



# Structural Interpretation of the Aeromagnetic and Landsat Data of Benin and Its Environs, Southern Nigeria

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**Abstract:** The study area is part of the Niger Delta, comprising of Benin and its adjoining areas situated in the Gulf of Guinea. The area is located within latitudes 5°30'- 6°30' N and longitudes 4°30'- 5°30' E. Structural interpretation of the Aeromagnetic and Landsat Data of Benin and its Environs, Southern Nigeria was carried out to determine depth to the magnetic basement, delineate the basement morphology and relief, and delineate the structural features associated with the basin and to infer the effects of such structures to the general tectonic history and basin geodynamics of the study area. The aeromagnetic and Landsat data were subjected to various image and data enhancement and transformation routines using ILWIS 3.2 Academic and Erdas imaging softwares. Results of the study revealed that the dominant structural trend direction of the study area is in the NE-SW direction. Other lineament trend directions are in the NW-SE, N-S and E-W directions. The drainage pattern is dendritic which is indicative of lithological, structural and topographic differences and also indicative of alluvial rocks, which is typical of the geology of the area that consists mainly of sedimentary rocks. The lineament density map revealed the presence of high-density fracture zones around Atyere and Salawa-Odo areas. Results of the 2-D spectral analysis revealed a two-layer depth model. The shallower magnetic source (D<sub>1</sub>) has an average depth of 0.37 km while the deeper magnetic source bodies (D<sub>2</sub>) have an average depth of 3.47 km. The shallower magnetic anomalies is as a result of basement rocks which intruded into the sedimentary rocks while, the deeper magnetic anomalies is associated with intra-basement discontinuities like faults. The average sediment thickness of 3.47 km obtained in this study is significant for accumulation and entrapment of hydrocarbons. However, there seem to be a correlation of the interpreted lineaments with areas of primary mineralization believed to be in the study area.

**Keywords:** Aeromagnetic, Landsat, Nigeria, Tectonic, Lineaments, Basement depths, Magnetic sources.

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## I. INTRODUCTION

Aeromagnetic data have long been used by the petroleum industry to map structure and to estimate depth to magnetic basement (Steenland, 1965). One application that became popular was estimation of depth to basement from potential field data, particularly aeromagnetic data (Spector and Grant, 1970). The basement is an assemblage of rocks that underlies a sedimentary basin and may also outcrop in some places. If it contains numerous magnetic rock units, such as igneous intrusions or extrusives, magnetic sediments or magnetic metamorphic units, these can provide information on the morphology of the sedimentary basin and its structure (Onyedim *et al*, 2006). All rock units are magnetic, but not all give rise to readily observable magnetic effects. Correlation between basement features and magnetic expressions can readily be established because of the response of basement rocks to magnetic effect.

In many sedimentary basins, magnetic anomalies arise from secondary mineralization along fault planes, which are often revealed on aeromagnetic maps as surface linear features. Most mineral deposits are related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embody tectonic or deformational concepts (O'Leary *et al.*, 1976; Ananaba and Ajakaiye.,1987). Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits. They include the traces of major (regional) lineaments, the intersection of major lineaments, major (regional) and local lineaments, lineaments of tensional nature, local highest concentration (or density) of lineament, between echelon lineaments, and lineaments associated with circular features (Ajayi, *et al*, 1991). Linear features are clearly discernible on aeromagnetic maps and often indicate the form and position of individual folds, faults, joints, veins, lithologic contacts, and other geologic features that may lead to the location of individual mineral deposits. They often indicate the general geometry of subsurface structures of an area thereby providing a regional structural pattern. Similarly, during the past two decades, the interpretation of Landsat imagery using manual or digital processing, finds application in designing new maps and/or revising and improving the pioneer maps on poorly outcropping areas (Wenmenga, 2005). Regional structural analysis by this process is effective and more with radar

interpretation (Carrère and Chorowicz, 1982; Odeyemi, 1983).

The Niger Delta basin is a major geological feature of significant petroleum exploration and production in Nigeria (Whiteman, 1982), now it is Africa's oil leading province (Reijers, 2011). The Niger Delta basin accounts for the entire hydrocarbon production at present day Nigeria and it's situated on the continental margin of the Gulf of Guinea in Equatorial West Africa between latitudes 3°N and 6°N and longitudes 5°E and 8°E (Reijers, 1996). The Niger Delta sediments comprise three broad formations, the Benin, Agbada and Akata Formations. The upper Benin Formation consists predominantly of fresh water bearing continental sands and gravel. The middle Agbada Formation consists primarily of sand and shale and is of fluviomarine origin. The lower Akata Formation is composed of shales, clays, silts (Short and Stauble, 1967). This research work presents an aeromagnetic and Landsat based structural interpretation of Benin and its environment in the Niger Delta area. The purpose of this study is to produce a lineament map of the study area and hence attempt an interpretation of the mineralization of the study area, to investigate the depth to the basement of the study area, to delineate and identify the structures associated with the area, to identify the trends/patterns of structures associated with the area and to make inferences of such structures on the mineralization of the area.

## II. GEOLOGY OF THE STUDY AREA

The geology, sedimentology and petroleum geology of the basin have been extensively discussed by various authors (Adediran and Adegoke 1987; Onuoha and Ofoegbu,1988; Murat, 1972; Adekeye, 2005). The study area lies at about latitudes 5°30'- 6°30' N and longitudes 4°30'- 5°30' E (Fig. 1). The Benin basin is a sedimentary basin that forms the onshore part of the West African miogeocline in western Nigeria. Sediments encountered in the onshore part of the basin range in age from late Cretaceous to Recent and exceed 7000 ft at the coast in western Nigeria.

The physiography of the basin can be described based on the structural elements in the entire basin. These include the Benin basin proper and the Okitipupa hinge which separates the former from the Anambra basin to the east and the Niger Delta basin to the southwest.

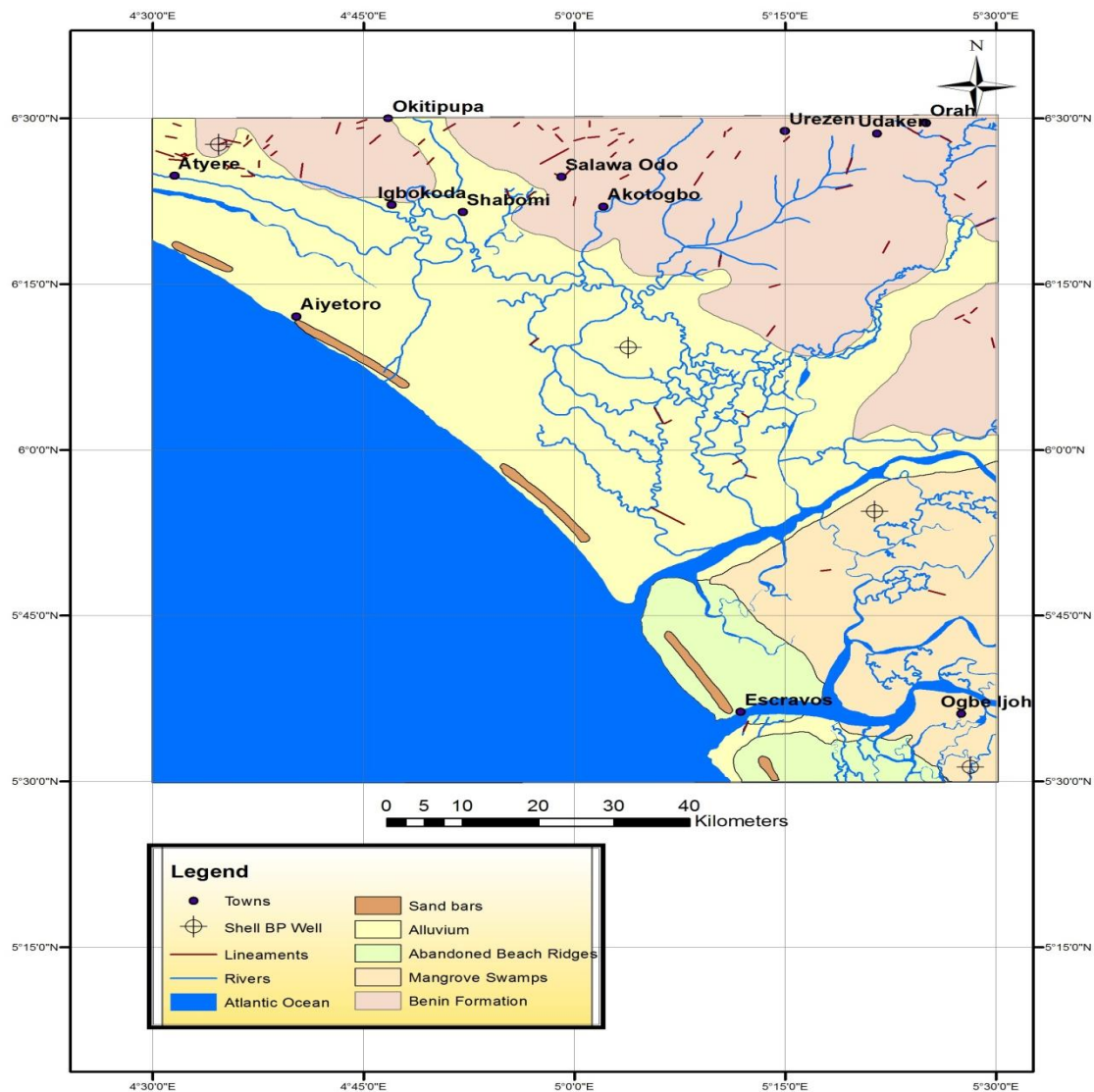


**Fig. 1: Geological map of the study area**

### III. MATERIALS AND METHOD

The materials and methods of data acquisition, processing, interpretation and analysis are presented as follows. The data used for the study were compiled using the geological map of the study area comprising Mahin (sheet 296), Okomu (sheet 297), Benin River (sheet 308) and Omolomo (sheet 309) and satellite image - Landsat 5 TM, Bands 432 with wavelengths 0.76-0.90  $\mu\text{m}$  (near - IR), 0.69  $\mu\text{m}$  (Red) and 0.52-0.60  $\mu\text{m}$  (green). A subset of the satellite data covering the study area was created using Erdas image processing software. Integrated Land and Water Information System (ILWIS) was used for creating several themes or layers from the satellite image. This software has the capabilities for various image enhancement techniques such as linear enhancement, statistical analysis, principal component analysis and normalized difference vegetation index. The following image analysis techniques were carried

out; Linear (edges) enhancement was carried out to improve the contrast quality of the image to aid better visual interpretation. Image enhancement operations carried out include contrast stretching, spatial filtering and edge detection, which were done to enhance sharpness of the satellite image for better visual interpretation, reduce noise in the image and to aid structural interpretation. Similarly, ArcView 9.3 was used to extract the lineaments and carry out statistical analysis of the interpreted lineaments in the area.

Normalized Difference Vegetation Index (NDVI) is a pixel transformation technique that was carried out to highlight areas where the green activity of chlorophyll (i.e. green plants) is dominant in the image using the NDVI Algorithm, which is given by  $\text{NDVI} = \frac{\text{TM3} - \text{TM4}}{\text{TM3} + \text{TM4}}$ . TM3 is the red region of the wavelength band of the electromagnetic radiation. TM4 is the near infrared region of

the wavelength band of the electromagnetic radiation. Highlighting areas where green plants are dominant and it's a pointer to groundwater occurrence.

The aeromagnetic data used were filtered for the purpose of highlighting linear features or edges – faults, fractures and joints, drainage patterns, and geological boundaries. The nature of filtering applied to the aeromagnetic data in this study in the Fourier domain was chosen to eliminate certain wavelengths and to pass longer wavelengths. Several potential field softwares with different analytical modules were used in the interpretations of the aeromagnetic map. These include Geosoft Oasis Montaj 7.8 HJ version, U.S. Geological Survey Potential-Field geophysical software Version 2.2, Surfer 12 and Matlab 7.6. Regional - residual separation was carried out using polynomial fitting. This is a purely analytical method in which matching of the regionals by a polynomial surface of low order exposes the residual features as random errors. For the magnetic data, the regional gradients were removed by fitting a plane surface to the data by using multi-regression least square analysis. The expression obtained for the regional field  $T(R)$  is given as:

$$T(R) = 7612.158 + 0.371x - 0.248y \dots \dots \dots (1)$$

The regional trend is represented by a straight line, or more generally by a smooth polynomial curve. The fitting of polynomials to observed geophysical data is used to compute the mathematical surface giving the closest fit to the data that can be obtained within a specified degree of details. This surface is considered to approximate the effect of deep seated or regional structures if it's of low degree. Other analytical methods used include Reduction-to-pole, second vertical derivatives and trend surface analysis 2-D spectral analysis. Reduction-to-pole (RTP) transformation was applied to the aeromagnetic data to minimize polarity effects. These effects are manifested as a shift of the main anomaly from the center of the magnetic source and are due to the vector nature of the measured magnetic field. The RTP transformation usually involves an assumption that the total magnetizations of most rocks align parallel or anti-parallel to the Earth's main field. Similarly, second vertical

derivative filters were used to enhance subtle anomalies while reducing regional trends. These filters are considered most useful for defining the edges of bodies and for amplifying fault trends. In mathematical terms, a vertical derivative can be shown to be a measure of the curvature of the potential field, while zero second vertical derivative contours defines the edge of the causative body. Thus, the second vertical derivative is in effect a measure of the curvature, i.e., the rate of change of non-linear magnetic gradients. The zero magnetic contours of the second vertical derivative often coincide with the lithologic boundaries while positive and negative anomalies often match surface exposures of the mafic and felsic rocks respectively.

Average depth values to buried magnetic rocks using the power spectrum of total intensity field were achieved using spectral analysis. These depths were established from the slope of the log-power spectrum at the lower end of the total wave number or spatial frequency band. The application of spectral analysis to the interpretation of potential field data is therefore sufficiently well established. The method allows an estimate of the depth of an ensemble of magnetized block of varying depth, width, thickness and magnetization. Most of the approaches used involves fourier transformation of the aeromagnetic data to compute the energy (or amplitude) spectrum. This is plotted on a logarithmic scale against frequency. The slopes of the segments yield estimates of average depths to magnetic sources of anomalies.

#### IV. RESULT PRESENTATION AND INTERPRETATION

For this study, aeromagnetic sheets 296, 297, 308 and 309 were used. The aeromagnetic map was digitized along flight lines at 2 km intervals. Various visual interpretation of the satellite image was carried out after the pictorial quality of the image was improved through linear enhancement and filtering of the image. The regional gradients were removed by fitting a plane surface to the data using multi-regression least squares analysis.

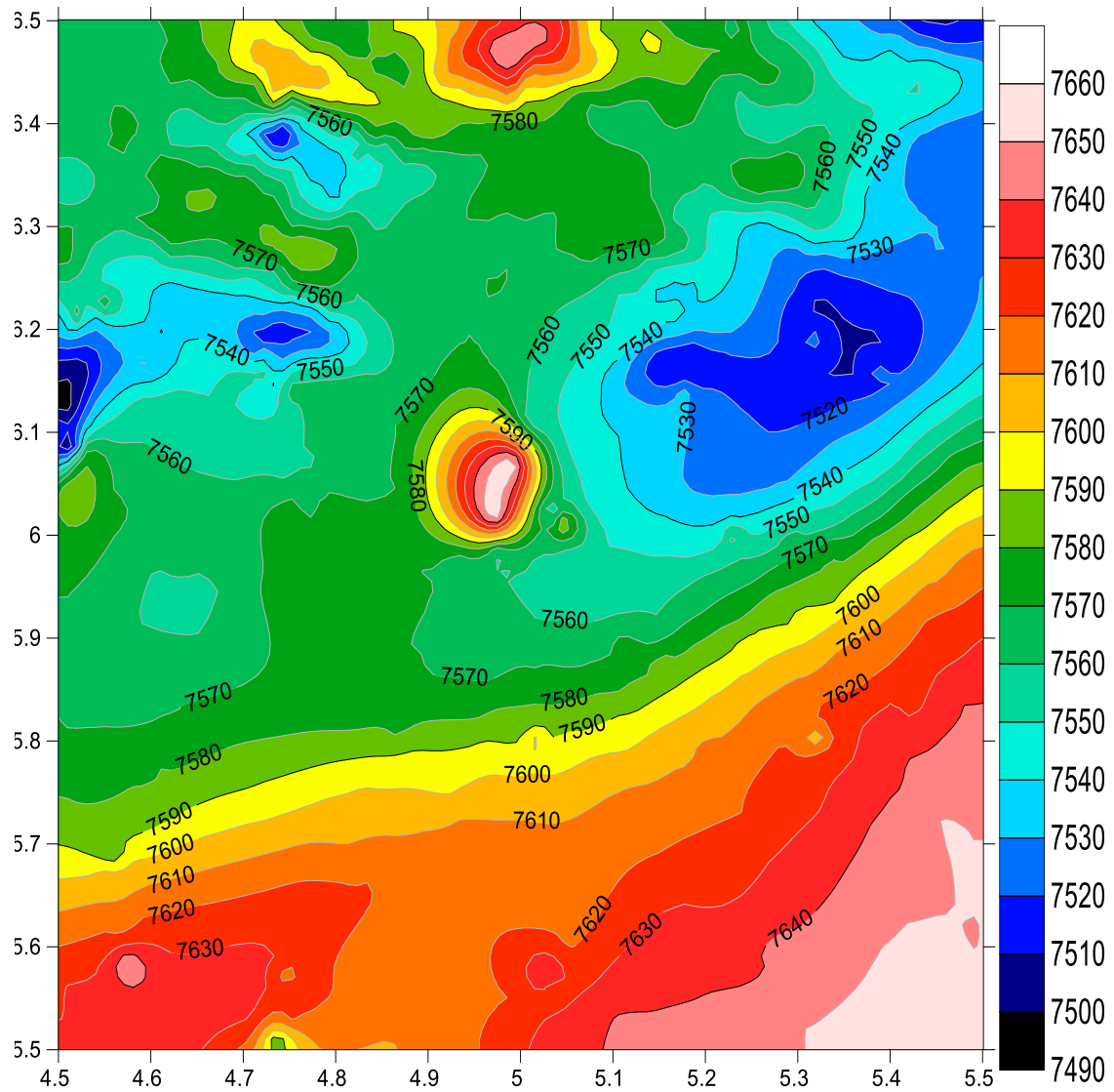


**Fig. 2: Total magnetic field intensity map of the study area**

Figure 2 is the total field aeromagnetic data of the study area as a contour map with the magnetic intensity values ranging

from 7490-7660 nT, while figures 3 is the 3-D surface map of the total magnetic field intensity of the surface area.

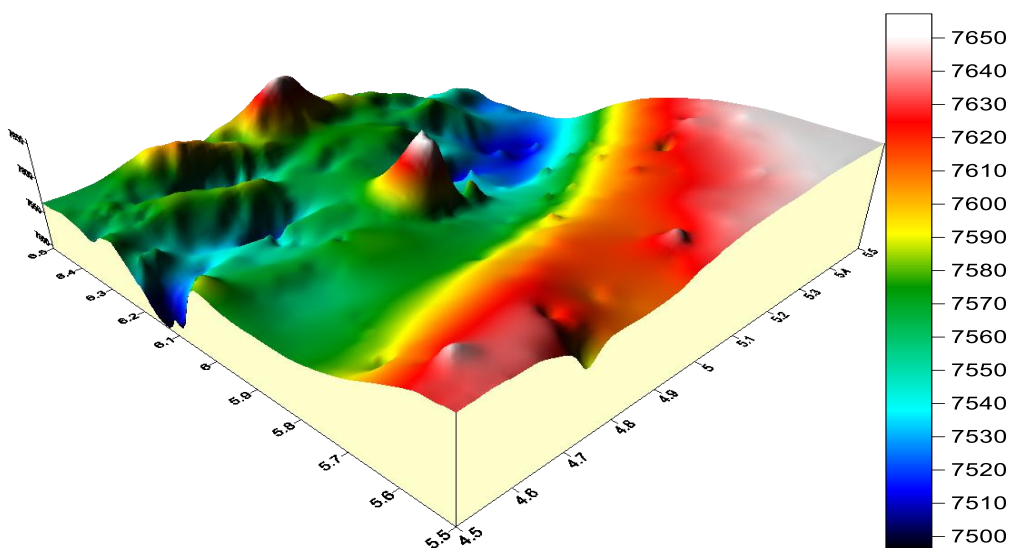


**Fig. 3: The 3-D surface map of the total magnetic field intensity of the study area**

The total field of the aeromagnetic data revealed that at the Western and Northwestern part of the map, the intensity ranges from 7550 gammas to 7590 gammas. Magnetic anomalies both short and long wavelengths were interpreted within the study area. These are represented by magnetic highs and lows. The drainage of the area is easily visible on the landsat TM image. The drainage pattern was digitized and draped on the lineament map (Figure 4) to check if the lineaments are of hydrographic origin. The drainage pattern is dendritic which is indicative of lithological, structural,

and topographic differences. It is also indicative of alluvial rocks, which is typical of the geology of the area that consists mainly of sedimentary rocks. The drainage texture of the area is variable (coarse to fine). It is characteristic of sedimentary rock and variable permeable soil material, such as the alluvium. The directions of flow of surface water are controlled by topography and geological structures. This flow direction no doubt influences the hydrographic network of groundwater in the area.

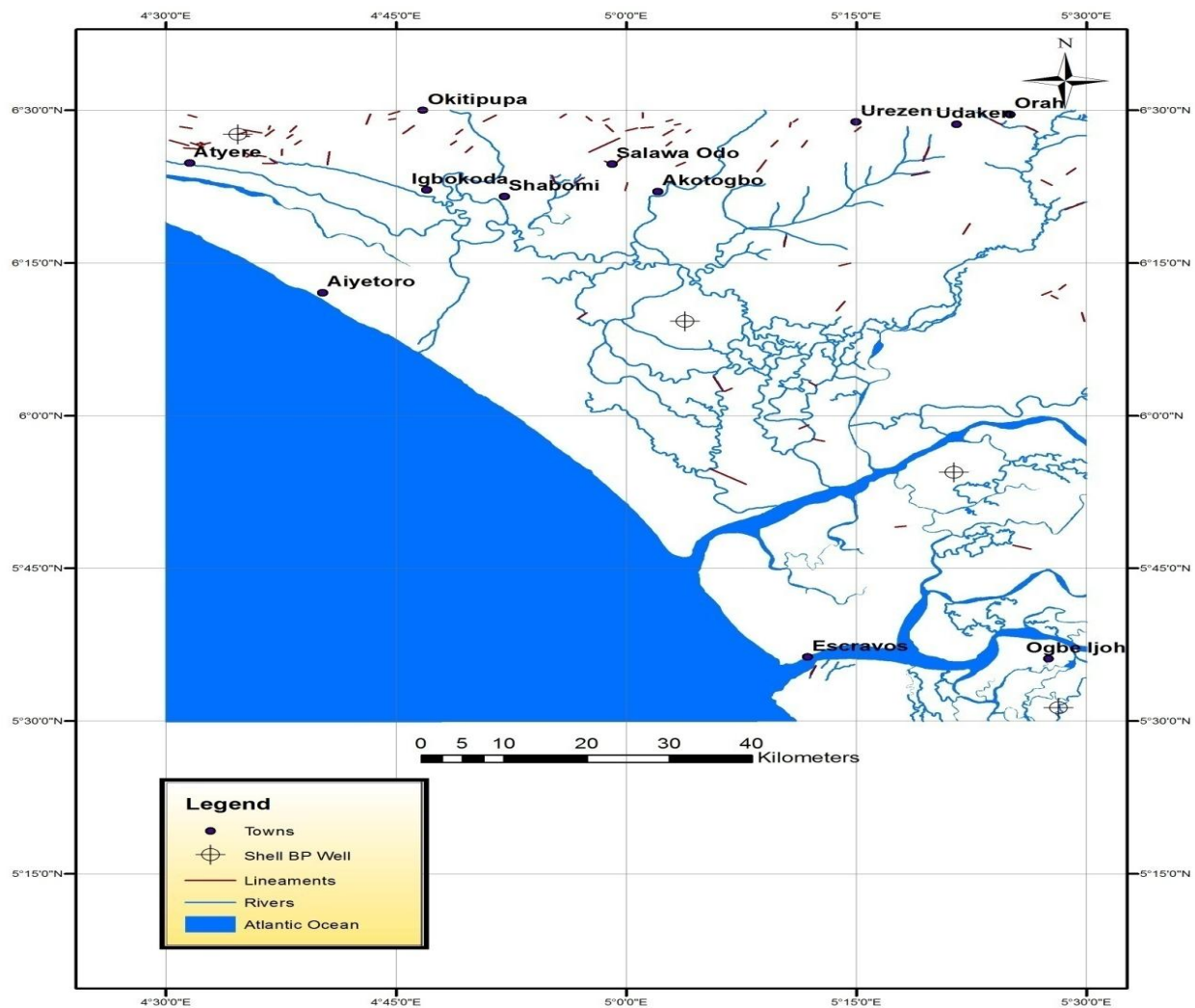


**Fig. 4: Lineament draped on the drainage map of the study area**

Digital image processing technique was carried out to highlight areas in the image (figure 5) where vegetation/green plants are more active. Two major classes of objects in the shades of gray in the landsat image are light tone and dark tone. The very light tone areas are areas where

vegetation occur and the light-dark tone areas represent rock outcrops/bare surfaces, and the blue areas represent water bodies. Also, the first to fourth degree regional and residual fields are presented in figures 6 and 7 respectively.

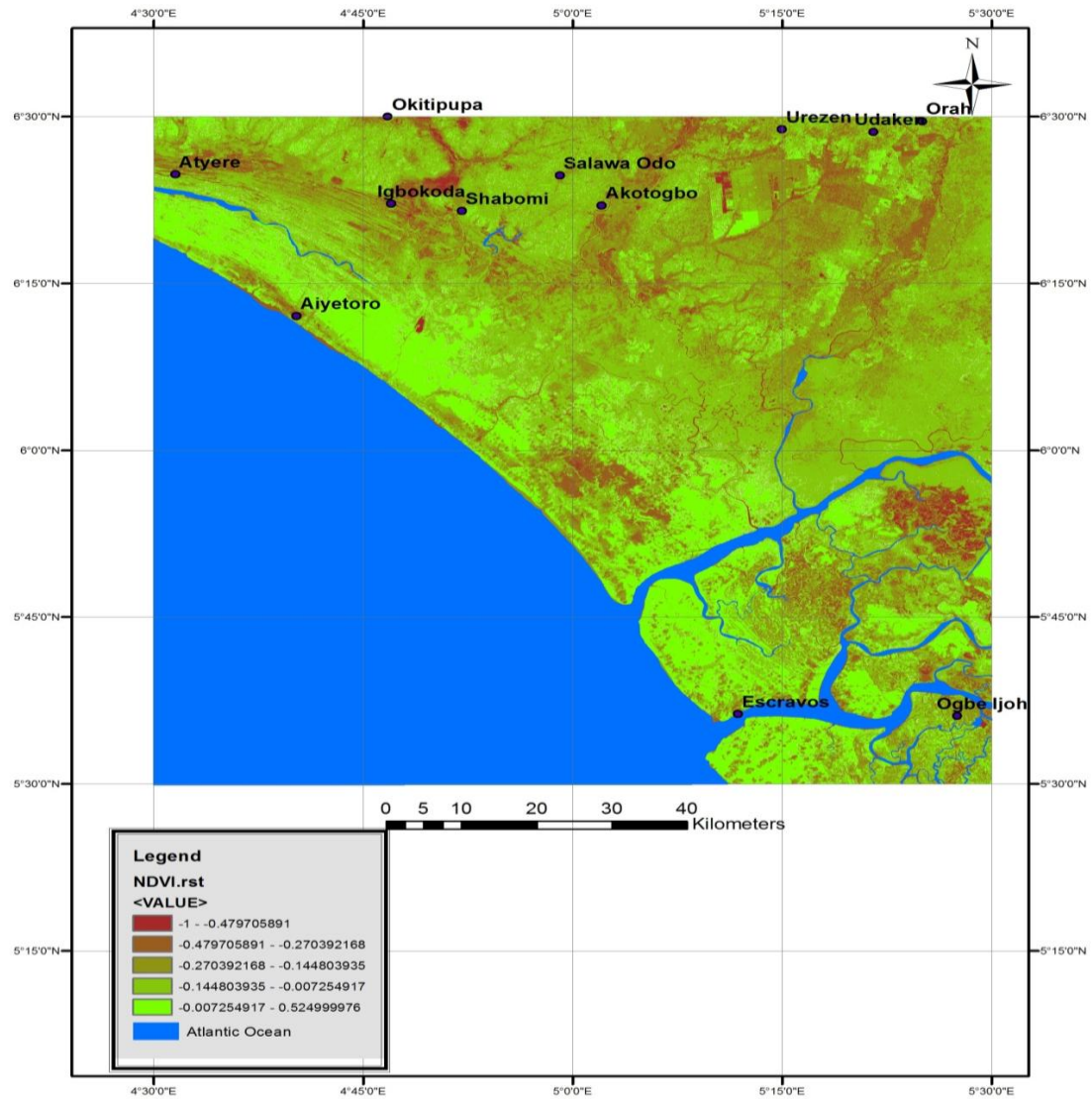
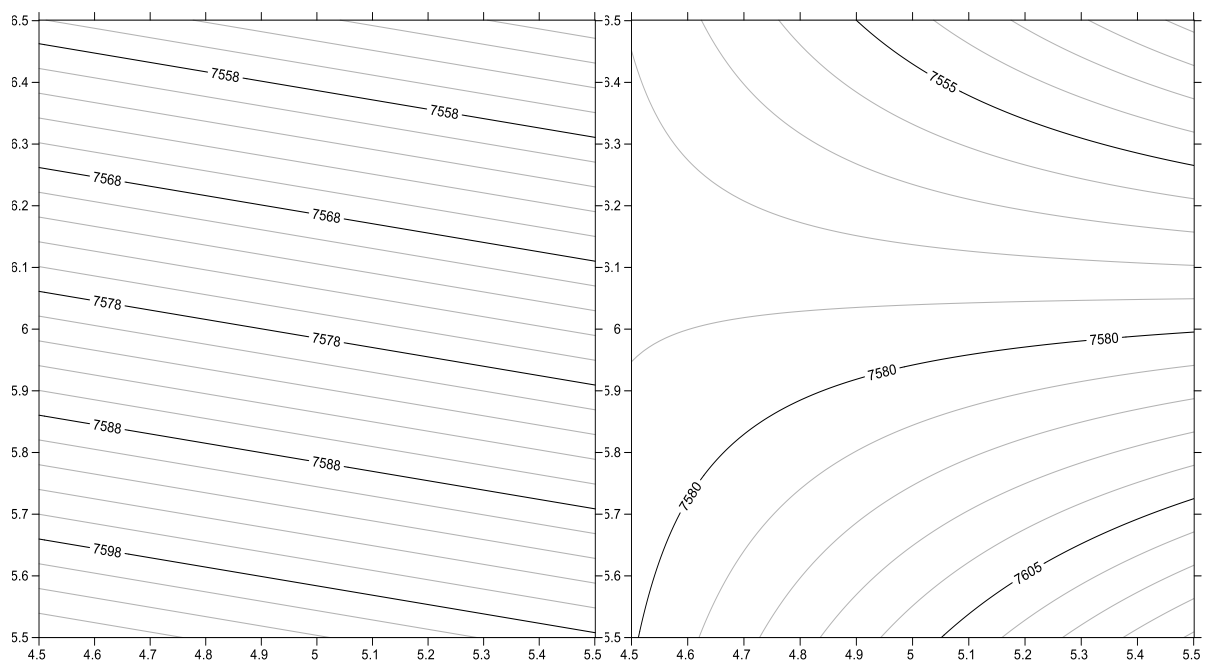


Fig. 5: Normalized Difference Vegetation Index (NDVI) map of the study area



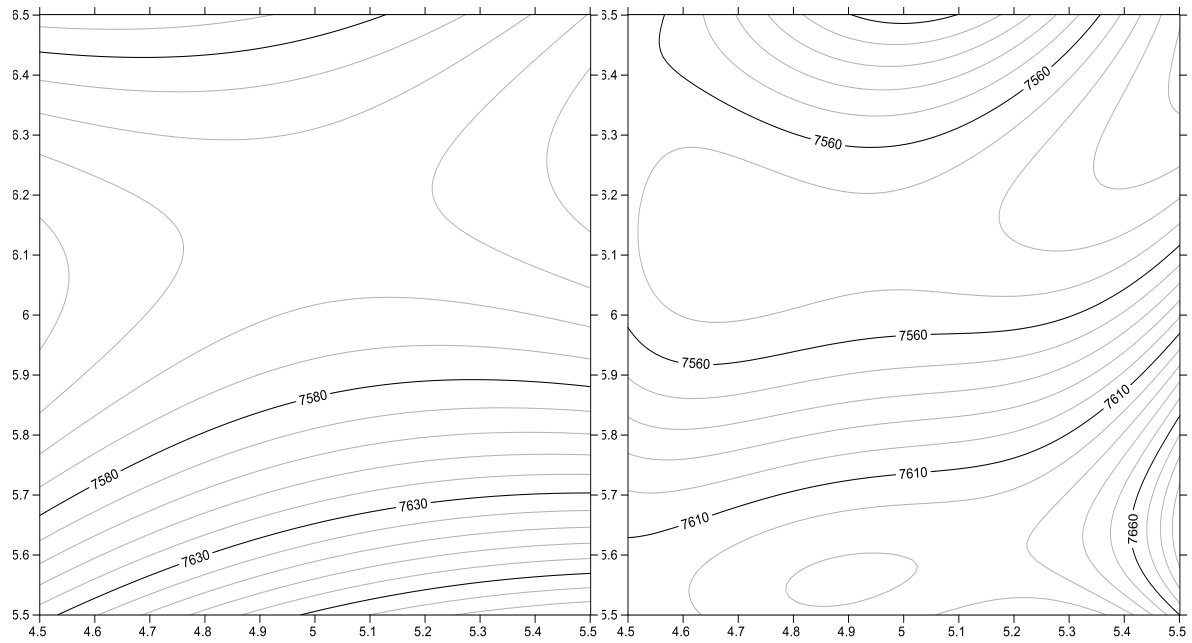


**Fig. 6: First to Fourth regional field map of the study area**

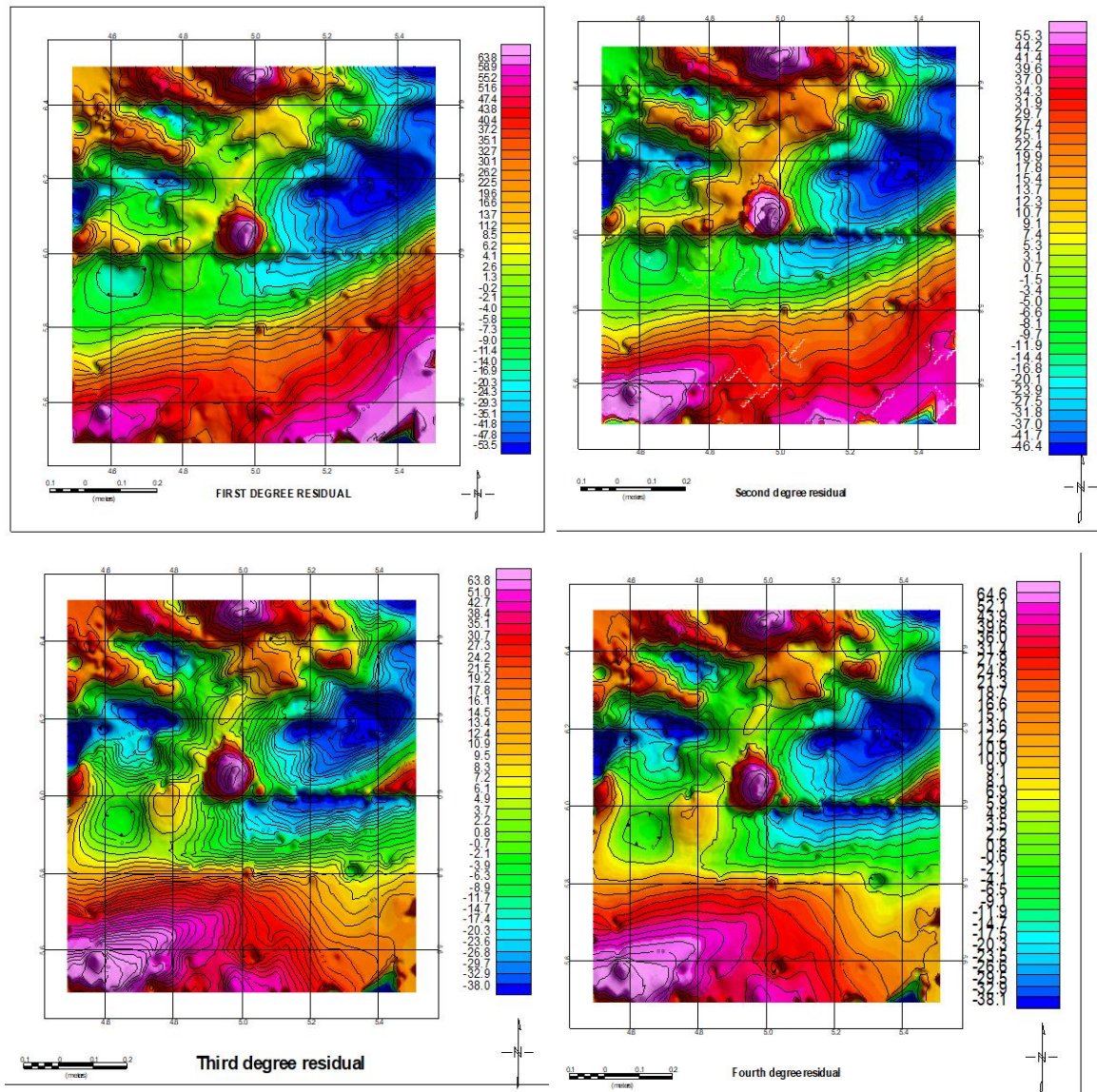


**Fig 7: First to Fourth residual map of the study area**

For the spectral determination of depths to layers of magnetization, the study area was divided into four (4) blocks. In doing this, adequate care was taken so that essential parts of each anomaly were not cut by the blocks. In order to achieve this, the blocks were made to overlap

each other. Graphs of the logarithms of the spectral energies against frequencies were obtained for various blocks and the estimated depths to magnetic basement are shown as D1 and D2 (Table 1).

**Table 1: The Spectral Computed (Depths in Km) Of the Study Area**

| SPECTRAL<br>BLOCK | LOCATION    | LONGITUDE      |                | LATITUDE       |                | DEPTH (KM) |      |
|-------------------|-------------|----------------|----------------|----------------|----------------|------------|------|
|                   |             | X <sub>1</sub> | X <sub>2</sub> | Y <sub>1</sub> | Y <sub>2</sub> | D1         | D2   |
| A                 | MAHIN       | 4.50           | 4.75           | 6.25           | 6.50           | 0.60       | 3.67 |
| B                 | MAHIN       | 4.75           | 5.00           | 6.25           | 6.50           | 0.39       | 3.46 |
| C                 | MAHIN       | 4.50           | 4.75           | 6.00           | 6.25           | 0.38       | 4.50 |
| D                 | MAHIN       | 4.75           | 5.00           | 6.00           | 6.25           | 0.20       | 3.10 |
| E                 | OKOMU       | 5.00           | 5.25           | 6.25           | 6.50           | 0.20       | 3.60 |
| F                 | OKOMU       | 5.25           | 5.50           | 6.25           | 6.50           | 0.32       | 4.10 |
| G                 | OKOMU       | 5.00           | 5.25           | 6.00           | 6.25           | 0.90       | 3.30 |
| H                 | OKOMU       | 5.25           | 5.50           | 6.00           | 6.25           | 0.35       | 4.30 |
| I                 | OMOLOMO     | 4.50           | 4.75           | 5.75           | 6.00           | 0.20       | 3.70 |
| J                 | OMOLOMO     | 4.75           | 5.00           | 5.75           | 6.00           | 0.10       | 3.20 |
| K                 | OMOLOMO     | 4.50           | 4.75           | 5.50           | 5.75           | 0.20       | 3.20 |
| L                 | OMOLOMO     | 4.75           | 5.00           | 5.50           | 5.75           | 0.10       | 3.12 |
| M                 | BENIN RIVER | 5.00           | 5.25           | 5.75           | 6.00           | 0.90       | 3.23 |
| N                 | BENIN RIVER | 5.25           | 5.50           | 5.75           | 6.00           | 0.10       | 3.10 |
| O                 | BENIN RIVER | 5.00           | 5.25           | 5.50           | 5.75           | 0.20       | 3.00 |
| P                 | BENIN RIVER | 5.25           | 5.50           | 5.50           | 5.75           | 0.80       | 2.95 |

The first layer depth (D1), which is the depth to the shallower source, varies from 0.10 km to 0.90 km, with an average of 0.37 km. The second layer depth (D2) varies from 2.95 km to 4.50 km, with an average of 3.47 km. This layer may be attributed to magnetic rocks of the basement, lateral variations in basement susceptibilities and intra-

basement features like faults and fractures. Depth to the shallow magnetic layer is attributed to magnetic rocks which intruded into the sedimentary formations. The basement depth (sedimentary thickness) contour map of the study area is shown in figure 8 below.

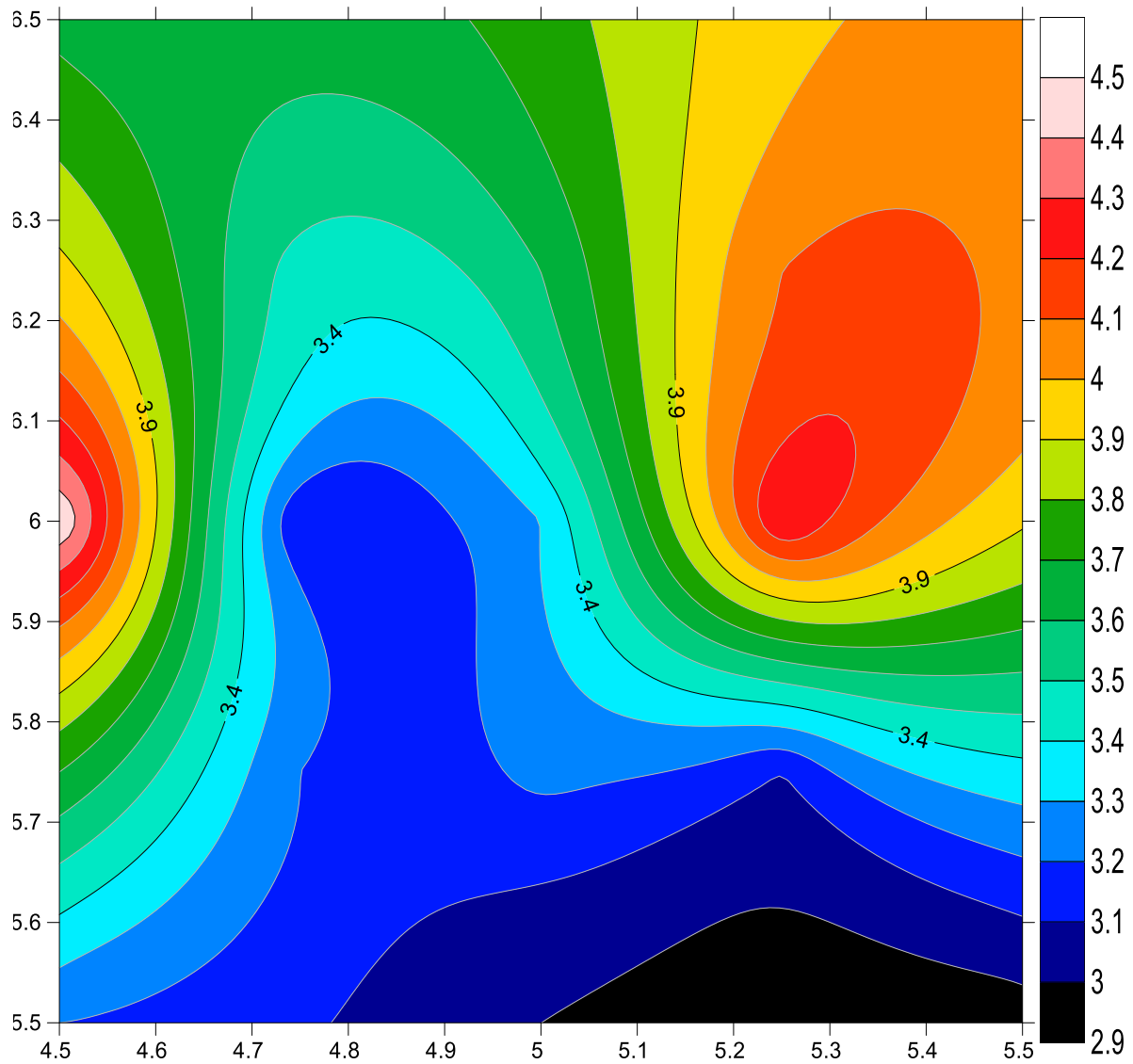


**Fig. 8: Contour map of the depth to magnetic basement estimated from spectral analysis**

The DEM of the Study area is shown in figure 9 below. The highest peaks represented by the pink colour are seen as small patches following a topographically high feature. This feature is interpreted as sandstone ridge, with its slope identified where yellow, orange and brown colours are closely packed together; representing a sudden change in topography. The green parts in the northern part of the map stretching in the NW-SE direction are interpreted as the

mangrove swamps and it's also suspected to be part of the Benin formation. The blue part of the map represents alluvium and the abandoned beach ridges around Escravos. The southwestern area of the map, represented in the map with white is dominated by the Atlantic Ocean and Gulf of Guinea. The area is characterized by numerous streams, gullies and rivers.

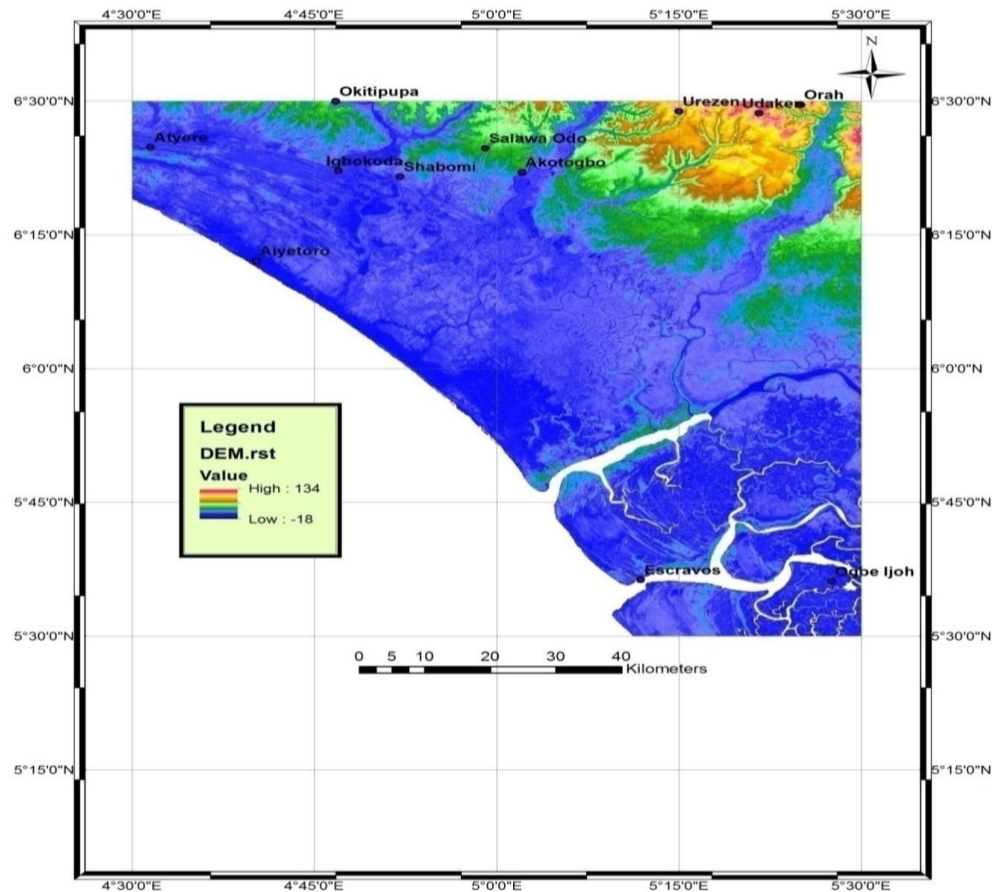


**Fig 9: Digital elevation model (DEM) map of the study area**

It will be correct to interpret the topographic high areas as characterized by sandstone and the low areas as characterized by shale and mud rock. This is justified by the dendritic drainage pattern expressed in the low lying area, which points to an underlying clayey lithology.

## V. CONCLUSION

Since the objective of this study is to identify structures expressed as lineaments, it was necessary to process the aeromagnetic and Landsat-TM data in a manner that would both enhance trends and facilitate the computation of locations and depths to magnetic sources. Drainage pattern, termination of potential field (gravity or magnetic) map anomalies on a linear trend, termination of drainage line on linear trends and straight stream segments were the basic hypothetical models used to map fractures. Ajayi, *et al.*, (1991) believes that lineaments can also be revealed on aeromagnetic maps by breaks in anomaly trends (lengthwise) and prominently narrow magnetic lows (broadwise) and sharp gradients of anomaly. The aeromagnetic analysis and interpretation as well as digitally processed satellite remotely sensed data have revealed that the prominent structural patterns in the study area are trending in the NE-SW and E-W directions respectively. It can be deduced that the D2 values obtained from spectral plots represent the average depths to the basement complex

in the blocks considered. Magnetic basement is an assemblage of rocks that underlines sedimentary basins and may also outcrop in places. Onyedim *et al.*, (2006) believes that if the magnetic units in the basement occur at the basement surface, then depth determinations for these will map the basin floor morphology and its structure appropriately. Result of the lineament analysis of the Landsat Imagery revealed a number of lineaments and mega lineaments trending in the NE-SW, NW-SE, E-W and N-S directions. Surface trend analysis of the tectonic and structural features of the area shows that the area has a rugged topography and it is partly deformed by tectonic activities. The present study is therefore in agreement with previous studies which suggested that Nigeria has a complex network of fractures and lineaments with dominant trends of NE-SW, NW-SE, N-S and E-W directions. These linear structures running NE-SW observed from the study are suggested as the continental extension of the known pre-Cretaceous oceanic fracture zones viz. Charcot and Chain fracture zones which run along the trough axis beneath the sedimentary cover (Ananaba, 1991). Furthermore, it is geologically plausible that the landward intersections of the transform fracture zones may have influenced the formation of the river patterns and basin formation. Therefore, the structural and tectonic facts put in were in accordance with those of previous workers. Also, the correlation of these

lineaments with mineralization in the area has been ascertained by previous authors [Ananaba *et al.*, 1987; Onyedim, 1996, Udoh, 1988.] In conclusion, this study has shown beyond doubt that both landsat TM and aeromagnetism has a lot of research potential for geologic application.

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