

ASSESSMENT OF HYDROCARBONS IN NCHALO, CHIKWAWA DISTRICT USING GRAVITY DATA

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DEDICATION

The study is dedicated to the geology students at large, as it shows how GIS and remote sensing can be used to search for Hydrocarbon resources, but can be applied to Hydrogeology, ground water modeling among others.

Secondly, the study helps in the field of science and technology as the it used unique software, and techniques which when utilized well, can help to monitor and evaluate geophysical features. The software was used by scientists in other advanced countries to help monitor the weather, determine and estimate disasters though modelling and mapping and prevent all sorts of unfortunate events in various fields like the environment, geology and Health.

ABSTRACT

Petroleum exploration is being pursued by several companies in regions that shows potential as the Hydrocarbons are a key resource for the fumes that power the industries, transportation, agriculture etc. The exploration is done usually through the geophysical methods like seismic survey, gravity survey which can be done on air, land and at sea. These provide information on the subsurface about depth, anomalies, though use of software the data can be manipulated to show models that do display various parameters on the size of sediments, reservoir spanning or size, trapping system as well as the potential of an area having these resources.

The study used remote sensing and geophysical data and techniques to assess the potential of Chikwawa district having these resources. It is through structures like faults, seepages, anticlines and synclines that can show an area have the potential of having the resources or not, this however must be referenced with geological data such as rock types, formation types, lithologies as well as wellbore data in order for it to make sense. In the study is on the assessment of hydrocarbons in the Chikwawa using Hydrocarbon potential using GIS and RS it used Landsat file was used to formulate lineaments, to identify surface features, and to calculate the NDVI of the vegetation.

The DEM files were used to show the drainage as well as the topography of the areas, The results showed positive results through presence of source rocks, faults in the area, rock formed in formations with high organic matter and the drainage system that showed erosion in the area is currently low and evidence of the place undergoing changes through the rifting and deposition in the low area regions that indeed in Chikwawa there is potential of the area having the Hydrocarbons.

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Special gratitude to my supervisor, Mr. Shaba for his support and guidance throughout my research study. He made sure that I would complete my study within the fixed research period. Thank you for having confidence and understanding in me.

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Chapter 1: General Introduction

1.01. Background Information

Malawi is located within the East African Rift System, a large rift zone in eastern Africa where tectonic forces are slowly splitting the continent's crust to form new plates. This rift system consists of two main valleys - the Eastern Rift Valley and the Western Rift Valley. The Eastern Rift Valley starts in Ethiopia and runs south through several countries, including Kenya, Congo, Uganda, Rwanda, Burundi, Tanzania, Malawi, and Mozambique (Rotimi & Ngalawa, 2017). The rift valley in Malawi is part of the western branch, which includes the valley of Lake Malawi. This western branch extends over 900 km from southern Tanzania.

The eastern rift branch can be thought of as a tectonic plate boundary where new crust is slowly spreading apart. This rifting process explains the unique geological features seen across the region (Graham & Ovadia, 2019) .

Malawi's past exploration activities by Malawi Geological Survey's regional mapping work in 1970 revealed that sedimentary rocks, which may contain petroleum resources, are found in only two parts of the country. These are the Lake Malawi area, where lacustrine sediments are currently being deposited, and the Lower Shire Valley in the southern region of Malawi (Mattick, 1984).

There has been n lack of exploration activity in the southern region because of the lack of rock exposures and thin layers that were assumed to be in the area. On the contrary, there is confidence that the region can have the hydrocarbon resources as the recent studies confirmed the presence of faults and areas of thick sediments in the Shire basin in Chikwawa the recent airborne geophysical survey has added the geophysical information on the sedimentary basins in Malawi (Chisenga et al., 2019; Malunga Fimmm, 2018).



Figure 1 - Map of the Eastern and Western Branches of the East African Rift System

The rifting has created deep basins between the splitting crust segments. Many of these basins contain the ingredients for oil and gas formation - source rocks, reservoirs, seals, and traps. Several countries along the rift system have found hydrocarbon deposits in these rift basins. The presence of source rocks, faulting, and sedimentary basins makes the region very promising for more discoveries (Rop, 2016). The East African Rift System is seen as having huge potential for future oil and gas production. Major companies have invested in exploration and production after large reserves were discovered.

Studies show the rift system has strong hydrocarbon potential due to proven source rocks, including ongoing deposition in the rift lakes. The deep, stratified lakes allow organic-rich shales deposited during high stands to be preserved and generate oil and gas. Suitable reservoirs exist as carbonates and sands laid down during low stands. Numerous traps related to rifting are also present (Saunders, 2009). Complete petroleum systems are proven by over 10 discoveries in the Albert Basin. Seismic models predict additional hydrocarbon development across the rift lakes and basins. The geologic factors, analog basins, and oil seeps indicate significant remaining potential in the relatively unexplored East African Rift system.

Exploration of petroleum started in Malawi in 1980s by drilling wells in the northern region of the country. Unfortunately, these initial attempts did not discover enough oil or gas that could be commercially viable. In 2012, the Malawian government introduced an Economic Recovery Plan (ERP) with the aim of utilizing the country's abundant natural resources, including oil, to improve the lives of its people (Chimwala., 2017). As part of this plan, several companies were granted licenses for petroleum exploration in different areas. Surestream Petroleum secured licenses for Blocks 2 and 3 in Lake Malawi North, while SacOil Holdings obtained a license for Block 1. RAK Gas was granted licenses for Blocks 4 and 5, and Pacific Oil was awarded a license for Block 6.

These licenses allowed these companies to explore the respective blocks for potential oil resources. To ensure that oil exploration and production are conducted responsibly, the government of Malawi developed legal and policy frameworks, to regulate the activities of oil exploration and address environmental concerns while also considering the socioeconomic rights of the people.

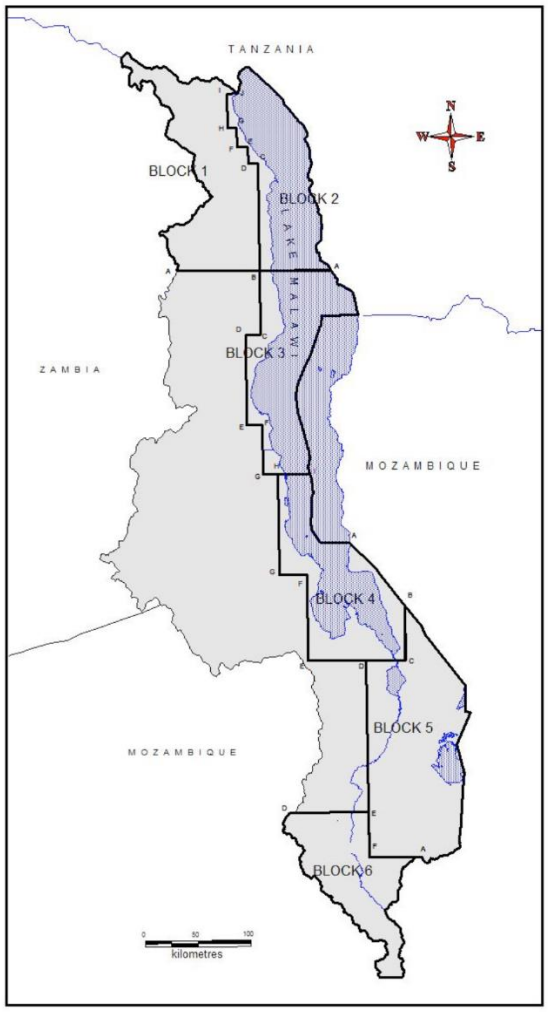


Figure 1: Showing Demarcation of Blocks in Malawi

1.1. Problem Statement

Malawi's nascent petroleum industry is facing challenges in evaluating the hydrocarbon potential in sedimentary basins, including Chikwawa district. The country lacks expertise and specialized knowledge within its borders to properly assess geological prospects nationwide (Whaley, 2017). Additionally, there is a lack of airborne data collected across different districts, leading to an inadequate understanding of the petroleum resources in Malawi's basins. Insufficient technical capacity further hinders the acquisition of comprehensive data (Mining, 2023). This shortage of information, expertise, and equipment severely limits efforts to promote exploration and production activities in promising areas like Chikwawa. While Malawi is formulating national policies to facilitate the growth of the sector, there are significant gaps in evaluating the petroleum resources in various districts data (Mining, 2023). Targeted initiatives are required to develop local expertise, institutions, and geological data acquisition capabilities in order to determine the hydrocarbon potential accurately. These initiatives would also help attract investment in upstream petroleum activities, unlocking benefits for Chikwawa district and the country as a whole.

1.2. Research Questions

The study is guided by the following research questions in pursuit of its objectives:

i. What is the regional geological context of the study area based on analysis of surface lithology, structures, and available spatial datasets? How does it compare to existing literature on the regional geology?
ii. Can detailed lineament analysis reveal significant structures and structural grain that provide insights into the subsurface structural controls and deformation history of the area?
iii. Based on a prospectivity analysis integrating favorable factors identified through surface data analysis, what specific zones exhibit geological characteristics indicating potential for hydrocarbon generation and trapping?

1.3. Research Objective

The main objective of this research is to “assess the hydrocarbon potential in Chikwawa district, using Geophysical Information System GIS and Remote Sensing RS techniques”

1.3.1. Specific objectives

To achieve the main objective stated in the previous section, the following are the specific
objectives:

i. To identify and analyze surface geology to understand structural controls and sedimentary basins in the area.
ii. To integrate available geospatial datasets to characterize the regional geological context and identify potential petroleum system elements.
iii. To use lineament analysis to delineate major structures and understand the structural grain of the area.
iv. To highlight zones that exhibit geological characteristics favorable for hydrocarbon generation and trapping, based on comprehensive analysis, for further investigation

1.4. Significance of Study

The assessment of hydrocarbons in Nchalo, Chikwawa district will hold both great scientific and economic significance. For researchers in the field of hydrocarbon exploration, it will provide an opportunity to expand knowledge of the geological characteristics and potential trapping systems in the area, which can advance understanding and improve exploration techniques. The findings can serve as valuable references to guide future research endeavors. Additionally, the study may help develop better methodologies and technologies. From an industry perspective, identifying any hydrocarbon deposits could open up new opportunities by increasing reserves, supporting growth in the petroleum sector through investment and job creation. The study's insights into the geology and potential systems can help industry decision-making by informing exploration strategies to optimize resource allocation and minimize risks.

Chapter 2: Literature Review

Hydrocarbon exploration, an essential activity in petroleum geology, progresses through various stages from initial land surveys to seismic surveys to the drilling of test wells. Remote sensing (RS) data and geographical information systems (GIS), when guided by geoscience expertise, allow petroleum exploration efforts to tap into new technological and economic potential. Among available RS platforms, Landsat 8 offers a well-suited system for mapping surface geological features relevant for oil and gas exploration (Saha, Remote Sensing and Geographic Information System Applications in Hydrocarbon Exploration: A Review, 2019). GIS enables spatial analysis and visualization of exploration data like seismic surveys, reservoir properties, and surface features. It allows integrating and interpreting multi-disciplinary data in map formats. GIS improves prospect evaluation through raster analysis of well data and subsurface properties. It creates customized thematic maps representing exploration variables. Overall, GIS enhances data management, analysis, and decision making across key exploration activities like surveys, prospect mapping, and data interpretation (Ovramenko, 2022).

Remote sensing (RS) and GIS recently, have been successfully utilized for basin-wide assessments to identify areas favorable for hydrocarbon exploration. This involves integrating and analyzing RS-derived multi-spectral geological data on sedimentary basins, lithology, landforms, terrain, structures, and tectonics. Geomorphic anomalies detected through RS and digital elevation models, such as anomalous drainage patterns and surface lineaments related to subsurface structures, are commonly used in onshore hydrocarbon prospecting (Ahmed, 2019). Overall, RS provides a valuable basin-scale perspective for oil and gas exploration by enabling detection and mapping of surface geological indicators that can reveal prospective hydrocarbon zones worth pursuing through more targeted subsurface investigation methods (Behadili & Sayed, 2019).

Geographic Information System (GIS)

A Geographic Information System (GIS) is a computer system that captures, stores, analyzes, and displays data related to positions on Earth's surface. It can show many different kinds of data on one map, such as streets, buildings, and vegetation, which enables people to more easily see, analyze, and understand patterns and relationships (ESRI, n.d.). Geographic information systems (GIS) are computer-based tools for capturing, managing, analyzing, and visualizing spatial or geographic data. GIS enables the mapping, modeling, and spatial analysis of diverse earth science phenomena to reveal trends, relationships, and patterns that support research and decision-making (GISRSStudy, 2019).

A geographic information system (GIS) integrates hardware, software, and data to facilitate the management, visualization, modeling, and analysis of location-based information (California, 2021). GIS provides advanced capabilities for mapping and understanding geographic distributions, processes, and relationships to support tasks such as geologic mapping, earth science research, resource management, and spatial planning.

ArcView Image Analysis takes advantage of various image data types that are widely available, such as satellite imagery, aerial photographs, orthorectified aerial images, and other remotely captured data. This image analysis supplements and supports different GIS applications by providing additional layers of visual data (Shah, 2006). Readily accessible remote sensing resources can be analyzed and incorporated into geographic information systems projects.

Remote sensing

Remote sensing refers to the technique of gathering information about objects or areas by analyzing data collected at a distance, without direct physical contact (Lillesand & Kiefer, 2003). In geographic information systems (GIS), remotely sensed digital data constitutes a major input, especially for studying large regions that require frequent re-evaluation. Remote sensing utilizes technologies like satellites, aircraft and drones to observe, measure and interpret the earth's surface, atmosphere, other planets, and even outer space (Shah, 2006). It provides the capability to acquire detailed widespread measurements not feasible through in situ methods alone. With sensors continuously improving in spatial, spectral and temporal resolution, remote sensing has become an indispensable tool for studying dynamic phenomena at local to global scales by leveraging an overhead vantage point beyond the earth's surface.

Applications of Geographic Information System (GIS) and Remote Sensing

Geographic information systems (GIS) bring together principles from fields such as geography, cartography, computer science, and mathematics. The versatility of GIS

allows its capabilities to be applied across industries and disciplines, both directly and indirectly. One area that has extensively utilized GIS is natural resource management, including applications like groundwater and hydrogeological assessments, mineral exploration, and oil and gas prospecting (Gimond, 2023).

Mineral exploration

The use of remote sensing images for geological mapping and mineral exploration typically involves studying the physicochemical characteristics of rocks and weathering soils, such as mineralogy, geochemical signatures, landforms, and the nature and distribution of lineaments (Wang, Du, & Carranza, 2017).

Researchers recently utilized geographic information system (GIS) technology to map and analyze gold mineralization in Egypt's Eastern Desert (Yousef, Kreuzer, Nykänen, & Hronsky, 2019). The team leveraged advanced multispectral data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite system. By integrating specialized processing techniques like band rationing and principal component analysis, the researchers were able to differentiate and map key lithological units across the Fawakhir area. Additionally, alteration zones associated with gold deposition were efficiently delineated using ASTER's spectral data and supervised classification algorithms. Field sampling and lab analysis helped validate the alteration mineral zones identified, which included sericite, clays, quartz, carbonates, and pyrite.

The team also auto-detected structural lineaments in the ASTER imagery that represent deformation zones related to secondary porosity. These fracture patterns often channel mineral-rich hydrothermal solutions and correlate spatially with alteration zones. By combining the lithological, alteration, and structural maps within a GIS framework, researchers identified zones with the highest probability for gold mineralization. The integrated prospectivity map demonstrated close correlation to historical gold deposits, validating the predictive power of the GIS-enabled analysis.

Hydrology

Remote sensing provides critical data for mapping water resources, measuring hydrological fluxes, and monitoring droughts and floods. GIS offers effective tools for water resource and flood risk management (Wang & Hongjie, 2018). For example, GIS and RS can be used for; mapping water resources, measuring rainfall, simulating runoff, delineating water bodies and flooding, and risk management.

A recent study (Alexakis, et al., 2014) used geographic information systems (GIS) and remote sensing (RS) technology to analyze flood hazards related to land use changes in Cyprus. The team focused on the Yialias River watershed, developing a calibrated hydrological model to study three sub-basins within the catchment area. The model incorporated land use, soil, and hydrometeorological data from various sources. Rainfall

and streamflow records came from local gauge stations, while satellite-derived land use and soil data were extracted using object-oriented algorithms on ASTER imagery.

To predict future land use patterns, the researchers applied a cellular automata-Markov chain analysis to ASTER scenes, generating a 2020 land cover projection. This was integrated into the hydrological modeling. Results indicated increased runoff and flood hazards across the watershed due to extensive urban expansion over the past decade detectable through the RS analysis. The study demonstrated how coupling RS data with hydrological modeling within a GIS framework could reveal the flooding impacts of land use changes over time.

Oil and Gas prospecting

Hydrocarbons are important non-renewable resources that need prudent long-term management. Finding and producing oil and gas involves examining large, multifaceted data sets to comprehend subsurface geology which is intricate. Since oil and gas deposits exist underground, identifying potential areas relies significantly on analyzing surface geological structures and landforms that may point to hydrocarbon presence below (Prabaharan, Lakshumanan, & Subramani, 2017). Satellite remote sensing offers a comprehensive overview useful for pinpointing and outlining lines, terrain qualities, and other surface characteristics that serve as signs of subsurface possibility (services, 2017).

Geographic information systems (GIS) enable the successful combination and evaluation of diverse remote sensing materials along with other spatial data to gauge hydrocarbon potential. Remote sensing and GIS methods have been widely employed for mapping prospective hydrocarbon zones and prioritizing exploration.

A study evaluated the use of remote sensing and GIS for mapping prospective hydrocarbon zones in a region of India (Prabaharan, Lakshumanan, & Subramani, 2017). IRS-P6 LISS III false color composite satellite imagery of the area was geo-referenced and visually interpreted alongside 1:50,000 topographic maps and field data to classify key geomorphic features such as fluvio-marine sediments, faults and lineaments. These interpreted geological features were then compared against gravity, magnetic and structural information obtained from additional datasets such as topographic maps.

Areas where fluvio-marine sediments intersected with interpreted lineaments were observed to demonstrate higher prospectivity for oil and gas. Vector maps revealed connectivity of faults from the Jurassic period to present, suggesting continued tectonic activity. Some lineaments that cut across tributaries were also inferred to represent active faults. When validated against locations of known oil and gas wells, the mapped geomorphology and lineaments corresponded well.

Delineated hydrocarbon prospective zones were generated by integrating all interpreted remote sensing and GIS data layers. This case study thereby demonstrated the potential of applying such techniques for timely and cost-effective identification of geological trends indicative of hydrocarbon reservoirs, enabling more informed decision-making regarding hydrocarbon exploration and development activities in the region

Surface Features that Indicate Hydrocarbon Subsurface Prospectivity

Remote sensing and GIS enable identification and analysis of key surface features that can indicate subsurface hydrocarbon prospectivity. Important geological and geomorphological indicators that can be mapped and examined using satellite data and spatial analytical techniques include:

1. **Sedimentary Basins:** Remote sensing enables lithological mapping to delineate potential reservoir rocks and source rocks based on spectral characteristics. GIS helps analyze basin morphology and terrain to understand depositional settings critical for hydrocarbon systems (Saha, 2022). Remote sensing allows mapping surface structural lineaments related to subsurface trapping geometries. GIS integrates diverse basin datasets to delineate sweet spots with optimal reservoir, source, seal and trap conditions.

2. **Geomorphology:** Remote sensing derived DEM data enables identifying geomorphic anomalies like drainage changes linked to subsurface structures and hydrocarbon migration. Surface lineament mapping from satellite imagery reveals faults and fractures indicating enhanced permeability (Abdullah, Nassr, & Ghaleeb, 2013). Hyperspectral sensors detect mineral alteration zones and vegetation changes related to subsurface hydrocarbon micro seepage. GIS allows overlaying geomorphological indicators with other evidence to determine high potential zones.

Steps used to Analyze Multi spectral Images

Remote sensing plays a valuable role in hydrocarbon exploration by aiding the interpretation of large spatial datasets. Effective analysis requires collecting, preprocessing, integrating and examining relevant information through geographic information systems.

1. Data Collection

The first stage in analyzing multispectral images for hydrocarbon assessment is the data collection phase. Here, relevant spatial datasets are gathered that can provide insights into the geology and hydrocarbon prospectivity of the study area. A wide range of data sources needs to be considered to obtain a comprehensive understanding seepage (Shi,

Fu, Ninomiya, Sun, & Li, 2012). Geological maps and reports provide information on rock types, faults, and structures.

Geophysical surveys such as gravity, magnetic, and seismic mapping reveal subsurface features. Geochemical analysis of soil, water or mud gas samples detects hydrocarbon micro. Remote sensing imagery offers significant landscape context over large spatial extents. Each type of data addresses different aspects of the subterranean profile. Collection of diverse yet complementary datasets present the fullest picture. Both primary data acquired from fieldwork and pre-existing secondary data are compiled.

2. Data Preprocessing

The datasets are preprocessed to ensure compatibility and readiness for analysis. This may involve cleaning data, transforming data formats and integrating datasets. The preprocessing prepares the data by removing errors and inconsistencies so it can be analyzed in GIS software (services, 2017).

i. Radiometric Correction

Radiometric calibration is important for quantitative analysis and change detection over time. It accounts for internal sensor variations and conversion factors to report accurate spectral measurements in radiance or reflectance units (VANDENABEELE, 2022). Atmospheric correction models such as 6S are commonly used to remove the scattering effects of dust, water vapor and other atmospheric constituents that skew readings. This improves spectral quality and enhances feature detection.

ii. Geometric Correction

Orthorectification is a rigorous geometric correction process that produces geodetically aligned outputs suitable for mapping. Terrain relief, sensor orientation and other metadata are analyzed to project pixel locations onto ground space. Registration ties images to reference datasets like GIS layers within a single coordinate system, thereby aligning features across images (VANDENABEELE, 2022). This allows change analysis between dates and integration with collateral mapping resources.

iii. Enhancement and Contrast Adjustment

Histogram equalization spreads and redistributes the most frequent intensity values, creating a flatter histogram that highlights details in both bright and dark regions. Linear stretching manipulates the dynamic range to occupy the full spectrum of reflectance levels, facilitating interpretation. Together these intensify contrast for subtle features lost in clustered pixel values (services, 2017) .

iv. Noise Reduction

Noise arising from sensor and environmental effects can obscure expected patterns. Smoothing filters like Gaussian apply a weighted average to diminish flecks and grains without degrading edges. Principal component analysis transforms the original bands into uncorrelated components that separate meaningful data from superfluous variance, improving clarity (Geolearn.in, n.d.).

3. Data Integration

The different spatial datasets are integrated into a single database or GIS project. This includes spatially matching, fusing and aggregating data from multiple sources into a unified format for combined analysis.

Spectral Data Integration

Band stacking consolidates multispectral channels into a single layer, preserving their spectral distinction. This allows analyzing wavelengths together to better identify features. Indices like NDVI mathematically combine bands to measure qualities like greenness. PCA transforms correlated bands into orthogonal components concentrating variability into few layers, streamlining analysis.

Spatial Data Integration

Image fusion blends datasets to profit from each's benefits. For example, merging high-resolution panchromatic and lower-resolution multispectral images yields improved spatial-spectral imagery. Co-registration precisely geometrically matches all inputs to a shared coordinate system, enabling accurate pixel-level overlay and comparison. Overlaying classified land covers with soil maps may reveal relationships between land use and soil conditions.

Temporal Data Integration

Time series analysis examines imagery sequences to monitor gradual or periodic changes over time. Phenological changes in vegetation, urban expansion, and deforestation are examples detectable via change detection between historical and current imaging.

Attribute Data Integration

Joining sample site data with spectral measurements combines biophysical measurements with spectral signatures, helping model landscape properties from spectral profiles.

Interpolation infers missing data values based on neighboring cells' attributes, filling in gaps.

Model-Based Integration

Weather data integrated with hydrologic models enhances runoff and flooding predictions. Machine learning algorithms leverage large, multidimensional remote sensing and GIS training datasets to automatically classify landscapes and detect anomalies.

3D Data Integration

LiDAR's point clouds combined with optical data derives high-resolution DEMs and DSMs while distinguishing vegetation from buildings. Stereoscopic analysis restitutes 3D topography from the parallax in dual oblique camera views.

4. Data Analysis

GIS software is used to analyze the integrated spatial data and identify potential hydrocarbon zones. Techniques like spatial data mining, modeling and visualization are employed to interpret the data and recognize areas likely to contain oil and gas deposits.

Land cover classification: Involves assigning each pixel a categorical label based on its spectral properties. Supervised classification uses known "training" sample pixels to statistically determine class membership for unlabeled pixels. Unsupervised approaches group spectrally similar pixels without prior labels. Object-based classification first delineates image-objects based on texture and shape then classifies these contiguous parcels.

Change detection: It reveals transformations by differencing pixel values in multi-date imagery or thresholding percentiles to isolate altered areas. Advanced techniques like post-classification comparison classify each date independently then compare classifications pixel-by-pixel to pinpoint changes.

Vegetation analysis: It measures "greenness" with normalized difference vegetation index, which contrasts near-infrared and red reflectance. Enhanced vegetation index augments NDVI sensitivity. Time-series profiling monitors phenological cycles or disturbances.

Geospatial analysis spatially relates features. Proximity analysis determines distances between points or area borders. Overlay analysis finds feature coincidences and intersections. Spatial statistics quantify clustering, dispersion and correlation between neighboring pixels/points.

Terrain analysis derives topographic attributes from digital elevation models. Slope indicates maximum rate of change while aspect indicates downhill orientation. Feature extraction then models hydrologic flow paths and watershed boundaries.

Hydrological modeling simulates flood inundation risk by routing surface flows across watersheds considering rainfall, soils and topography.

5. Data Validation

   Data validation is a crucial step in analyzing multispectral imagery that assesses the accuracy, quality, and reliability of analytical results. The primary goal is ensuring information extracted from images is trustworthy and corresponds to real-world conditions.

   Ground truthing: involves physically visiting study areas and comparing observed features to interpreted ones from imagery analysis. For example, land cover classification validation would entail field-checking land types.

   Accuracy assessment: quantifies analysis performance by comparing outputs to reference data collected through ground truthing or authoritative sources. Metrics like overall, producer's, user's accuracy and Kappa coefficient evaluate classification quality or other analyses.

   Data validation: identifies errors or discrepancies like misclassifications or omissions revealed. Corrective actions can then refine algorithms, reprocess data, or adjust parameters to boost accuracy.

   Quality control: ensures data and processing methods used adhere to high standards, checking for issues like sensor calibration, atmospheric correction, geometry, and consistency.

Challenges faced when using RS and GIS techniques

Terrain can pose a challenge to RS and GIS analysis; rugged topography can make it hard to obtain accurate satellite or aerial imagery due to issues like shadows and variable illumination across slopes. Dense vegetation can also obscure surface features. This leads to errors and omissions during analysis like extracting elevations or identifying geological structures.

Data Availability can be a major limitation in RS and GIS analysis especially in remote areas, there may be lack of recent, high-quality geospatial data like high-resolution imagery. Gaps in datasets like weather, soils or infrastructure information also hamper analysis. Limited historical records constrain change detection to monitor areas over time.

Resolution is another challenge faced when using RS and GIS techniques, low spatial resolution of older satellite data, say 30m pixels, makes it difficult to discern small hydrocarbon indication targets, especially in geologically complex terrain. Coarser temporal resolution also limits phenology-based studies and change capture.

Data Integration can also pose a challenge when using RS and GIS techniques; when combining multi-sensor, multi-platform data requires ensuring all datasets align spatially and temporally. Integrating disparate file types, formats and projections complicates pre-processing. Incompatible metadata further challenges unified analysis.

Lastly lack of expertise is another challenge in RS and GIS techniques like digital terrain modeling, subsurface prospecting and advanced classification rely on specialized skills that may be lacking locally. Complex algorithms or analytical workflows demand experienced remote sensing scientists or GIS analysts.

Chapter 3: Methodology

3..1 Description of the study area

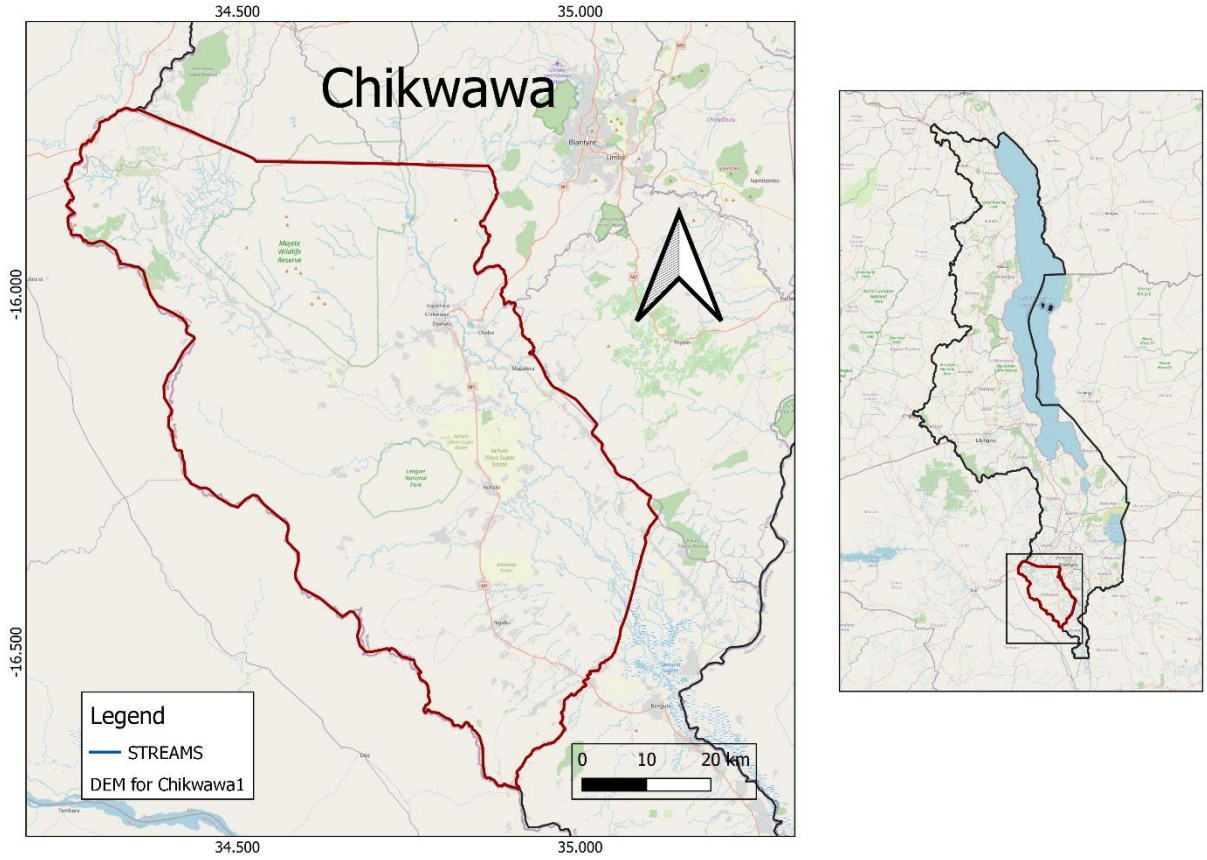


Figure: Showing Study area

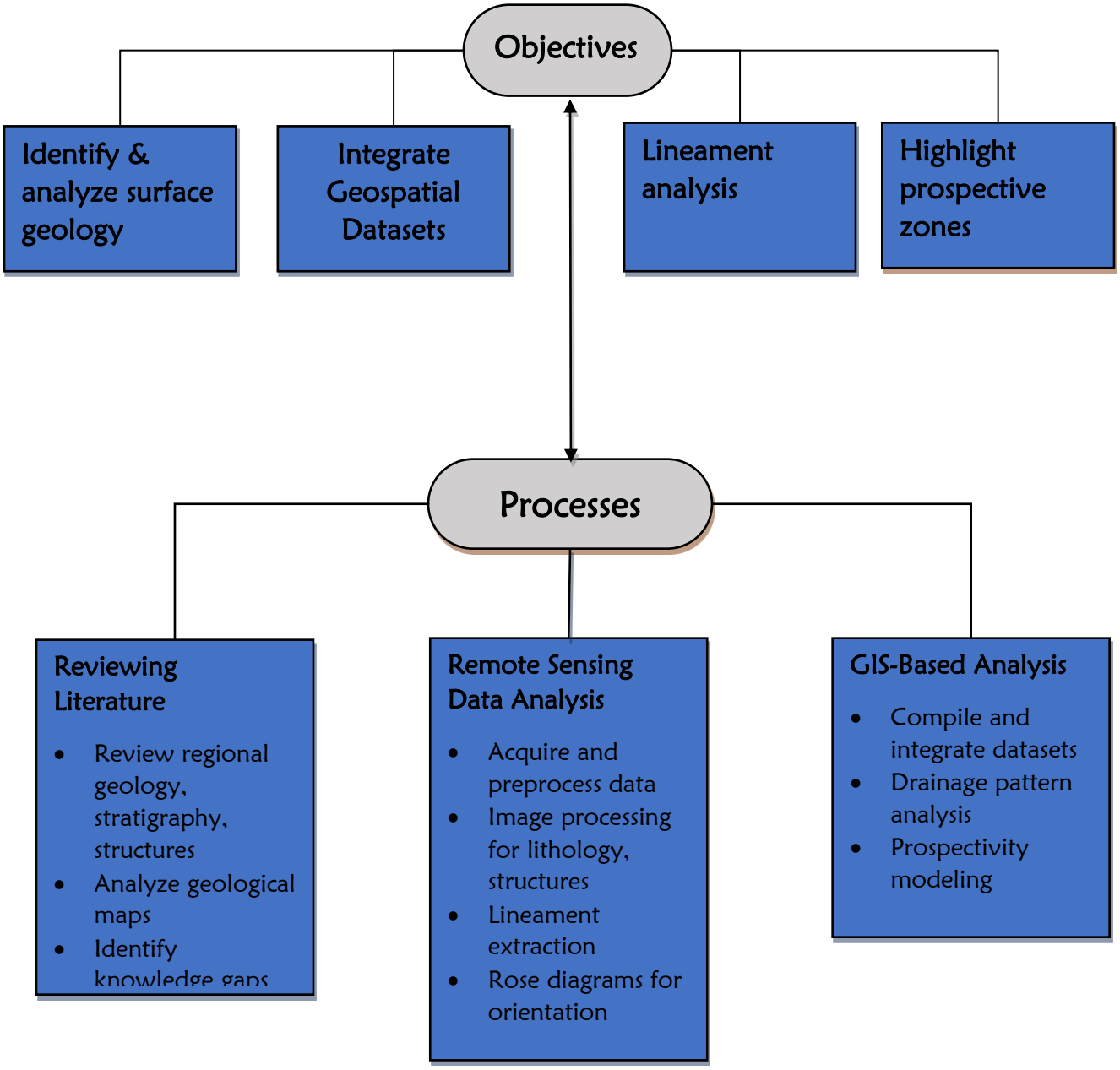
The Lower Shire Basin is a rift basin that formed during the Mesozoic era as part of the East African Rift System. This basin is filled with fluvial and lacustrine sediments of the Karoo Supergroup, composed predominantly of sandstones, siltstones, mudstones, and coal beds (Carington & Chilton, 1983). The depositional environment was influenced by regional climate, tectonics, and volcanism. Given its sedimentary rocks and depositional history, the Lower Shire Basin has potential for both hydrocarbon and coal resources (Panchu, 2019).

Previous airborne geophysical surveys over Chikwawa district and the Lower Shire Basin included magnetic, radiometric and gravity data acquisition. The magnetic and gravity data helped reveal subsurface geological structures and distribution of sedimentary units, while the radiometric data characterized radioactive element concentrations related to mineral deposits.

Specific anomalies in the magnetic and gravity data near Nchalo and Chapananga in Chikwawa were interpreted to represent thick sediment accumulations in the subsurface (Malunga, 2018). This is a favorable indicator for potential hydrocarbon reservoirs. A study by Dr. Chisenga also used drilling data to identify substantial alluvial sediment deposits in western Chikwawa. The presence of coal deposits and shales in the district further points to possible hydrocarbon source rocks (Chisenga, Dulanya, & Jianguo, 2019).

3.2. Research Design

The study is an observational descriptive study design which utilizes a purposive sampling approach, to assess the hydrocarbon potential of Chikwawa District (Lower shire basin). To answer the research questions and achieve the objectives, secondary data will be used in order to test for different parameters. The research design has been grouped into two sections as follows;



3.3. Data collection and Analysis

3.3.1 Regional geology

Secondary sources such as published literature, books, articles, was reviewed to characterize the regional geology of the study area. This information helped in establishing the types of rocks, sedimentary basins, faults, and other geological structures found within the study area. The base geological dataset, Country boundary shapefiles

and Malawi fault shapefiles were downloaded from the World Geological Maps, Diva-GIS, and zenodo.org websites respectively.

The vector datasets were then loaded into QGIS and set to the same Coordinate Reference System to maintain proper alignment. The geological data was styled using distinct colors, symbols and patterns to differentiate the various rock units and geologic features.

The administrative boundary was used to clip the full geological data to the specific study area or district of interest. The fault lines were also styled distinctly using appropriate line styles and colors to make them clearly visible on the map. Relevant labels for both geology and faults were added to provide details. A legend was designed to explain the symbology and colors used for both the geology and faults. A topographic basemap or satellite imagery was included to provide geographic context. Once the geological map was finalized with all necessary layers and styling, it was exported as an image. The result was a clearly styled and informative geological map specific to the study area with integrated fault line data.

Structural Analysis

1. Extracting Lineaments

To do lineament extraction the Landsat 8 files, and Digital Elevation files were used, the files are first imported into PCI Geomatica software. All the datasets were checked whether they share the same coordinate system and are accurately georeferenced using the Georeferencing tool located in the tools to ensure that they are accurately located on the map. For PCA, the Red, Green, Blue, and NIR bands (Bands 4, 3, 2, and 5) was used as input bands. These bands capture different aspects of the electromagnetic spectrum and help in emphasizing linear features like faults.

The selected bands are stacked into one file, using the stack band option in Multispectral menu. The stack band file was preprocessed through radiometric correction to reduce atmospheric effects and ensure consistency in pixel values. The Landsat 8 files were mosaicked with another Landsat files, and clipped to unsure the whole study area is covered using boundary shapefiles.

Image enhancement techniques was then be used, such as applying contrast and color adjustments to improve visibility of lineaments in the imagery. A Hillshade model was also generated from the DEM files to highlight topographic features. Next, PCI Geomatica's lineament extraction modules were used to automatically detect lineaments, by using the Principal Component Analysis (PCA), in Multispectral menu on the stack band file. Finally, the optimized lineament data was exported in a vector format like shapefiles, for additional analysis in QGIS software.

2. Rose diagram of Lineament orientation

To create a rose diagram showing lineament orientations in QGIS, the "Line Orientation" plugin was installed through the Plugin Manager. After activating the plugin, lineament data was digitized or imported into a dedicated line layer. Azimuth values for each lineament were calculated in the attribute table using the Field Calculator (azimuth(start_point($geometry), end_point($geometry))), providing the key directional data.

The "Line Orientation" plugin was then used to generate the rose diagram. This was done by accessing the plugin under the Plugins menu, selecting "Line Orientation", and choosing the "Rose Diagram" option. The line layer and azimuth field were specified as inputs. Parameters like the number of bins were adjusted to customize the diagram's appearance.

3. Drainage pattern analysis

To perform drainage pattern analysis in QGIS, several key geospatial datasets were integrated. First, a high-resolution Digital Elevation Model (DEM) of the study area was acquired to provide essential elevation data. River network or hydrography data was also obtained to map existing rivers and streams. Land cover data was incorporated to assess the influence of different land cover types on drainage development.

The DEM was preprocessed in QGIS by clipping to the study area extent and applying modifications like sink filling to ensure continuous flow. The Flow Accumulation tool was then used on the DEM to generate a raster showing accumulated flow, highlighting potential drainage patterns. The Stream Network tool delineated the main drainage channels based on the flow accumulation raster.

Next, stream segments were classified by their drainage pattern such as dendritic or trellis using QGIS tools. Visualization options like customized symbology were applied to depict the drainage patterns.

Chapter 4: Results and Discussions
Geology of the study area

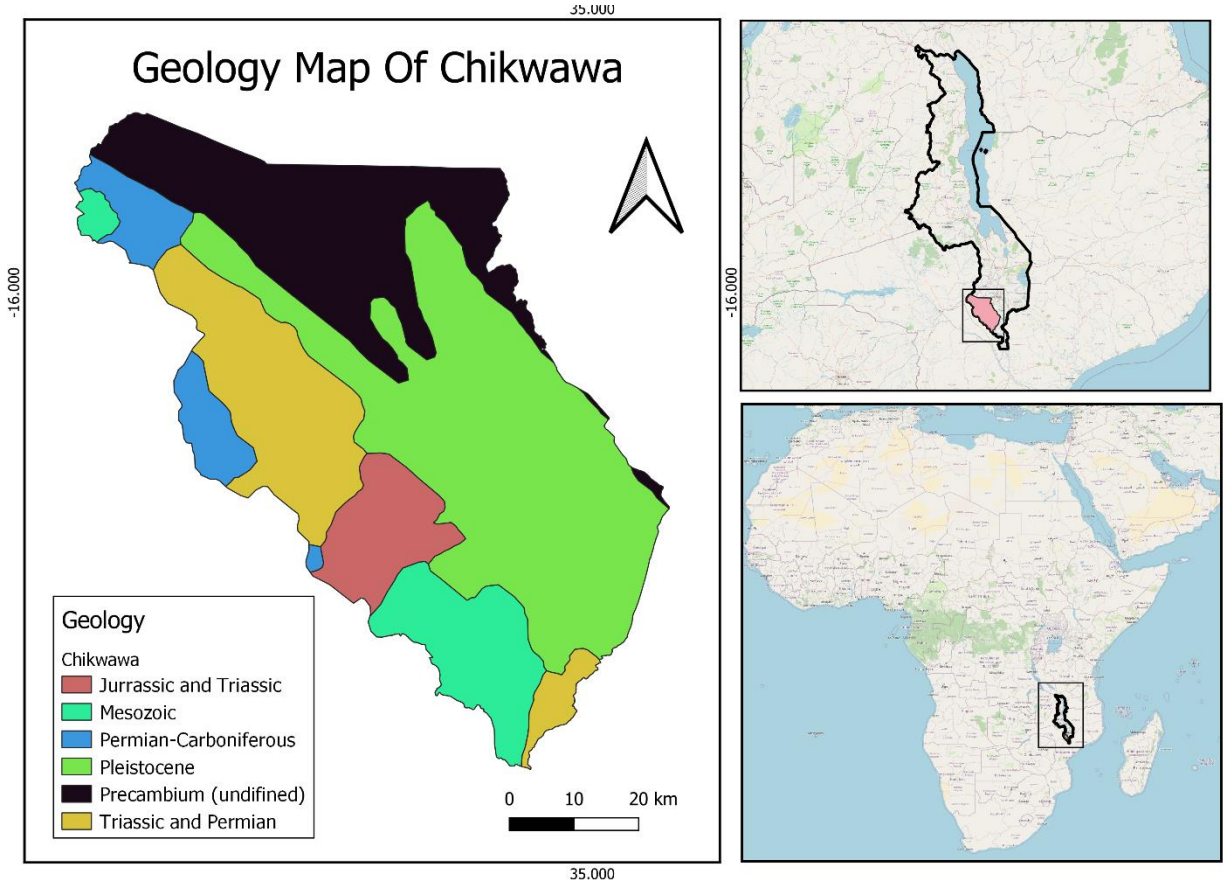


Figure Showing the Geology of Chikwawa

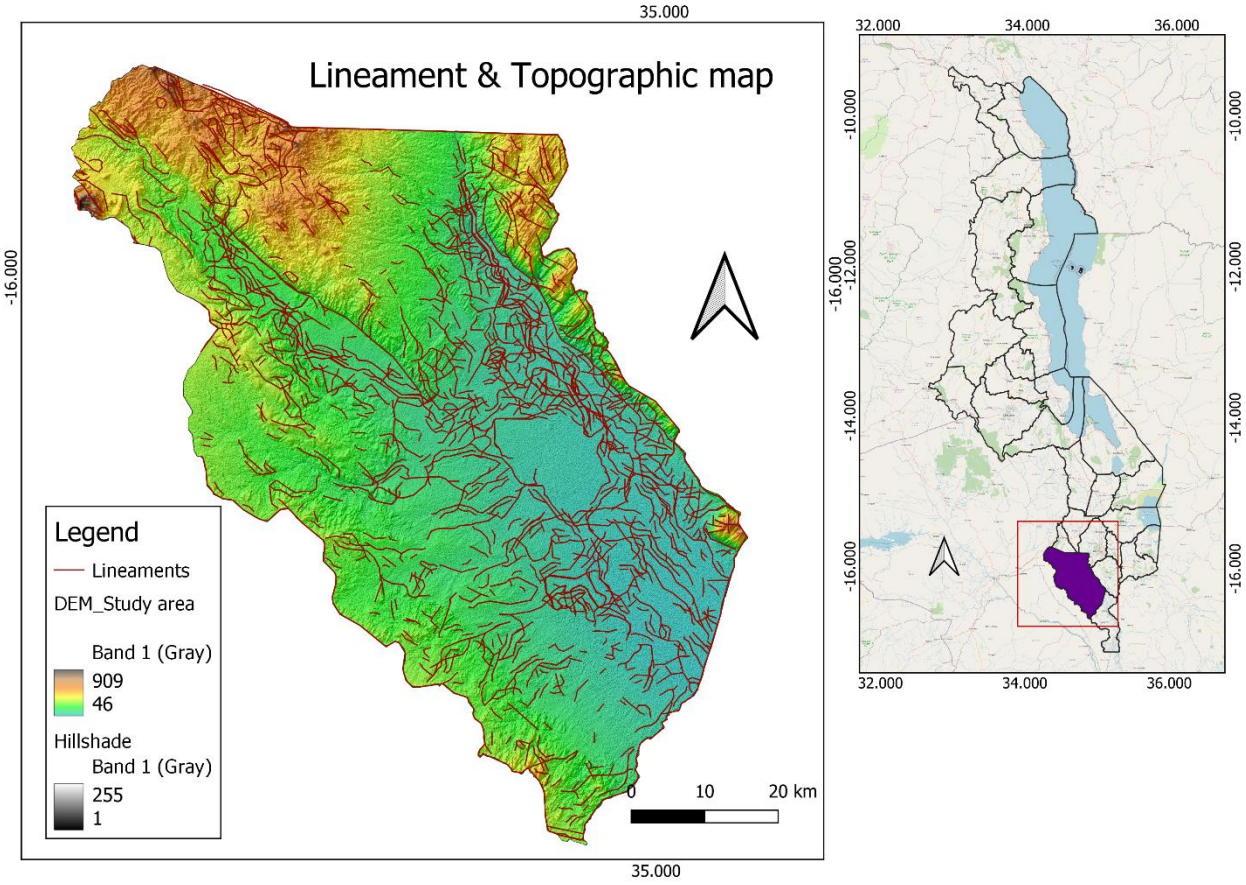
The geology of Chikwawa includes formations from the Mesozoic Era spanning 252 to 66 million years ago, including the Triassic, Jurassic, and Cretaceous periods. Geological maps of the area show Jurassic-period rocks containing salts and mudstones (Mbewe, 2018). The Jurassic was characterized by diverse organisms, so rocks formed during this time likely contain high organic matter. This provides a prospect for finding hydrocarbons in zones with Jurassic formations (Goldstein, 2015). Maps also indicate Permian rocks in the northwestern section, while the southwestern region contains Jurassic, Carboniferous and Permian formations. The presence of these lithologies suggests both areas may hold hydrocarbon-rich deposits based on their typical organic matter content. This is also confirmed in a study in Malawi (Shali, 2009) on mineral resources of Malawi and mining potential that showed Mesozoic era sediments are found in the lake and the lower shire basin in (basement complex) due to tectonic metamorphic activity during that time as evidenced by karoo sediments.

In contrast, the northern and eastern parts of Chikwawa formed in the Precambrian Era, resulting in igneous, metamorphic and sedimentary rocks associated with ancient tectonic

processes. The probability of finding hydrocarbons in these regions is very low . Central and eastern Chikwawa contains Pleistocene sediments, as evidenced by the low-lying topography suitable for deposition. This relates to rifting processes in Africa, as Precambrian rocks form the highlands in the northeast part of Chikwawa.

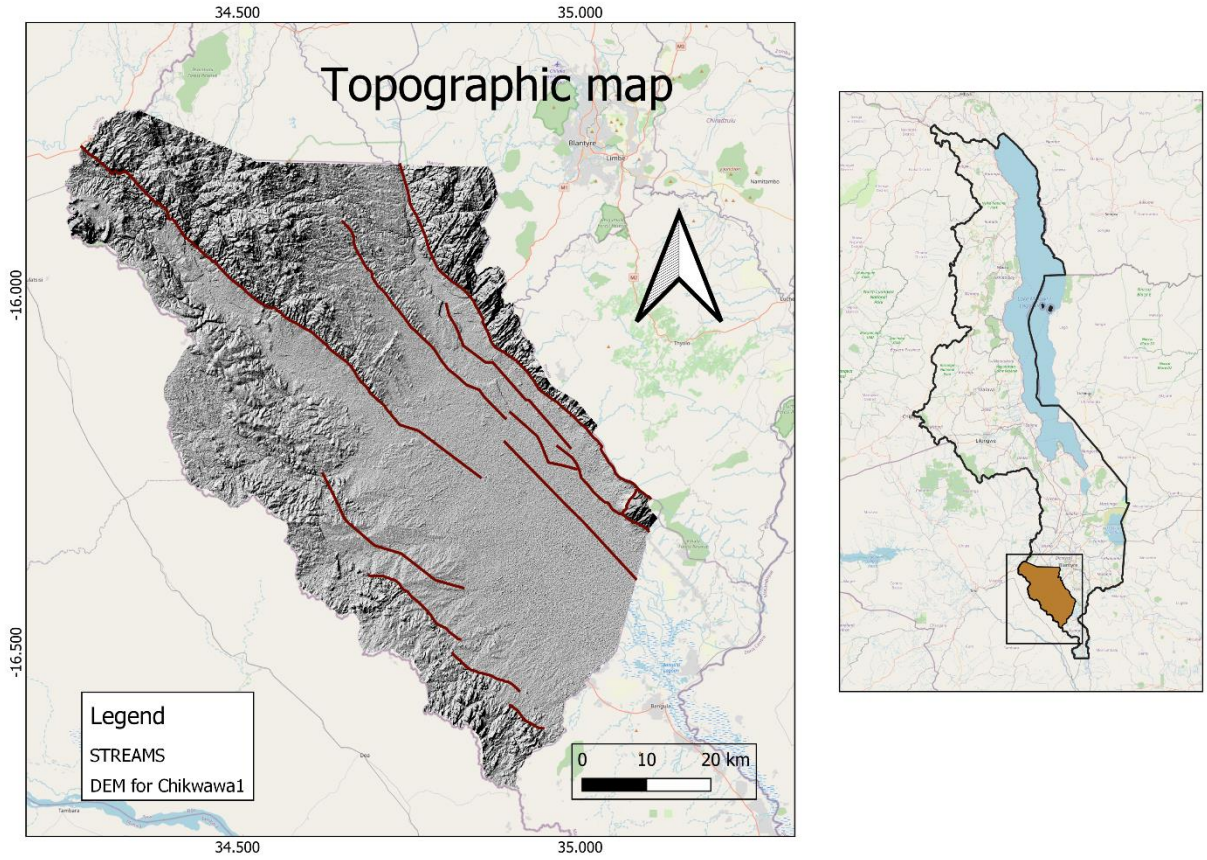
Lineaments within the Study area

The lineaments in the Map showed some continuity in some parts indicating faults in the area. For example, the Northeast part has several continuous lineaments which indicates the presence of faults. The geophysical survey indicated the presence of faults in Chikwawa including the ones to the west of Mwanza Fault and Makhanga to the west of Thyolo Escarpment Fault (Malunga, 2018). The Eastern part of Chikwawa has continuity as well indicating another potential faulting system. Since the geology of the area has both sedimentary and igneous lithologies, it means the areas of continuous faulting can be potential areas of traps or migration of these resources.

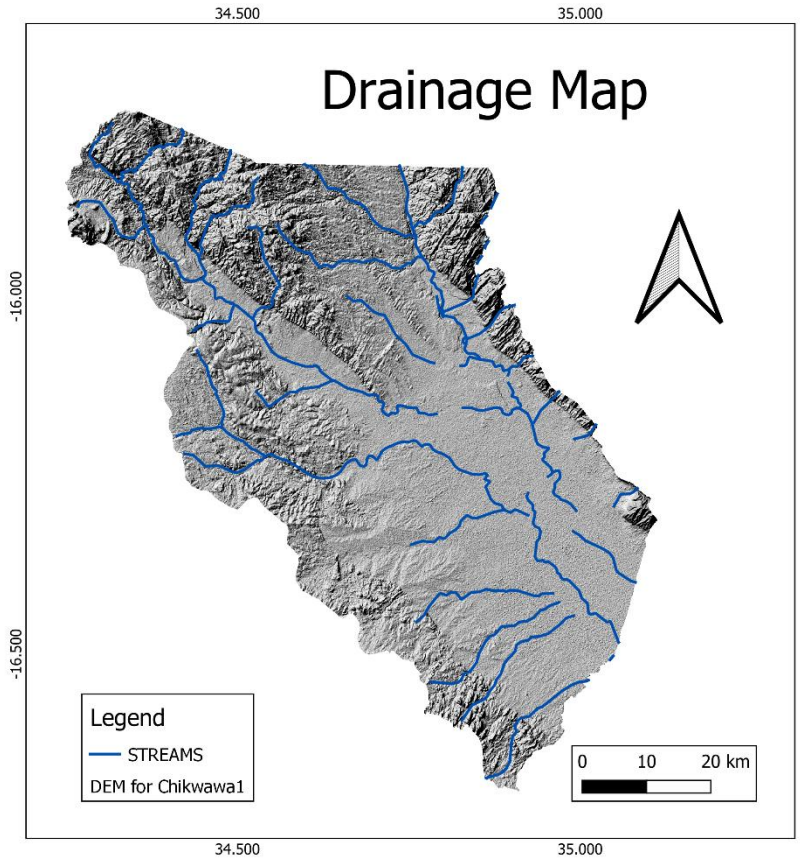


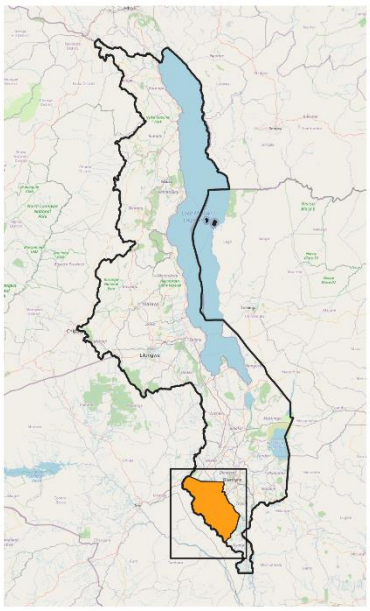
Another map showing the Malawi fault system, indicates that in Chikwawa there is indeed faulting in the district and these faults do correlate with the lineament map. The faults are characterized as active and in-active faults. A study confirmed presence of new faults within Chikwawa in which some were overlain by alluvium sediments (Chisenga,

Dulanya, & Jianguo, 2019). Medium range lineaments in the western side shows that there are some faults in the southern and western region of the district.



Drainage Pattern

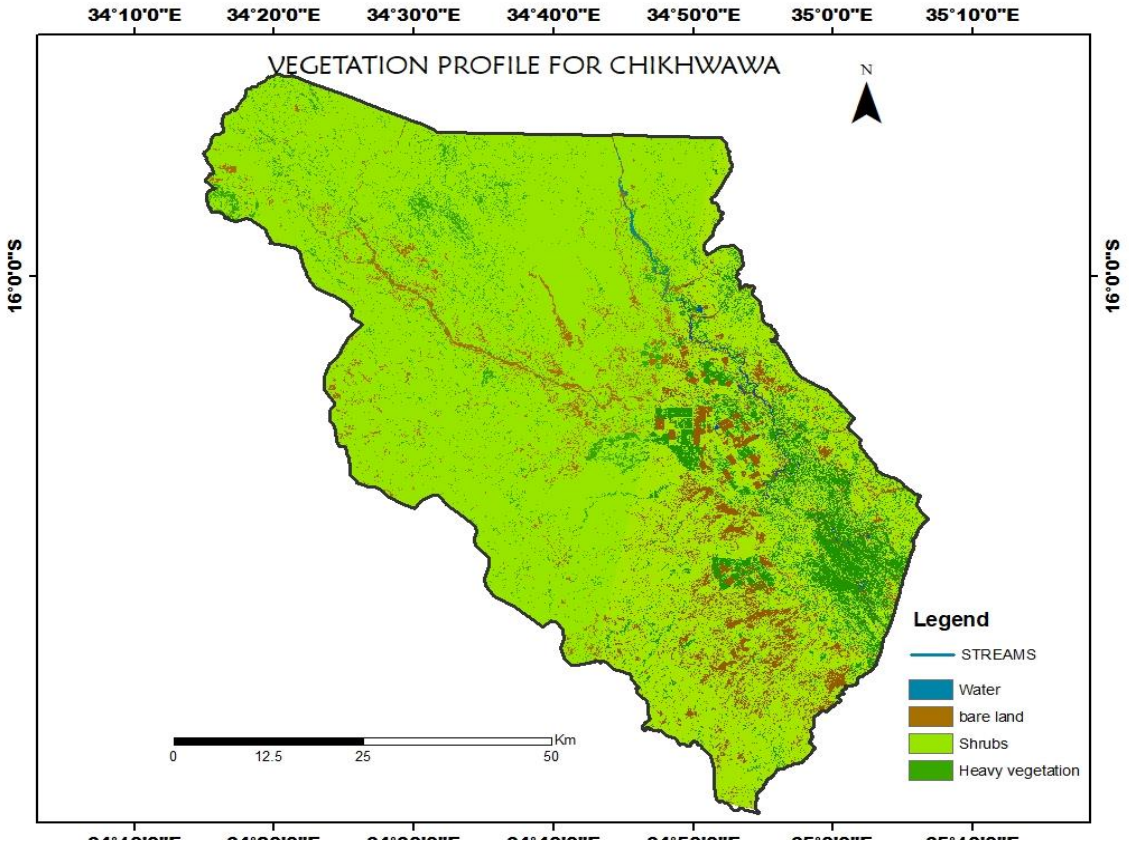




The drainage as indicated on the ma is towards the south eastern direction and the flow is actually low as the topography usually is gentle, so only livers found near the Northern part of the study area have a large flow as compared to the other rivers. So deposition is expected to be evenly distributed along the plain and only the areas near the Hily area have erosional surfaces.

Vegetative analysis

The vegetative analysis shows reflection of shrubs as well as the Heavy vegetation normal as majority of the reflectance is on the Shrubs followed by the heavy vegetation then the bare areas. This indicated that there is no interaction of the Hydrocarbons on the surface as hydocarbons do suppress the reflectance of the vegetation which is not the case in this case. So there is no evidenve on seepage .



Geological correlation

The evidence from literature review on the presence of source locks, and presence of formations with high organic matter, the continuous lineaments on the map and correlation of the faults in the region, and evidence on presence of faults in the area suggest possible interaction of the faults and lithologies in these areas.

Chapter 5: Conclusion and Recommendations

5.1. conclusion

Petroleum exploration in an unexplored region usually begins with geophysical methods to analyze the surface features. Seismic and magnetic surveys help to analyze the subsurface conditions, which can lead to drilling if potential is determined. This is because there is a big risk in exploring for these resources. The study was conducted to assess the hydrocarbon potential of Chikwawa district through geological analysis, and geophysical analysis with RS and GIS techniques.

The study found out that Chikwawa has got geological formations, which are reach in organic matter based on the geological formation periods (Mesozoic, Jurassic, Carboniferous, and Permian time or periods). The literature review showed two source rocks like Shale and coal deposits which are found in the region, discovery of new faults within the sedimentary basins, and thick sediments in the central and western part of Chikwawa. The lineaments from the RS and GIS analysis showed presence of multiple faults in the region due to continuity of the lines, and presence of multiple crossing of the lines in the southwestern part of the region indicated also presence of new small faults. The faults act as trapping and migrating paths for the hydrocarbons.

Finally, the NDVI analysis showed good growth of the vegetation in the area, as there was high reflectance in the Heavy Vegetation, followed by Shrubs with less of the non-vegetative land. This indicates there are no seepage of the petroleum resources in the area and as such there is a high chance that these sediments are actually deeper.

5.2. Recommendations

GIS and RS techniques study the surface features through maps and satellite images and correlate with other geological data to pin point possible locations where further exploration can be done. The results findings and geological literature review of Chikwawa district showed that it has petroleum. This used qualitative methodology to identify the areas but there is a need to quantify the probability with quantitative data through seismic surveying, reservoir modeling, and drilling so that to have true reflection of the Basin's lithologies and characteristics. This is because similar surface structures in other countries they have found the Hydrocarbons and are now exploring and exploiting the hydrocarbon resources.

Further, GIS analysis must be done in an area with the development of new techniques in the industry, upgrades of the software, and new data though the developmental goals the government has in order to develop models for the hydrocarbons through parameters such as; 3D or 2D models of the basin, anomaly studies etc.

Study limitations

Though the study was a success, there were some challenges that were faced when conducting the study that did delayed and disturbed the overall progress of the study:

The data was supposed to be both primary and secondary data, but only the secondary data was used which has been the biggest challenge, this was due to lack of equipment and resources used for mapping lithologies, money for field visits to analyze, learn from experts and acquisition of data from various companies in the field.

Slow response from the industry, it was observed in this study that data which was supposed to help solidify some objectives were either delayed or denied, As such, objectives, methodology was changed which resulted to late submissions, and delayed progress.

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