


MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY
NDATA SCHOOL OF CLIMATE AND EARTH SCIENCE
DEPARTMENT OF EARTH SCIENCE

# APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM FOR PETROLEUM EXPLORATION IN LOWER SHIRE BASIN: MALAWI

LEYARD KAMANGA PRE/012/18
Thyolo, Malawi

Proposal submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Petroleum Geoscience.

10 November, 2023

## DECLARATION

I, Leyard Kamanga declare that this research project presents my work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature: 

Date: 8 November 2023

DISSERTATION APPROVED BY:

SUPERVISOR:

Mr R. Mvula Signature: 

ASSESSOR:

Title, Initials, Name Signature: _____

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## ABSTRACT

In the realm of petroleum exploration, the comprehensive analysis of various datasets, ranging from satellite imagery and surface geological studies to subsurface data, plays a pivotal role in uncovering valuable insights. This research project harnesses the exceptional advantages offered by Remote Sensing technology, primarily emphasizing its synoptic perspective, which enables a holistic and integrated understanding of the intricate relationships between diverse land features. Remote Sensing facilitates access to multi-spectral data, bolstered by the advanced capabilities of digital image processing techniques, further enhancing its utility in delineating lithological contacts and geological structures with an unprecedented level of precision and accuracy. A cornerstone of this research project lies in the utilization of Geographic Information Systems (GIS) as a robust decision support system. GIS serves as a powerful tool for the efficient storage and overlay analysis of spatial data originating from various sources, thereby fostering the interconnection of disparate datasets. This interconnectedness allows for seamless layering, visualization, and manipulation of data in map form, thereby affording an unparalleled avenue for comprehensive analysis and potential discovery. The synergistic application of Remote Sensing and GIS technologies in this research significantly transforms the landscape of petroleum exploration. It promises a paradigm shift, offering a means to achieve higher accuracy, expedited processes, and cost efficiency. Through this research, the future of exploration stands to benefit from a more intricate and nuanced understanding of the geological complexities, ultimately paving the way for optimized resource discovery and utilization.

## ACKNOLEDGEMENT

I want to express my praise to God Almighty for providing me with strength and direction while I completed my bachelor's degree in Petroleum Geoscience (oil and gas) at the Malawi University of Science and Technology.

My supervisor, Mr. Mvula, deserves special recognition for his stimulating suggestions, constructive criticism, inspiration, and support that made it possible to conduct and complete this study. I also want to thank him for taking the time to proofread and fix all of my errors during this process.

I would also like to extend my gratitude to the Kamanga and Manda Family for their support and prayers during this period.

Finally, I would like to thank Chimwemwe Jere, and Alfred Manda for their knowledge, criticism, and assistance that helped me complete this study.

# Table of Contents

CHAPTER 1: INTRODUCTION ..... 1
1.1 Background ..... 1
1.2 Problem statement ..... 2
1.3 Objectives ..... 3
1.3.1 Main objective ..... 3
1.3.2 Specific objectives ..... 3
1.4 Research Questions ..... 3
1.5 Significance of the study ..... 3
CHAPTER 2: LITERATURE REVIEW ..... 5
2.1 Petroleum exploration techniques ..... 5
2.2 Geology of the lowershire basin ..... 6
2.3 Previous work in the area ..... 6
2.4 Application of GIS in exploration ..... 7
2.5 Application of Remote Sensing in exploration ..... 8
2.6 Remote sensing and structures associated with faults ..... 9
2.6.1 Normal and reverse faults ..... 9
2.6.2 Reverse faults ..... 9
2.6.3 Strike-slip faults ..... 10
CHAPTER 3: STUDY AREA ..... 11
3.1 Location of the study area ..... 11
CHAPTER 4: METHODOLOGY ..... 12
4.1 Methods ..... 12
4.2 Research Design ..... 13
CHAPTER 5: DATA ANALYSIS ..... 15

5.1 Utilizing DEM data for geologic analysis. ..... 15
5.1.1 Application of DEM data ..... 15
5.1.1.1 Elevation Map ..... 16
5.1.1.2 Slope ..... 16
5.1.1.3 Hillshade ..... 17
5.1.1.4 3D Map ..... 18
5.2 Drainage analysis ..... 19
5.2.1 Automatically Generated Drainage System ..... 20
5.3 Lineaments and Related Features in the Study Area ..... 21
5.3.1 Lineament Extraction ..... 21
5.4 Lithology of The Study Area ..... 23
5.4.1 Carbonate ..... 23
5.4.2 Metasedimentary ..... 24
5.4.3 Extrusive volcanic ..... 24
5.4.4 Alluvium-Fluvial ..... 25
5.5 integration of Structural features and lithology ..... 25
CHAPTER 6: RESULTS AND DISCUSSIONS ..... 27
6.1 Structural Features ..... 27
6.1.1 Lineaments and Faults ..... 27
6.1.2 Folded Structures ..... 27
6.2 Lithology of the Area ..... 28
6.2.1 Carbonate ..... 29
6.2.2 Metasedimentary Rocks ..... 29
6.2.3 Extrusive Volcanic Rocks ..... 29
6.2.4 Alluvium-Fluvial Deposits ..... 29
CHAPTER 7: CONCLUSION AND RECOMMENDATION ..... 31

7.1 Conclusion.....31

7.2 Recommendation.....31

*REFERENCE*.....32

# Table of figures

Figure 1.Map of Study Area....11
Figure 2: Methodology Flow Diagram....14
Figure 3: Chikwawa Elevation....16
Figure 4: Chikwawa Slope Map....17
Figure 5: Hillshade Map....18
Figure 6: 3D map....19
Figure 7: Drainage System....20
Figure 8: Lineament....22
Figure 10: Geological Map....26
Figure 11: Structural features....27
*Figure 12: Lithology Map*....28

## List of Tables

Table 2: Satellite image data .....12
Table 3: Other Secondary Dataset.....13
Table 4: Software.....13

ACRONYMS/ABBREVIATIONS

| | |
|---|---|
| **RS** | Remote Sensing |
| **GIS** | Geographical Information System |
| **DEM** | Digital Elevation Model |
| **USGS** | United States Geological Survey |

# CHAPTER 1: INTRODUCTION

## 1.1 Background

The global energy landscape is undergoing significant transformations due to growing concerns about sustainability, energy security, and the environmental impacts of conventional energy sources (IEA, 2020). This has led to an increased emphasis on identifying and exploring new hydrocarbon reserves in previously unexplored or underexplored regions.

On the African continent, which has gained prominence as a promising frontier for hydrocarbon exploration, Malawi occupies a strategic position. The country's untapped potential for petroleum resources is of particular interest, given its proximity to established oil-producing regions in East Africa (Kwimbi et al, 2013). As a landlocked nation nestled in the southeastern part of the continent, Malawi's pursuit of energy self-sufficiency holds immense significance for its economic growth and regional stability (Kumar, 2011).Within Malawi, the Lower Shire Basin emerges as a prime focus of this study. Situated in the southern region of the country, this basin exhibits geological characteristics conducive to petroleum accumulation (Kalipeni, 2013),. The Lower Shire Basin's unique geological history and its location in close proximity to the Mozambique Rift System further underscore its potential as a petroleum reservoir.

In the broader context of petroleum exploration, traditional methods like seismic surveys, well drilling, and geological mapping have been employed extensively. However, these approaches are often cost-prohibitive and time-consuming, especially in regions with limited infrastructure. Herein lies the significance of remote sensing and GIS (Geographic Information Systems). These cutting-edge technologies offer a cost-effective and efficient means of surveying large and remote areas, enabling the identification of potential hydrocarbon reservoirs through the analysis of geological and geographical data. By harnessing the power of remote sensing, which involves

the collection of data from satellites and aerial platforms, and GIS, which facilitates the integration and analysis of geospatial data, this project aims to revolutionize petroleum exploration in the Lower Shire Basin.

## 1.2 Problem statement

The Shire Basin in Malawi is a rift basin that has been identified as a potential hydrocarbon province, based on the presence of thick sedimentary sequences, organic-rich source rocks, and structural and stratigraphic traps. However, the basin lacks comprehensive geological data and information that could help in its sustainable management and development (Kalipeni, 2013). Previous exploration activities in the basin have been limited and unsuccessful, as they relied on conventional methods such as aeromagnetic and seismic surveys that showed only thin and discontinuous sedimentary layers overlaying Precambrian basement rocks (Mattick, 1984).

Remote sensing and GIS techniques are a powerful tool that can be used to improve the geological and structural mapping of the basin and reduce the uncertainty risk in hydrocarbon exploration (Laake, 2021). However, there is a lack of research on the application of remote sensing and GIS techniques for petroleum exploration in the Lower Shire Basin, according to (NJunga, 2015), who provided a geological overview of the basin and its hydrocarbon potential based on seismic, gravity, magnetic, and geochemical data. Therefore, the central problem at hand is the absence of a comprehensive study that leverages integrated remote sensing, GIS, and image processing techniques to assess the hydrocarbon potential of the Lower Shire Basin and provide essential insights for sustainable resource management and development (Kalipeni, 2013).

## 1.3 Objectives

### 1.3.1 Main objective

The main objective of this work is to apply Remote Sensing and geographic Information Systems for petroleum exploration in the Lower shire basin with special focus on detailed lithological and structural mapping.

### 1.3.2 Specific objectives

- ✓ To identify the lithological units of the lower shire basin.
- ✓ To map the structural features of the lower shire basin.
- ✓ To integrate the lithological and structural data of the lower shire basin.

## 1.4 Research Questions

- ✓ What are the lithological units present in the lower shire basin?
- ✓ What are the structural features of the lower shire basin?
- ✓ How can lithological and structural data be integrated to generate a comprehensive geological map of the lower shire basin?

## 1.5 Significance of the study

The study will help further understand the basin within the scope of oil and gas exploration in the area and make an informed decision about the targeted drill points. This will enable us to add to archives in petroleum scientific data (Lloyd, 2012). The study will also contribute to developing the oil and gas industry in Malawi by providing reliable and updated information on the hydrocarbon potential of the Shire

basin. It will address some of the existing knowledge gaps and challenges in the exploration of the basin, such as the complex geology, the limited data availability, and the environmental sensitivity (Kumar, 2011). It will support the sustainable and responsible use of natural resources and the environment by applying remote sensing and GIS techniques that minimize the need for invasive and costly field surveys.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Petroleum exploration techniques

Oil exploration can be divided into two broad categories: surface and subsurface methods. Surface technique involves observing and measuring surface features and phenomena that indicate the presence or absence of hydrocarbons, such as oil spills, oil flashes, pitting, poor vegetation, and soil geochemistry. Subsurface methods involve the investigation of subsurface geology and patterns using geophysical, geochemical and geological methods such as seismic, gravity, magnetic, electrical, electromagnetic, electrical and well penetration. Surface and subsurface methods are often combined and supported by remote sensing and GIS technologies to provide spatial information and analytical capabilities for petroleum exploration (Lloyd, 2012).

Remote sensing is the science of obtaining, processing and interpreting images and data from satellites and aircraft, and recording the interaction between matter and electromagnetic energy. Remote sensing data can be obtained in different areas of electromagnetic fields such as visible, infrared, thermal and microwave regions. Remote sensing data can provide information about the geology, topography, hydrology, vegetation, land use and environment in the survey area. Remote sensing data can also be used to identify and map surface and subsurface structures associated with hydrocarbon accumulation, such as faults, folds, fractures, anticlines and traps. Remote sensing data can be processed and enhanced using a variety of techniques such as image classification, key feature analysis, score contrast, spectral analysis and pattern recognition. It provides important information for oil exploration (Kumar, 2011).

GIS is a system consisting of hardware, software and data that can store, process, analyze and display data and information. GIS can integrate and manage different types of spatial data, such as remote sensing data, geophysical data, geological data, geochemical data, and oil quality data, in a joint venture. GIS can perform a variety

of analysis functions such as overlay, buffering, proximity, interpolation, and modeling to support gas exploration. GIS can also create and display various types of maps, charts, graphs, and reports to communicate the results and findings of oil exploration.

## 2.2 Geology of the Lower Shire basin

The lowershire basin is a part of the larger shire basin that extends from Lake Malawi to the Zambezi River in Mozambique. The basin is a rift basin that formed during the break-up of Gondwana in the Mesozoic era (Kumar, 2011). The basin is filled with continental sediments of fluvial, lacustrine, and deltaic origin, ranging in age from Jurassic to Cenozoic. The basin has been subjected to several phases of tectonic activity, including faulting, folding, and uplift (Rolf A. de By et Al, 2001).

The basin is considered to have potential for hydrocarbon exploration, as it contains thick organic-rich shales and coal beds that could act as source rocks, as well as sandstones and carbonates that could act as reservoir rocks (Aturinde et Al, 2019). However, the basin is poorly explored and the available geological information is scarce and outdated. Only a few wells have been drilled in the basin, none of which reached the target depth or encountered hydrocarbons.The basin also lacks adequate geophysical data, such as seismic, gravity, and magnetic surveys, that could help to map the subsurface structures and identify potential traps. Therefore, the basin presents a unique set of challenges and opportunities for hydrocarbon exploration, and requires more comprehensive and systematic geological studies to assess its prospectivity (Kumar, 2011).

## 2.3 Previous work in the area

Previous works done in the lower shire basin, Malawi which, may include; the structure re-interpretation of the lower shire basin in the southern Malawi rift using gravity data (Chisenga, 2019). The study uses a combination of the gravity data and geological information to create a new structural model for the basin. It concluded

that the basin is composed of the series of the half grabens that are separated by normal faults, also discovery of new faults that were not previously recognized in the basin.

Dulanya 2016, conducted a study in the lower shire basin, a review of the geomorphotectonic evolution of the Southern Malawi rift. The paper provides a review of the geomorphotectonic history of the southern end of the middle shire basin, the study is based on the integration of existing geomorphotectonic processes in the latter part of Cenozoic. The study area adjoins the NW-trending lower shire basin to the lake Malawi-upper shire rift and is key to understanding geomorphotectonic processes in the latter part of the Cenozoic despite the absence of well-developed basins and sediment archives.

Mineral potential of the lower shire area in Malawi by Grain Malunga, the paper discusses the minerals associated with the sedimentary deposition and remobilization of the ultrabasic intrusions in the lower Shire area. The main minerals of the interest are nickel, copper, chrome, gold, uranium, oil and gas. The study indicates that the recent airborne geological survey has revealed areas with thick sediments greater than 2.0 kilometer around Nchalo, Chapananga, to the west of Mwanza fault and Makhanga to the west of Thyolo escarpment fault. These depths are favourable for the formation of oil and gas.

## 2.4 Application of GIS in exploration

GIS is an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or geospatial data in order to support decision making for planning and management. Using GIS in mineral exploration encourages a more efficient use existing data which is cost effective (Tagwai, 2023). Exploration cost are rising, exploration drilling can be expensive, rate of discovery of large world class ore bodies is decreasing, however reanalysis of existing data both modern and historical through GIS 2D and 3D modelling allows for more targeted and cost-effective drilling operation. The other important contribution of GIS is time efficiency, this is because GIS can combine data and databases from different sources

with ease, can link directly from modelling software to databases of results ensuring the most recent assay information analytical (Quinter, 2022).

GIS and database management for mining exploration (Wambo, 2022). The paper aims at how geographic information systems and database management can help in mineral exploration, it focusses on building a database and GIS system capable of assessing the validity of geological/ geographical data taken from the field and effectively managing mining data in GIS designed to positively influence any mining exploration project from its earliest stages to the end of the project. Application of GIS in geology (AL-Shehab, 2007). The study provides an overview of the application of GIS in geology, it discusses how GIS can be used to analyze geological data, create geological maps, and model geological processes.

## 2.5 Application of Remote Sensing in exploration

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected emitted radiation at a distance (USGS). Generated images in remote sensing are extensively used to explore mineral deposits. The Images facilitate mapping geological features and lineaments and identifying rocks by spectral signature. These images are usually gathered either through synthetic aperture sensors or optical sensors (Munawar, 2022).

Remote sensing for mineral exploration (Sabins, 2009). The paper discusses how remote sensing can be used to explore minerals; it explains that remote sensing is a technique for obtaining information about distant objects without being in physical contact with the object. Remote sensing collects electromagnetic or acoustic signals to gather information about the object.

Remote sensing application in oil and gas industry (Sizov, 2014). The study is about monitoring environmental impact of oil and gas activities by using remote sensing. It explains the remote sensing is an effective tool for the environmental monitoring

because it provides wide coverage of area of interest, high temporal resolution, precise location, automatic processing and a large set of extracted parameters.

## 2.6 Remote sensing and structures associated with faults

### 2.6.1 Normal and reverse faults

Normal and reverse faults are often near-vertical at the surface, are characterized by a linear trace, and are frequently indistinguishable. They are identified by an escarpment, offset landforms, by juxtaposition of differing lithologies, or an abrupt change in strike or dip across the trace. Where there are no outcrops, or they are covered by vegetation, near-vertical faults may appear as vegetation or soil tone alignments, often because of near surface groundwater. Linear stream segments or linear valleys extending several kilometers suggest fault control, since the broken rock in the fault zone is readily eroded into valleys. Alignments of springs reveal groundwater ponding against a fault (Christopher D Lloyd, 2002)..

Prost, 2012 & reference therein, Listric normal faults tend to be arcuate or scoop-shaped in plain view. Faults concave toward the downthrown side are probably listric. Rotation of bedding and continued faulting leads to a sequence of steep to shallow dips as one proceeds basin ward. Growth faults, a type of listric fault, are characterized by dip reversal into the fault (rollover).

### 2.6.2 Reverse faults

Reverse faults bound many uplifts. A linear mountain front with parallel zones of fractures and faults within the uplift suggest the uplifted block is bounded by reverse faults and overhangs the basin. These parallel zones are probably relaxation features that developed following uplift (Price, 1959). The fault and uplifted basement can form an updip seal ("overhang play").

### 2.6.3 Strike-slip faults

Prost, 1992, and reference therein Strike-slip faults are recognized by a consistent lateral offset of units, streams, alluvial fans, roads, etc. En echelon folds develop at 30-450 to the fault and perpendicular to the maximum horizontal compression. The Newport-Inglewood trend in the Los Angeles basin has produced much oil from en echelon folds. Strike-slip faults can also be recognized by pull-apart basins or sag ponds at releasing bends, and by buckle folds and "flower" structures at restraining bends. Pull-apart basins can form depocenters that accumulate source and reservoir units; flower structures often contain folds that trap hydrocarbons.

# CHAPTER 3: STUDY AREA

This research was carried out in Chikwawa district. The district is located in the shire lowlands in the Southern region of Malawi. The district covers an area of about 4755 km$^2$. It is located at the 16.1958° S, and 34.7741° E. Below is the figure showing the study. The study area was chosen because is one of the places that show potential and is favourable for the formation of oil and gas (Malunga, 2014).

## 3.1 Location of the study area

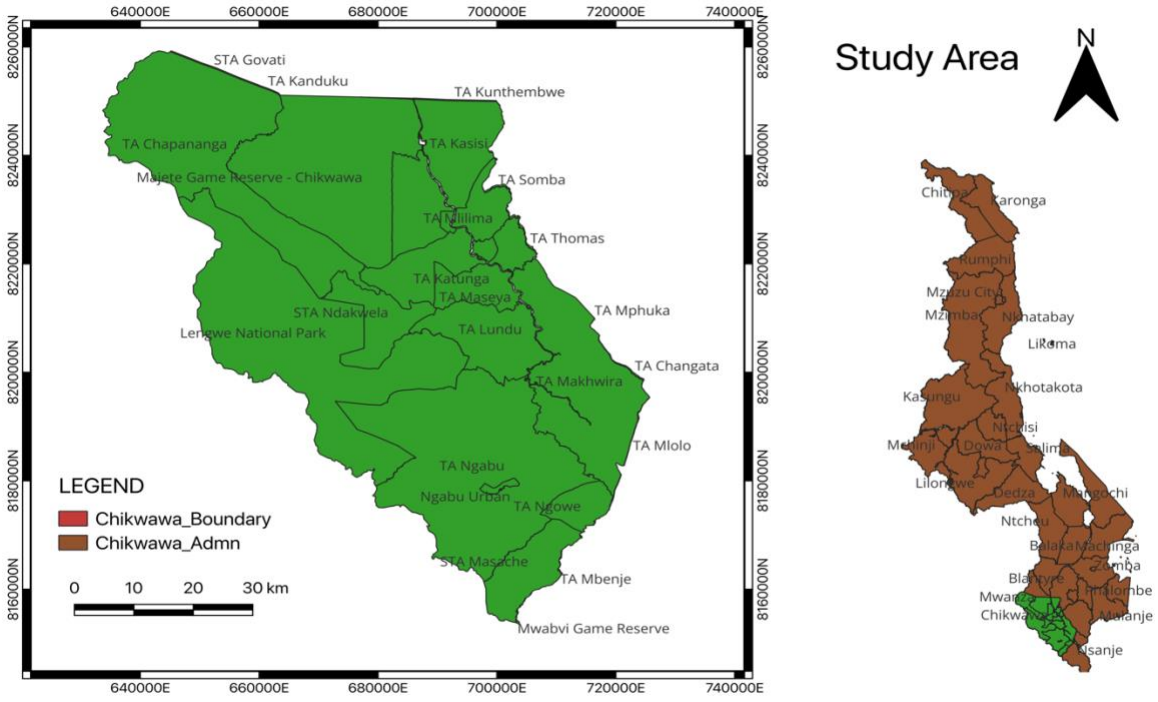



*Figure 1.Map of Study Area*

# CHAPTER 4: METHODOLOGY

## 4.1 Methods

The methods that were used in this research include overlay techniques such as clipping, selection. This methodology was used to create maps showing the different features of the study area to understand the relationships between the map features adequately and identify the geology or the lithology of the study area. By using the best available data, it was possible to produce results rapidly. For example, selection (the process of choosing and highlighting specific features within a layer) was done to come up with the study area (Chikwawa) from the entire dataset of the country, as for clipping which is the process of creating a new dataset by extracting only the parts of the dataset that fall within a specified geographic boundary. This is typically done by overlaying one layer with another and retaining the features that intersect with a chosen boundary, in this case the geology of the Chikwawa was clipped from the entire country (Malawi) dataset.

## 4.2 Data Collection Method

Most of the data used in this research was downloaded from the internet.

Table 1: Satellite image data

| Dataset | Source | Date | Path | Row | Resolution |
|---|---|---|---|---|---|
| Landsat8 OLI/TIRS | USGS | 2023/09/24 | 168 | 071 | 30m |
| SRTM DEM | EarthData | | | | 30m |

Other secondary dataset

Table 2 : Other Secondary Dataset

| Dataset | | Source |
|---|---|---|
| Vector | Geology data | USGS |
| | Administration data | Diva GIS |
| Raster | Lithology data | Africa Lithology |

## 4.3 Software

Different softwares were used in this research project for different purposes.

Table 3: Software

| Software | Purpose |
|---|---|
| PCI Geomatica | • Lineament extraction |
| Qgis 3.3.2 | • Data processing<br>• Data visualization<br>• Data analysis<br>• Data management |

## 4.4 Research Design

Secondary dataset was used to answer the research questions that helped attain the main objective of the research. Below is the flow diagram

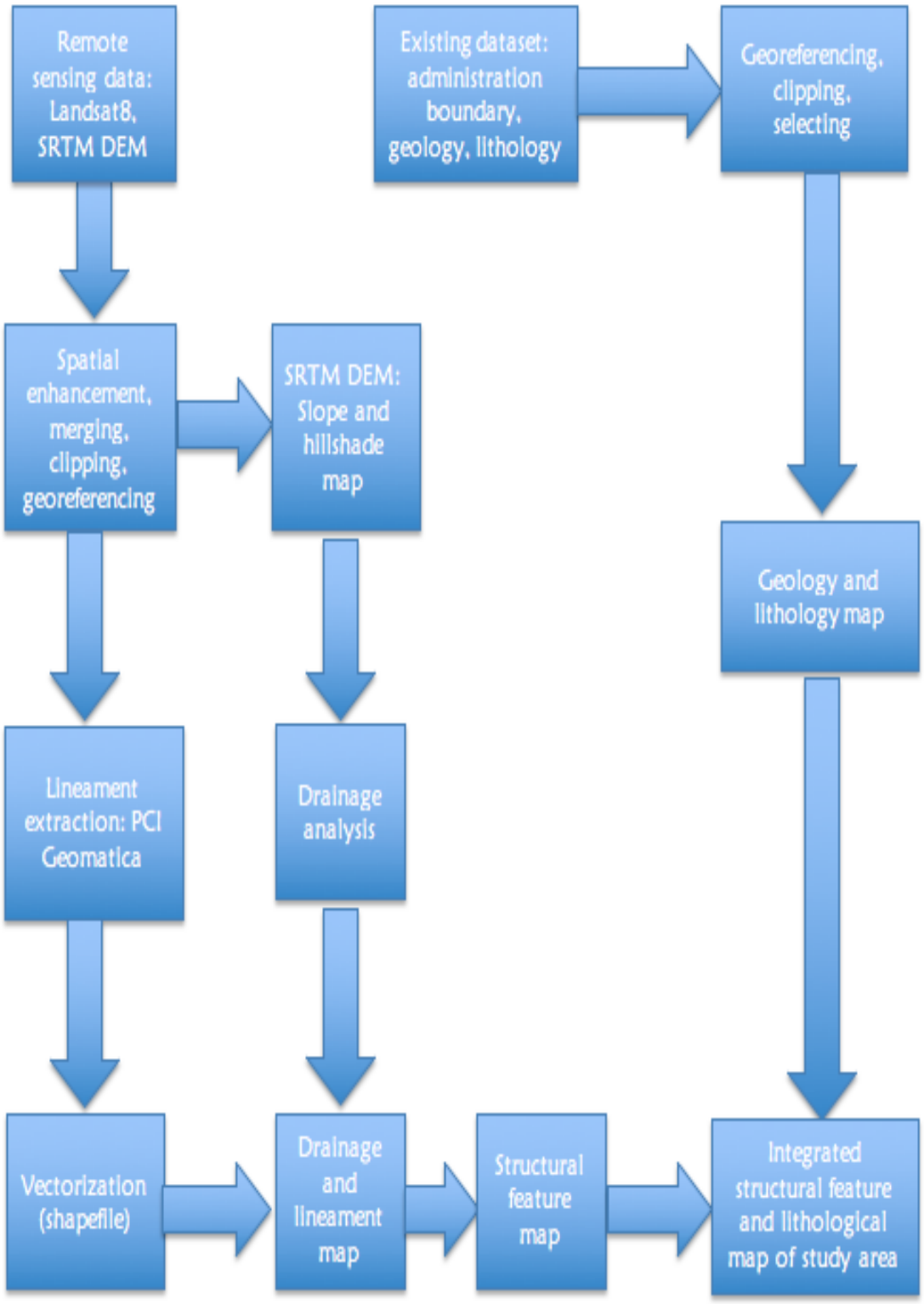



Figure 2: Methodology Flow Diagram

# CHAPTER 5: DATA ANALYSIS

## 5.1 Utilizing DEM data for geologic analysis.

Utilizing Digital Elevation Model (DEM) data for geologic analysis is a fundamental practice in the field of geology and earth sciences. DEMs provide a detailed, three-dimensional representation of the Earth's surface, including elevation and terrain information (Ibrahim, M. 2020). Geologists leverage DEM data to investigate and interpret various geological features and phenomena, such as fault lines, landform characteristics, slope analysis, and drainage patterns. This data is particularly valuable for geomorphological studies, helping geologists identify geological structures and understand the evolution of landscapes. DEMs also facilitate geological mapping, allowing researchers to delineate rock outcrops and structural boundaries more accurately (Chenrai, 2012). By integrating DEM data with other geospatial information, geologists can gain valuable insights into geological processes, making it an indispensable tool for geological research and exploration.

### 5.1.1 Application of DEM data

Incorporating surface DEM (Digital Elevation Model) data serves to rectify the geometric distortions resulting from terrain relief in remote sensing imagery. This correction significantly enhances the positional accuracy of remote sensing data and facilitates the generation of lifelike 3D images. Furthermore, it offers precise geographic coordinates crucial for surface surveying (Xiong, 2021).

The digital elevation data is particularly valuable for creating detailed valley and trench maps, as well as comprehensive drainage maps. In this particular study, a 30-meter SRTM DEM dataset has been employed for the analytical purposes.

### 5.1.1.1 Elevation Map

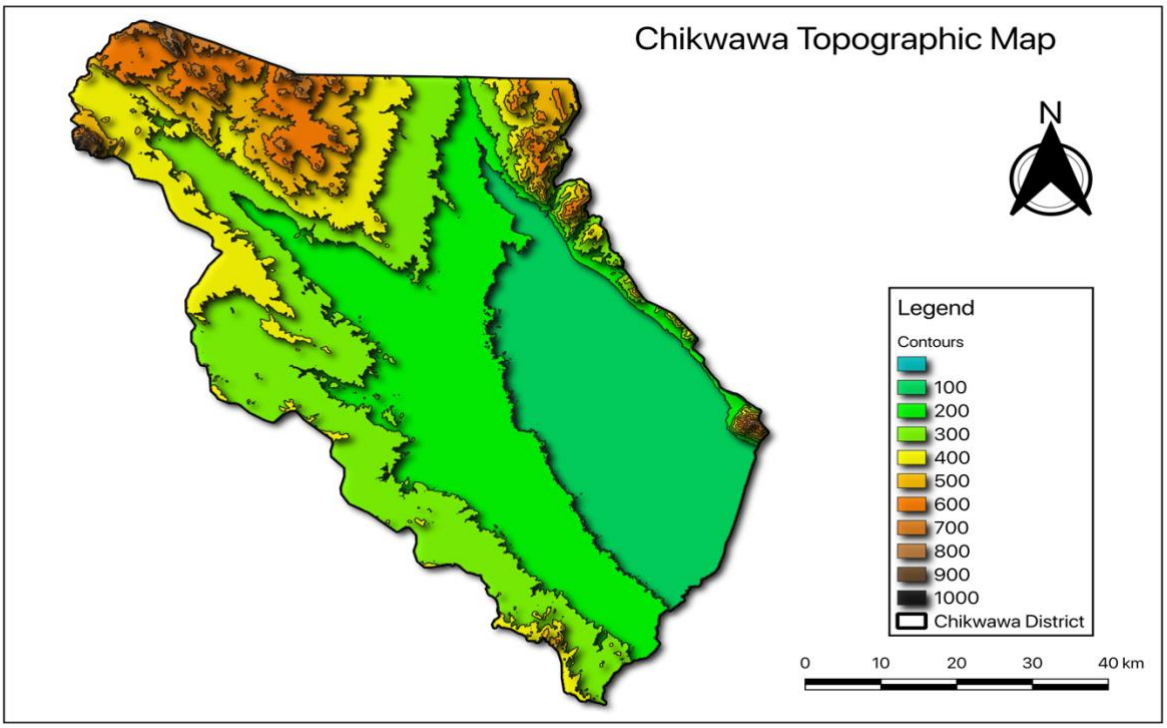



*Figure 3: Chikwawa Elevation*

After the DEM analysis the Northern and North-West part of the study area have a very high elevation of about 900m, to the South and South-East of the study area has the lowest elevation of about 46m.

### 5.1.1.2 Slope

A slope map was produced using QGIS, utilizing terrain analysis techniques to extract slope information from the 30-meter SRTM dataset. This slope map provides a visualization of the variations in surface slope within the study area (Buckley, 2017). Notably, abrupt changes in slope across the landscape can serve as indicators of structural characteristics. In the slope maps, the identified lineaments may correspond to the locations of fault scarps.

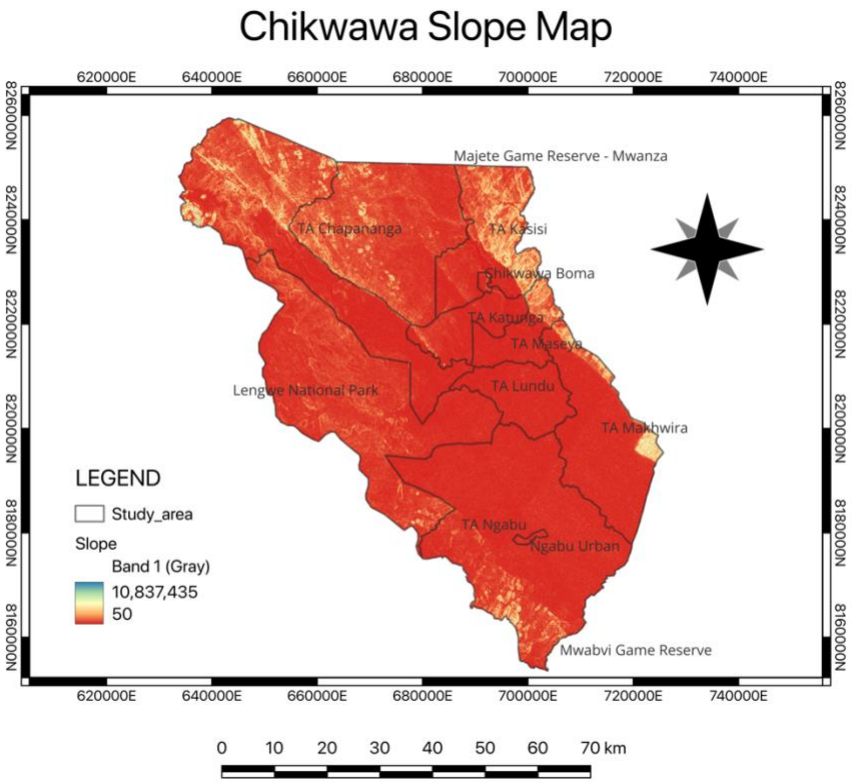



*Figure 4: Chikwawa Slope Map*

The resultant image encompasses slope values ranging from 50% to 10,837,435%. Upon closer examination of the slope map within the study area, it becomes evident that a discernible linear shift in slope angles is present. This transition is visually represented by the change from red to yellow colors, as depicted in Figure 5. Furthermore, it's worth noting that this systematic alteration in slope angles aligns precisely with the variations in elevation observed across the tonal geomorphic features, such as lineaments.

### 5.1.1.3 Hillshade

A hillshade map in QGIS is a visual representation that simulates the shading and shadows on a terrain model, providing a three-dimensional appearance of the landscape (Frye, 2009). It is created from Digital Elevation Model (DEM) data, the SRTM (Shuttle Radar Topography Mission) dataset, to visualize the terrain's variations in elevation and slope. The map aids in the identification of key terrain characteristics,

such as hills, valleys, ridges, and slopes, which are valuable for landform analysis and geological investigations.

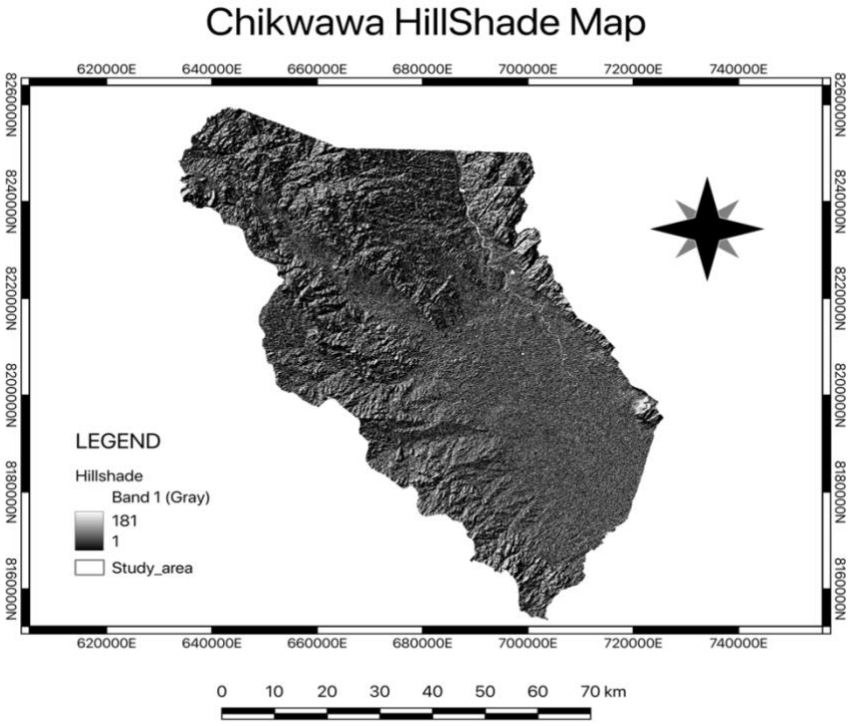



*Figure 5: Hillshade Map*

### 5.1.1.4 3D Map

3D maps generated from SRTM data offer vital insights that significantly enhance the understanding of the study area compared to traditional 2D maps. By incorporating elevation data, these 3D maps unveil the intricate terrain, allowing exploration teams to identify favorable drilling sites, understand the impact of elevation on hydrocarbon reservoirs, and analyze potential geological hazards such as fault lines and structural complexities (USGS, 2018). Moreover, these maps facilitate precise drainage pattern analysis, helping in the assessment of watersheds and how they influence the migration of fluids beneath the surface. In essence, 3D maps derived from SRTM data provide petroleum exploration experts with a more realistic, comprehensive, and geologically insightful representation of the subsurface landscape, enabling better-informed decision-making and improved resource assessment for hydrocarbon prospecting. The 3D map was created using QGIS using Qgis2threejs plugin.

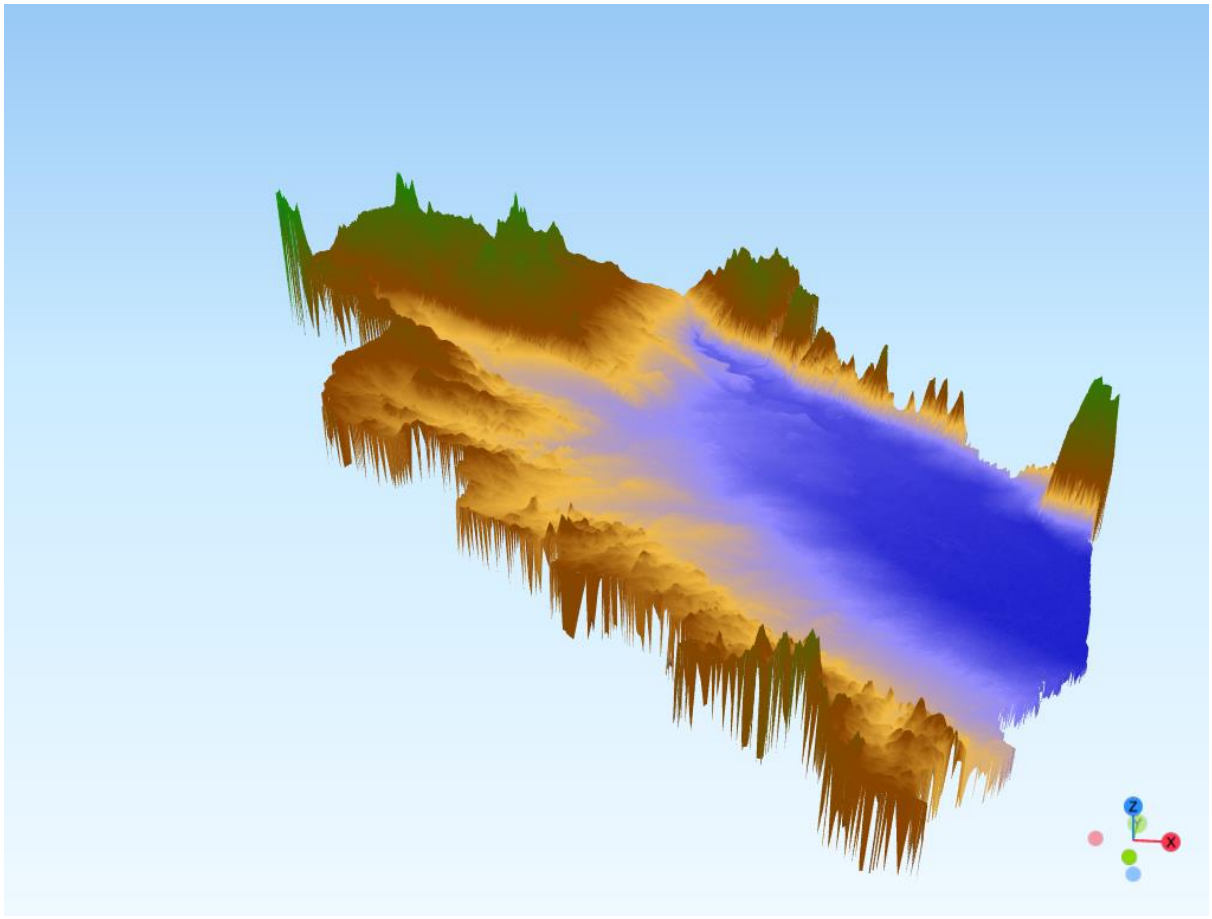


*Figure 6: 3D map*

## 5.2 Drainage analysis

As stated in Prost (1992), In alluvial terrain, streams can exhibit distinctive angular patterns that correlate with subsurface buried structures. These angularities often result from fractures that propagate vertically due to reactivation, or they may be induced by the bending of rock layers due to drape over subsurface structures. The control exerted by these fractures on stream channel erosion can lead to the formation of abrupt, nearly right-angle bends in the river channels. Understanding and identifying these geomorphic features can provide valuable insights for geoscientists and petroleum explorers, as they can indicate the presence of subsurface geological structures, potentially aiding in the detection of hydrocarbon reservoirs or exploration targets.

### 5.2.1 Automatically Generated Drainage System

The use of Geographic Information Systems (GIS) for the automatic extraction of drainage networks from Digital Elevation Models (DEMs) has become a prevalent and valuable practice in the field of hydrology. Saraf et al. (2004) emphasized this growing trend in their research. This method enables efficient and accurate mapping and analysis of river networks, watershed boundaries, and other hydrological features by utilizing the spatial data within DEMs. The automated extraction of drainage networks not only expedites the process but also enhances the precision of hydrological studies, making it an essential tool for water resource management, flood modeling, and environmental planning on a global scale.

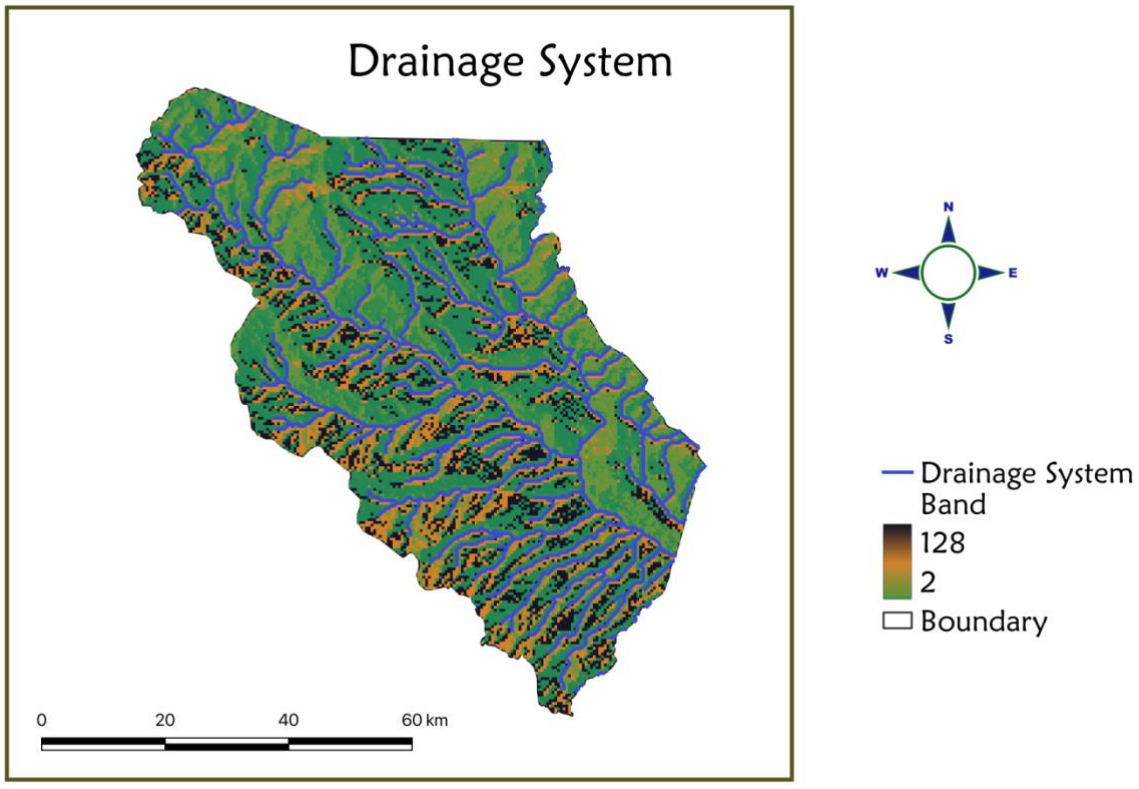



*Figure 7: Drainage System*

The series of procedures outlined in the terrain processing of ArcHydro extension, as depicted in Figure 7, represents a crucial workflow for hydrological analysis. It begins with "flow direction," where the software determines the direction in which water

flows out of individual pixels or cells in a Digital Elevation Model (DEM). Subsequently, "flow accumulation" and "stream definition" stages calculate and identify potential stream channels, followed by "stream segmentation" to further refine and delineate the stream network.

The process continues with "catchment grid delineation," which defines the boundaries of individual catchment areas or watersheds. This information is then used in "catchment polygon processing" to generate polygon features representing these watersheds. Finally, "drainage line processing" refines the representation of drainage lines and stream features in the dataset.

## 5.3 Lineaments and Related Features in the Study Area

Lineaments, as defined by O'Leary, Friedman, and Phon (1976), are distinct linear features on the Earth's surface that can be mapped and exhibit straight or gently curving alignments. These linear features noticeably differ from the surrounding landscape and are thought to indicate subsurface geological phenomena. Sabins (1997) further elaborates on the nature of lineaments, stating that the surface features constituting a lineament may be either geomorphic, resulting from relief and topographic changes, or tonal, arising from differences in surface contrast, such as variations in vegetation cover or color.

Lineaments can manifest as various surface features, including landforms, linear boundaries between different terrain types, or interruptions in otherwise uniform landscapes. Geomorphic expressions of lineaments may include straight stream valleys or aligned segments of valleys. Lineaments can be either continuous or discontinuous. In the case of discontinuous lineaments, individual features align consistently in a particular direction and are relatively closely spaced, making them valuable indicators for geological and environmental analysis.

### 5.3.1 Lineament Extraction

Lineament extraction in PCI Geomatica using Landsat8 Band 9 involves a comprehensive process to identify and map linear features on the Earth's surface.

Landsat 8's Band 9, part of the Thermal Infrared Sensor (TIRS), is particularly useful for this purpose as it captures thermal information that can reveal subtle surface temperature variations. The extraction process begins with image enhancement and preprocessing to improve the visibility of lineaments in Band 9. Subsequently, the processed image is segmented to identify potential lineament candidates. This is followed by further filtering and classification techniques to isolate and refine the linear features. After identifying the lineaments, the next step is vectorization, which entails converting these features into a shapefile format. The shapefile can then be seamlessly integrated into QGIS, where it can be overlaid with other geospatial data, such as hillshade maps, to analyze the relationship between lineaments and terrain features. This integrated approach allows for a more comprehensive understanding of geological and environmental characteristics.

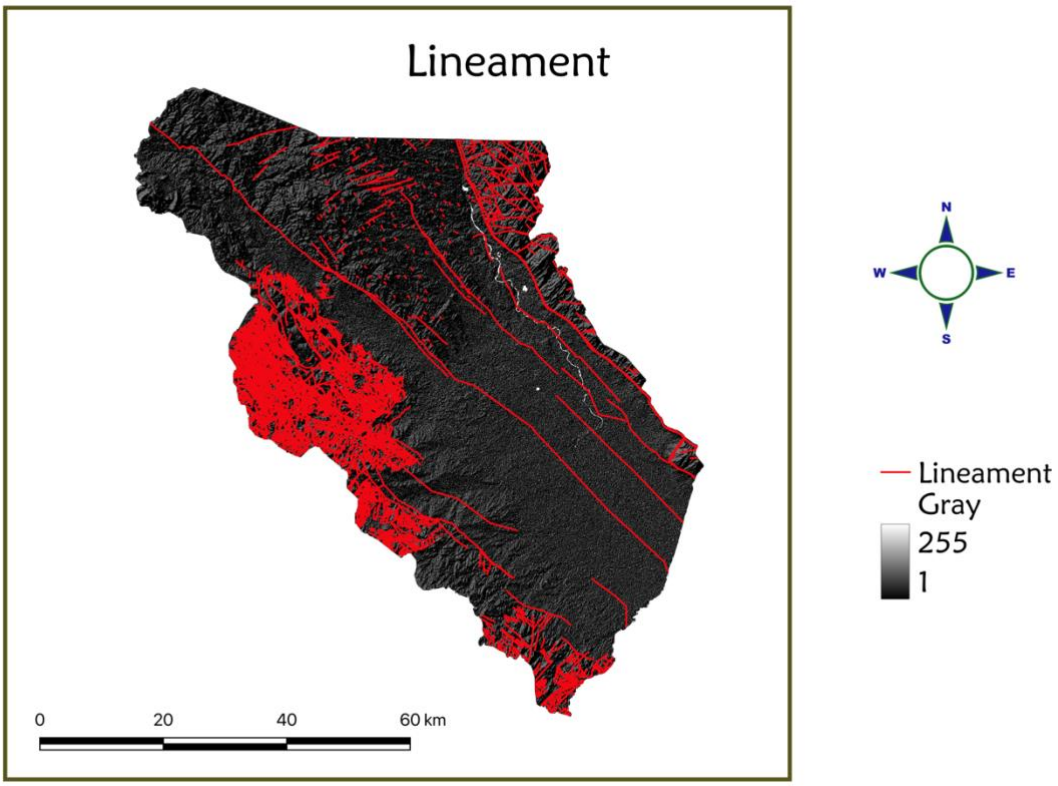



*Figure 8: Lineament*

## 5.4 Lithology of The Study Area

Lithology refers to the study and description of the physical characteristics, composition, and mineralogical content of rocks and sediments in the Earth's crust. It encompasses the analysis of various geological features, including the type of minerals present, the texture, color, grain size, and other observable attributes of rocks and sediments. Lithology plays a crucial role in the field of geology and is fundamental to understanding the Earth's history, processes, and the formation of various geological formations. Geologists use lithological information to categorize and interpret rock types, which, in turn, helps in characterizing the geological history of an area, identifying potential natural resources, and assessing the suitability of rock layers for various engineering and environmental applications.

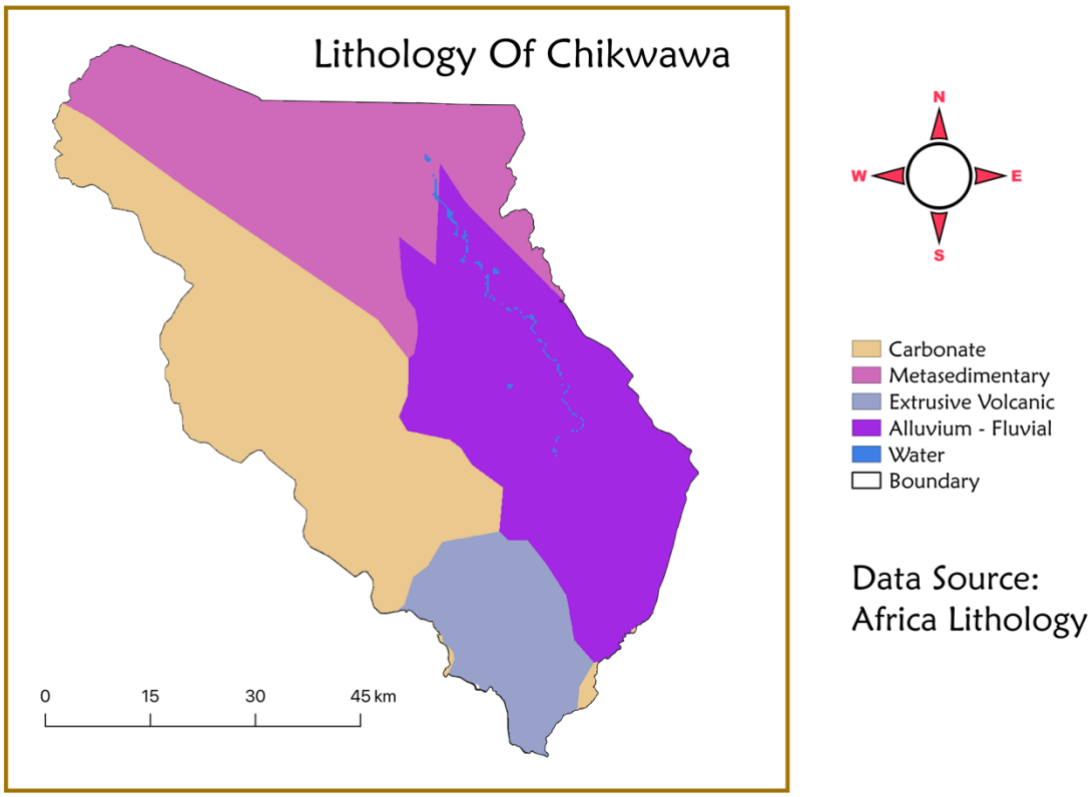



*Figure 9: Lithology of Chikwawa*

### 5.4.1 Carbonate Rocks

Carbonate rocks are sedimentary rocks primarily composed of carbonate minerals, with calcium carbonate ($CaCO_3$) being the most common mineral (Campeny, 2014). These rocks often originate from the accumulation of organic materials like shells, corals, and microorganisms in marine environments. Limestone and dolomite are common types of carbonate rocks. Carbonate rocks are typically characterized by their light-colored appearance, and they can vary in texture from fine-grained to coarse-grained. They often form distinct geological formations and may contain fossils, making them valuable for understanding Earth's history and paleoenvironments.

### 5.4.2 Metasedimentary Rocks

Metasedimentary rocks are sedimentary rocks that have undergone significant metamorphic changes due to heat and pressure within the Earth's crust (Scofield, 2021). These rocks were originally formed from sediments like sand, silt, clay, or organic material. Metamorphism transforms these sediments into new rocks with altered textures and mineral compositions. Common examples of metasedimentary rocks include slate, schist, and gneiss. Metasedimentary rocks provide valuable insights into the geological history of an area and the tectonic forces that have acted upon it.

### 5.4.3 Extrusive volcanic Rocks

Extrusive volcanic rocks are igneous rocks that form on the Earth's surface from the rapid cooling and solidification of molten lava erupted from volcanoes (Newton, 2021). These rocks typically have a fine-grained or glassy texture due to the quick cooling process. Common types of extrusive volcanic rocks include basalt, andesite, and rhyolite. They often have a dark-colored appearance and can contain various mineral crystals. The composition and characteristics of extrusive volcanic rocks can provide information about the type of volcanic activity and the geological history of a region.

### 5.4.4 Alluvium-Fluvial Rocks

Alluvium refers to unconsolidated sediments, including sand, silt, clay, and gravel, that are deposited by flowing water, typically in river channels and floodplains. Fluvial refers to processes and features associated with rivers and their action (Johnson, 2019). Alluvium-fluvial deposits are sediments that have been transported and deposited by river systems. They can range from fine silts to coarser gravels, depending on the energy of the river. Alluvium-fluvial deposits are important for understanding river dynamics, sediment transport, and can be valuable for groundwater aquifers in some cases. These deposits often reflect the current or historical activity of rivers and their role in shaping the landscape.

## 5.5 integration of Structural features and lithology

The creation of a geological map in a study area involves the integration of various geological components, including structural features such as lineaments and major rivers, with lithology. This integrated approach is crucial for a comprehensive understanding of the region's geological characteristics. Lineaments and structural features can reveal subsurface geological structures, fault lines, and potential hydrocarbon reservoir locations, providing critical insights for petroleum exploration. Major rivers, on the other hand, offer information on the drainage patterns and sedimentary deposits that may indicate areas conducive to hydrocarbon accumulation.

Lithology helps identify the rock types and formations, allowing geologists to determine the geological history, the presence of source rocks, and the potential traps for hydrocarbons. A geological map, thus, serves as a valuable tool for petroleum exploration, as it aids in the identification of favorable areas for hydrocarbon deposits, assisting in resource assessment, well site selection, and overall exploration strategies. This integrated mapping approach is essential for optimizing the success and efficiency of petroleum exploration efforts in the study area. The integrated map is shown below.

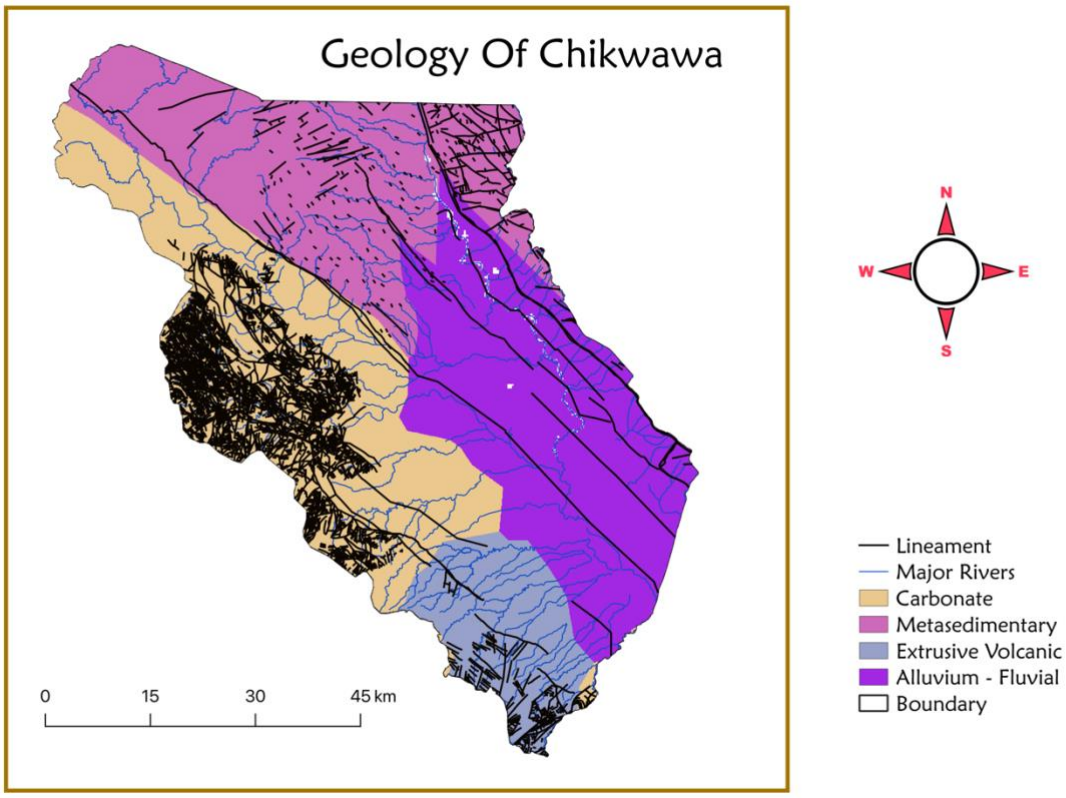



*Figure 3: Geological Map*

# CHAPTER 6: RESULTS AND DISCUSSIONS

## 6.1 Structural Features

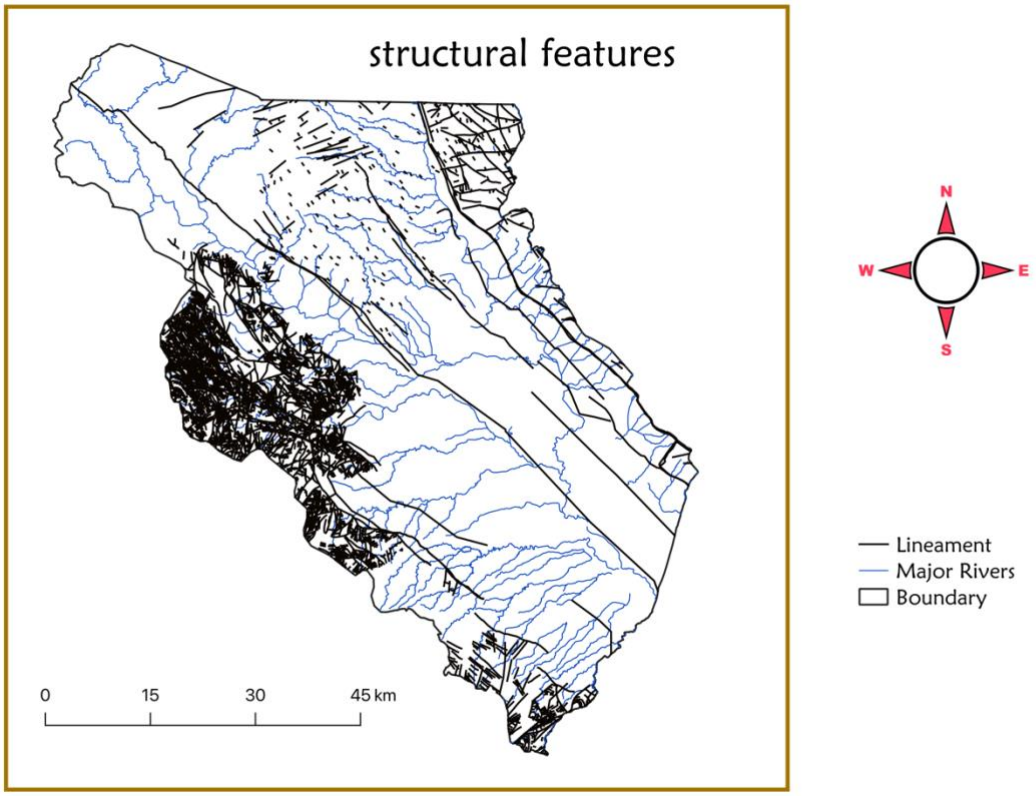



*Figure 4: Structural features*

### 6.1.1 Lineaments and Faults

The presence of lineaments and faults in the region is an essential structural component. Lineaments represent linear features on the Earth's surface that can reflect subsurface geological structures, such as fault zones and fractures. Faults are particularly important as they can act as both conduits and barriers for the migration of hydrocarbons. Identifying and mapping these structural features is vital for locating potential reservoirs and understanding the pathways of hydrocarbon migration.

### 6.1.2 Folded Structures

The study area also exhibits various folded structures resulting from tectonic forces. These folds can create structural traps for hydrocarbons, as anticlines and synclines often serve as excellent reservoirs and seals, respectively. The examination of these folded structures is critical in determining potential trapping mechanisms for petroleum accumulations.

### 6.1.3 Major Rivers and Drainage Patterns

The major rivers and their associated drainage patterns in the region are instrumental in understanding sedimentary processes and the deposition of potential source rocks and reservoirs. The interaction of rivers with geological structures can influence the accumulation of hydrocarbons in subsurface traps. Studying these features aids in identifying areas where sedimentary basins may contain organic-rich source rocks.

## 6.2 Lithology of the Area

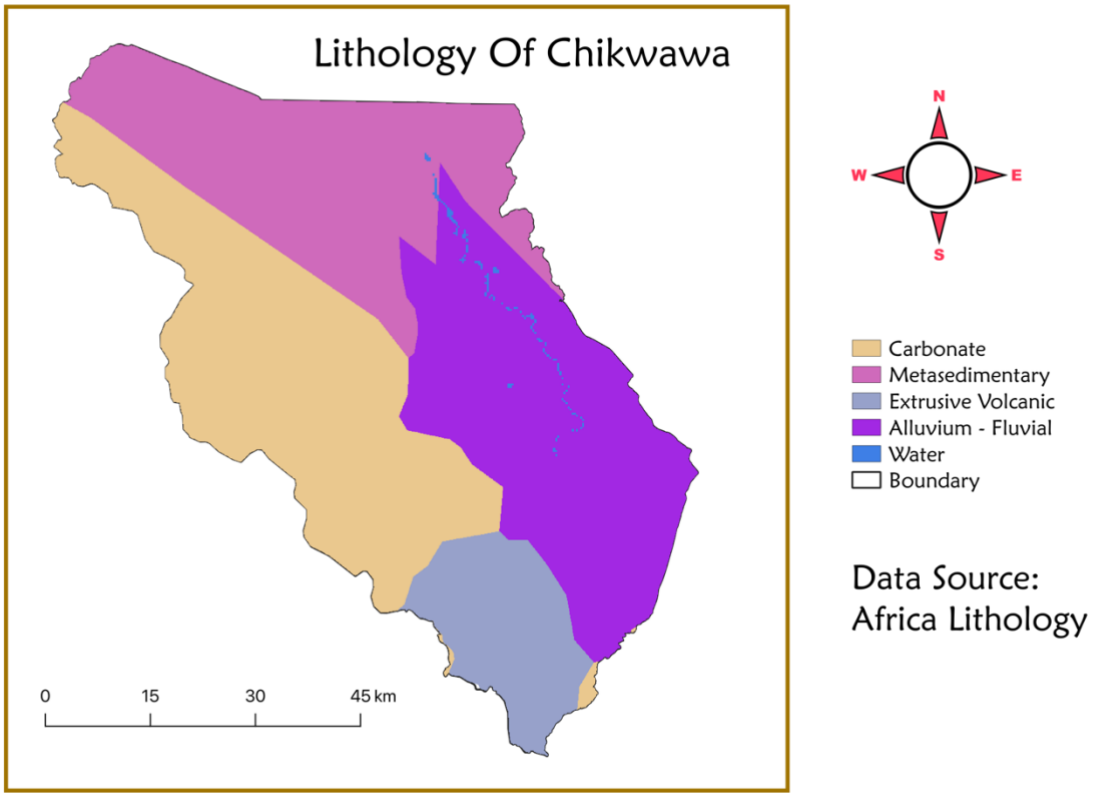



*Figure 5: Lithology Map*

### 6.2.1 Carbonate Rocks

The identification of carbonate rocks in Chikwawa District, such as limestone and dolomite, signifies the presence of ancient marine environments. These carbonate formations serve as promising reservoir rocks due to their high porosity and permeability, making them capable of storing and transmitting hydrocarbons. Moreover, carbonate lithology often indicates the existence of favorable conditions for the accumulation of oil and gas, making areas with significant carbonate content potential targets for further exploration efforts.

### 6.2.2 Metasedimentary Rocks

Metasedimentary rocks found in the district, including schist and gneiss, indicate the presence of rocks that have undergone metamorphism. While metasedimentary rocks themselves may not be primary reservoirs, they can act as source rocks, providing organic material essential for hydrocarbon generation. Understanding the metamorphic history of these rocks is crucial, as it provides insights into the thermal maturity and potential hydrocarbon content of adjacent formations.

### 6.2.3 Extrusive Volcanic Rocks

The occurrence of extrusive volcanic rocks, such as basalt and andesite, suggests past volcanic activity in the region. Volcanic rocks can serve as both reservoirs and seals in petroleum systems. Vesicles and fractures within volcanic formations can store hydrocarbons, while well-sealed volcanic rocks can act as effective traps, preventing the migration of hydrocarbons to the surface. Therefore, areas with extrusive volcanic lithology warrant detailed exploration to assess their hydrocarbon potential.

### 6.2.4 Alluvium-Fluvial Deposits

Alluvial and fluvial deposits in Chikwawa District represent unconsolidated sediments, including sands, silts, clays, and gravels, which have been transported and deposited by rivers. These deposits often form productive reservoirs due to their high porosity and permeability. Additionally, the presence of alluvial-fluvial lithology indicates the proximity of sedimentary basins and river systems, which can act as

conduits for hydrocarbon migration. Exploring these areas is vital as they can host accumulations of economically viable oil and gas reserves.

# CHAPTER 7: CONCLUSION AND RECOMMENDATION

## 7.1 Conclusion

Interpreting remote sensing imagery and incorporating subtle signs of geological structure in petroleum exploration is a game-changer for several reasons. Firstly, it allows for a more accurate, faster, and cost-effective approach to exploration. This is particularly beneficial when dealing with remote, rugged, or poorly-mapped terrains, where traditional exploration methods may be challenging and time-consuming. These subtle signs of structure, both direct (e.g., fault offsets and dips) and indirect (e.g., drainage alignments), can be effectively detected and analyzed using remote sensing and Geographic Information Systems (GIS).

The application of remote sensing and GIS technology offers the oil industry an efficient means of exploration that surpasses traditional techniques. It provides a rapid and systematic way to survey large and often inaccessible areas, facilitating the identification of potential petroleum reservoirs. The ability to collect and analyze geospatial data, such as satellite imagery and topographic information, enables geologists and exploration teams to make informed decisions about drilling locations, reducing the risk of dry wells and minimizing exploration costs.

## 7.2 Recommendation

- Detailed geological fieldwork is required for some surface expressions of the off-setting faults.
- High resolution grid 2D and 3D seismic lines and further interpretation of the existing data.

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