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Ground Based Gravimetric for the Detection and Depth Mapping of Subsurface Geological Features of Ilesha, Southwest Nigeria

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Abstract
This paper presents the analysis and interpretation of ground gravity data of Ilesha and its environs in southwest Nigeria. The work is aimed at complementing researches done in this locality with magnetic survey for both ground and airborne data. The ground gravity data of the area within latitude (7°30' - 8°00') N and longitude (4°30' - 5°00') E was acquired from the Nigerian Geological Survey Agency (NGSA). The data set was interpreted qualitatively and quantitatively to derive information about the structural features of the subsurface. The qualitative analysis was carried out by filtering techniques and interpreted by making visual inspection of grids to map low and high-density regions. Equally, the quantitative interpretation employed were Euler 3-D deconvolution and Source Parameter Imaging (SPI) methods, which revealed the boundary, location and depth of gravity sources defining the study area. The minimum and maximum depths of anomalous sources obtained are 781.43 m and 4,208.85 m, while the average depth to the target is 2,537.215 m. The average depth of gravity anomalous sources estimated predicted the area to hold a worthy prospect for the accumulation of near surface rock minerals.

Keywords: Density, Filtering, Gravity, Qualitative, Quantitative.

1. Introduction
Gravity survey is one of the various geophysical surveys that relies on the variations of densities of bodies within the subsurface of interest (Telford et al., 1976). Gravity method is a non-destructive geophysical method that is responsive to density contrast in the natural field of interest (Kevin, 1997; Nicolas, 2009; Barnes et al., 2011).

Geophysical surveying offers a rapid way of information (data) gathering about the subsurface geology of an area (Keary and Brooks, 1984). The application of geophysics is largely dependent on the needs of the society such as environmental protection and exploration of mineral resources (Chemin et al., 2006). In the broad categorization, gravity and magnetic survey methods are potential field measurements as well as passive methods, because they detect variations using the natural fields associated with the Earth. However, the basic difference between them is that; gravity is an inherent property of mass while the inducing fields and the orientation of magnetic domains determines the magnetic state of matter (Telford et al., 1976; Blakeley, 1995; Mendonca and Silva, 1995; Adegoke and Layade, 2019).

This study was aimed at evaluating the depth of gravity anomalous sources of Ilesha and its environs. In achieving this aim, the ground gravity data was processed and the residual anomaly interpreted both qualitatively and quantitatively. This is to visualize the geological object of interest within the subsurface in order to make reliable inferences through interpretations (Pajot et al., 2008; Hammer, 1939; Reeves, 2005).

There are depth estimation methods that can be employed to reveal near surface distribution of subsurface varying parameters within a study area. These include; 3-D analytic signal (Roest et al., 1992), Werner deconvolution (Hartman et al., 1971) and multiple source Werner deconvolution (Hansen and Simmonds, 1993). In this study, 3-D Euler deconvolution method as described by Reid et al. (1990) and Source Parameters Imaging (SPI) method were used to show the burial depth and locations of geologic sources (Whitehead and Musselman, 2005) defining Ilesha and its environs.

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Aeromagnetic and ground magnetic techniques have previously been employed to yield the depth of sources in the area. Ozebo et al. (2014, 2017) interpreted the high-resolution aeromagnetic data of Ilesha using different depth techniques. Local Wave Number (LWN) having a depth range of 0.478 – 1.51 km and Analytical Signal Method (ASM) has 0.348 – 1.28 km; while Peter's half slope method yielded the depth range of 2.40 – 10.8 km for thin body, 1.8 – 7.93 km for the intermediate thickness and 1.41 – 6.35 km for a very thick body, respectively. The depth to basement of magnetic sources in Ilesha and its environs was calculated using Euler deconvolution technique as 0.5 – 1 km (Olurin, 2017). Furthermore, Kayode et al. (2013) delineated the different rock units of Ilesha area using the ground magnetic survey data.

2. Description and Geology of the Study Area

This study was carried out in Ilesha and its environs in Osun state, southwestern Nigeria. The region covers an area of about 3,025 square kilometers and corresponds to sheet number 243 on the Nigeria Geological Survey Agency (NGSA) sheet index map (Figure 2).

Ilesha and its environs is bounded in the south, north, east and west by Ondo, Kwara, Ekiti and Oyo states respectively. The study location is within latitude 7°30' - 8°00' N and longitude 4°30' - 5°00' E and also belongs to the southwestern Nigeria basement complex (Obaje, 2009) within the Dahomey Basin. Dahomey basin extends from the west of southeast Ghana to the Western wing of the Niger Delta part of Nigeria. The crystalline Basement complex of Precambrian to Cambrian age and sedimentary rocks that are cretaceous to recent in age (Abraham et al., 2014) are the rock groups underlying this study location as shown in Figure 1.

The geomorphological division of Ilesha and its environs are two major segments of fractured zones, namely: the Ifewara faults in the western parts and the Iwaraja faults in the eastern region (Rahaman, 1976; Elueze, 1988).

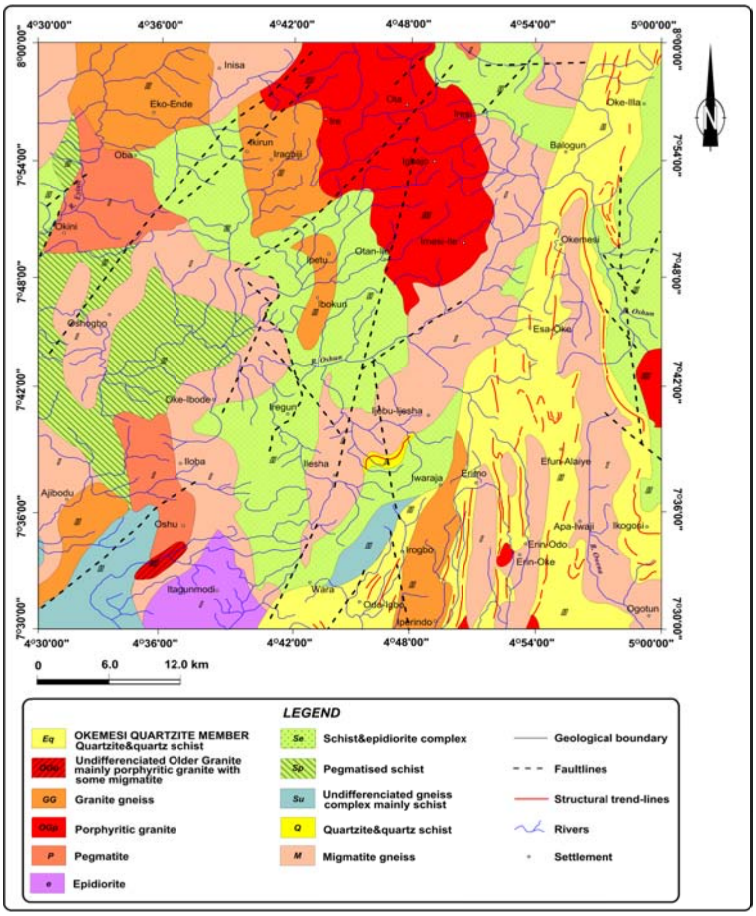

Figure 1. Geological Map of the study area (NGSA, 2009).

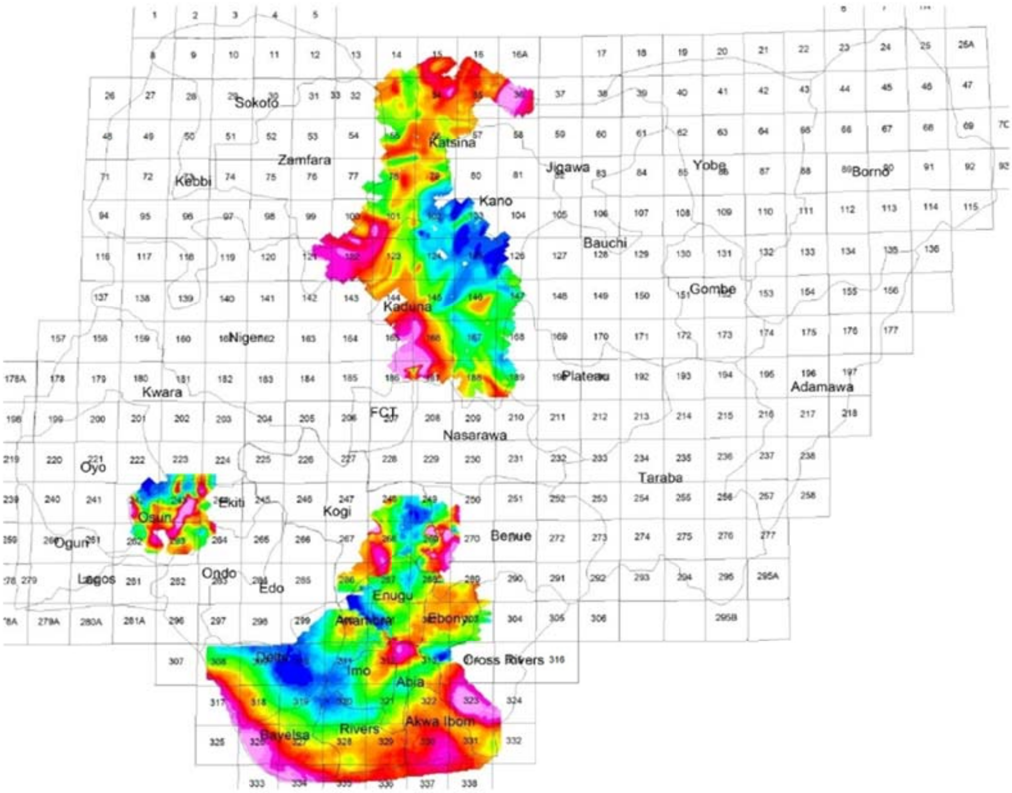

Figure 2. Nigerian Gravity Survey Coverage (NGSA, 2009).

3. Data Sources and Acquisition

The data of Ilesha and its environs used in this research was obtained from NGSA. The gravity data was acquired using Lacoste and Romberg gravimeter, and American Pauline system altimeters. The method of data acquisition used is the close loop method with spacing interval of 200 m tied to the International Gravity Standardization Net of 1971 (IGSN 71).

4. Materials and Method

4-1. Data Processing Techniques

The geophysical mapping tools were used for the processing, analysis and interpretation of data. The dataset was re-projected from World Gravity Station of 1984 (WGS 84) and Universal Transverse Mercator of zone 32 Northing (UTM 32N) to WGS 84 of UTM zone 31 Northing (UTM 31N), this is in order to remove near surface noises associated with the shallower anomaly features (Cyril, 2019).

The dataset is gridded after re-projection using the minimum curvature algorithm as described by Briggs (1974) to produce the Bouguer gravity field (Figure 3) representing the total area under study. Figure 3 (Bouguer gravity anomaly) was then further separated into the regional (Figure 4) and residual (Figure 5) anomaly grids through first order polynomial of data (Ngozi et al., 2019; Houghton et al., 2007; Reynolds, 1997; Dobrin, 1976; Johnson, 1969) to remove the noise from the gravity field.

The residual anomaly grid (Figure 5), which is the high frequency anomalies was subsequently filtered to yield the grid derivatives. First Vertical Derivative (FVD) (Figure 6), Second Vertical Derivative (SVD) (Figure 7), First Horizontal Derivative (FHD) (Figure 8), Second Horizontal Derivative (SHD) (Figure 9) and Analytic Signal (Figure 10), were produced using the one-dimensional fast Fourier transform (FFT1D) algorithm (an extension of Oasis Montaj) in order to attenuate low frequencies anomalies associated with regional effects (Hesham and Hesham, 2016).

The quantitative approaches used in this study are the Source Parameters Imaging (SPI) and 3-D Euler Deconvolution methods to reveal the locations and depths to regolith of gravity anomalous sources present in the area.

Thurston and Smith (1997) developed the SPI, otherwise known as the Local Wave Number (LWN) method represented by Equation (1). Potential field source depths evaluation by this technique is profile or grid-based and it uses the first and the second order derivatives in its computation and thus can be susceptible to both interference effects and noise in the data (Nwosu, 2014).

The first and second-order local wave numbers are used to determine the most appropriate model and a depth estimate independent of any assumptions about a model (Salako, 2014). The basis for the standard 3-D Euler Deconvolution method is the Euler's homogeneity equation (Equation 2) that connects potential field and its gradient components to source location with the degree of homogeneity 'η' which may be interpreted as a Structural Index (SI) (Thompson, 1982). The SI is taken to be an exponential factor representing the rate at which the potential field falls off with distance, for a source of a given geometry. The coordinates of the measuring point are x, y, and z; x_0, y_0, and z_0 are the coordinates of the source location whose total field is detected at x, y, and z; b is a base level; and η is structural index (SI). All the structural indexes were tried on the data while the plot solutions for SI = 0, is presented as Figure 12 (Euler Solution Map of Ilesha).

The source parameter imaging otherwise known as local wavenumber (k) given by:

$$K(x,y) = \sqrt{\left(\frac{\partial\theta}{\partial x}\right)^2 + \left(\frac{\partial\theta}{\partial y}\right)^2}$$

$$\text{and } \theta = \frac{\frac{\partial T}{\partial z}}{\sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}} \tag{1}$$

where θ is the local phase of the total field (Thurston and Smith,1997).

While the Standard 3D form of Euler's equation (Reid et al., 1990) is defined as;

$$x\frac{\partial T}{\partial x} + y\frac{\partial T}{\partial y} + z\frac{\partial T}{\partial z} + \eta T = x_0\frac{\partial T}{\partial x} + y_0\frac{\partial T}{\partial y} + z_0\frac{\partial T}{\partial z} + \eta b \tag{2}$$

5. Results and Discussion

The Bouguer anomaly map of Ilesha and its environs in Figure 3 reveals a gravimetric range of -10.03 to 15.61 mGal, which may be as a result of lithological variations in the basement. The map (Figure 3) with a very high gravity values range of 8.47 to 15.61 mGal around the southern and central portions of the study area predicts the presence of near surface interfering mineral rocks and also suggest that there are high density bodies beneath the measurement point. The low density contrast range of -10.03 to –3.35 observed at the top northwestern and faintly trending from northern region through northwestern region reveal that longer wavelengths anomalies are characterizing the area and possibly predict the presence of fault, void, contact, fracture and/or crack. There was an absence of contour gradients (on all maps produced) around latitude (7°35' - 7°38') N and longitude (4°57'30" - 4°57'30") E as well as latitude (7°46' - 7°50') N and longitude (4°57'30" - 4°57'30") E that correspond to Ikogosi (large waters area) and Okeemesi (hilly and rugged terrain), respectively. This may be due to the inaccessibility of these areas since the survey is ground-based.

Anomalies' separation by polynomial fitting birthed the regional (Figure 4) and residual (Figure 5) anomaly fields. The regional anomaly map (Figure 4) is the long wavelength anomalies of deeply seated sources with density contrast range of -5.82 to 7.66 mGal, and it is herein treated as the noise. Figure 5 is the residual anomaly map with gravity values ranging from -8.00 to 10.82 mGal and of three distinct features of gravity highs (pink colored areas), gravity lows (blue colored areas) and intermediate values (green, yellow and red colored areas). The gravity highs, dominating the southern and central parts of the study area reveal the presence of near surface metamorphic rock minerals, which are likely to be pegmatite, epidiorite and schist and quartzite and quartz complexes when compared with the geological map of Ilesha and its environs (Figure 1). The gravity lows observed at the northern, eastern and faintly around the southwestern portions represent certain geological signatures (Parasnis, 1986; Fieberg, 2002), which can be fracture or contact between two rock formations.

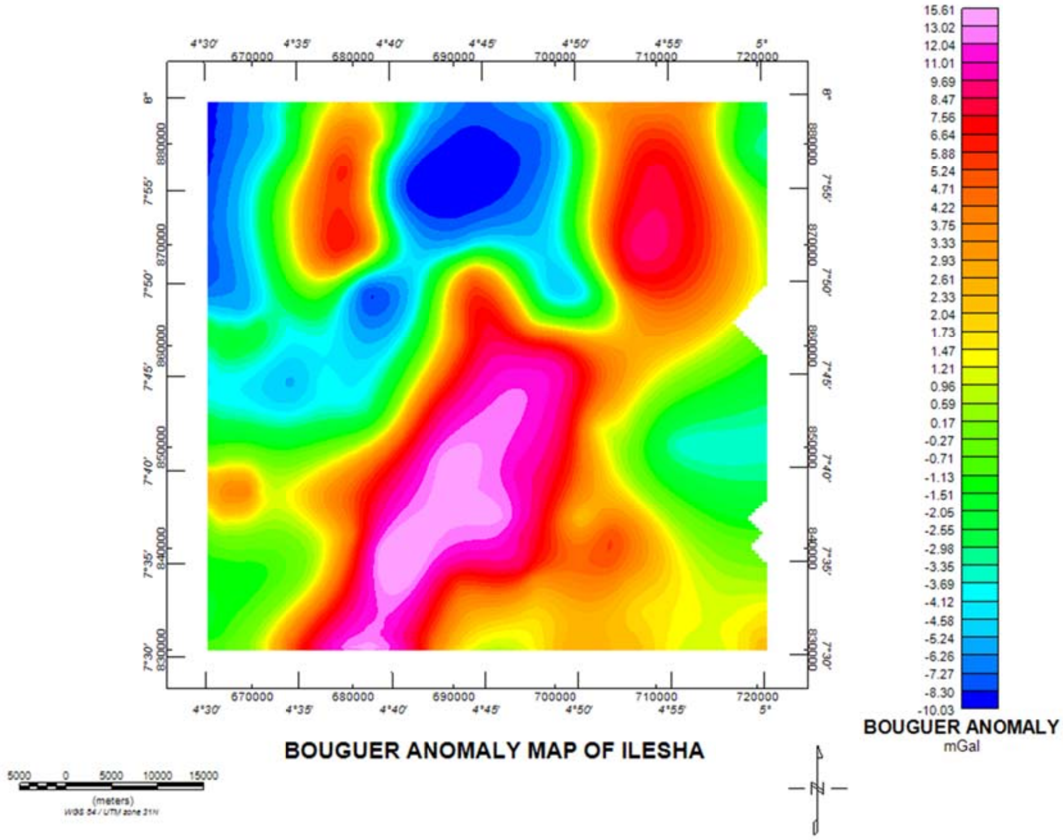

Figure 3. Bouguer gravity field.

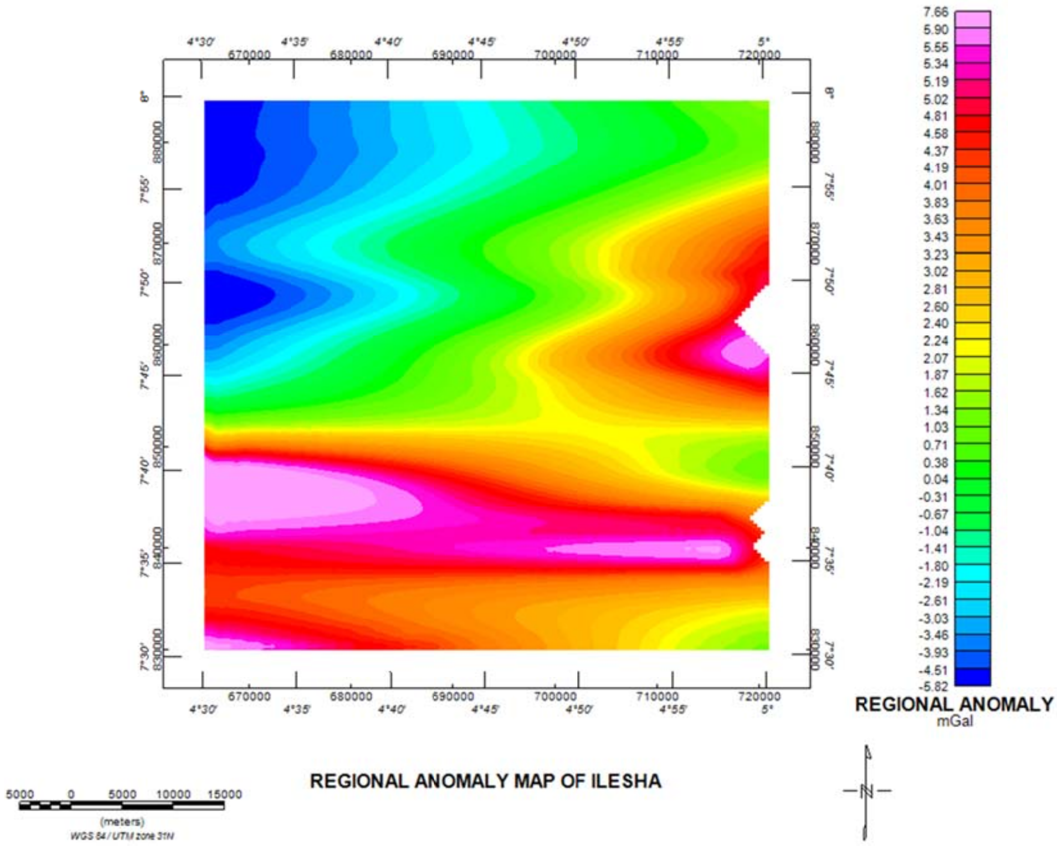

Figure 4. Regional anomaly field.

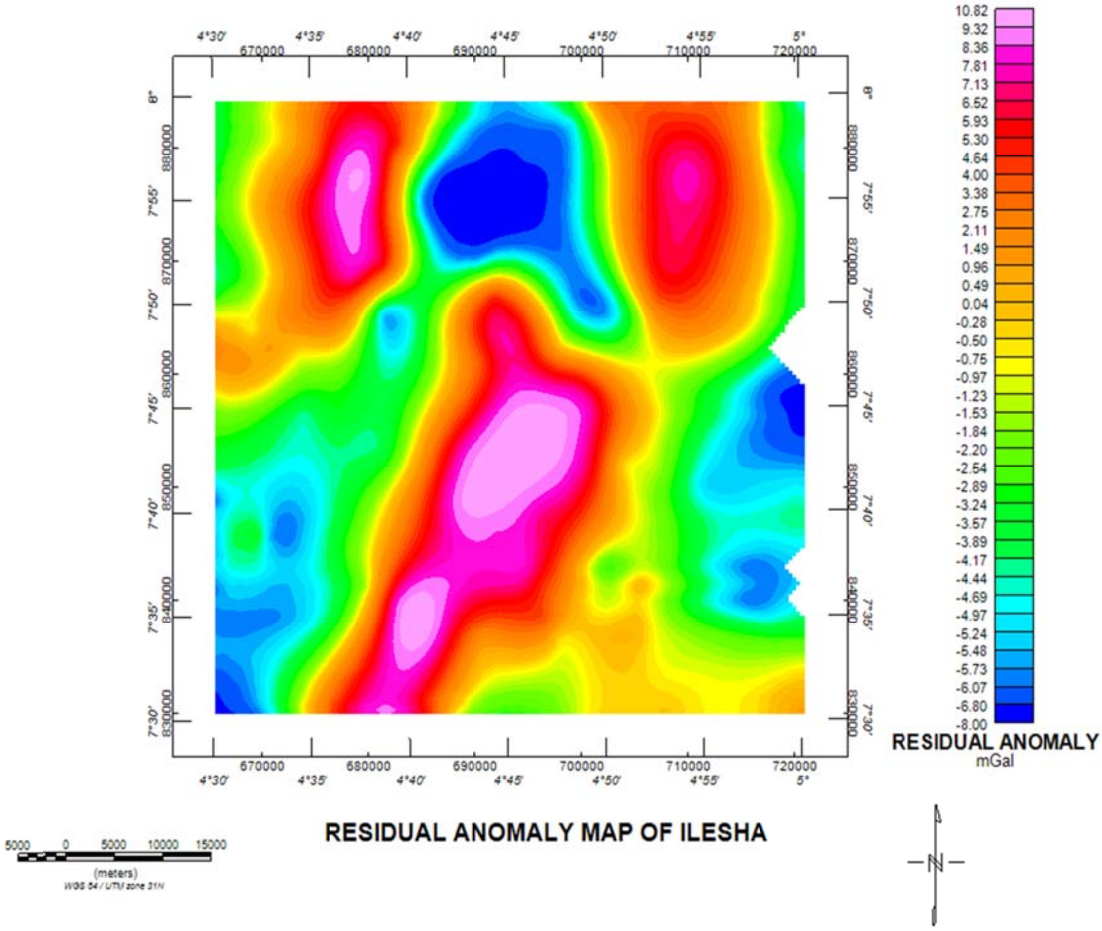

Figure 5. Residual anomaly field.

In further enhancement of the residual anomaly map (Figure 5) that produced the derivative maps (Figures 6 to 9) and the analytic signal map (Figure 10) we accentuate shallow geologic sources obscured by broader regional trends. Figures 6 and 8 represent both the First Vertical Derivative (FVD) and the First Horizontal Derivative (FHD) maps with their high gravity signatures commanding the southern, northwestern and northeastern zones of the area. FVD and FHD have gravimetric range of -0.00267 mGal/m to 0.00333 mGal/m and -0.00343 mGal/m to 0.00321 mGal/m, respectively. The Second Vertical Derivative (SVD) and the Second Horizontal Derivative (SHD) maps are presented as Figures 7 and 9, respectively, and are produced from further differentiation of the FVD and FHD. SVD (Figure 7) and SHD (Figure 9) have lateral orientation of high gravity responses trending N-S. The SVD is ranged -0.000002091 mGal/m^2 to 0.000001815 mGal/m^2 while the SHD is ranged -0.0000018 mGal/m^2 to 0.0000021 mGal/m^2. Fairly yellowish and pinkish colored areas with gravimetric values of 0.0000000 mGal/m^2 (no values) observed on the legend of the SHD (Figure 9) correspond to areas where there are no gravity responses and possibly depicts that the areas contain no or less denser bodies.

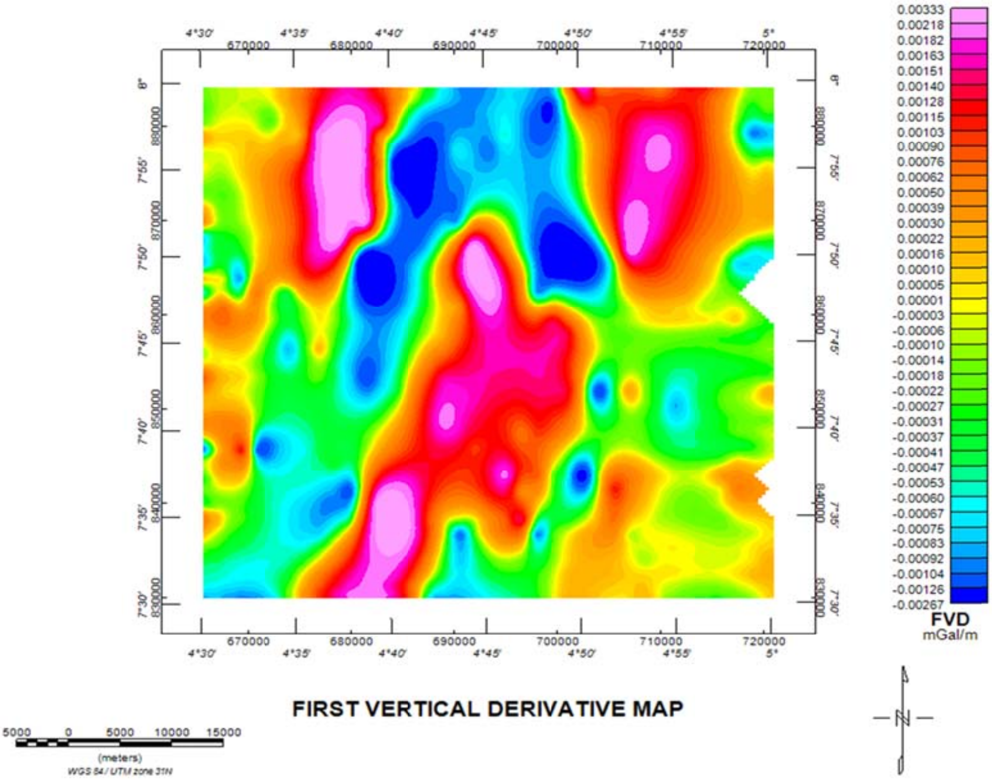

Figure 6. Vertical derivative map of the first order showing gravity sources.

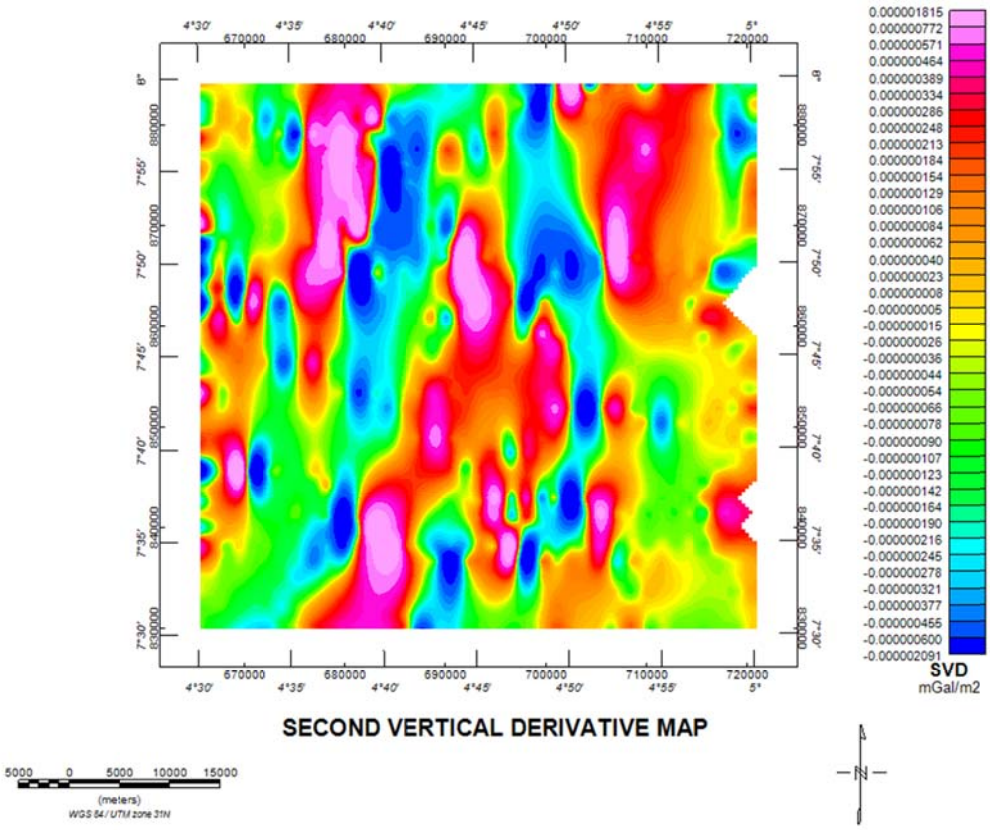

Figure 7. The second vertical derivative map.

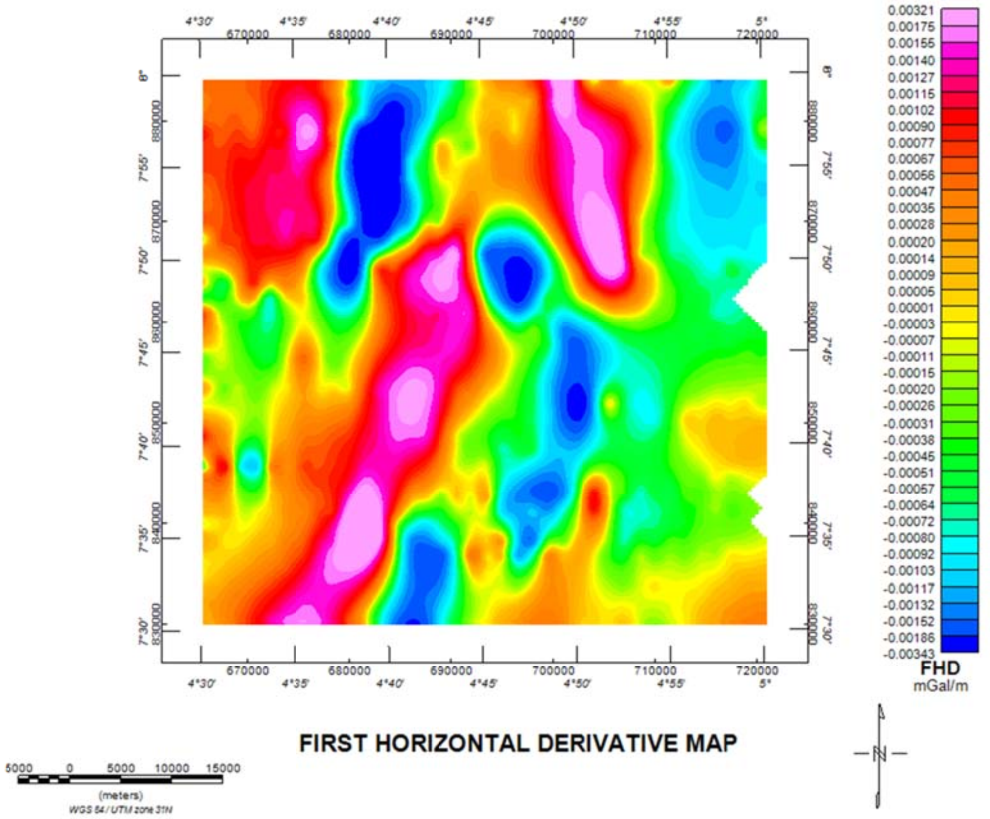

Figure 8. The first horizontal derivative map.

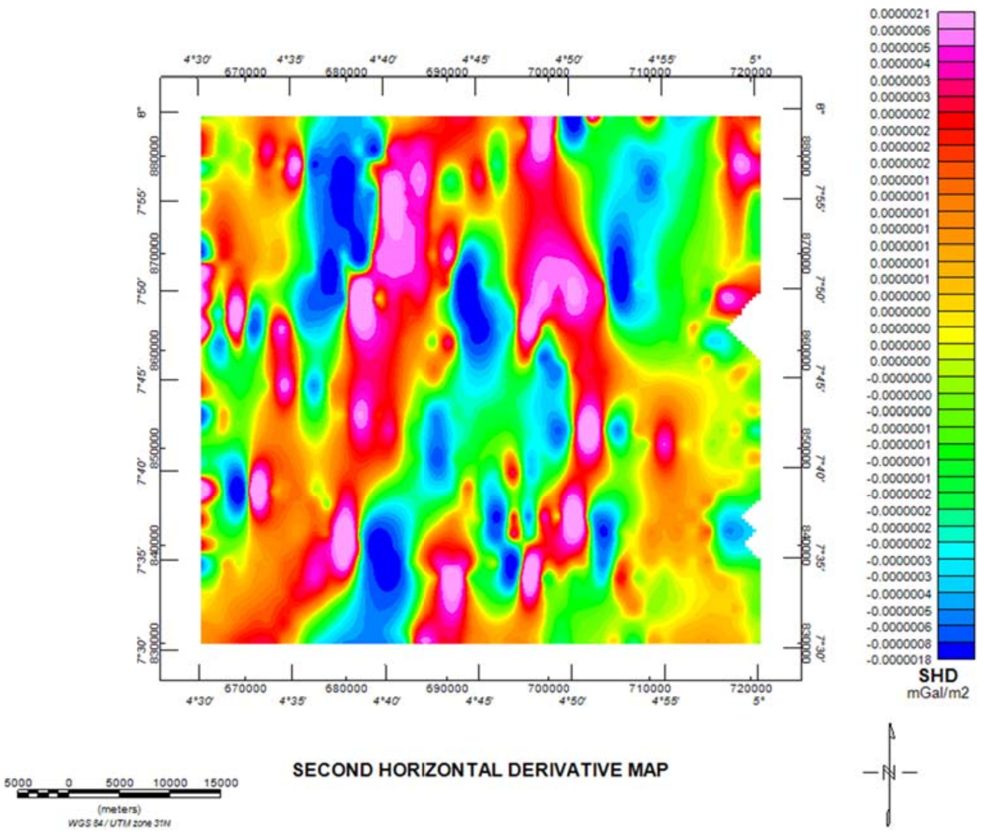

Figure 9. Horizontal derivative map of the second order.

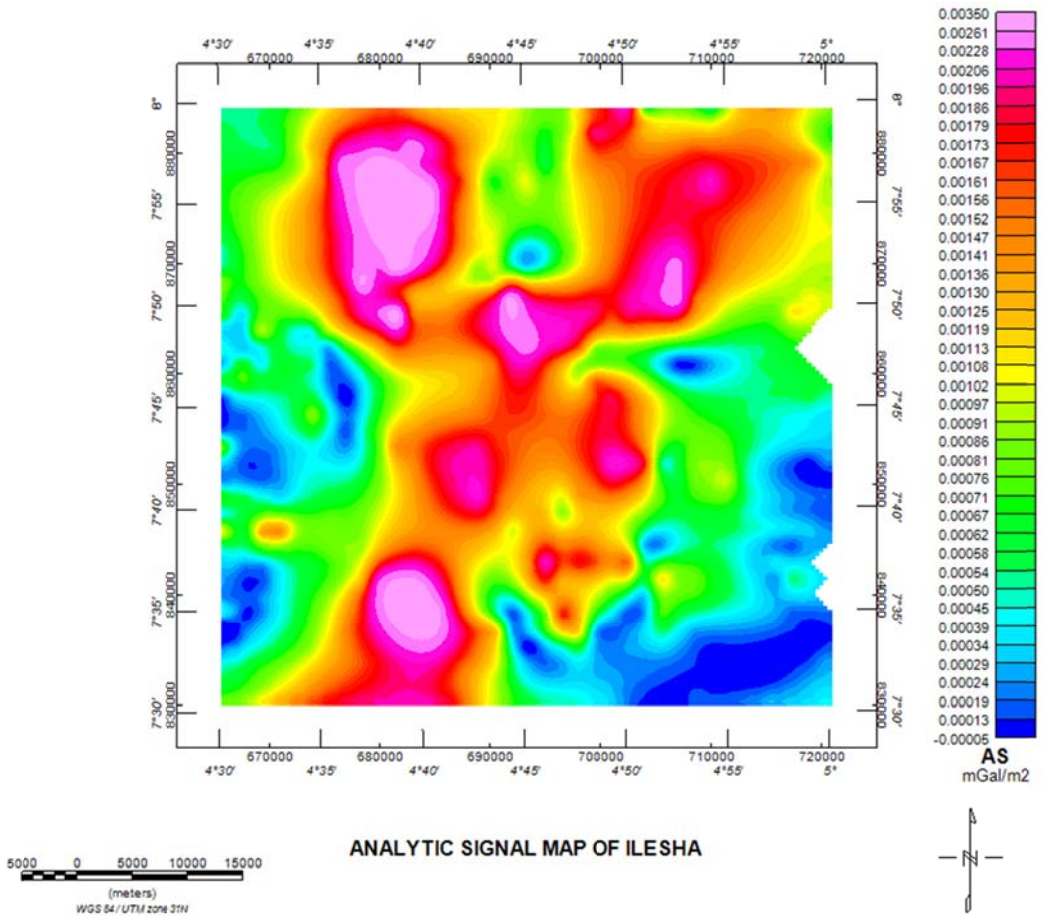

Figure 10. Analytic signal map of Ilesha and its environs.

The gravimetric amplitude range of the Analytic Signal (AS) map as presented in the legend of Figure 10 is -0.00005 mGal/m^2 to 0.00350 mGal/m^2. The amplitude of the gravity values are believed to be proportional to the density concentration of an area. The areas are mostly dominated by the spread of positive anomalies (pink, green and yellow areas), which indicate the presence of materials in varying densities. The AS map (Figure 10) shows the boundary and location of geologic sources more clearly. Areas of pronounced gravity lows are possible indicators of major faults in the study location while places characterized by steep and loose gradients are likely to be outcrops and deeply seated anomalies' zones, respectively.

Generally, the different filters of FVD, SVD, FHD, SHD and AS show a common trend of high values of gravity responses concentration from the southern region, spreading out through to the central and northern regions. By geological implications, these trends are possible entrapments for commercial mining of metamorphic rock minerals.

The Source Parameter Imaging (SPI) method result is presented in Figure 11, with its minimum depth ranged 854.39 m to 1,444.49 m and averaged at 1,149.44 m while its maximum depth range is 4,872.51 m to 6,241.60 m and average maximum depth of 5,557.06 m. The total average depth of the study area is 3,547.995 m and can be considered as the target depth of gravity sources in the study area. The result obtained from the SPI fairly agrees with the previous research of Ozebo et al. (2017) with aeromagnetic data.

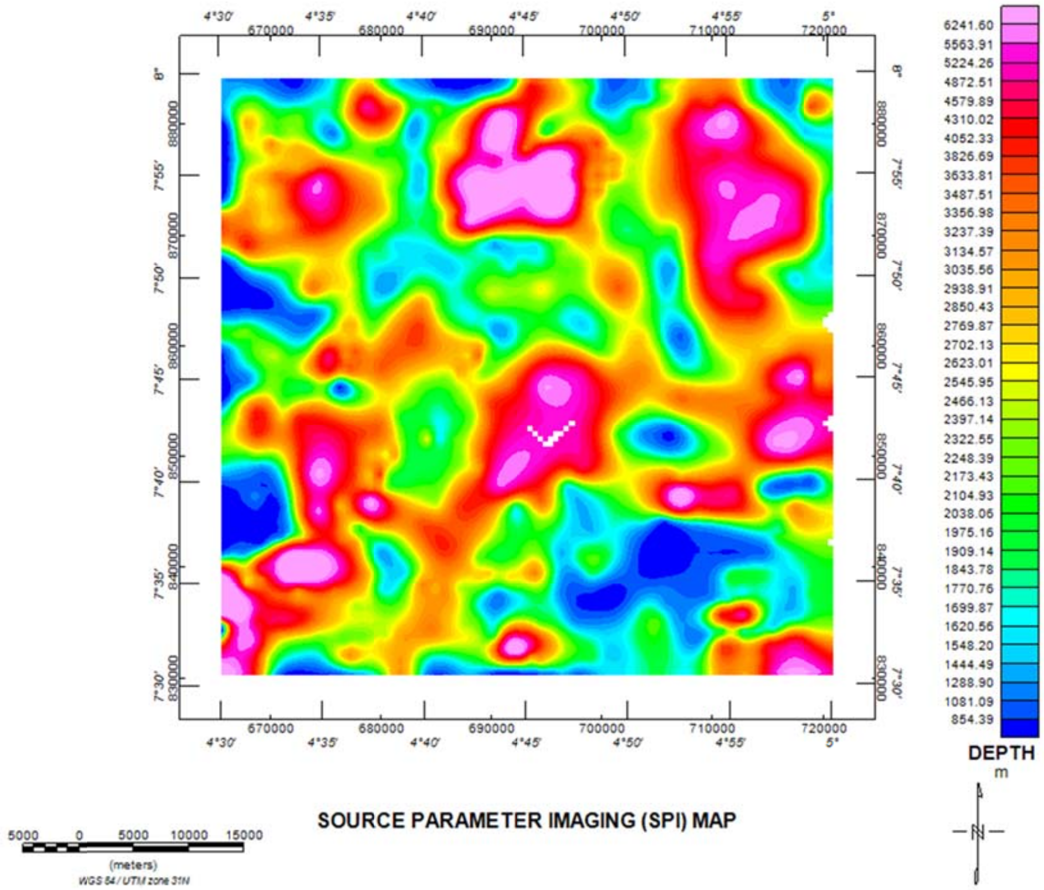

Figure 11. SPI map showing the depth range of gravity sources.

The result of the 3-D Euler deconvolution method is presented in Figure 12, the SI equals 0 (SI = 0), which corresponds to thin sheet edge as the gravity source yielded the best clustering solution. The minimum and maximum depth of anomalous sources obtained are 781.43 m and 4,208.85 m, while the average depth to the target is 2,495.14 m. The maximum depth range of sources coincides with deeper regions while the minimum depth range possibly corresponds to the shallower areas in the study area. An approximate average depth of 2.5 km evaluated in this research is the average burial depth of anomalies.

Figure 13 compares the results obtained from 3-D Euler deconvolution and SPI methods relatively. Four major towns of Ajibodu, Eko-Ende, Itagumodu and Ibokun were examined in the study area. The results of 3-D Euler were 731 m, 3961.38 m, 902 m and 1735.03 m; while SPI for the four towns were 854.39 m, 3826.69 m, 1288.9 m and 1843.78 respectively. Ajibodu area has its gravity anomalous sources to be at 731 m for Euler deconvolution and 854 m for SPI. An average depth of 792.5 m estimated from the two depth estimation techniques is likely correspond to the depth of migmatite-gneiss complex prevalent in that area. The granite-gness is predicted to be at an average depth of 3,893.5 m computed from Euler and SPI depth techniques in the Eko-Ende area. The depth of sources in the Itagunmodu area of the study area was estimated to be 902 m and 1,288 m for Euler and SPI respectively, which suggest the depth of epidiorite to be at an average depth of 1,095 m. The granite-gneiss dominating the Ipetu area can be found at an average depth of 1,789 m. The depths of sources evaluated from these techniques reveal very close relationship as shown by the curves in Figure 13.

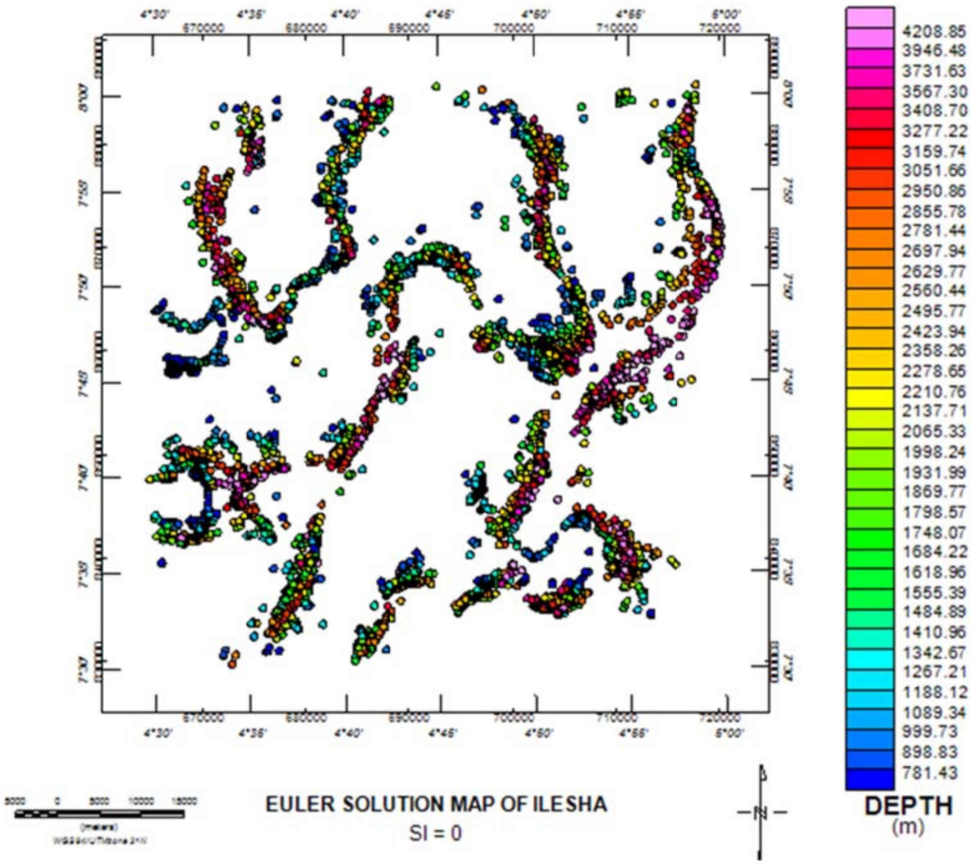

Figure 12. Euler map of Ilesha and its environs.

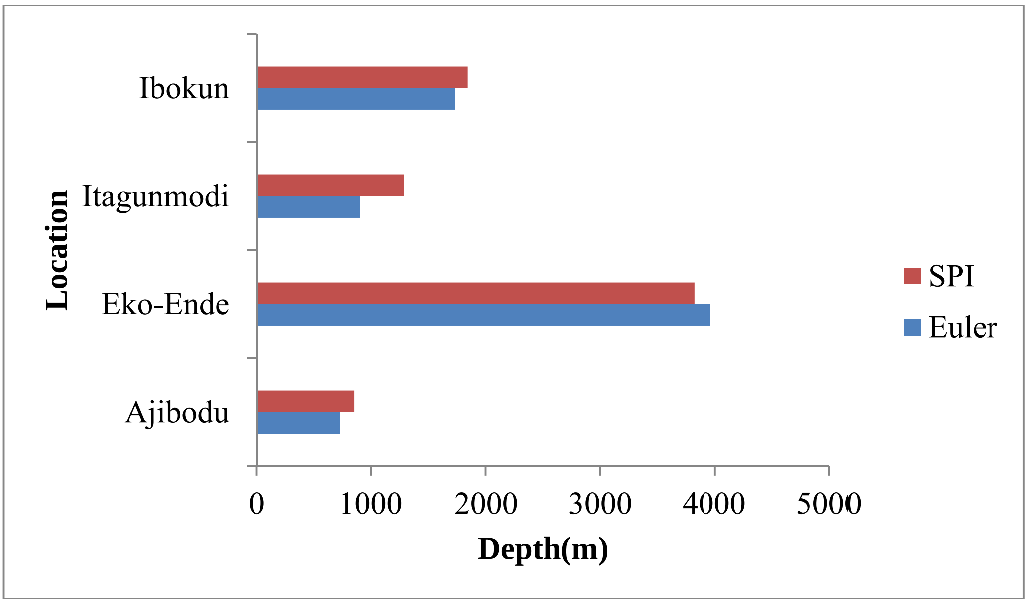

Figure 13. Comparison of Depth results between Euler and SPI methods.

6. Conclusion

High resolution ground gravity data of Ilesha and its environs has been processed, analyzed and interpreted qualitatively and quantitatively to reveal the subsurface features in the area.

Qualitative interpretation showed variations in the density contrasts of bodies that confirmed the presence of minerals of different densities suspected to be metamorphic rock minerals.

The boundary, location and depths of gravity sources were estimated through quantitative interpretation. The minimum depth range of gravity sources obtained from the quantitative approaches of 3-D Euler deconvolution and SPI methods correspond to the depth of metamorphic rock minerals in the area.

In conclusion, the average depth of sources computed indicates that the study location holds a worthy prospect for the accumulation of near surface rocks.

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