STABILITY ASSESSMENT OF EARTH DAMS IN THE MIGMATITE-GNIESS COMPLEX OF NIGERIA USING AEROMAGNETIC DATA

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Abstract

Sheet 201 and 223 part of Ilorin, southwestern Nigeria was studied. The aim was to evaluate the foundation conditions to assess the stability of the selected earth dams. The data set was interpreted to identify dykes, lineaments and magnetic sources controlling subsurface geology. The extracted lineament structures were employed to examine features controlling the distribution of surface and subsurface hydraulic substances cum stability of dam slope. The length and parallelism of magnetic lineaments in some parts of the area suggested emplacement under tensional stress field along pre-existing zones of weaknesses. Magnetic susceptibilities are not uniform in the area and were categorised *viz*: high, moderate, and low. Magnetic intensity range at Asa, Agba and Apodu dam are 126.56 to -20.90 nT, -215.09 to 111.42 nT, and -644.19 to 285.40 nT. The north western part of the Asa and Agba dam area shows little or no sign of faulting and appears to be more stable structurally than the other part of the study area. Thus, the northwestern part where the two dams are located, is fairly stable structurally. Also, the north eastern part of the study area where the Apodu dam is located shows little or no sign of faulting and appears to be more stable structurally. In conclusion, all the three dams are in less structurally active zones and could only likely to have a functional failure rather than structural because the areas near the dams are structurally stable.

Key word: Aeromagnetic, Geologic structure, Dams stability

1.0 Introduction

Previous experiences of dam construction in Nigeria and the world over show that many of the dams have defects related to several factors, among which are geological and geotechnical problems, for

example, Cham dam in Gombe State, Gusau dam in Zamfara State, Challawa dam in Kano State, Ojirami dam in Edo State and others. This dam failures is attributed largely to poor investigations (geological and geotechnical) prior to the design and construction of the dams and improper maintenance and monitoring of the dams after construction. This trend needs to be checked and possibly reversed hence the need for this research in order to avert future occurrences of dam failures. It is important to scrutinize any proposed dam site for geologic, Structural, topographical, geotechnical and hydrologic characteristics because these will determine to a large extent the success or failure of such a dam. The selection of sites for the construction of structures like a dam is based on a combination of topographic, geologic, structural, geotechnical, and economic factors (Ako, 1976).

Dam's structures require a low tolerance of water seepage; besides, the design of dam structures must be adapted to the existing site conditions (Ajayi *et al*., 2005) to minimize the losses. Failure to do any of these may invariably result in seepage and consequential total collapse of the structure (Olorunfemi et al., 2000a, b). Biswas and Charttergee (1971) examined causes of dam failures worldwide and discovered that 25% of the failures were due to structural, and foundations problems associated with piping, seepage, inadequate seepage cut-off, faults, settlements, and landslides.

Aeromagnetic surveying is the determination of the variation in geomagnetic field that occurs as a result of changes in the percentage of magnetite in rock. This reflects the variation in the distribution and type of magnetic minerals in the rocks, whether at the subsurface or at the surface. Sedimentary formations do not usually have appreciable magnetic properties, this is because of the minute contribution of detrital remnant magnetism while igneous and metamorphic rocks exhibit greater variations and become useful in exploring bedrock geology (Odumade and Jayeoba, 2015).

The failure of dams does not only have economic consequences, but also adversely affects the environment and value of life. In addition, the populations are at a risk in locations down streams of major dams (Leulalem *et al*., 2016). Failure of dams can be due to structural inadequacies, lack of

maintenance, ageing, differential settlement, seepage, overtopping and rockslide. Dam failures are comparatively rare, but can have immense damage and loss of life when it occurs (Ezugwu, 2013). Available records also indicate that some dams are constructed with little or no foundation investigations prior to construction. As solution to these problems, geological and geotechnical investigations of a dam site selected for detailed evaluation is directed to the determination of geological structures and faulting, foliation and groundwater conditions and erosion at dam foundation and reservoir area, including the abutments. This would provide valuable information on the condition of such dams which will assist in taking quick safety decisions, determine appropriate mitigation methods and also protect the dam investments.

1.1 Study Area

The study area is located within the basement complex region of southwestern Nigeria. The dams investigated are Asa, Agba and Apodu dams located in Ilorin and Malete towns, Kwara state. The study (Figure 1) area falls within the coordinate that follows; Asa dam $8^0 26' 24.55'' N$ and $4^0 33' 15.28'' E$, Agba dam, $8^0 28' 23.23'' N$ and $4^0 35' 05.22'' E$; and Apodu dam $8^0 45' 27.80'' N$ and $4^0 27' 34.19'' E$ respectively. The study areas are fairly accessible by footpath, minor and major road especially Ilorin-Shao-Malete road and Asa Dam road including various tarred road within Ilorin metropolis. Accessibility to the different sample locations was possible through footpaths and un-tarred roads, some of which were newly created. Accessibility was hindered by thick vegetation, marshy and swampy areas, and rivers especially around the dam axis and reservoir areas.

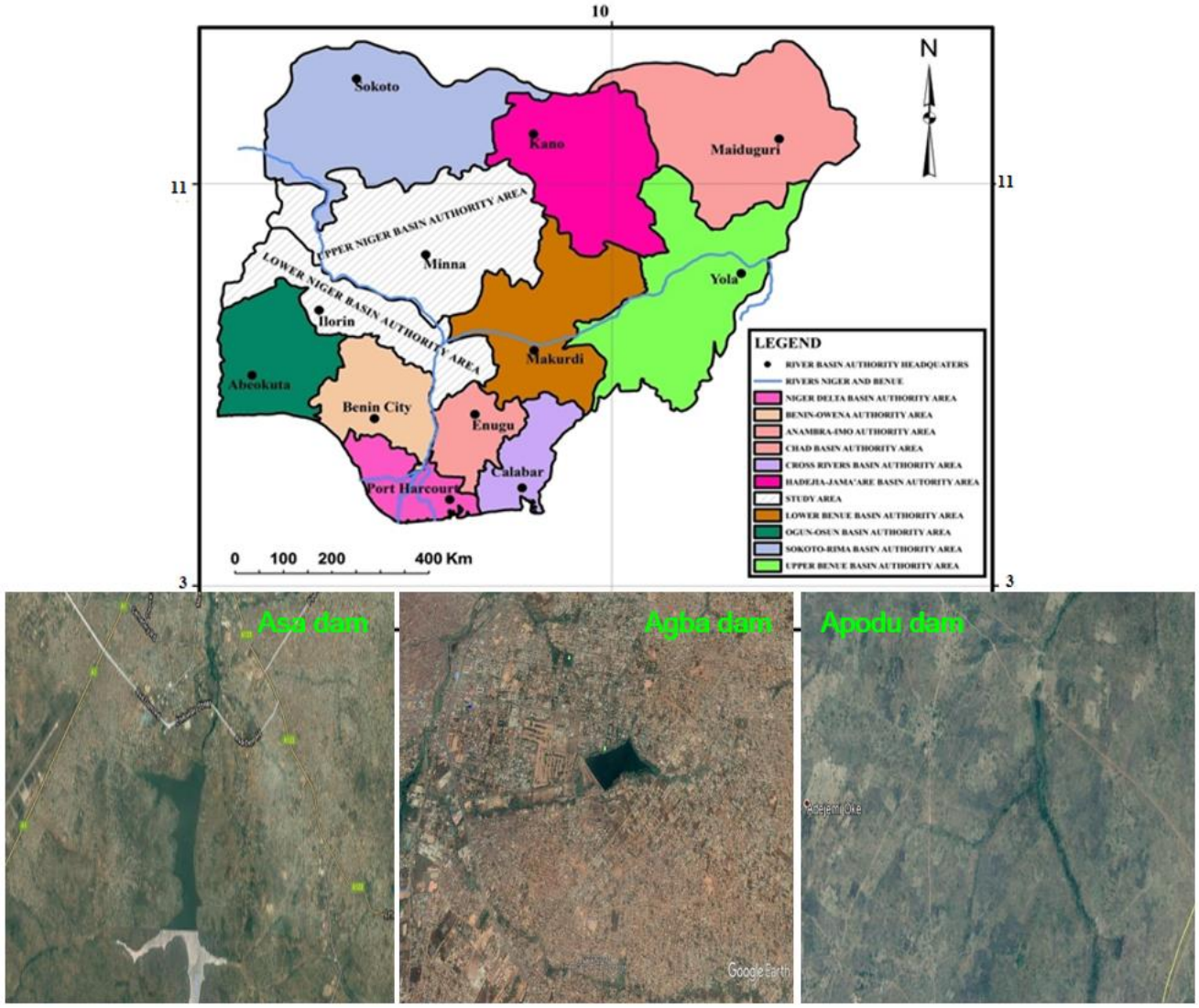


Fig 1: Location of Asa, Agba and Apodu dam

1.2 Geological Setting

The study area falls within the basement complex of southwestern Nigeria and is Archean to early Proterozoic in age according to Talabi (2013). It is within the Migmatite-gneiss Complex of the Nigeria basement complex rock which is generally considered as the basement complex sensu stricto (Rahaman, 1988; Dada, 2006) because of it's widespread of occurrence in the Nigerian basement terrain. Lithologies identified from the geologic map of the study area (Figure 2a&b) includes; migmatite-gneiss, granite-gneiss, porphyritic-granite, biotite rich granites, and quartz veins.

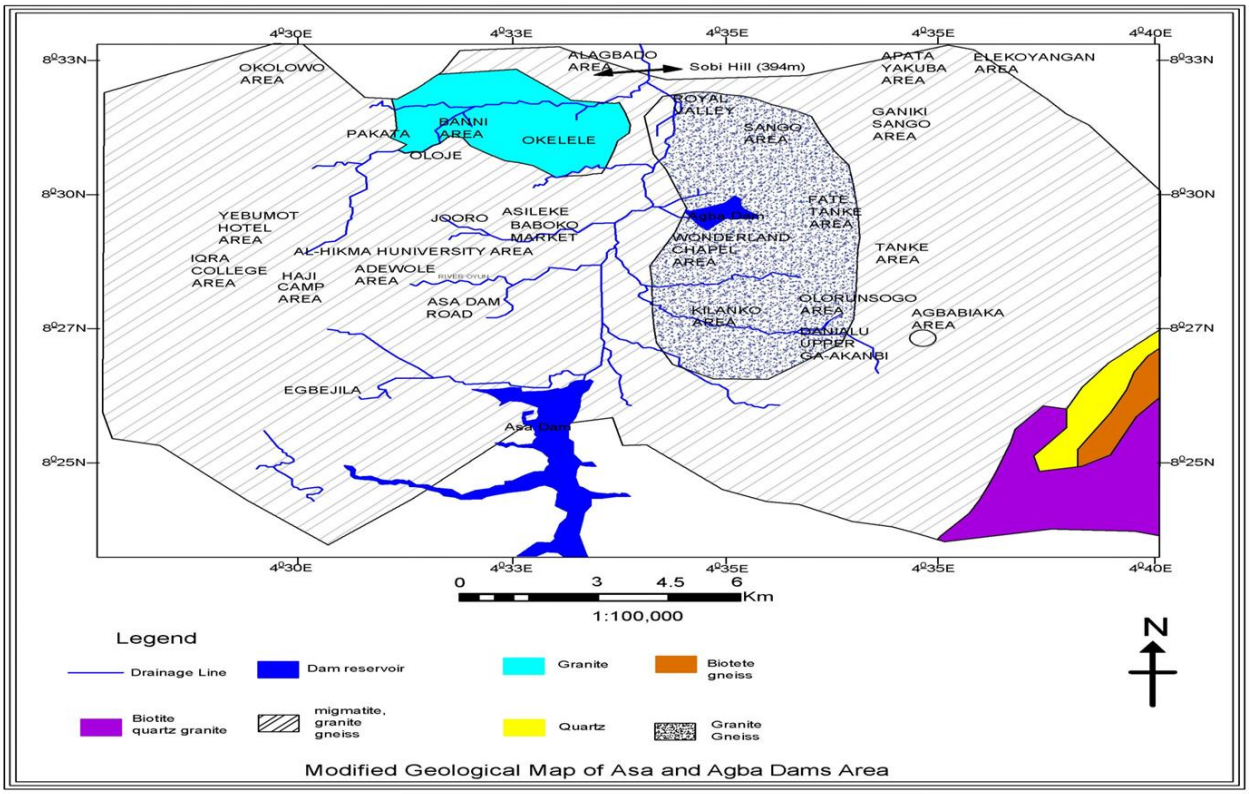


Fig 2a: Updated Geological map of Asa and Agba dam area (Modified after NGSA, 2017)

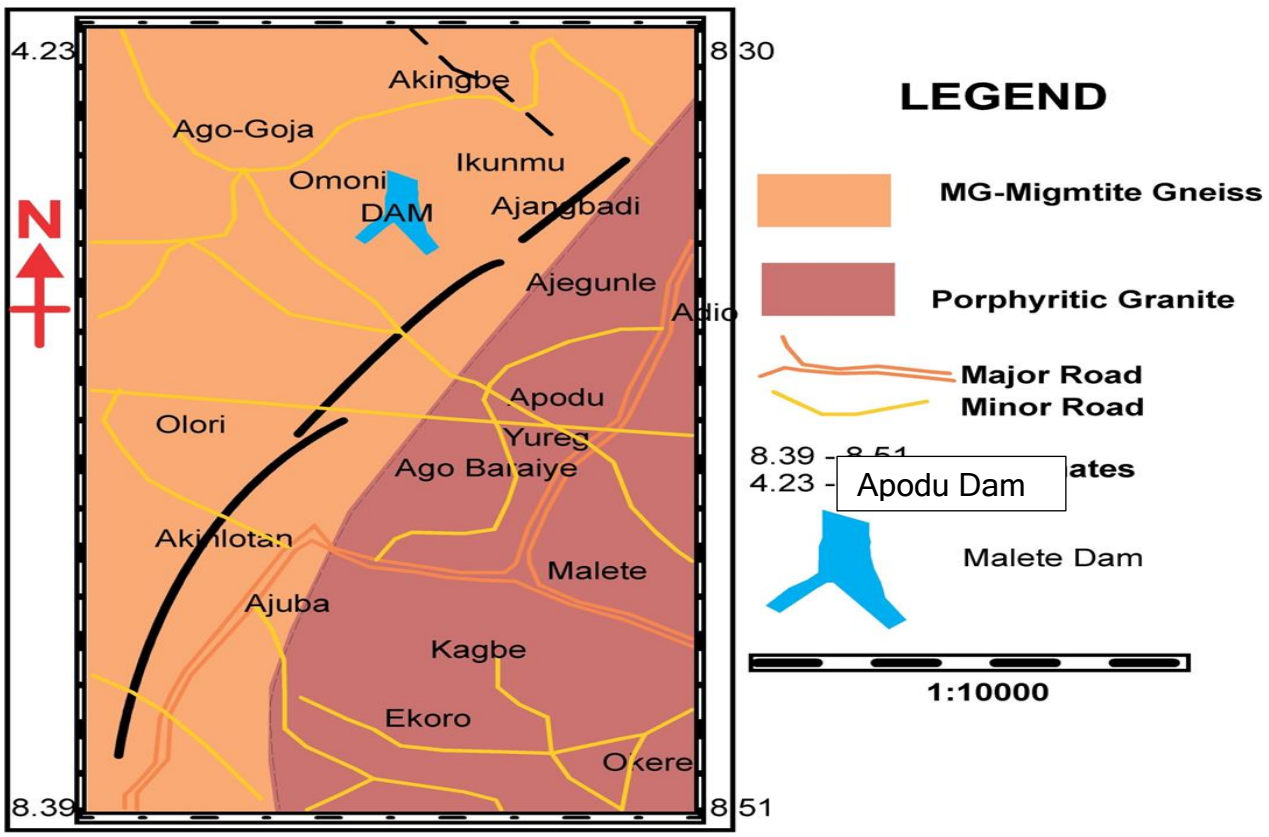


Fig 2b: Updated Geological map of Apodu dam area (Modified after NGSA, 2017)

2.0 Materials and Methods

High resolution aeromagnetic data acquired using Scintrex CS3 Cesium Vapour Magnetometer and processed by Fugro Airborne was obtained from the Nigeria Geological Survey Agency in 2019 (MMSD, 2019). The data was collected systematically using Scintrex CS3 Cesium Vapor magnetometer which is highly sensitive and measures in the range of pT (1 pT = 0.001 nT) in a measuring bandwidth of 1 Hz and this sensitivity does not deteriorate as the measured ambient field decreases. It measures between 15,000 nT and 100,000 nT. The aeromagnetic survey was carried out by fixed wing (Cessna) aircraft covering a total of 235,000 line kilometers with a flight spacing of 200 meters and a terrain clearance of 80 meters. The flight direction was NW-SE (135) with flight-line spacing of 200 meters and tie-line direction of NE-SW (45).

A recording interval of 0.1 secs and a grid mesh size of 50 meters were applied in the World Geodetic System of 1984 (WGS84) within UTM Zone 36S and with the Clark 1880/Arc 1960 coordinate system. The aeromagnetic data was processed using *ENVI 5.1* image processing and analysis software. The processed airborne magnetic field intensity was enhanced through the removal of the International Geomagnetic Reference Field (IGRF) over the area. This was eventually used in the production of an aeromagnetic map. The aeromagnetic intensity data set of the area around Asa, Agba and Apodu dam (Sheet 201 and 223) was processed using *Geosoft Oasis Montaj*™ version 6.4.2 (HJ) software.

Other software applications used include *Surfer* ™ Version 12 and *ArcGIS* version 10.2 for data analysis and integration. The aeromagnetic data set was upward continued to a height of about 100 m to remove near- surface noise and enhance the magnetic anomalies over the study area. Other data enhancement techniques applied includes the Reduction to Equator (RTE), residualization, Total Horizontal derivative and Euler Deconvolution, applying various structural indices to the magnetic anomaly map. The RTE was carried out to remove magnetic inclination effect usually associated with low latitude regions. Residualization was performed to remove the effect of deep seated sources.

Spectral Analysis was performed through the application of the Fast Fourier Transform (FFT) approach to estimate Depth to Magnetic Basement (DMB). The Source Edge Detection (SED) function was used to locate edges, i.e. geological contacts or peaks from potential field data by analysing the local gradients. SED was used to estimates the location of abrupt lateral changes in magnetisation and identifies maxima on a grid of horizontal gradient magnitudes using the technique of Cordell and Grauch (1982, 1987).

3.0 Results and Discussion

3.1 Residual Magnetic Intensity (RMI)

The RMI image obtained from the software shows high magnetic susceptible areas in low magnetic values (blue) while less magnetic susceptible areas are depicted as high magnetic values (pink colour) except for the analytical signal image and reduction to the pole image where high magnetic susceptible areas are shown as high anomalies. The residual magnetic intensity map Asa and Agba dam (Figure 3.1) shows that the magnetic intensity values ranged from high (132.3 nT) to low (-79.2 nT). Negative anomalies were observed in the area which may be due to the presence of low magnetic rocks (e.g. shale, sandstone, limestone) are noted for low magnetic signatures. Removal of the regional magnetic anomaly from the measured anomaly gives negative RMI values.

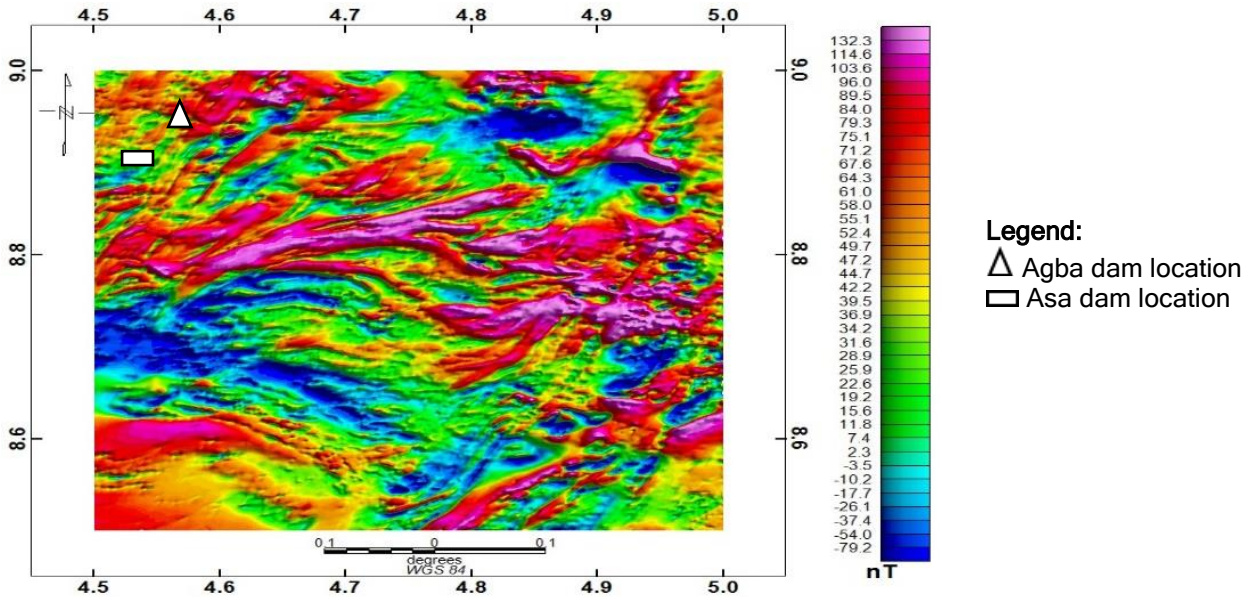


Figure 3.1: Residual Magnetic Intensity map of Sheet 201 (Asa and Agba Area)

The residual magnetic intensity map Apodu dam (Figure 3.2) shows that the magnetic intensity values ranged from high (127.94 nT) to low (-88.47 nT). Negative anomalies were observed in the area which may be due to the presence of low magnetic rocks (e.g. shale, sandstone, limestone) in the area, that are noted for low magnetic signatures. Removal of the regional magnetic anomaly from the measured anomaly for sheet 223 also gives negative RMI values like that of Sheet 201.

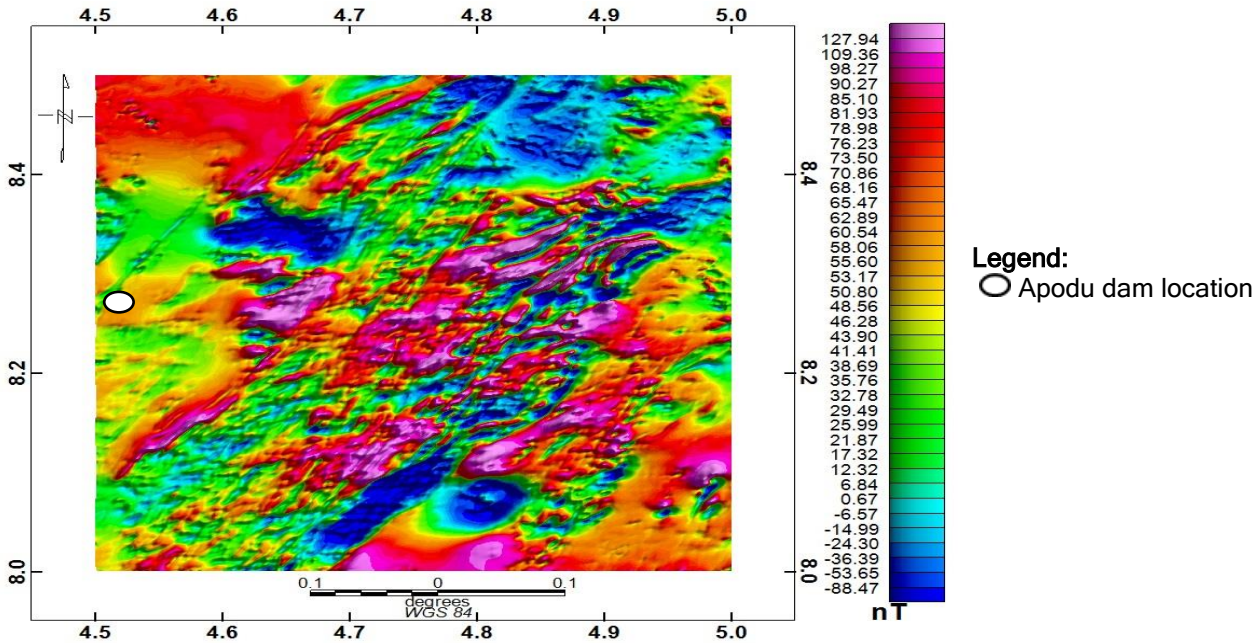


Figure 3.2: Residual Magnetic Intensity map of sheet 223 (Apodu dam area)

3.2 Reduction to pole (RTP)

Figure 3.3 and 3.4 show the RTP map of Asa, Agba and Apodu dam area. The RTP map depicts frequency variations present in the magnetized rocks of the area. The RTP places anomalies from residual magnetic field directly over the magnetic field resulting from causative rocks producing these anomalies. The areas that were displayed as high and low magnetic anomaly zones in RMI maps are now shown as a low and high magnetic anomaly zones respectively. Further, contacts between the low and high magnetic susceptible zones have also been enhanced. Various structures such as folds, faults, and rock lithology contacts have also been enhanced. Most of the low magnetic signatures emanates from rocks that have fewer magnetic minerals in them, while high signature are being produced by rocks that have high magnetic minerals in them. The area of study falls within the basement complex of Nigeria, the basement complex is characterized by rocks of various ages and

compositions. The area contains rocks such as migmatite, gneiss, granite, granodiorite and schist. Most of the low magnetic anomalies come from the meta-sediments while high magnetic susceptibilities are from the competent basement rocks. The patterns that were observed on the RTP map are due to rock deformation especially at the central part of both sheet. The basement rocks have been folded during several phases of deformation and these had allow the magnetic minerals that are present in such rocks to also reshape itself in the manner that the host rocks have done. The southwestern part of RTP map (Figure 4.3) shows moderate magnetic signature and has little or no structure. In the same vein, the northwestern part of RTP map (Figure 4.4) shows low to moderate magnetic signature variation and has limited structures when compared to the rest of the area. The orientation in the two maps is the NE-SW direction which correlate the structural trends that were measured during the geological field mapping undertaken and has reported by various authors on the basement complex of Nigeria.

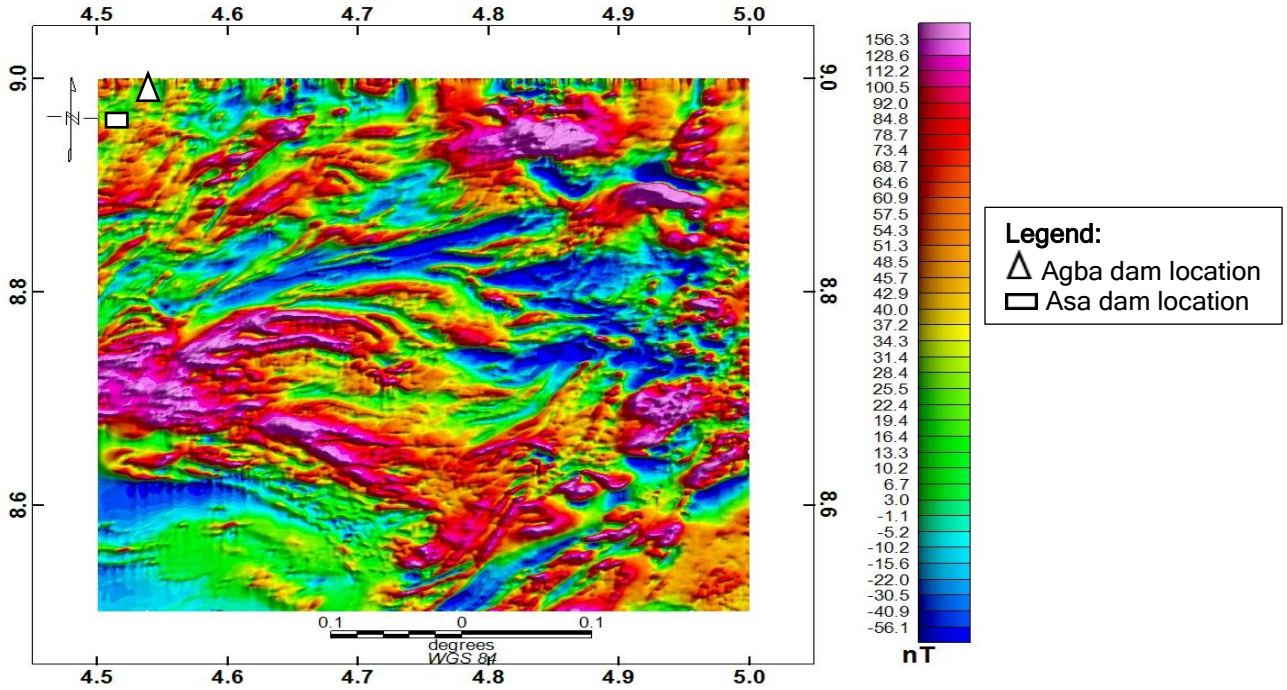


Figure 3.3: Reduced to pole map of Sheet 201 (Asa and Agba area)

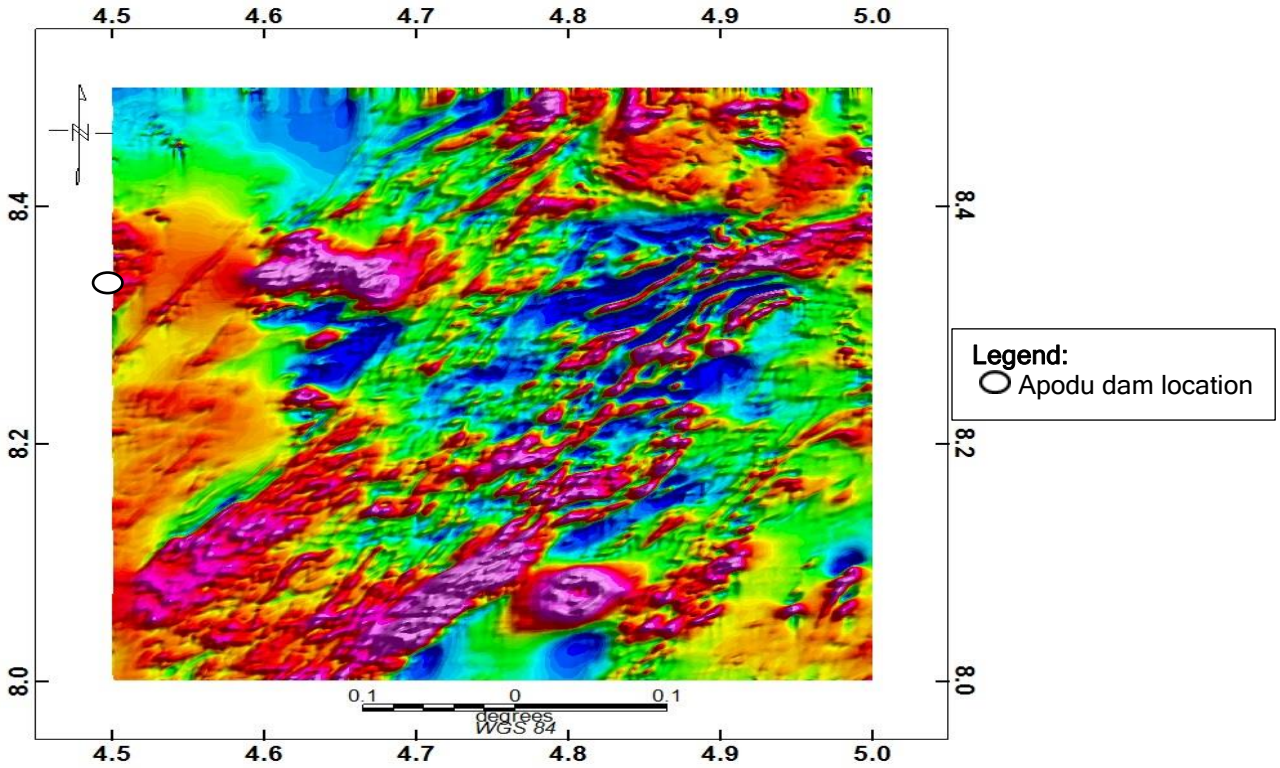


Figure 3.4: Reduced to pole map of sheet 223 (Apodu dam area)

3.3 First vertical derivative (FVD)

Figure 3.5 and 3.6 shows the first vertical derivative map of the area of study. The FVD grid was upwardly continued to a hundred meters so as to subvert the effects of deep source magnetic features and enhance shallow source magnetic features that are associated with geological structures. The red lines in figure 4.5 and 4.6 represents lineaments which are structural deformations that are related to geological features and arched zones or even geological contacts. Magnetic minerals are mainly concentrated along or aligned with some structures and lineaments were delineated by observing the abrupt change between the positive and negative magnetic anomalies. This gives a rough idea of the structure and lithologic deformations in the study area.

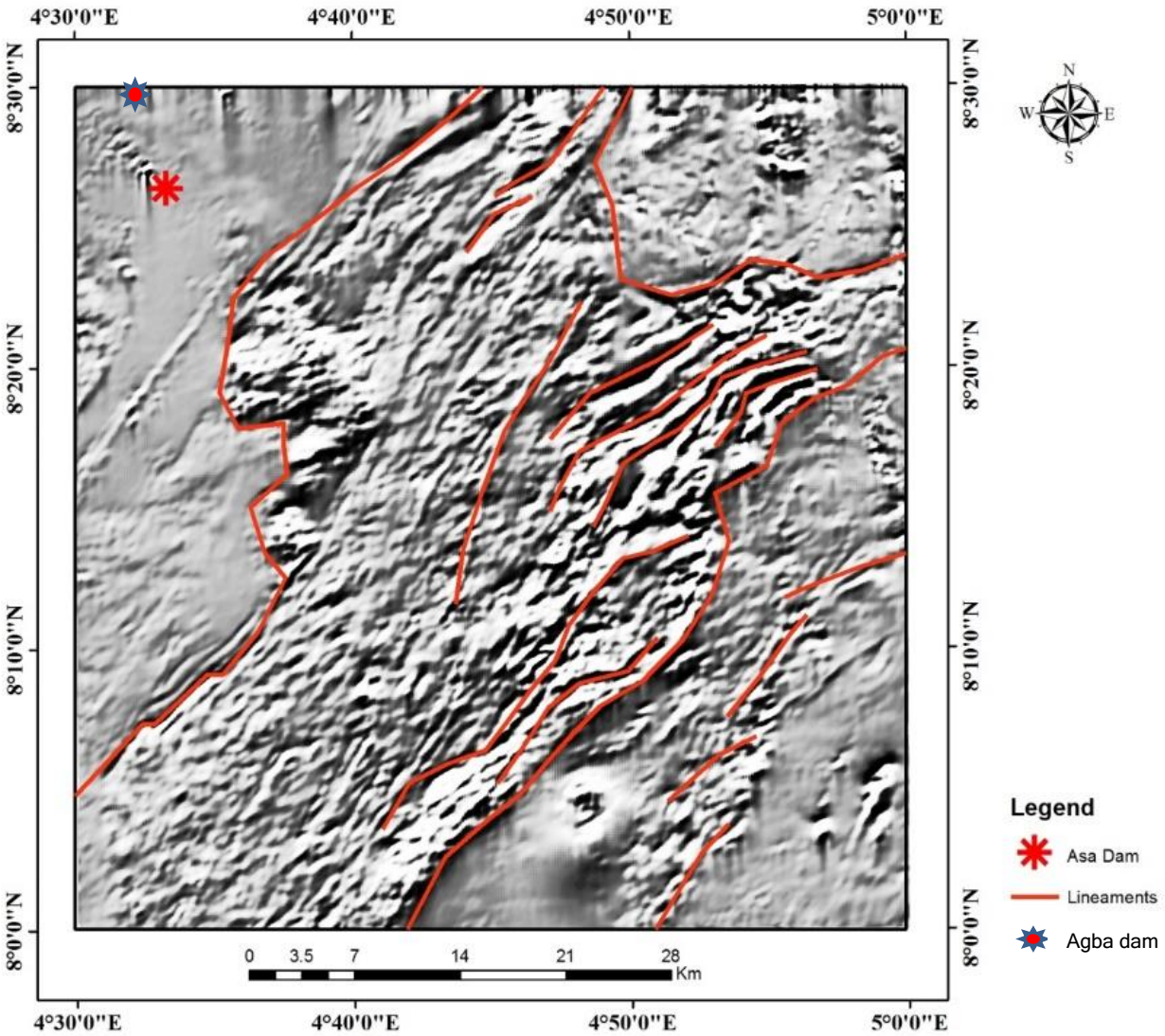


Figure 3.5: First Vertical Derivative map showing lineaments in Asa and Agba dam area

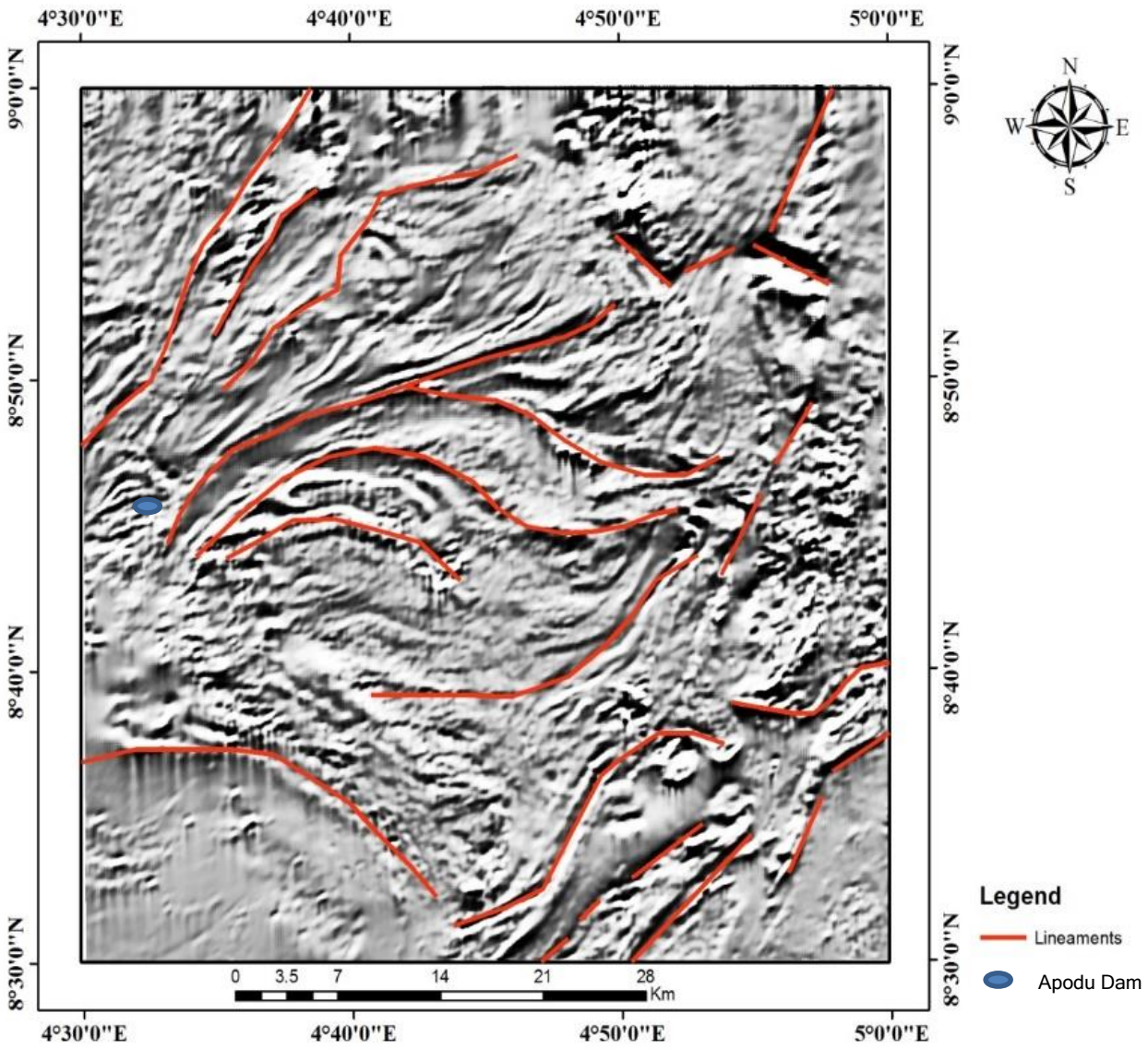


Figure 3.6: First Vertical Derivative map showing lineaments in Apodu dam area

4.0 Conclusion

The current area of study falls within the basement complex of Nigeria as observed above. This basement complex has undergone several episodes of deformation (polycyclic) according to Rahman, 1984. The patterns of folding and faulting observed on the FVD map (Figures 3.5 & 3.6) were formed during the various episodes of deformation that the basement rocks have undergone. The basement rocks have been folded during several phases of deformation and this has allowed the magnetic minerals that are present in such rocks to also reshape itself in the manner that the host rocks have done.

Prior to recommending an area for dam construction, the area must be tectonically stable, with little or no active faults nearby. This is because the presence of active tectonic structures near the vicinity of the dam will increase significantly the construction cost, technicalities required for its construction and maintenance or may even lead to failure of the dam in the long run which may also affect lives and properties situated around the dam area especially the downstream. As seen in Figure 3.5 and 3.6, most of the lineaments are concentrated in the mid-part of the area of study and trends in a NE-SW direction. It is evident that shearing is also taking place in the middle part of the area of study. The style of folding and faulting in the area of study suggests this area could be a shear zone i.e. a place where several shearing are taking place, and as such is not suitable for dam emplacement without proper foundation treatment. This would however make dam construction in such area more challenging and expensive. The north western part of the Asa and Agba dam study area (Figure 3.5) shows little or no sign of faulting and appears to be more stable than the others. It is not surprising that Asa and Agba dam had been emplaced in such an area. The area is fairly stable structurally. Also, in the north eastern part of the Apodu dam study area (Figure 3.6) where the Apodu dam is located, shows little or no sign of faulting and appears to be more stable than the other area of the map. We could therefore deduce from the above that all the three dams were located in less structurally active zones and could only likely to have a functional failure rather than structural because there are no visible tectonic structures near the dams' area.

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