et al., 2015):

One-dimensional (1D) hydraulic models include HEC-RAS and MIKE 11, which simulate water surface profiles, and channel hydraulics. CCHE2D, RIVER2D, and BASEMENT are examples of two-dimensional (2D) hydraulic models that simulate more sophisticated flow patterns, sediment transport, and morphological changes.

Sediment transport equations and models: Using empirical or physics-based sediment transport equations and models (e.g., Meyer-Peter and Müller, Engelund-Hansen, HEC-RAS Sediment Transport) to estimate sediment transport rates and forecast erosion/deposition patterns.

### Geomorphic Assessment and Classification (Fryirs & Brierley, 2012):

Rosgen stream classification: The "Rosgen Stream Classification System" by David Rosgen describes how to classify river reaches based on channel geometry, pattern, and bed material.

River Styles Framework: The "River Styles Framework" by Gary Brierley and Kirstie Fryirs classifies river reaches based on their morphological traits, catchment environment, and evolutionary trajectory.

Fluvial Audits: Conducting complete assessments of river condition, behavior, and recovery potential in accordance with Gary Brierley and Kirstie Fryirs' "Fluvial Audit" technique.

## 2.5. The concept of LULC Change

Land use change involves the conversion of land from one type of use to another while as Land cover change involves the alteration of the physical and biological materials covering the Earth's surface, such as vegetation, water bodies, or artificial structures. LULC refers to the process of changing the way land is used and the physical properties of the Earth's surface throughout time (Kang & Kanniah, 2022). These changes can be caused by a variety of natural and human factors, and they have far-reaching consequences for environmental processes, biodiversity, and ecosystem services.

## 2.6. Causes of LULC

Below are most of the factors that affect land use and land cover:

Population Growth: Demand for residential, commercial, and agricultural land rises with population growth.

Economic Development: Land use patterns are influenced by economic activity, industrialization, and urbanization.

Policy and Zoning Regulations: Land use can be directed by zoning rules and government policies, which establish what can be developed or farmed in particular regions.

Technological Advances: Changes in land use, such as higher agricultural output or more effective transportation systems, can be made possible by technological advancements.

Cultural and Social Factors: Land use decisions, such as the preservation of culturally significant locations, are influenced by cultural traditions and community ideals.

Environmental Considerations: Ecological and environmental considerations, such as the prevention of pollution or the preservation of natural habitats, frequently impact land use decisions.

Climate and Geography: Decisions on land use are influenced by natural elements such as soil types, climate, and geography. For example, farming is more common in areas that are fruitful and level.

Infrastructure and Accessibility: Roads and railroads are examples of transportation networks that can promote industrial activity and urban growth.

Land Ownership and Land Markets: Land use decisions and development are influenced by real estate markets, land tenure regimes, and property ownership.

Historical Legacy: Past land use practices, such as deforestation or mining, can leave a lasting legacy on current land cover and land use patterns.

Planning for future changes in land use and sustainable land management require an understanding of these influencing factors on land use and land cover. It enables decision-makers in government and land management to strike a balance between the preservation and conservation of the environment and human needs (Trigg et al., 2020).

## 2.7. Impacts of River morphology in Malawi

Flooding and erosion: Several studies have shown that river form exacerbates flood dangers and erosion in Malawi. Floods occur frequently in the country, especially in the Lower Shire Valley and along the Shire River basin, causing major damage to infrastructure, agricultural grounds, and human settlements (Chavula, 2009).

Water availability and quality: The form of rivers in Malawi has a significant impact on the distribution and quality of water resources. Monjerezi et al. (2011) discovered that changes in channel patterns, sediment deposition, and vegetation cover in the Shire River basin had influenced water availability for agriculture and residential usage.

Ecosystem effects: River form has a direct impact on the health and function of Malawi's aquatic and riparian ecosystems. Changes in channel form, flow regimes, and sediment dynamics have been demonstrated in studies to disturb the habitats of many species, resulting in shifts in species composition and biodiversity loss (Shela, 2000).

Changes in river shape have impacted the stability and integrity of Malawi's infrastructure, including bridges, dams, and water supply systems. For instance, excessive erosion and silt deposition in the Shire River have weakened the foundations of bridges and water intake facilities, resulting in costly maintenance and repair activities(Chavula, 2009; Shela, 2000).

Agricultural productivity: In Malawi, where agriculture is a substantial economic contributor, river topology can have a significant impact on agricultural production. Flooding and erosion induced by changes in river shape have resulted in the loss of fertile agricultural land, particularly in the Lower Shire Valley and Shire River basin(Chavula, 2009; Shela, 2000).

# CHAPTER 3. METHODOLOGY

## 3.1.0. Study Area

The Balaka District is situated in the Republic of Malawi's Southern Region. Its boundaries with Ntcheu, Mangochi, Machinga, Zomba, Blantyre, and Neno are in the northwest, northeast, southeast, south, and southwest, respectively. 2.4 percent of Malawi's total land

area, or 2,193 $km^2$, is covered by the district. Latitude 14°59'15.38"S and longitude 34°57'22.23"E are the coordinates for Balaka District. Due to its location on the eastern end of the Great Rift Valley, the Balaka District has a varied topography with elevations varying from around 350 to 800 meters above sea level (Balaka District Council, 2017).

Ridges and natural drainage networks make up the district's topographical features. May and September are transitional months between the two separate seasons in the Balaka district. These are the two seasons: October to April is the rainy season; the cold, dry season runs from June to August. The region receives 750 mm of rain on average every year. The best rains for agricultural planting often occur in mid-December, however the rainy season officially begins by the end of October (Jury, 2014). The ideal period to grow food with rain-fed agriculture is between December and March, when the soils are moist. With an average annual temperature of 25°C, the district frequently sees hot to warm weather, with the highest temperatures occurring around the Shire River. In the district, temperatures are usually lowest in June and July and highest in October and November (Balaka District Council, 2017).

T/A Nkaya is found to the south of Balaka district and it has a total population of 45,351 people according to 2018 Malawi Population and Housing Census main report. It has households approximately 10,078.

Major rivers in the district are Shire, Rivirivi, Chimwalire, Nkasi, Lisungwi, Naliswe, Mulunguzi, Muthe, and Kalambo (Balaka District Council, 2017). The Rivirivi River basin lies between the central region district of Ntcheu and the southern region district of Balaka. It is divided into three parts: the upper and lower portions of the kirk ranges, the middle valley, and the lower valley, which fall within the great east African Rift Valley System. The river is vital to residence of Balaka as farmers use it for irrigation farming, fishing, domestic and other commercial activities to improve their livelihoods (Chimtengo et al., 2014).

Chimtengo et al., 2014 analyzed the changes in water availability to assess environmental water requirements in the Rivirivi River and the aim was at investigating some of the causes

of these changes. Mavuto Chimtengo conducted another study on the Rivirivi River in Ntcheu District in 2010 to investigate the effect of traditional water allocation practices on environmental flows.

However, there's a need to analyze morphological changes of this river as it shows that it is shifting towards Manyonga Village, T/A Nkaya in Balaka District (google images to be shown at the appendix as scientific proof of this slow onset event). All elements of vulnerability are exposed to this risk. Houses, mosque and graveyard are at high risk of being collapsed by the meandering of the river.

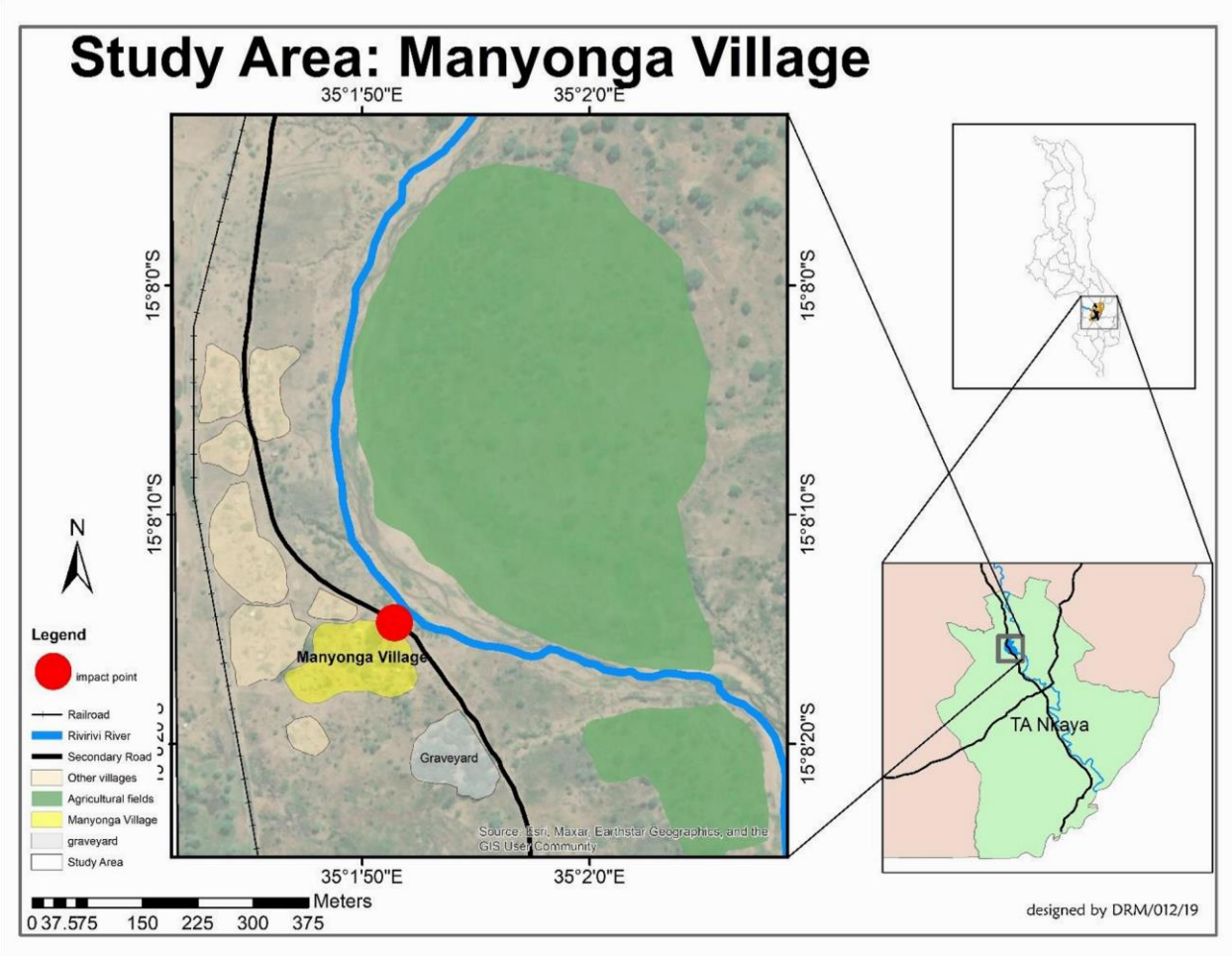



*Figure 3.1: Shows a Study Area Map.*

## 3.2.0. Research Design

A quasi-experimental research methodology was used to examine the morphological changes that have occurred in the Rivirivi river system over time. The intrinsic difficulties in carrying out a real experimental design with random assignment of treatments in the context of researching natural riverine habitats make this approach necessary (Kabir, 2016).

The study compared remote sensing data obtained at three separate time intervals (1993, 2008, and 2023), which represented the pre-, middle and post-intervention eras. The intervention in this case consisted of natural processes and events that may have changed river morphology between the three data collecting periods such as land use.

Purposive sampling was used to choose the study region and the particular river sections, with the existence of notable morphological changes and the availability of high-quality remote sensing data serving as guiding variables. Due to the chronological order of the data collecting periods, river reaches were assigned to the pre-intervention, middle, and post-intervention groups in a non-random manner.

Given the nature of the study, having a real control group may not be possible or relevant. Instead, the pre-intervention data was used as a comparison point, allowing for the measurement of changes in river morphology in relation to the original conditions.

The study was carried out in a natural riverine setting, where morphological changes are caused by a variety of natural processes such as erosion, sedimentation, and hydrological events. A controlled experimental design cannot be implemented in this natural situation.

Satellite imagery was obtained at three independent time points: pre-intervention, mid-intervention, and post-intervention. The data was processed and evaluated to determine essential morphological factors including channel width and meandering using ArcGIS.

To compare the morphological parameters between the pre-intervention, middle-intervention, and post-intervention periods, statistical analyses were carried out using Excel software. The data were represented as maps and charts.

Quantitative approach was used to analyze the rainfall and discharge as auxiliary data using Excel software. Descriptive statistics was used to calculate common statistical measures like mean, median and standard deviation. Correlation tool was used to determine the correlation coefficient between rainfall and discharge data. Regression analysis assisted to perform linear or non-linear regression analysis to model the relationship between rainfall and discharge. Linear graphs were created to visualize the distribution of rainfall or discharge data.

### 3.3.0. Materials and Methodology

The following materials were used from the data collection stage to the interpretation stage: ArcMap, Google Earth Pro and Excel. The table below shows the sources where data was collected.

*Table 3.1: Shows the data used and sources.*

| DATA | ACQUSITION | SOURCE |
|---|---|---|
| Remote Sensing Images | Landsat 5 TM (16/10/1993) | United State Geological Survey (USGS)explorer (https://earthexplorer.usgs.gov/) |
| | Landsat 7 ETM+ (17/10/2008) | |
| | Landsat 8 OLI (12/10/2023) | |
| Rainfall and Discharge Data | From 1993 to 2023 | Department of Climate Change and Meteorological Services (DCCMS) & Department of Water Resources (DWS) |

The Satellite Images were retrieved from United State Geological Survey (USGS) explorer in path 167 and row 71 of 30m spatial resolution. The world geodetic system 1984 (WGS84)/UTM zone 36S was used to project the study area on a map. The images were pre-processed in ArcMap using geometric and radiometric corrections to remove internal and external distortion and correct the DNs recorded by a sensor. This was done to ensure that each pixel in the image is in its proper plan metric (x, y) map location (Patel & Thakkar, 2016) and to remove systematic errors or inconsistencies in the data caused by various factors (Jenerowicz et al., 2023) respectively.

Band composite was carried out in ArcMap for visual interpretation; that is, features on the Earth's surface that reflect or absorb light differently in those bands were more easily distinguished by the human eye by assigning different spectral bands to the red, green, and blue channels of an RGB color image (Chuvieco & Huete, 2009). This was done to each image in three years, 1993, 2008 and 2023.

The image were classified to 5 categories of land use: farm-land, grassland, water body, bare land and built-up land. These were done in ArcMap using supervised image classification tool. This tool enables the user to classify the land manually. LULC cover map was generated for the study area and accuracy assessment was performed. By conducting an accuracy assessment, it was easy to quantify the reliability of the LULC map, identify potential sources of error, and make informed decisions about the suitability of the map for its intended applications (Rwanga & Ndambuki, 2017).

The land use/ land cover image was vectorized to come up with polygons for categorized features. The polygons representing the Rivirivi River of 1993, 2008 and 2023 were overlayed to detect changes based on the shifting of the course and Manyonga village was taken as reference point.

Rainfall and discharge data were retrieved from DCCMS and DWR from 1993 to 2023. The discharge data was of Rivirivi River. The data was descriptive statistically analyzed and the mean and the standard deviation was calculated using Excel Software. Rainfall and discharge were correlated to determine the correlation coefficient between these two variables. Linear regression was also calculated to perform linear or non-linear regression analysis to model the relationship between rainfall and discharge.

The **figure (5)** below depicts the sequence of steps constituting the methodological approach employed to tackle the specific objectives outlined in this research study.

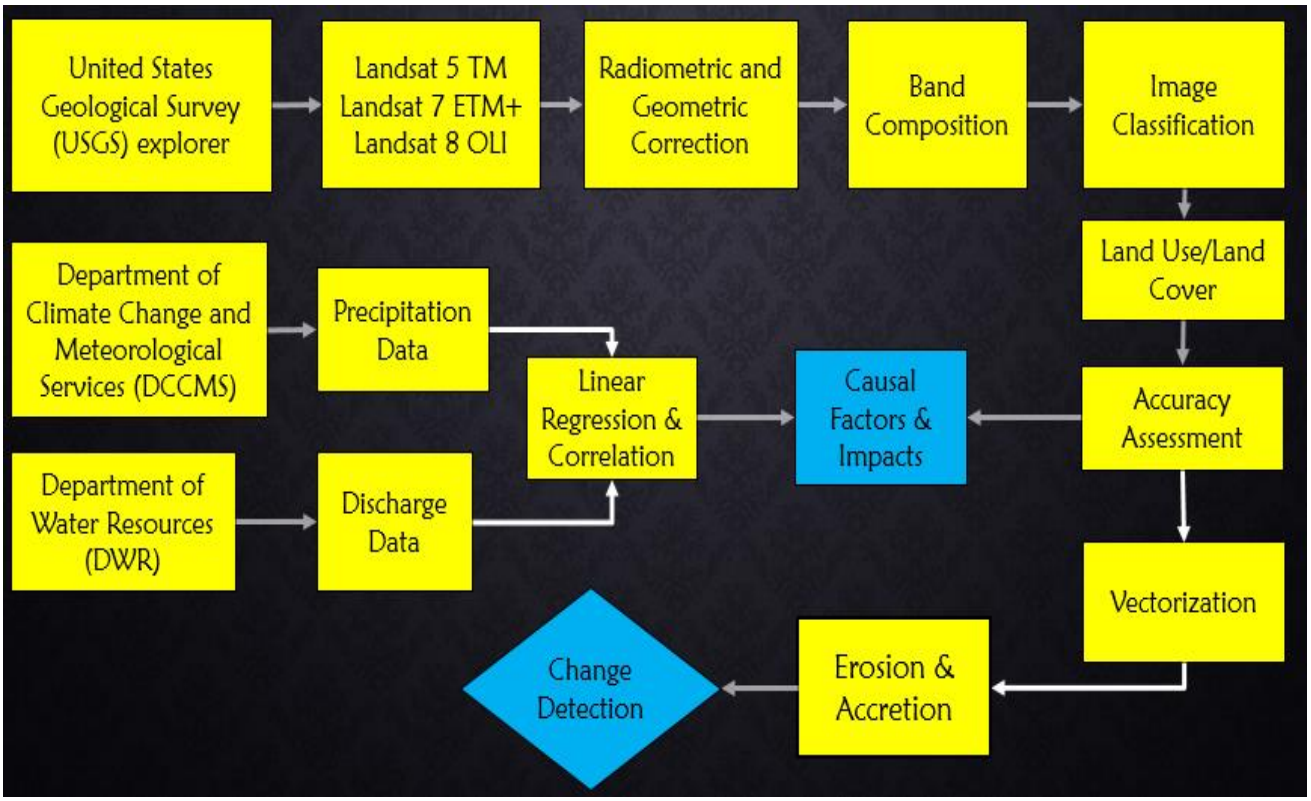



***Figure 3.2:*** *Shows the Process for the Methodology.*

# 4. RESULTS AND DISCUSSIONS

## 4.1. Results

Morphological changes of Rivirivi River from 1993 to 2023:

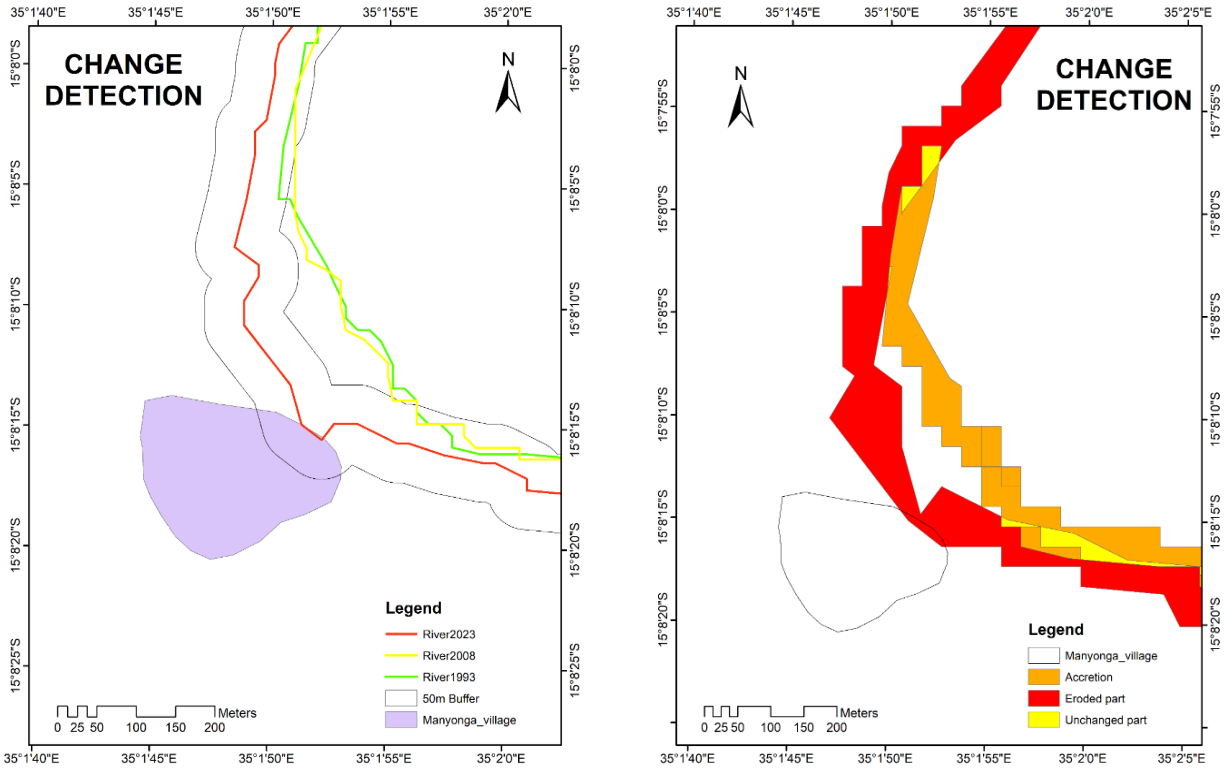



***Figure 4.1:*** *Shows Change Detection Map. Left Map shows the centerline of the shifting river of 1993, 2008 and 2023. Right Map Show the erosion, accretion and unchanged parts of the shifting Rivirivi River.*

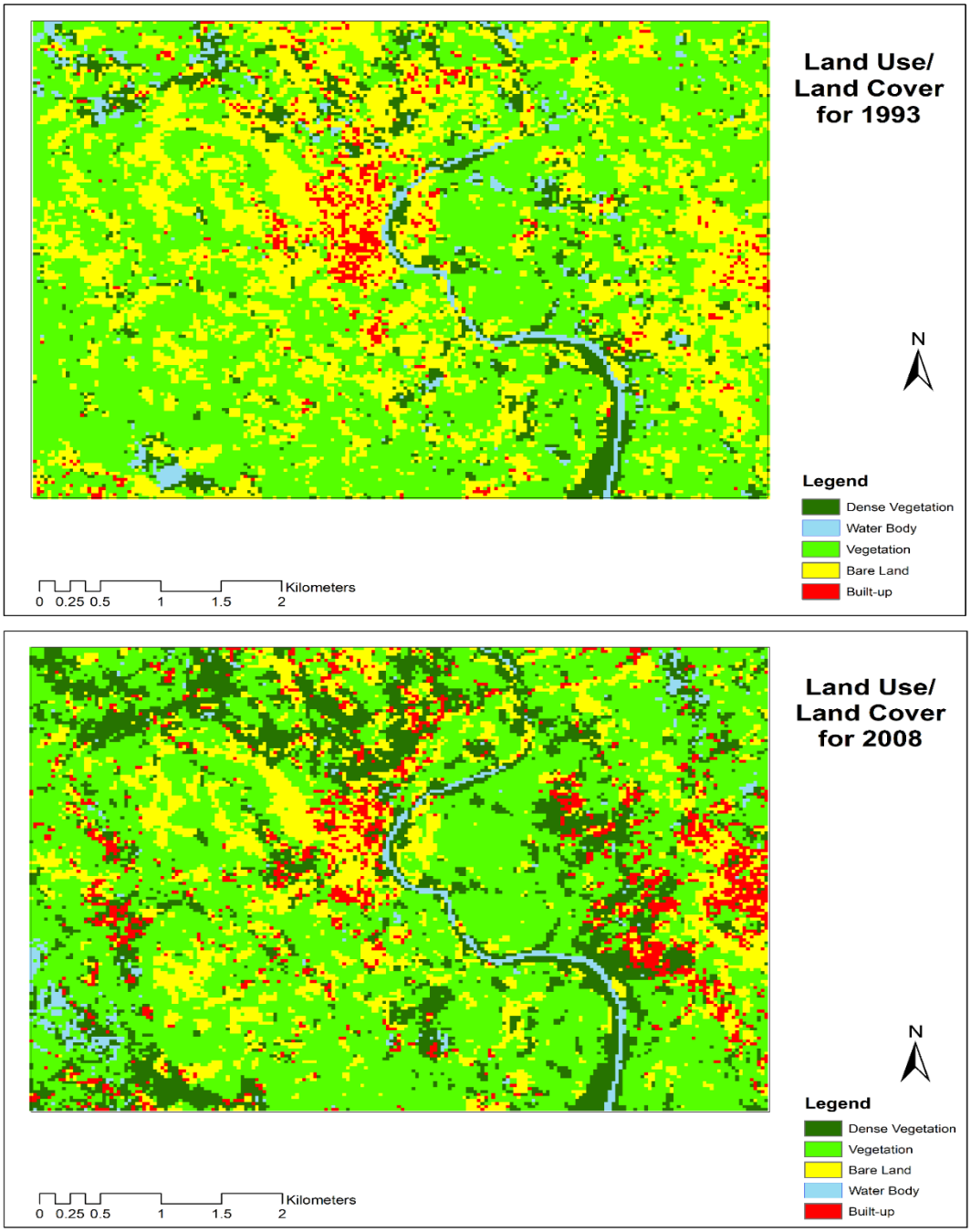



***Figure 4.2:*** *The Top Map is LULC for 1993 and the bottom map is LULC for 2008.*

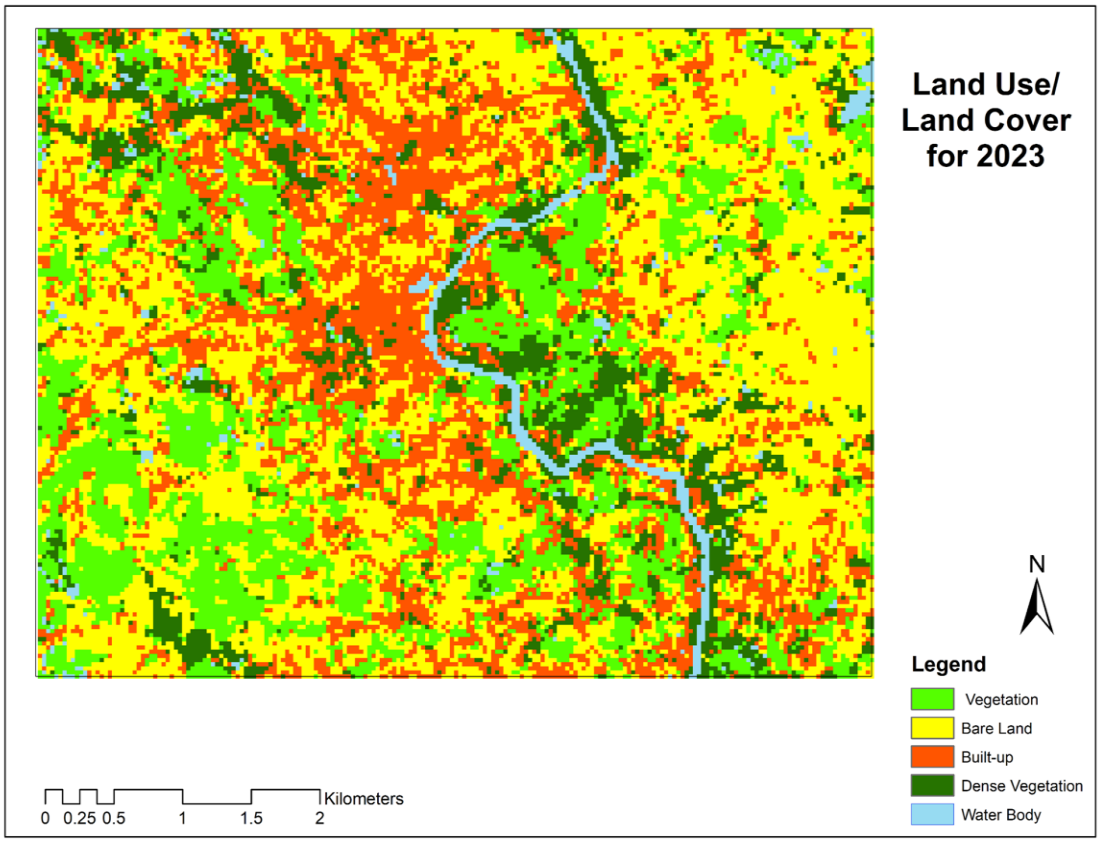



*Figure 4.3: Shows the LULC for 2023.*

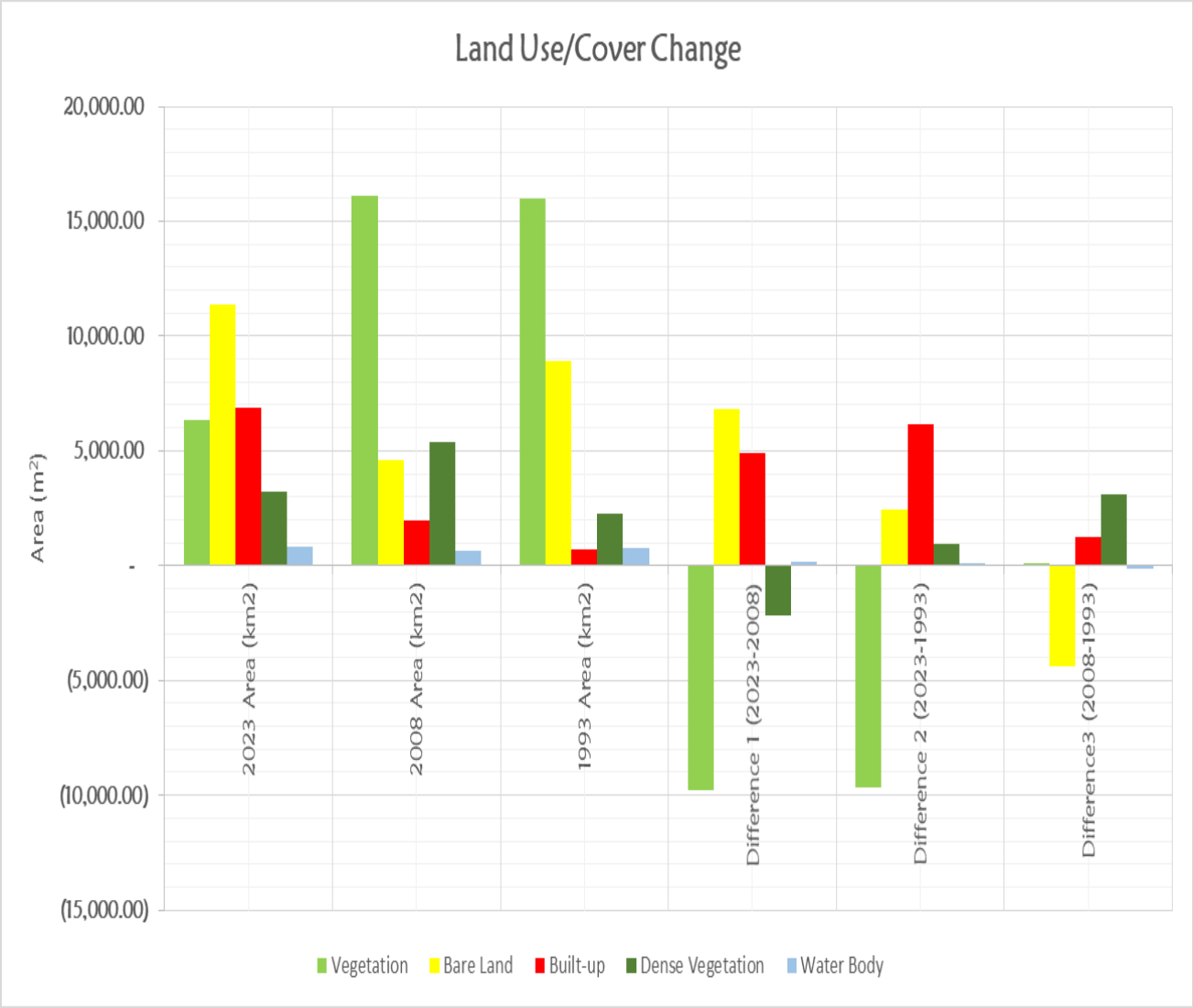



***Figure 4.4:*** *Shows the LULC change from 1993, 2008 to 2023.*

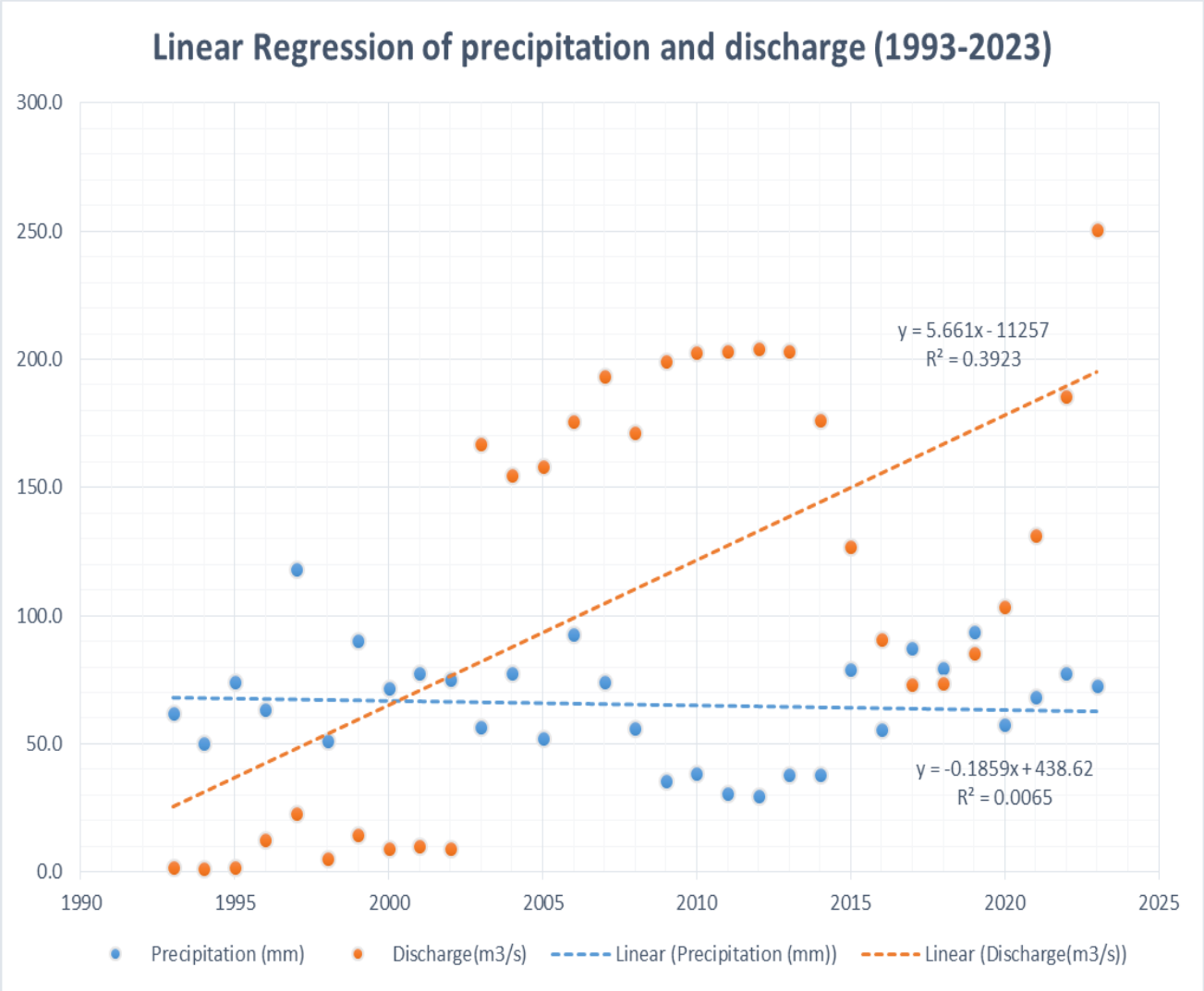



*Figure 4.5: Shows the Linear Regression of Precipitation and Discharge.*

## 4.2. Discussions

According to Figure 1(b), a shift in the course of the Rivirivi River was observed through an analysis of Landsat images, which quantified the extent of erosion and accretion affecting the Manyonga Village area. The total eroded area was approximately 288,448.64 square meters, while the accretion area covered 75,573.63 square meters, and the unchanged portion spanned 14,703.74 square meters. These figures translate to 76.16% of the area experiencing erosion, 19.95% undergoing accretion, and 3.88% remaining unchanged. Notably, Manyonga Village accounted for 0.26% of the eroded area. The river has undergone substantial changes

between 2008 and 2023. Approximately, in 1993, the river's course was situated approximately 100 meters away from the current location of Manyonga Village.

The vegetation cover in the area has undergone substantial transformation between 1993 and 2023. New residential and urban areas have been developed, and the amount of bare land has increased, as evidenced by the LULC change analysis depicted in Figures 2 and 3. These changes indicate that extensive human activities have taken place in the region, leading to the destruction of vegetation through practices such as clearing for agricultural purposes, settlement expansion, and other developmental projects, including the construction of a railway within the study area. The conversion of land for agricultural and residential uses has resulted in an increase in impervious surfaces, altering the hydrology of the watershed. This alteration has led to higher peak flows, increased runoff volumes, and higher sediment loads, causing channel erosion, incision, and changes in the river's channel geometry. Additionally, deforestation and the removal of riparian vegetation may have destabilized riverbanks, increased erosion rates, and altered the sediment supply to the river, contributing to changes in the channel's morphology.

The precipitation and discharge data shows that the precipitation amount is decreasing and the discharge is increasing from 1993 to 2023 based on the figure 4. The data suggests an inverse relationship between precipitation and river discharge, where neither variable significantly influenced the other. The precipitation data was obtained from Balaka, and it did not substantially impact the river's discharge. This implies that precipitation occurring upstream, specifically originating from the Kirk Range Mountains in Ntcheu District, potentially had a direct correlation with the river's discharge. Consequently, the rise in water levels, potentially triggered by upstream precipitation, could have been a contributing factor to the erosion, deposition, and flooding observed along the river channel. The observed morphological changes in the river channel might not necessarily stem from the precipitation patterns or rainfall amounts experienced within the study region.

The morphological transformations observed in the river have had profound impacts on the surrounding communities. The changes in the river's morphology, such as channel migration

and aggradation (sediment deposition), as depicted in Figure 1(b), have likely increased the risk of flooding in adjacent areas. Flood events can cause significant damage to properties, infrastructure, agricultural lands, and pose threats to human life. Furthermore, the erosion of riverbanks, resulting from alterations in the river's course or increased flow velocities, has led to land loss, adversely affecting properties, agricultural lands, and infrastructure situated near the riverbanks, as evidenced by Figures 1(b) and 4. The migration of the river towards Manyonga Village has impacted the route that previously passed between the river and the village, disrupting commercial activities and the movement of goods and people from the Shire north via Nkaya to Balaka town (this route can be easily observed on an image before the erosion of the river, as shown in the study area map). Moreover, the alterations in the river's morphology might have disrupted aquatic ecosystems, affecting the habitats of various species, potentially leading to biodiversity loss and ecological imbalances within the area of interest and beyond.

# 5.0. CONCLUSION AND RECOMMENDATIONS

## 5.1. Conclusion

The examination of changes in the form and structure of the Rivirivi River over time has yielded several significant insights. Firstly, the river's course has experienced notable shifts, with its bends and curves moving sideways across the landscape. These lateral migrations can be explained by the combined effects of fluctuations in water flow rates, sediment loads carried by the river, and the erosive power exerted on the riverbanks.

Secondly, the analysis has highlighted how human activities like urbanization and agricultural practices have influenced the morphological evolution of this river system. Such anthropogenic factors have altered the natural patterns of water flow and sediment transport, resulting in unintended consequences.

Overall, this study underscores the importance of continuously monitoring and comprehending changes in river morphology, as these have ramifications for flood risk mitigation, ecological preservation, and sustainable water resource management. The findings from this analysis can

guide decision-making processes related to river management strategies, land-use planning, and the development of effective measures to address the challenges posed by the morphological transformations occurring in the river system.

## 5.2. Recommendations

I suggest advancing environmentally-friendly land management approaches to curb soil erosion and halt the spread of desert-like conditions. Additionally, relocating the residents of Manyonga village to safer zones, formulating and enforcing land-use planning and zoning regulations to prohibit construction in high-risk regions, and actively involving local communities and relevant stakeholders in environmental decision-making processes pertaining to the area of interest and its surroundings.

## 5.3. Limitations of the Study

Utilizing remote sensing techniques to analyze morphological transformations in rivers offers invaluable insights into the dynamics and evolution of these natural systems. However, this study encountered several limitations when employing this approach:

Spatial resolution constraints: The level of spatial detail captured by remotely sensed imagery posed a limitation, particularly for the Rivirivi River or specific features of interest. High-resolution imagery was often necessary to accurately delineate river boundaries, identify changes in channel patterns, and quantify morphological parameters.

Challenges from cloud cover and atmospheric interference: Clouds, haze, and other atmospheric conditions obscured or distorted the remotely sensed data, making it difficult to accurately assess river morphology in certain areas or during specific time periods.

Complexities in data processing and interpretation: Extracting meaningful information from remote sensing data required intricate image processing techniques, such as atmospheric correction, geometric rectification, and image classification. These processes can introduce uncertainties and errors, affecting the accuracy of the derived morphological parameters.

Need for ground proofing and validation: Remote sensing data needed to be complemented with ground-based measurements and field surveys to validate the interpretations and ensure the accuracy of the morphological analysis. This was time-consuming and resource-intensive, as the study area extended from Thyolo to Balaka District, while other studies were conducted on the school campus.

Influence of environmental factors: Factors such as vegetation cover, soil moisture, and water clarity influenced the spectral signatures captured by remote sensing sensors, complicating the interpretation of river morphology in certain environments within the area of interest.

Despite these limitations, remote sensing techniques remain a valuable tool for monitoring and analyzing river morphological changes, especially when combined with other data sources, such as field measurements, hydrological models, and historical records. Advancements in remote sensing technologies, including higher spatial and temporal resolutions, as well as improved data processing and interpretation methods, continue to enhance the capabilities of this approach for river monitoring and management.

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