

PETROLEUM RESOURCE POTENTIAL ASSESSMENT USING GRAVITY DATA IN LOWER SHIRE BASIN

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DISSERTATION 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 GEOSCIENCES

DECLARATION

I Foster Chiumia declare that this research project represents 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 28 April, 2023.

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Signature: _____

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Abstract

The Lower Shire Basin of Malawi is a region with a significant potential for petroleum resources, however, the exact extent and location of these resources are not well understood. This study aims to assess the petroleum potential of the Lower Shire Basin using gravity data. The Bouguer anomaly map obtained from Geological Survey Department of Malawi was interpreted to identify the geological structure of the basin and the depth to the basement rocks. The results indicate that the Lower Shire Basin is composed of several faulted blocks. The depth to the basement rocks ranges from 0.5 km to 3.5 km. The gravity data also revealed areas of low density, which may be indicative of hydrocarbon accumulations. These results suggest that the Lower Shire Basin has a significant potential for petroleum resources and further exploration is warranted.

ACKNOWLEDGEMENTS

Firstly, I would like to express my deep and sincere gratitude to my research supervisor, Mr. W. Tchongwe for providing invaluable guidance throughout this research. His dynamism, vision, sincerity and motivation have deeply inspired me. Guiding me through the way and trusting my capabilities to handle this study. It was a great privilege and honour to work and study under his guidance. I would also like to thank him for his empathy, great sense of humour, patience and insightful feedback that pushed me to sharpen my thinking during the discussion during my research work and dissertation preparation, completion and success.

I would like to express my deepest gratitude and sincere appreciation to Dr C. Chisenga for the kind endless help, generous advice, guidance and support during the study and until this work came to existence.

I would like to forward my special thanks and gratitude to my family; father (Mr. Charles Chiumia), brothers (Gerald & Frank), Sister (Annie & Rufina) and brother in-law Davie Mwale for their love, prayers, caring and sacrifices for educating and preparing me for the constant source of encouragement and their financial help. Their endless supply of encouragement and support throughout this project kept me going and strong.

I would also like to recognize the help offered by Isaac Chiwaula (Mesho). Your expertise, advices and offering of your computer devices has led to the completion of this study. Special thanks also go to my friends and classmates whose comments and contributions have been of encouragement and inspired me to keep moving forward.
My thanks go to all the people who have supported me to complete the research work directly or indirectly. Above all, The Almighty God, through His love and grace, predestined my academic journey which today I give thanks.

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Acronyms/Abbreviations

EARS- East African Rift System

SGL – Sanders Geophysics Limited

THD – Total Horizontal Derivative

FFT – Fast Fourier Transformation

CBA – Complete Bouguer Anomaly

LG – Low Gravity

HG – High Gravity

3DED – 3D Euler Deconvolution

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CHAPTER 1

1.0 Introduction

1.1 Background

Exploration of hydrocarbon involves searching for undiscovered oil and gas resources with the purpose of obtaining a successful and profitable oil and gas extraction (Adelman, 1970). It is a costly, high-risk operation that necessitates a thorough understanding of the geological context and operational challenges, from discovery to reserve estimation, and finally moving the reserves to production (Mclay et al., 2003). The current exploration model for the oil and gas industry forces it to go through a lengthy and arduous process before reaching conclusions about the prospect potential of those regions. The process of identifying potential areas and risk reduction assessments prior to drilling the first exploratory well can take years and requires investments that the industry cannot currently justify. Many potentially attractive areas are left unexplored for long periods of time due to the cost, time, and risk involved in such exploratory campaigns. A new exploration model should enable a faster, less expensive, and more direct method of assessing the prospect of large exploratory areas and identifying oil and gas. The gravity survey method is one of the earliest techniques used in oil and gas exploration. Despite the introduction of seismology, it has remained an important early screening step in hydrocarbon subsurface mapping and exploration. Land-based and airborne (including satellite-based) surveys are the two most common methods for obtaining gravity data. For local/regional surveys, land-based gravity data is commonly used. They can, however, be difficult to obtain economically for large-scale area prospects and remote locations. The satellite-based gravity survey can be used for regional studies as a faster and less expensive alternative method to ground measurement (Yanis & Marwan, 2019; Zhang et al., 2019). With improved data processing technology

and gravity survey accuracy, in-depth gravity anomaly studies, such as characterization of Bouguer anomalies and isostatic residual anomalies, have become critical in the delineation and tracking of prolific regional and trap structures within potential hydrocarbon basins (Zhang et al., 2019). Gravity anomaly differences and characteristics between basins reflect variations in crustal thickness, basement properties, depth, stratigraphic framework, and overlying cover strata structures (Aghajan et al., 2011; Yanis & Marwan, 2019). However, there has been very limited research into using gravity data as an early screening step to select potential oil and gas fields. In this study, gravity data is used in the petroleum resource potential assessment in the Lower Shire Basin southern part of Malawi. Malawi is believed to contain potential petroleum resources that can be extracted for the development of the country(Mattick, 1986), hence it is divided into six blocks for oil and gas exploration as shown in **Figure 1** (Whaly, 2017). Lower Shire Basin is in block number six in the southern-end of Malawi. The Lower Shire Basin is a general term which refers to a number of depocenters/domains in the Lower Shire valley. Two domains were identified and these are Mwabvi domain and Lengwe domain at either end of the Lower Shire Basin(Castaing, 1991). In between these domains there is also a Ngabu domain as identified by (Chisenga et al., 2019). Lower Shire Basin is located within the East African Rift (EAR) region in southern part of Lake Malawi. The recent findings of hydrocarbons in Uganda and Kenya, among other recent discoveries attest to the untapped potential that exists in the EAR region (Chisenga et al., 2019). The availability of the recently-acquired high-resolution gravity data for the area which covers the Lengwe, Ngabu and Mwabvi domains and the areas in between, have been used to provide insight into the possible structural and geological trapping system of hydrocarbon in the Lower Shire Basin.

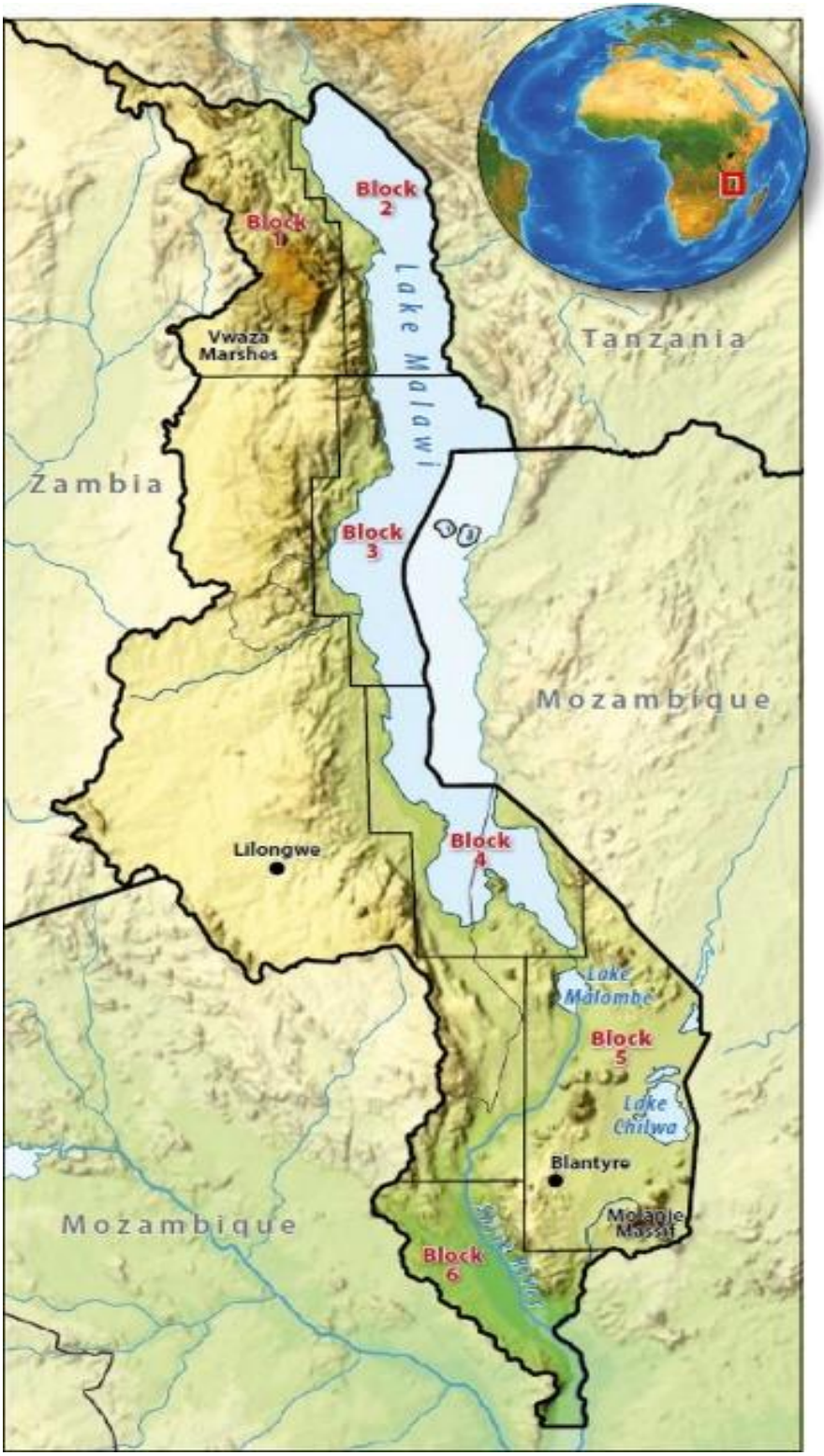


Figure 1. Map of Malawi showing oil and gas exploration blocks

1.2 Problem Statement

The human population in Malawi increases every year, causing the need for energy also increase. These energy sources can be in the form of petroleum fuels which is vital for the development of the country. Malawi depends on imported petroleum products because there are no identified reservoirs for production of petroleum that is oil and gas. These imported products are of high cost. Though Malawi is believed to contain potential petroleum resources, exploration of these resources has not commenced this is due to limited understanding of hydrocarbon geology system of the country. There has been very limited research into using gravity data as an early screening step to select potential oil and gas fields

1.3. Main objectives

The aim of the research is to perform petroleum resource potential assessment using gravity data.

1.4 Specific Objectives

The research has the following specific objectives:

i. Map up geological structures that are of potential for trapping hydrocarbon.
ii. To determine thickness of the sediments of the Lower Shire Basin.
iii. Estimate the size of potential oil and gas trapping structures.

1.5. Research questions

i. What is the structural geometry of the sedimentary basin of the study area?
ii. What is the thickness and depth of the sedimentary deposits?
iii. Is there any potential trapping structure for oil and gas?
iv. What is the size of potential oil and gas trapping structures?

1.6. Significance of study

The results from this research project will provide a further insight into the petroleum potential of Malawi and may also be used to assess other blocks of Malawi oil and gas exploration. The research will help in obtaining further knowledge of Malawi's petroleum geology and the results might attract foreign oil companies to explore further. The research will also help in making decision on whether to indulge in carrying out seismic survey to further explore the availability of petroleum products (oil and gas) based on whether the estimated size of potential oil and gas trapping structure contains oil and gas that may be of economic value to be extracted.

CHAPTER 2

2.0 Literature Review

2.1 Gravity Survey

In the early stages of exploration, geophysical methods are the most effective and successful for targeting prolific basins and delineating the boundaries of concealed and partially concealed basins and main structures within the basins. Magnetic, gravity and seismic surveys are the three main geophysical methods used in hydrocarbon exploration. Magnetic and gravity surveys are typically used prior to drilling, whereas seismic surveys are used for exploration and development. The seismic method is the most commonly used method for investigating subsurface structures. However, within salt provinces, the seismic quality deteriorates, and in this case, the gravity survey becomes more suitable. Seismic data is also costly to acquire, especially in offshore environments. Various studies show successful gravity data applications in hydrocarbon exploration(Liu et al., 2019; Sarsar & Guellala, 2016; Yanis & Marwan, 2019; Zhang et al., 2019). The gravity survey method measures the Earth's gravitational field at specific locations, revealing variations in subsurface lateral density. It is primarily used in basement structural mapping of sedimentary basins (De Castro D L and Bezerra F H R, 2011). Chen et al., (Chen et al., 2020), used an innovative method of machine learning based on a U-net deep neural network to determine salt structures directly from gravity data. Subsurface structures have different masses because they have a higher or lower density than the surrounding materials. The measured gravity data is influenced by the shape and rotation of the Earth, as well as tides and the Earth itself. Before delineating subsurface features, gravity data anomalies, which describe the local variations of the gravity field around the model field, must be corrected by removing these attributed factors (Mclean et al., 2009). **Table 1** depicts the various types of geophysical surveying methods, as well as the physical properties that are most sensitive to measure.

Table 1 List of geophysical methods and their characteristics(Kearey & Brooks, 1991)

Methods	Measured Parameters	Operative physical property
Seismic	Travel times of reflected/refracted seismic waves	Density and elastic moduli determine the propagation velocity of seismic waves
Gravity	Spatial variations in the strength of the gravitational field of the Earth	Density
Magnetic	Spatial variations in the strength of the geomagnetic field	Magnetic susceptibility and remanence
Electric Resistivity	Earth Resistance	Electrical conductivity
Induced Polarization	Polarization voltages or frequency-dependent ground	Electrical capacitance
Self-Potential	Electrical potentials	Electrical Conductivity
Electromagnetic	Response to electromagnetic radiation	Electrical conductivity and inductance
Radar	Travel times of reflected radar pulses	Dielectric Constant

2.2 Gravity Anomalies

Gravity is the attraction between two bodies, and the strength of this attraction is determined by the mass of the two bodies as well as their distance apart. Gravity is measured in the unit of gals where one gal equals one centimeter per second. Gravity is not the same everywhere on Earth due to a variety of factors. Gravity surveys use these small gravity changes caused by variations in subsurface rock density to learn about the planet's internal structure. Denser rocks have higher gravity values, while less dense rocks have lower gravity (Hill et al., 1997). Gravity anomalies are differences between the true gravity field of the Earth and the theoretical gravity of a reference body. In simple terms, the difference between the observed acceleration of an object in free fall on the surface of a planet and the corresponding value predicted by a model of the method of planet's gravitation field (Balmino & Bonvalot, 2016). Different types of gravity anomalies exists and these are, free-air gravity anomalies, Bouguer gravity, and isostatic gravity anomalies. The Bouguer anomaly (named after Pierre Bouguer) is a gravity anomaly that has been corrected for the height at which it is measured as well as terrain attraction. A free-air gravity anomaly is produced by the height correction alone. The distinction is in the types of corrections applied to the measured gravitational acceleration at the various stations (Ervin, 1977; Karl, 1971; Takin & Talwani, 1966; Zamora, 2013). Assuming uniform subsurface density, the Earth's gravitational field would be constant everywhere after the appropriate corrections were applied. On the other hand, gravity anomalies would be any "local variation from the otherwise constant gravitational field" caused by any lateral density variations caused by changes in subsurface geology (Ates et al., 1999).

CHAPTER 3

3.0 Data and Methodology

3.1. Study Area

3.1.1. Geographical Location

The Lower Shire Basin is situated in the southern part of the Malawi Rift, and was formed during the Karoo times. It experienced a resurgence in activity during the Cenozoic era due to the rifting associated with the East Africa Rift System (EARS), as noted by Castaing in 1991. The basin is located between latitudes -15° and -16° and longitudes 34° and 35°, and is bounded by the Malawi Mozambique boundary to the south. The Lower Shire Valley, which is the lowest topographic region of the country, is predominantly occupied by the Lower Shire River segment. The Lengwe and Mwabvi Karoo domains can be found in the north-western and south-eastern parts of the Lowest Shire Basin, respectively. However, a significant portion of the area between Lengwe and Mwabvi is concealed by thick superficial sediments from recent deposits by the Shire and adjacent rivers, according to (Dulanya, 2017)

3.1.2. Geological Location

The Malawi lift is situated in the southern part of Africa and is within the Mozambique belt. The crystalline rocks in the area are covered by sedimentary rocks from the Cretaceous and Permo-Triassic periods (Carter & Bennet, 1973). The topmost layers of the major drainage basins in the country are made up of younger sediments that were deposited during Cenozoic to recent rifting processes (Chisenga, 2019). The study area is composed of metamorphic rocks from the Proterozoic era that have both igneous and sedimentary origins and are part of the Basement Complex. These rocks are covered by Karoo volcano-sedimentary rocks and later by Cretaceous and Quaternary sequences. The Lengwe and Mwabvi regions are two of the most well-known Karoo regions within the study area.

3.1.3 Structural Setting

The most recent structural understanding of the Lower Shire Basin is drawn from the analysis of Lengwe, Mwabvi and Ngabu domains (Castaing, 1991; Chisenga et al., 2019). The Lower Shire Basin can be described as an area of repeated stress regimes beginning from the Karoo rifting period when NW-SE extension produced NE-SW grabens (Castaing, 1990, 1991). This regime was followed by sinistral slip systems with a slight normal component which enabled the NW-SE faults such as the Mwanza Fault to play a significant role in the evolution of the Karoo basins of the Shire Valley (Castaing, 1991). The Karoo sedimentation and magmatism of the Lower Shire Basin was controlled by NW-SE extensional tectonic regime in which the minimum stress of the δ3 was dominant from the Permian to the Lower Jurassic. The basaltic magmatic phase was initiated as the late phase of the basin development and were followed by Stomberg dolerite dyke injection that are a manifestation of the last phase of basin rifting during Gondwana evolution.

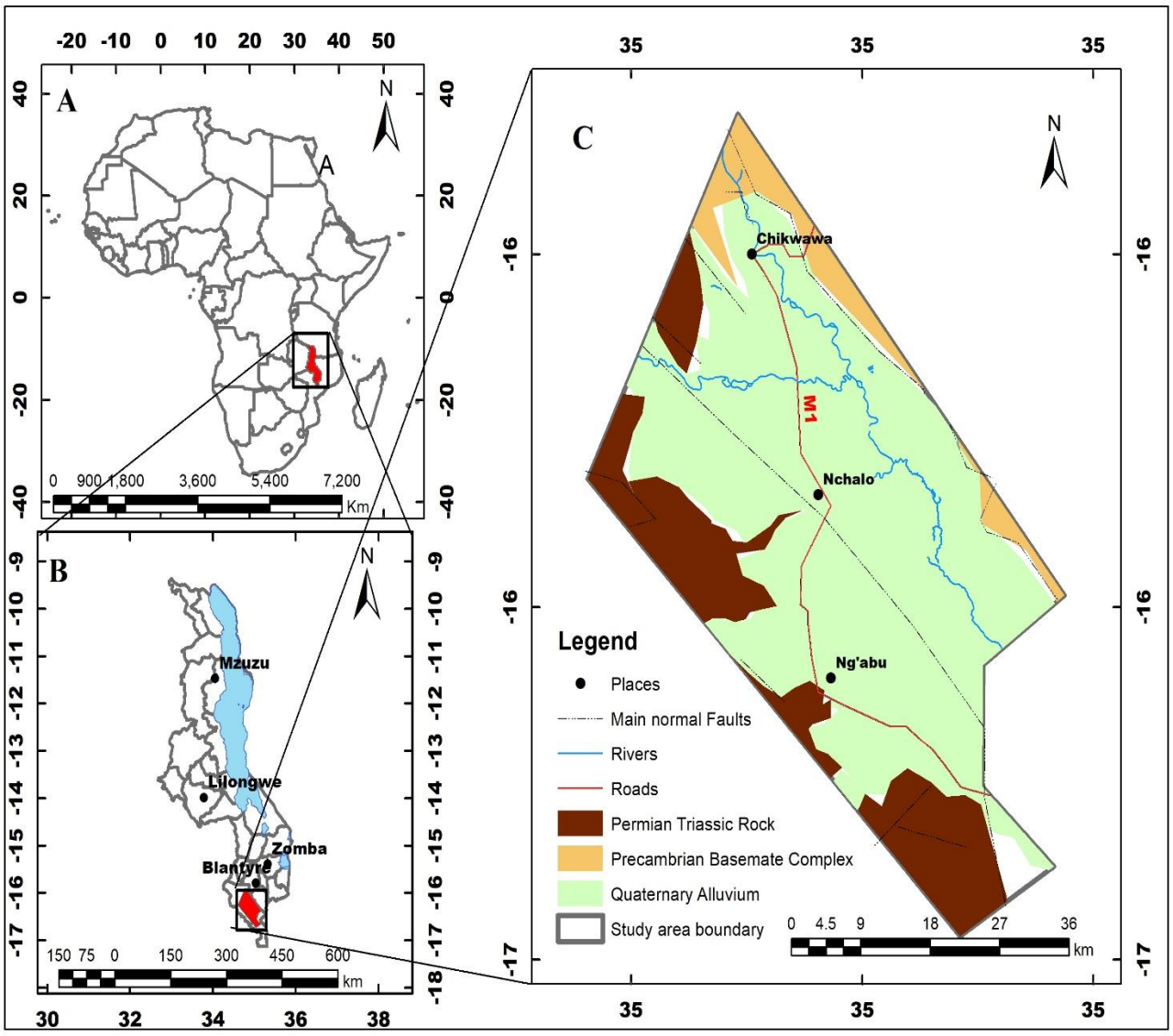


Figure 2 Location of Study Area: (A) Position of Malawi on the African continent, (B) Position of Study Area in map of Malawi, (C) Study Area structural map after Chisenga 2019.

3.2. Gravity Data Collection

In this study, Bouguer anomaly maps in the Lower Shire Valley area obtained from the Malawi Geological Survey Department is used. The data is part of the results of the country wide Airborne Geological Survey, led by Sanders Geophysics Limited (SGL) on behalf of the Malawi government. Detailed data specifications, data correction procedures and elevation data collection are described in the official Bates and Mechanef (2013a, 2013b) report. According to (Chisenga et al., 2019), the gravity data was recorded at 128 readings per second (128 Hz). Line spacing was 1000 meters apart in the 135° -315° direction with tie line spacing of 5000 meters in the direction of 0° -180°. Ground clearance was 60 meters +/-20 meters with the airplanes moving at 108 knots. The Bouguer anomaly map was gridded from the gravity reduced data using minimum curvature method (Smith & Wessel, 1990). Bouguer anomaly map obtained from the geopotential field data was filtered. Bouguer anomalies involves gravity signature due to the influence of both shallow and deep structures in the subsurface. **Figure 3** shows a topographic map of part of southern Malawi and location of the study area.

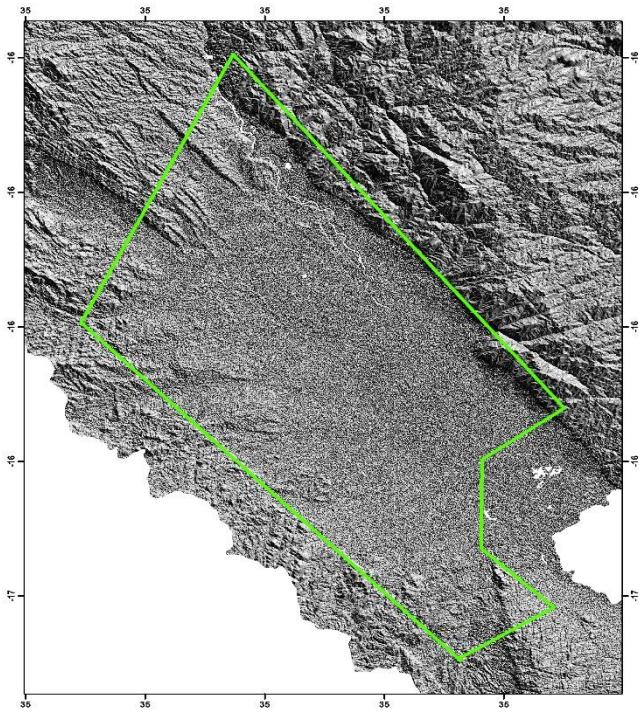


Figure 3 Topographic map of study area

3.3 Gravity Data Processing

3.3.0 Gravity Anomaly Separation

The observed gravity anomaly, G_{obs}, consists of high and low frequency components representing shallow and deep geological structures, respectively. These frequency components are known as residual (high), G_{res}, anomaly and regional (low), G_{reg}, anomaly:

$$G_{obs} = G_{res} + G_{reg}$$

Some mathematical methods are required to separate the map data into two components (Dobrin & Savit, 1988). The separation of these components must be performed in the spatial frequency domain via fast Fourier transform (FFT) known as a low-pass filter and a high-pass filter based on the method given by Harrison and Dickinson (Harrison et al., 1989). The regional gravity anomaly map is a product of a low-pass filter (long wavelength) that shows deep-seated structure while the residual gravity anomaly map is produced by the high-pass filter (short wavelength) that shows the shallow structure.

3.3.1 Total Horizontal Derivative (THD)

Total horizontal derivative (THD) is a well-known filtering method for potential methods to look at a different perspective of gravity anomaly, particularly to highlight a high gradient area that probably represents structural trends. It measures the change rate of the gravity field in two horizontal directions (x and y). The horizontal derivative method produces a maximum ridge of anomaly gradients over the contacts between different densities among subsurface rock units that are caused by features such as stratigraphic or structural contacts which juxtapose units of different densities (Whitehead and Musselman, 2006). Anomaly separation applies enhancement techniques to isolate various long wave-length components and provide a means to assess the relationship between the regional, local, shallow, and deep sources (Fajklewicz, 1976). One such technique is the first derivative that tends to increase the perceptibility of small amplitude

anomalies which are easily obscured by the regional gravity field. The first and second vertical derivative methods both enhance near-surface anomalies at the expense of deeper anomalies and are good at locating the edges of a body with subsequent modeling to determine the depth, density, susceptibility contrast and geometry of the anomalous sources.

3.3.2 Vertical Derivative

The First Vertical Derivative (FVD), computed using a fast Fourier transformation (FFT), is a high-pass filter designed to accentuate the more detailed features and structures in the subsurface(Cooper & Cowan, 2004; Marson, 1993). It is also a proven technique to help resolve anomalies over individual structures from the gravity field because the vertical gradient is more sensitive than gravity itself to structural features (Blakely, 1996; Marson, 1993). It is worth to underline that this transformation technique also amplifies the short wave length noises. The first vertical derivative of the gravity field g in the space domain is defined as:

$$\text{FVD} = \frac{\partial g}{\partial z}$$

where $(\frac{\partial \mathrm{g}}{\partial \mathrm{z}})$ is the derivative of the gravity field along the vertical direction.

3.3.3 The 3D Euler Deconvolution

The Euler Deconvolution technique of three orthogonal gradients along x, y, and z-axes of potential field was applied to integrally estimate subsurface locations in both horizontal and vertical (depth) dimensions of an anomaly source (Reid et al., 1990). In practice, Structure Index and Window Size are run together with gradient data in the least-square inversion to deconvolve the subsurface location (Hinze et al., 2012). Note that appropriate parameters of Euler calculation for ideal fault contacts were set at Structure Index of 0.0 and Window Size of 15 (Noor et al., 2021). The aim of 3D Euler deconvolution (3DED) is to determine the geometry, field source location and depth estimation of gravimetric anomalies (Bournas et al., 2003). The 3DED has successfully been used in discovering fault lineaments distribution including the dip direction and extension below the subsurface. This method was created by Thompson and Reid et al. (Reid et al., 1990; Thompson, 1982) who developed the equivalent method which

operated on magnetic data. Later, the method has been introduced to be used in gravity data such as in (Fairhead et al., 1994)

3.3.4. The Radial Spectral Analysis

Spector and Grant (Spector & Grant, 1970) had introduced a spectral factorization method to describes the frequency content of a signal based on a finite set of data (Igwesi & Umego, 2013), thus estimating the depth basements based on gravity sources that were controlled by wavenumber components. Spectral analysis of a gravity profile can be derived in the discrete Fourier Transform mathematically as the equation below:

$$\Delta g(xi) = \sum_{n}^{N} -1[An\ \cos\frac{2\pi nxi}{L} + Bn\cos\frac{2\pi nxi}{L}]$$

where n is the total amount of data in x direction, xi is the data interval in direction x, n is the harmonic number, A and B are the coefficient of cosine and sine, L is the length of the cross-section of the anomaly. Finally, the average depth of basement rock was estimated by calculating the slope gradient of the power spectrum curve and substituting the result of the slope in the following relationship:

$$Z = -\frac{m}{4\pi}$$

where z is the depth and m is the obtained slope from the power spectrum curve (Maus & Dimri, 1996). Gravity anomalies produced by a shallow structure are more dominated by high wavenumber components than those resulting from a deeper source. This effect may be quantified by computing the power spectrum of the anomaly since the long power spectrum has a linear gradient whose magnitude is dependent upon the depth of the source (Spector & Grant, 1970).

CHAPTER 4

4.0 Results and Discussion

4.1 Qualitative Interpretation

The Bouguer gravity anomaly maps in **Figure 4** provide a detailed look at geology and structure of the Lower Shire region. The Complete Bouguer gravity anomaly (CBA) map, which has been corrected for terrain, shows the main geological and structural patterns in the area. The regional CBA anomaly map displays the gravity source with long wavelengths, which is thought to originate from deep-seated bodies, and has been obtained by filtering using a low pass frequency filter of 30,000 m wavelength cut-off. This map provides information on the deeper geological structures and features in the region.

The residual CBA anomaly map is created by applying a high pass filter with a 30,000 m wavelength cut-off, which only allows the gravity source with short wavelengths to be retained. This map provides more detailed information on the shallow geological structures and features in the region as shown in. The residual CBA anomaly map was further processed to produce the THD map, which highlights the maximum ridge of the anomaly gradient that delineates geologic contacts or faults, distinguishing different densities of rock.

These maps are important for understanding the subsurface geology and the potential for hydrocarbon resources in the Lower Shire region. By identifying different gravity sources and their associated wavelengths, these maps provide insights into the types of geological structures that may exist in the subsurface, and where potential hydrocarbon traps may be located.

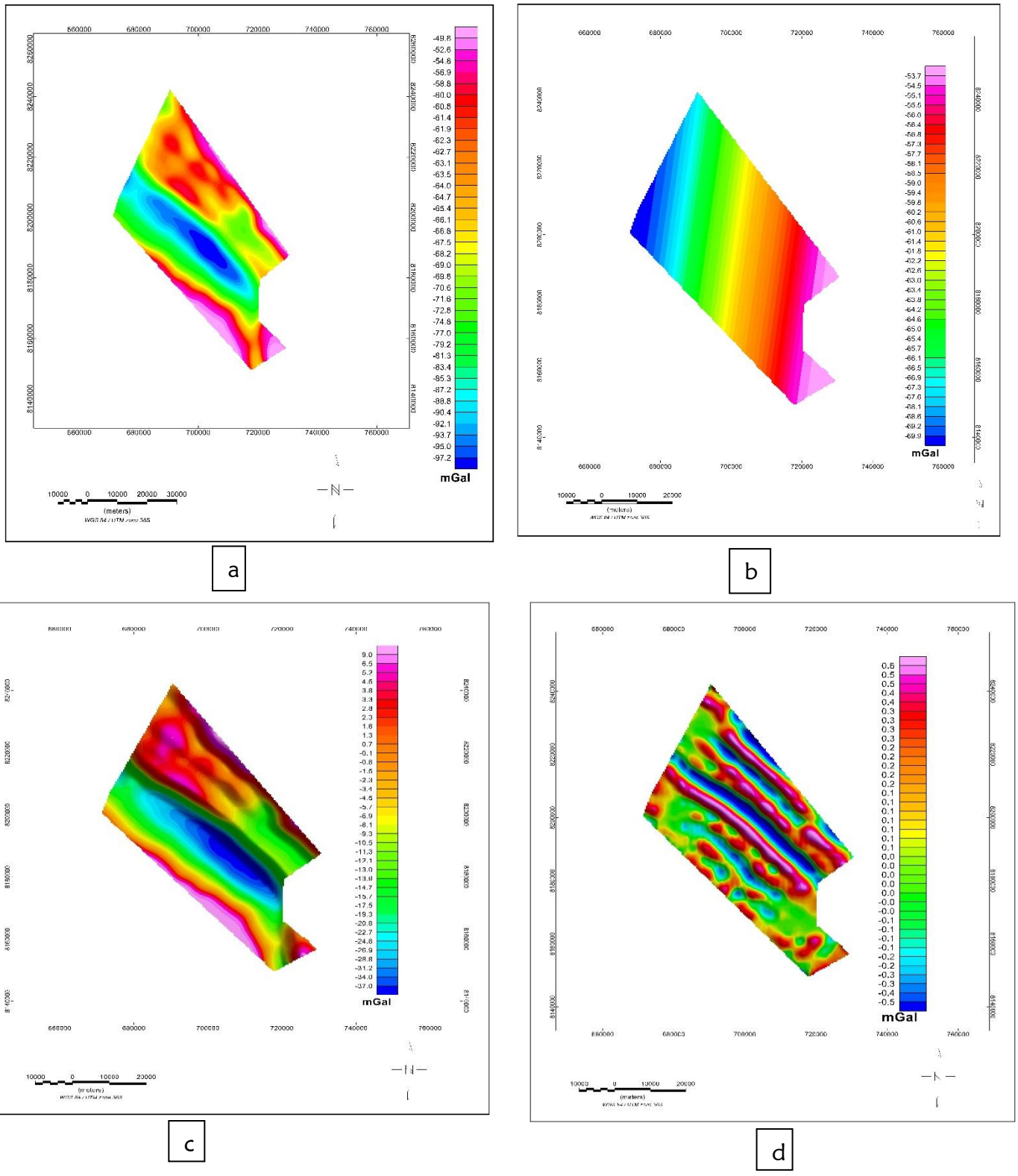
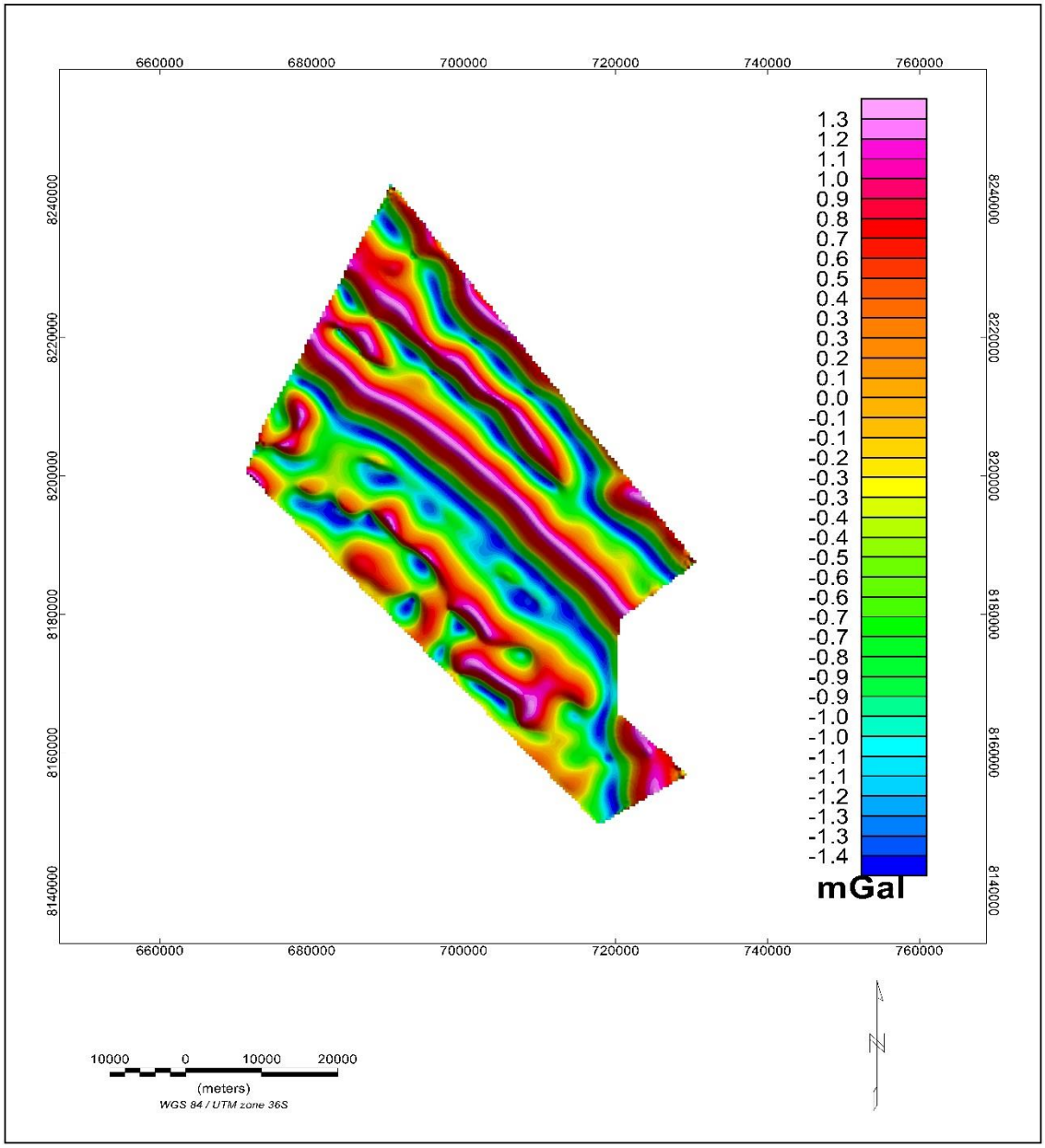


Figure 4. (a) complete Bouguer anomaly (CBA) map; (b) Regional CBA anomaly map; (c) Residual CBA anomaly map; (e) first vertical derivative CBA map


660000
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-0.5
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-0.7
-0.7
-0.8
-0.9
-0.9
-1.0
-1.0
-1.1
-1.1
-1.2
-1.3
-1.3
-1.4
mGal
10000
0
10000
20000
(meters)
WGS 84 / UTM zone 36S
N

e

4.1.1 Complete Bouguer Gravity Anomaly Map

Based on the map shown in **Figure 4(a)**, the pattern of the Bouguer gravity anomaly can be classified into low gravity zone, gravity anomaly values ranging from, −97.2 to −49.8 mGal. This low gravity zone can be further classified into Low, medium and high gravity zones, values ranging from −97.2 to −83mGal, −81.4 to −62.7mGal and −62.3 to −49.8mGal respectively. The LG regions can be observed and situated mostly in the northwest to southeastern part that consists of the quaternary alluvium formations of Nchalo and Ng'abu areas; mark the area of low topographic land as shown in **Figure 3**. The MG region is comprised of Precambrian basement complex formations, while the (HG) zone has been identified in Permian Triassic rocks (karoo) at the southwestern side. Variations in gravity anomalies were normally caused by variation in the density of the subsurface rocks (Noor et al., 2021)and they usually indicate faults or lithological contacts(Ade-Hall et al., 1974).

4.1.2 Regional CBA Anomaly Map

The regional CBA anomaly map in **Figure 4(b)** has a gravity anomaly range from −69.9 to −53.7mGal. The gravity reading increases towards the southern part indicating the development of crustal density towards the Ng'abu area. Moreover, this phenomenon has proved the statement regarding the thickening of Mesozoic sediment towards the southern region. The dense contour in the central part of the map, which split the negative and positive anomalies, suggests the extension of metamorphic rocks and surrounding rock formation contact at depth.

4.1.3 Residual CBA Anomaly Map

Figure 4(c) shows the responses of high frequency data that represents the shallow subsurface structures. The residual gravity values responded greatly in terms of sedimentary formations classification and lithological contacts compared to the CBA map (**Figure 4a**). For instance, Lower shire basin has a consistent high anomaly value (-37.0 to

9.0mGal). The highest gravity (LG) anomaly zone was detected in the Quaternary alluvium overlying the formation and indicating deep sedimentary basin thickness [46]

4.1.4 THD Anomaly Map

The THD anomaly map was derived from the residual CBA map. **Figure 4(d)** shows a dense and conspicuous feature of steep gravity gradient in the central, northeast, and southwest parts of the study area. In general, two dominant lineaments trending NW-SE were observed at the central part of the study area. One of these lineaments was perfectly overlapped on Mwanza Fault zone when THD and structural maps were superimposed to each other. Since one of the lineaments is perfectly matched to Mwanza Fault zone, the remaining lineaments close to it were also most likely associated with possible faults which have yet be determined (Chisenga 2019). Structural lineament analysis was then conducted by tracing the lineaments observed in both the THD anomaly map and structural maps. Trends of both lineaments are compared with topography map lineaments analysis, which represents general surface structures. The lineaments trends deduced from the topography map and THD residual anomaly map are shown in **Figure 5 a, b**, respectively.

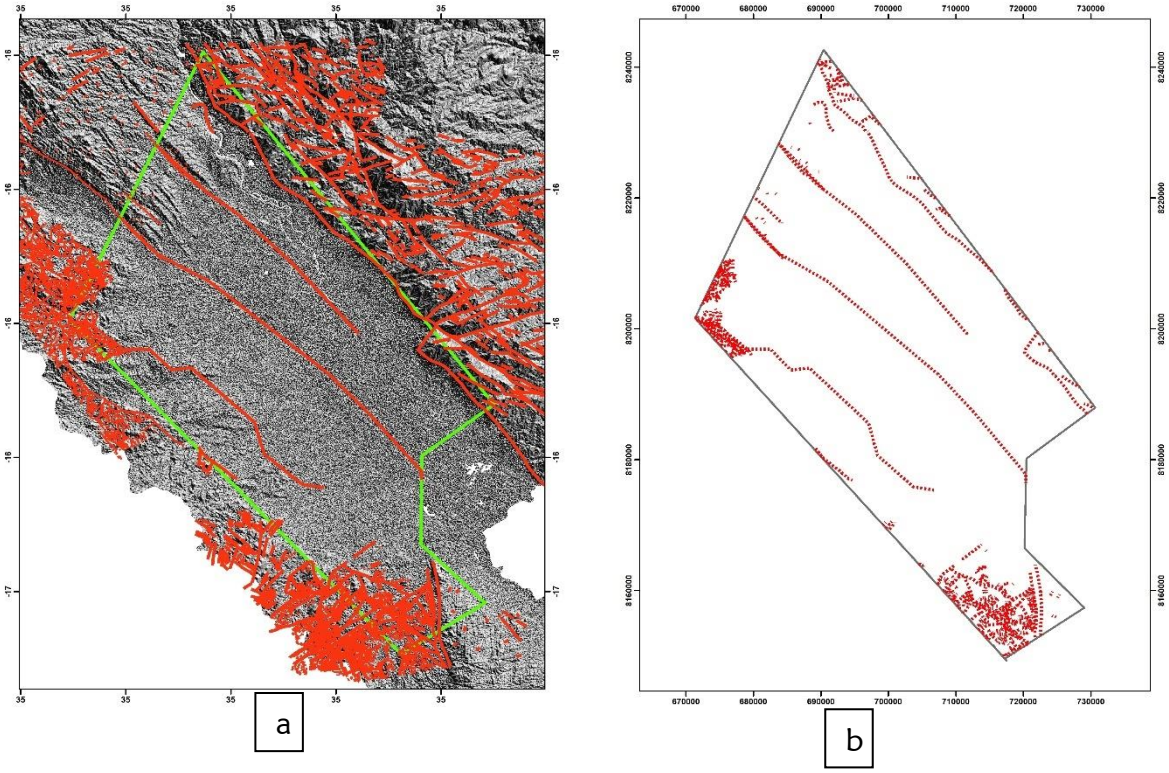


Figure 5 (a) Lineament traced from topography map; (b) Comparison of lineament trend traced from THD residual anomaly map and topography map

4.1.5 Vertical Derivative anomaly map

The first vertical derivative (FVD) anomaly map was derived from the residual CBA map. **Figure 4(e)** shows a dense and conspicuous feature of steep gravity gradient in the central, northeast, and southwest parts of the study area. In general, two dominant lineaments trending NW-SE were observed at the central part of the study area. One of these lineaments was perfectly overlapped on Mwanza Fault zone when FVD and structural maps were superimposed to each other. Structural lineament analysis shows a trend which represents general surface structures.

4.2 Quantitative Interpretation

The Euler Deconvolution and power spectrum analyses are used for quantitative interpretation to estimate any subsurface structure. The Euler deconvolution is used for resolving the 3D components of structural elements while the power spectrum analysis is used for estimating the subsurface source depth and possible interfaces.

4.2.1 Euler Deconvolution

In this study, Euler's solutions of the CBA map are generated using a structural index of 0.0 to delineate faults/lineaments contact with depth estimation based on Euler anomalies. A window size of 5 km × 5 km and 20 km × 20 km grid cells with a depth of tolerance of 15% were applied (**Figure 6**). Both Maps were overlayed on top of the Lowe Shire map with the known location of faults/lineaments adopted from the geological map of Malawi. A high concentration of Euler anomalies was observed along the Mwanza Fault. The depth range of Euler anomaly sources are ranging from less than 500m to more than 3000m. Mwanza Fault has the most significant number of Euler anomalies along the fault zone, with a shallow depth ranging from 1000m to 2000m at the Southeastern part and increasing towards the northwestern direction with a depth ranging from 2500m to more than 3000m.

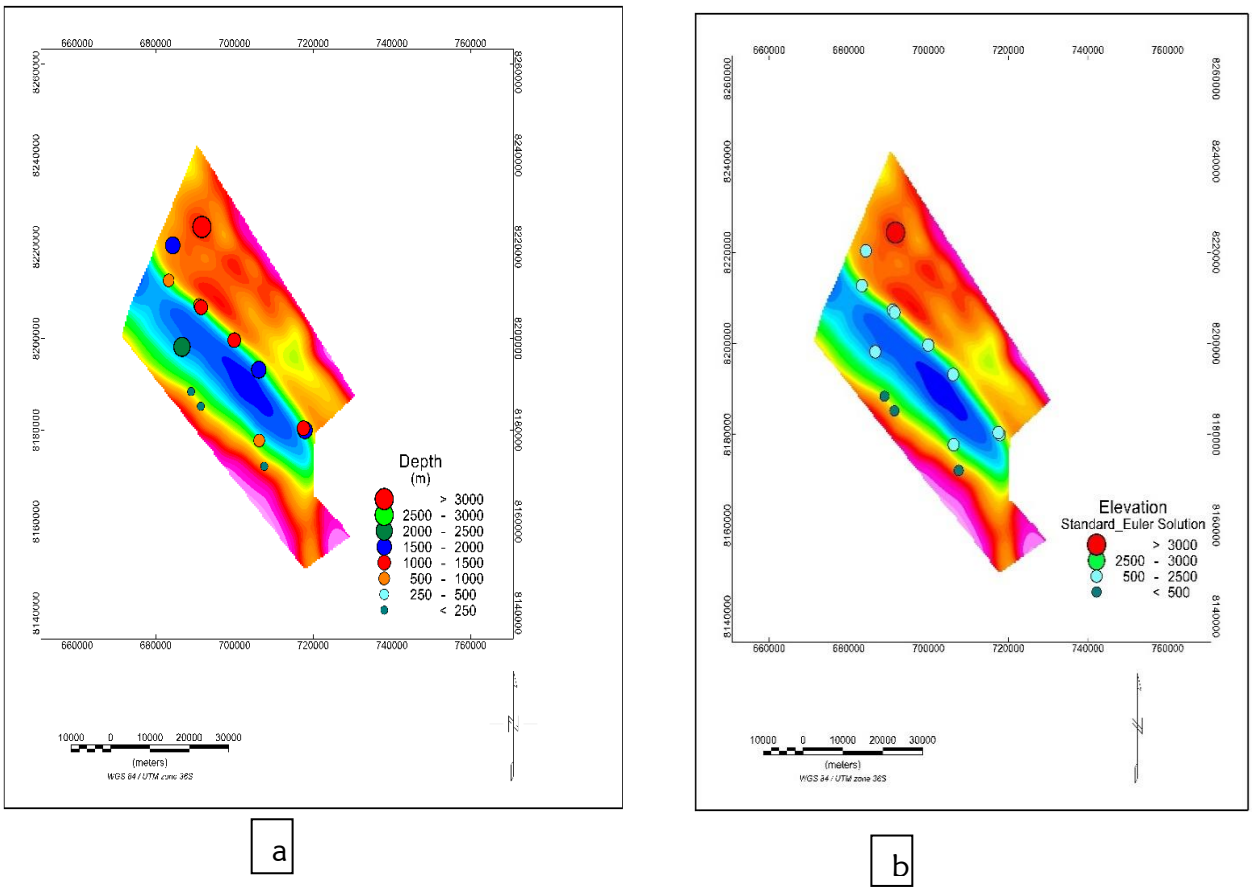


Figure 6 Two Euler solutions of the Bouguer anomaly map of structural index = 0.0, with a window size of (a) 20 km × 20 km, (b) 5 km × 5 km

4.2.2 Radially Power Spectrum Analysis

This analysis was conducted at 19 location points of 10 km × 10 km interval all over the study area, as shown in **Figure 7**. Each location point has a midpoint of a 20 km horizontal line. To control and validate the data, each profile was set to have 16 data points with the center of the lines representing the depth of deep and shallow sources. **Figure 8** shows selected spectral analysis curves of point 9 to 18 with the natural logarithm of the power spectrum against the wavenumber that describes the deterioration or decrease in the value of the power spectrum by observing in line with all other points. The depth due to gravity sources for each profile was measured from the slope of the curves based on the radial power spectrum. The low wavenumber power spectra curves pattern was interpreted as representing a deeper source and the high wave number power spectra curves pattern was interpreted as representing a shallow source.

Figure 9(a, b) shows maps of shallow to deep gravity source of the study area, respectively. In general, the depth of the shallow gravity source increases from northwest to southeast with a maximum depth of 1.77km from the surface located in the almost at the center of study area withing the confluence of Shire River and Mkombedzi River. A similar increasing trend pattern can also be observed on the map of deep gravity source with a maximum depth of 3.5 km from the surface.

Figure 10 shows four profiles across the topography with shallow and deep source maps. Based on these profiles, the maximum depth area, is located almost in the middle of the profile where most of the formations, lithological contact and weak zones were located. These indicate that subsurface structures play a significant role in establishing groundwater basin including petroleum reservoirs, basement depression and such sedimentary thickness may alarm further accumulation investigation in the area.

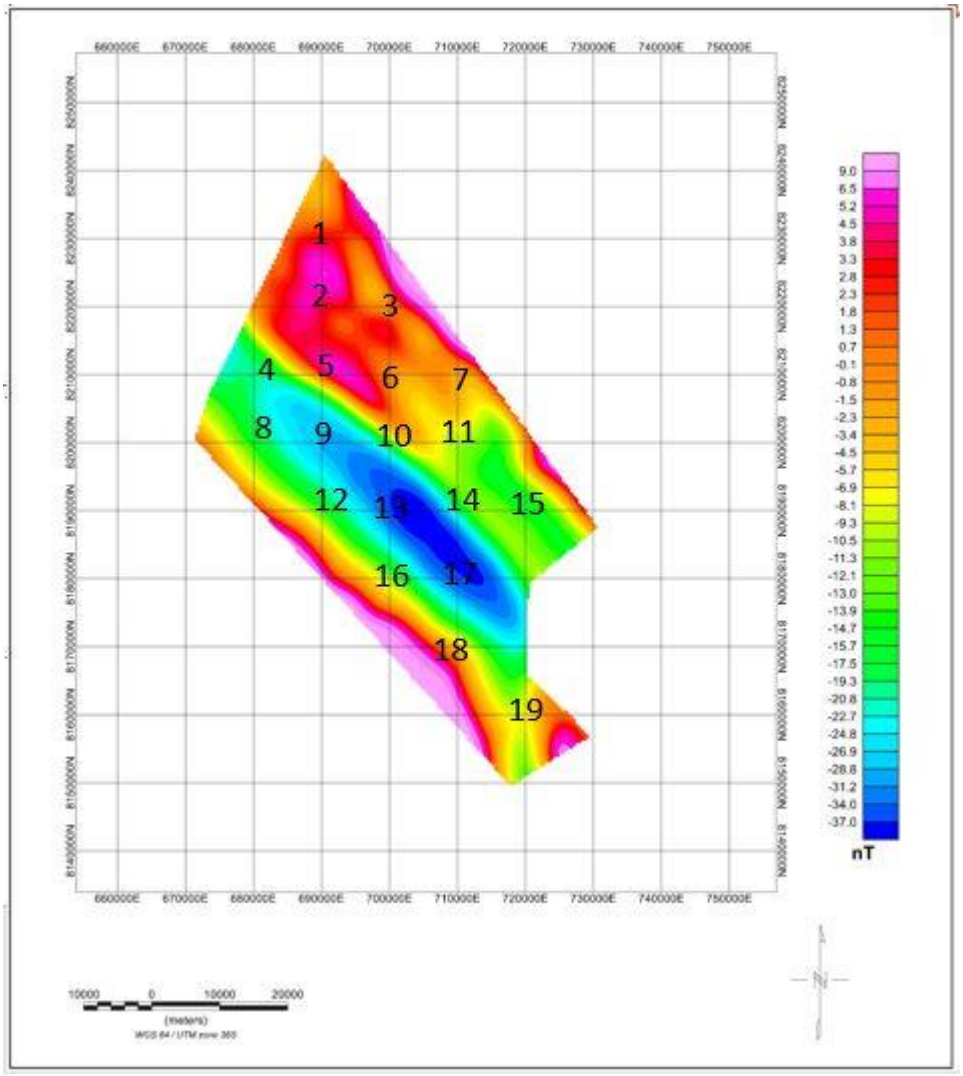
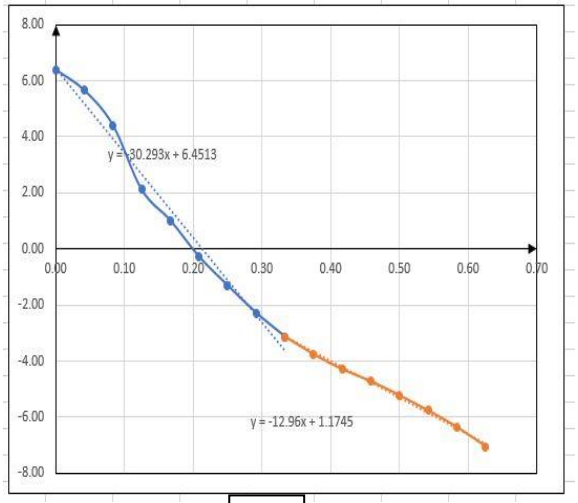
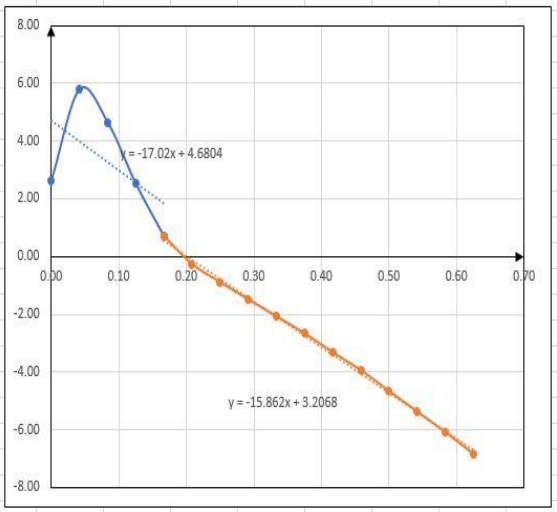


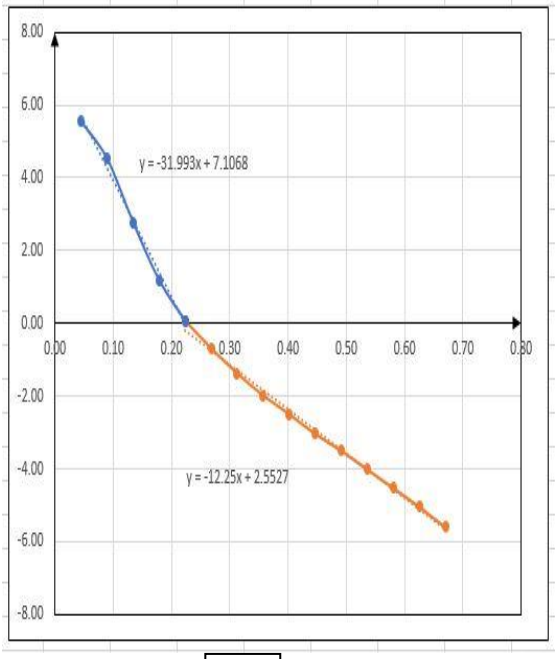
Figure 7 Power spectrum location map


y = -30.293x + 6.4513
y = -12.96x + 1.1745

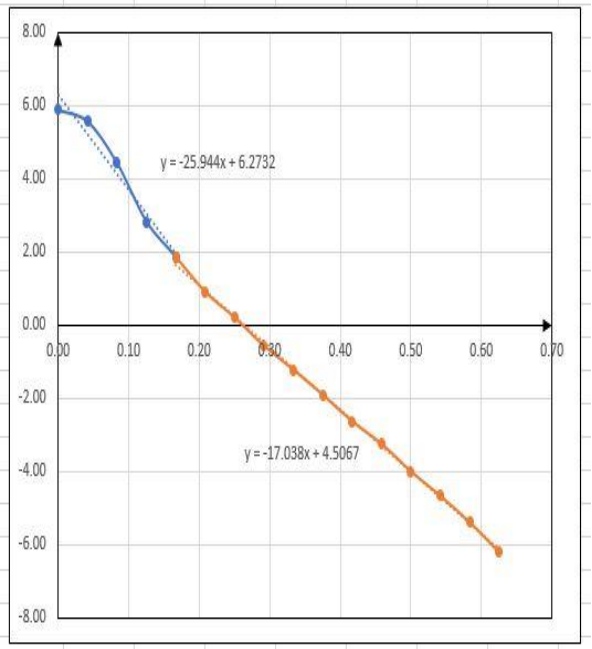
a


y = -17.02x + 4.6804
y = -15.862x + 3.2068

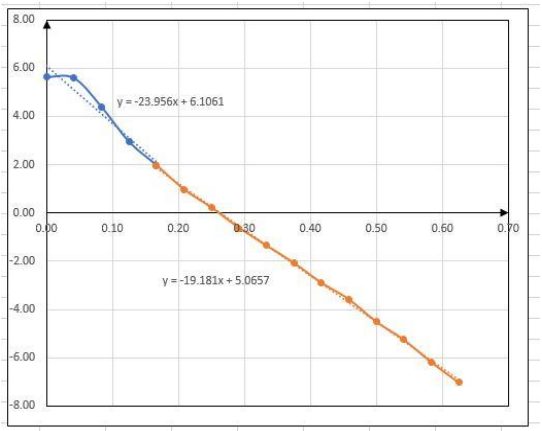
b


y = -31.993x + 7.1068
y = -12.25x + 2.5527

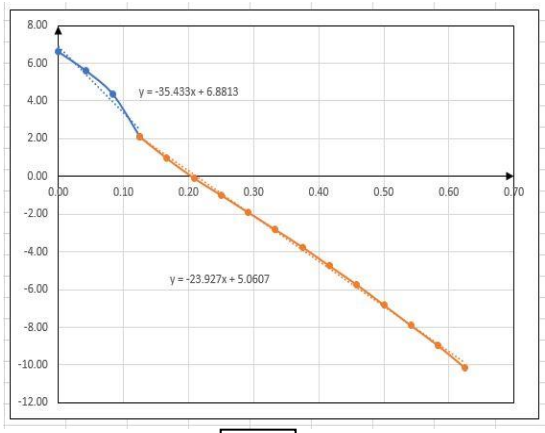
c


y = -25.944x + 6.2732
y = -17.038x + 4.5067

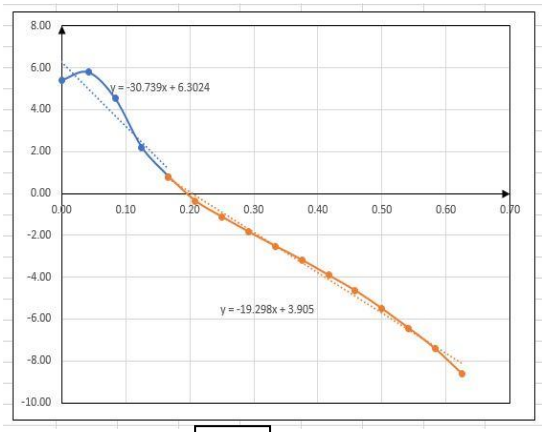
d



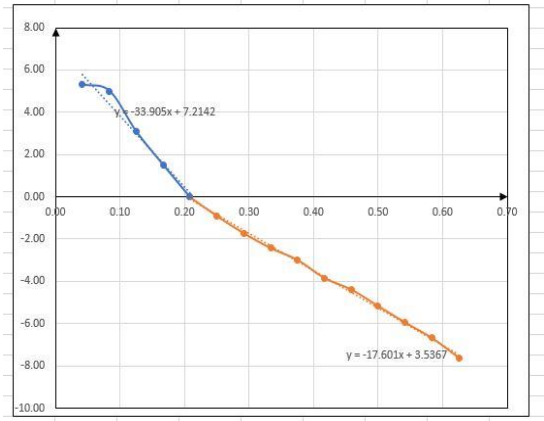
e



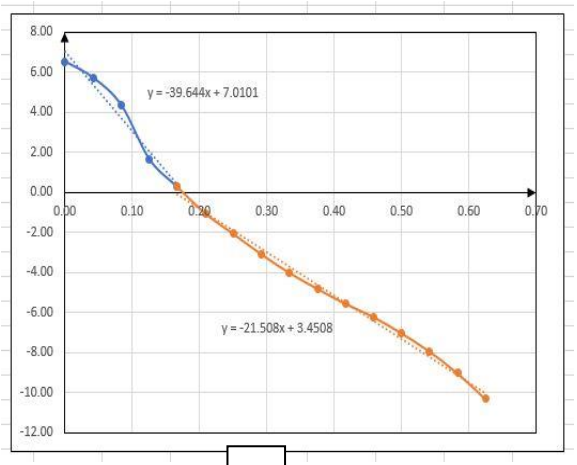
f



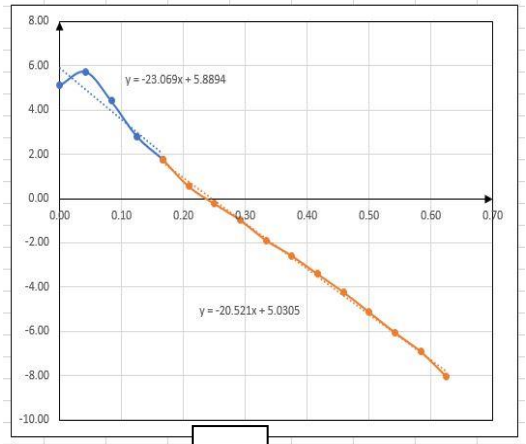
g



h



i



j

Figure 27 Log of spectra power *vs.* wavenumber of (a) Point 9; (b) Point 10; (c) Point 11; (d) Point 12; (e) Point 13; (f) Point 14; (g) Point 15, (h) Point 16, (i) Point 17, (j) Point 18.

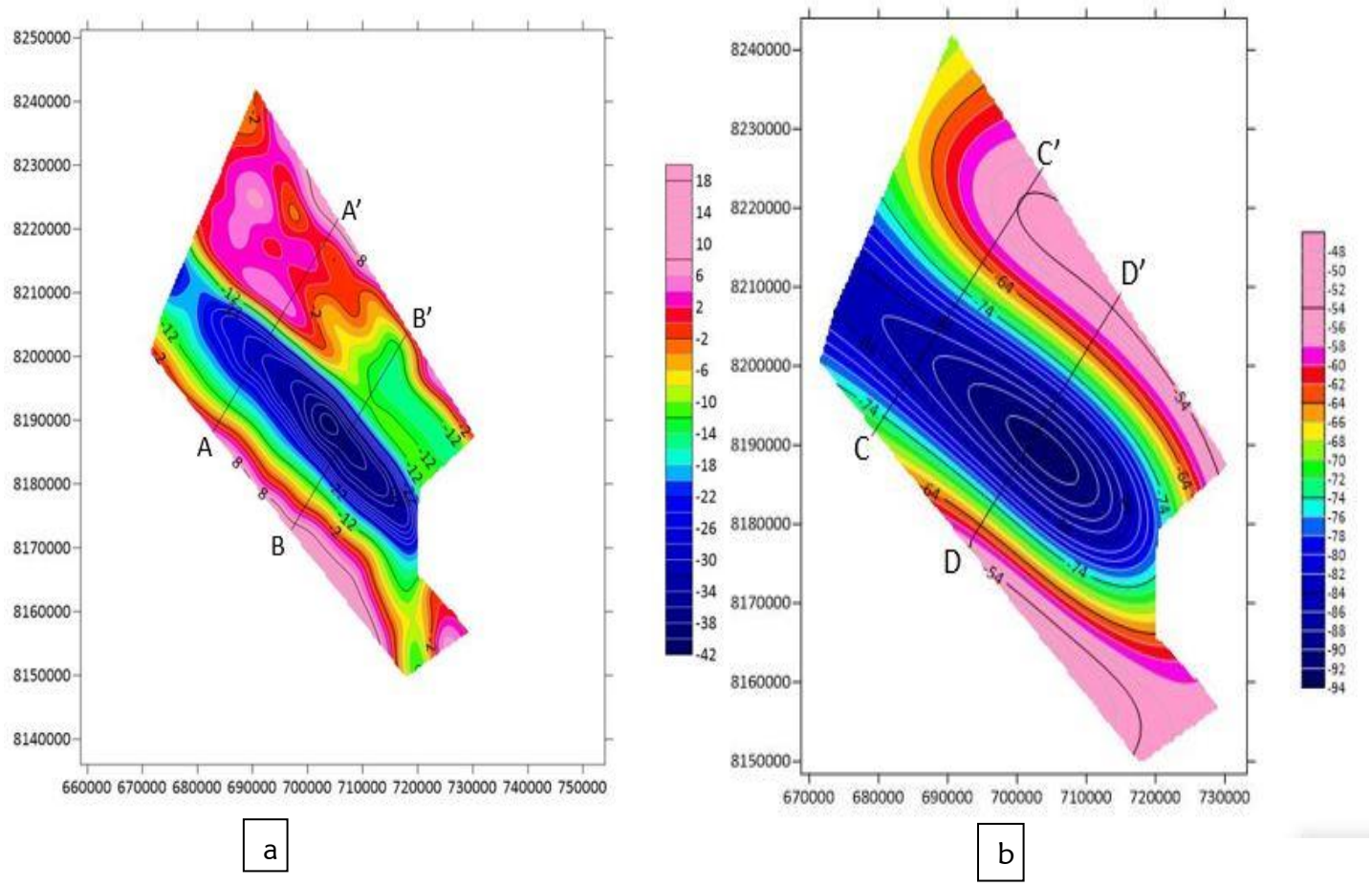
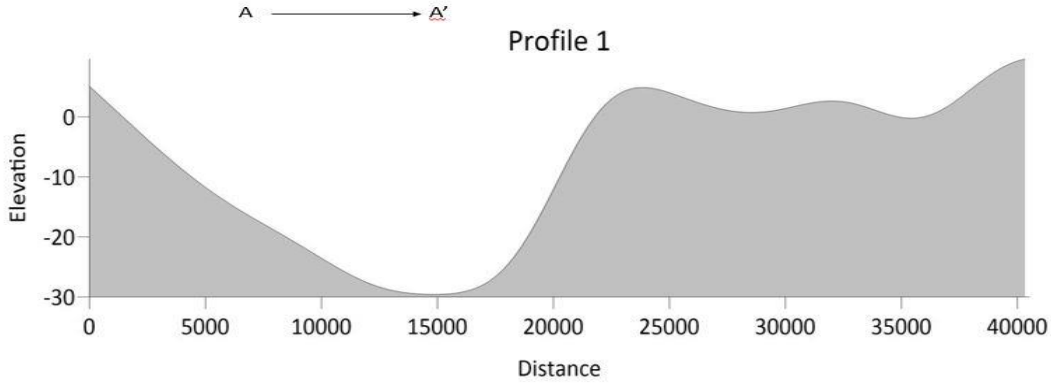
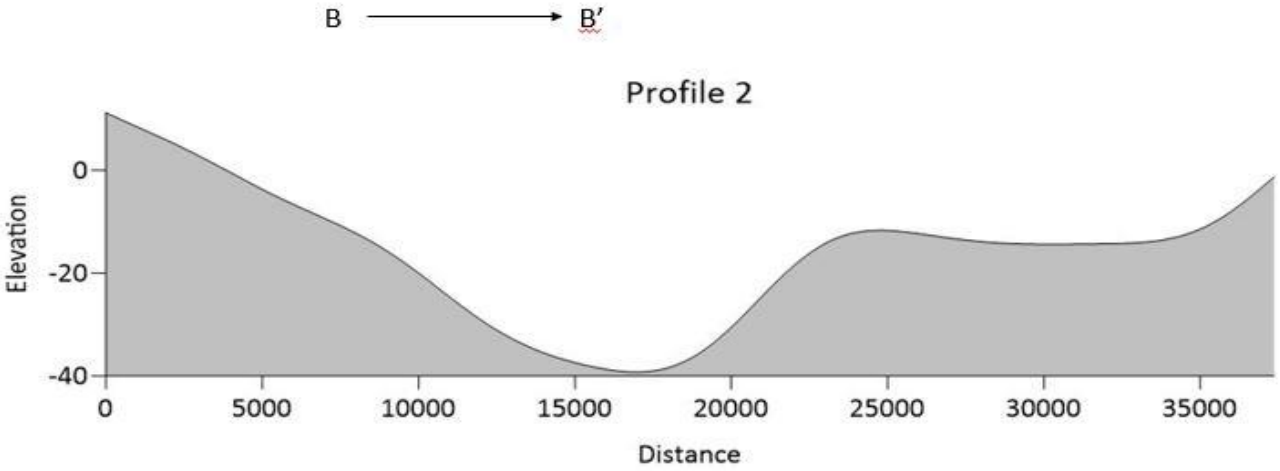


Figure 35. (a) Depth to shallow source map; (b) Depth to deep source map


A
A′
Profile 1
Elevation
0
-10
-20
-30
0
5000
10000
15000
20000
25000
30000
35000
40000
Distance


B
B′
Profile 2
Elevation
0
-20
-40
0
5000
10000
15000
20000
25000
30000
35000
Distance

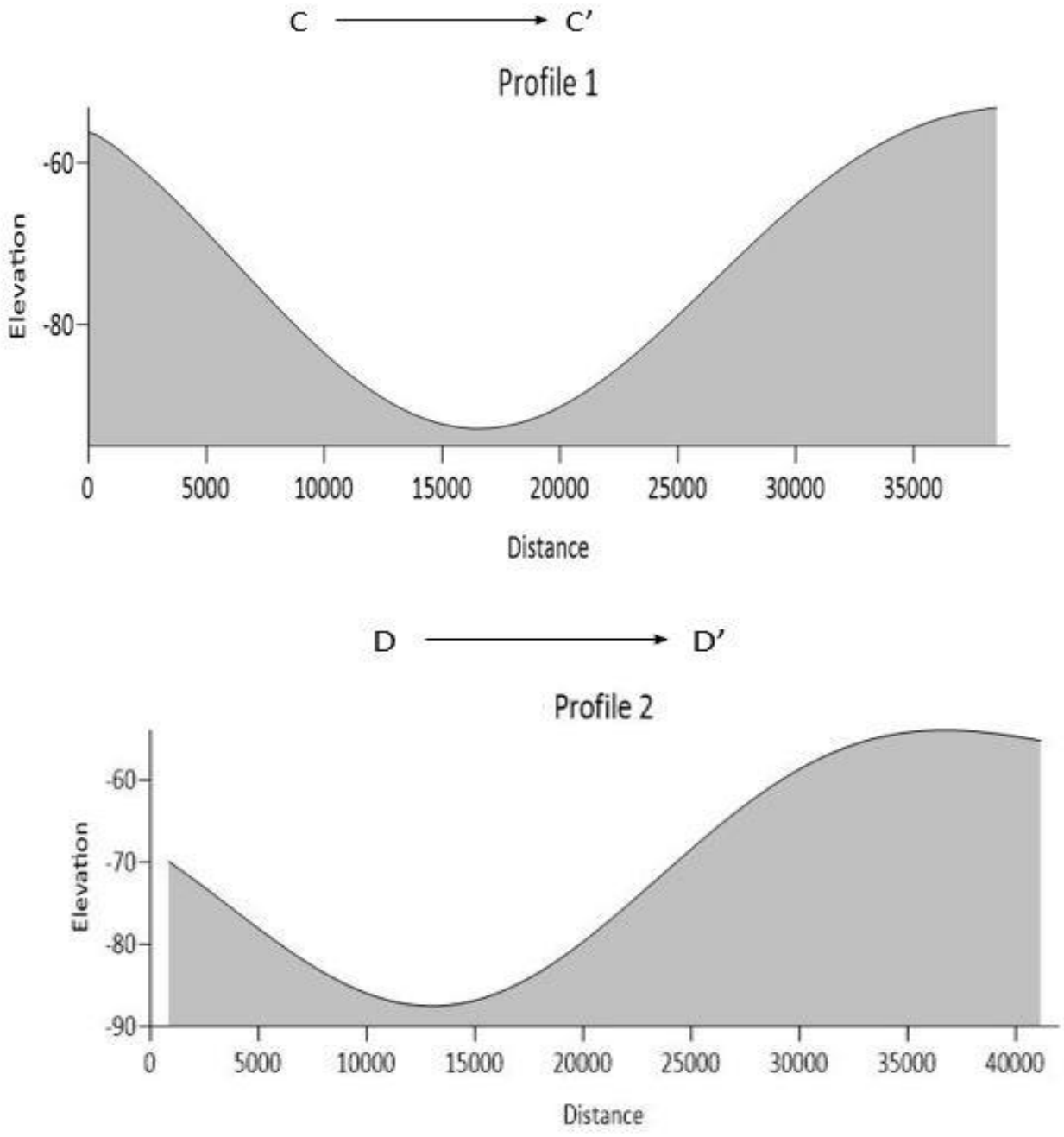


Figure 36. Profiles (a) Line A-A'; (b) Line B-B'; (c) Line C-C'; (d) Line D-D'

The lineament analysis from the THD residual anomaly map and topography map that represent shallow subsurface and surface structures have shown an identical trend of NW-SE and nearly NS in the southern and southeastern parts. The THD residual anomaly can be used to enhance the lineament data for general structural analysis, especially on the flat or non-topographic area. Two depth sources generated by spectral analysis to estimate the major sedimentary layer thickness of the basin for the presence of hydrocarbons and its subsurface structure contribute towards developing a hydrocarbons system. The shallow sources layer has a thickness range of 250 m to 800 m with an average thickness of 480 m, while the deep sources layer has a thickness range of 170 m to 975 m with an average thickness of 565 m. The study outcomes show that the optimal depths were found around the most prominent structural area at the southwestern part of the study area. Hence, this area contains considerable sedimentary thickness that may suggest further investigation. However, a more comprehensive analysis of other geophysical methods is required to get a more precise result.

CHAPTER 5

5.0 Conclusions

The petroleum resource potential assessment using gravity data in Lower Shire, Malawi, indicates that the region has the potential to host hydrocarbon resources. The integration of gravity data with other geological and geophysical data helped to build a comprehensive subsurface geological model, which identified several structural features that may have influenced the formation of hydrocarbon traps in the area.

The gravity data analysis revealed the presence of sedimentary basins in the Lower Shire region. These basins are characterized by different thicknesses of sedimentary layers and varying depths of basement rocks. These sedimentary basins are potential sources of hydrocarbons, as they provide the necessary conditions for the formation and accumulation of oil and gas.

The study also identified several structural features, including faults and folds, which may have created traps for hydrocarbons. The depth and geometry of these traps were estimated using the subsurface geological model, which provided a basis for assessing the petroleum resource potential of the Lower Shire region. The results of the study are consistent with previous structural studies of the region, which have suggested that the Lower Shire region has the potential to host hydrocarbon resources.

The identification of structural features, including faults and folds, suggests that there are potential hydrocarbon traps in the Lower Shire region. The sedimentary basins in the Lower Shire region are similar in nature to other sedimentary basins in East Africa, which have been productive in terms of hydrocarbon exploration and production.

The assessment of the petroleum resource potential of the Lower Shire region provides a basis for future exploration activities, which can be targeted towards areas with the highest potential for hydrocarbon accumulation. The study highlights the importance of using integrated geophysical and geological data to improve our understanding of the subsurface geology and the potential for hydrocarbon resources.

Overall, the petroleum resource potential assessment using gravity data in Lower Shire, Malawi, provides valuable insights into the geology of the region and the potential for hydrocarbon resources. The study highlights the importance of utilizing integrated geophysical and geological data to better understand the subsurface geology and the potential for hydrocarbon resources. The results of the study provide a basis for future exploration activities in the Lower Shire region and have significant implications for the economic development of Malawi.

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