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# GEOPHYSICAL ASSESSMENT FOR CHARACTERISING LEAKAGES FROM ASA DAM, NIGERIA

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***Abstract***

Aeromagnetic and Electrical resistivity tomography technique were used to evaluate the foundation conditions and stability of Asa earth dam located in Ilorin. The Aeromagnetic data set was interpreted to identify dykes, lineaments, and magnetic sources that is controlling the subsurface geology. The extracted lineament structures were employed to examine features that are controlling the distribution of surface and subsurface hydraulic substances which affects the stability of dam. The nature of the magnetic lineaments in some parts of the area suggests rock emplacement under a tensional stress field. Magnetic susceptibilities are not uniform in the area and were categorized *viz*: high, moderate, and low. The magnetic intensity range at Asa dam is 126.56 to -20.90 nT. The northwestern part of the Asa dam area shows little or no sign of faulting and appears to be more stable structurally than the other part of the study area. Characterization of Asa dam earth embarkments for seepage appraisal using resistivity tomography technique revealed that the Asa dam is well compacted with no sign of any seepage. In conclusion, the Asa dam is situated in a geologically stable environment as deduced from the aeromagnetic study, while the earth embarkments are well compacted with no sign of seepage as obtained from the electrical resistivity tomography technique of investigations.

***Keywords:*** Aeromagnetic, Resistivity tomography, Geologic structure, Dam Seepage

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## 1.0 INTRODUCTION

Many dams in Nigeria and around the world have flaws due to a variety of factors, including geological and geotechnical issues, as evidenced by the Cham dam failure in Gombe State, the Gusau dam failure in Zamfara State, the Challawa dam failure in Kano State, the Ojirami dam failure in Edo State, and other examples. This dam failure is attributed largely to poor investigations (geological and geotechnical) prior to their design and construction. Improper maintenance and monitoring of the dams after construction also contribute to the dam failures. This trend needs to be checked and possibly reversed hence the need for this research to avert future occurrences of dam failures. Any potential dam site must be thoroughly investigated for geology, 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 constructions must have a low tolerance for water seepage, and their design must be tailored to the existing site circumstances to reduce losses (Ajayi *et al.,* 2005). Failure to address any of them could lead to seepage and, as a result, ultimate collapse of the structure (Olorunfemi *et al*., 2000a, b). Biswas and Charttergee (1971) investigated causes of dam failures around the world and discovered that structural and

foundation issues related to piping, seepage, inadequate seepage cut-off, faults, settlements, and landslides accounted for 25% of the failures.

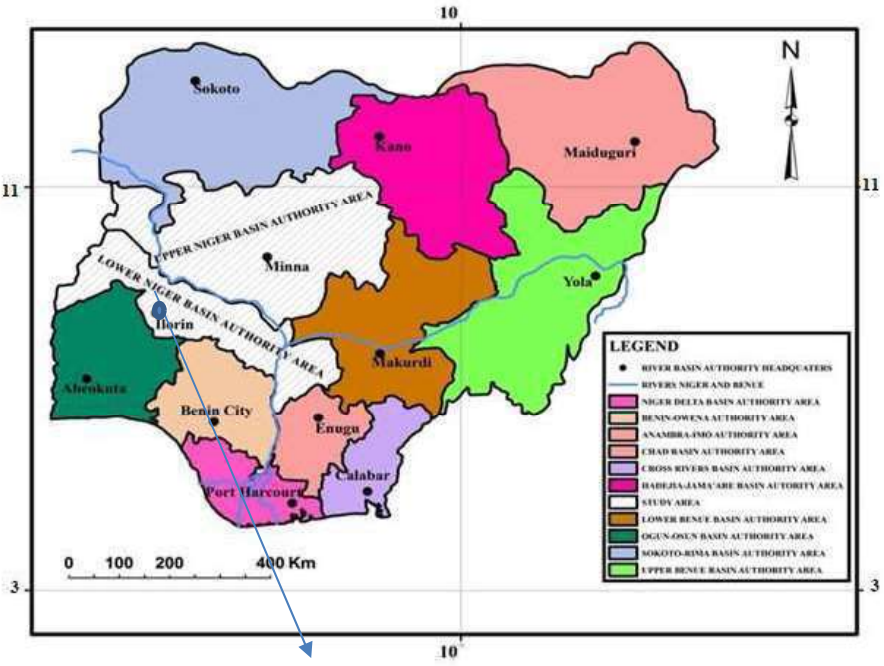
Aeromagnetic surveying is the measurement of variations in a geomagnetic field caused by changes in the amount of magnetite in the rock. This reflects differences in the distribution and types of magnetic minerals in rocks, whether subsurface or surface. Due to small contribution of detrital remnant magnetism, sedimentary formations do not usually have notable magnetic characteristics, but igneous and metamorphic rocks have greater fluctuations and can be used to investigate bedrock geology (Jayeoba A. and Odumade D., 2015).

Dam failure has a negative impact on the environment as well as the worth of life. Furthermore, inhabitants in areas downstream of big dams are at jeopardy (Leulalem *et al*., 2016). Dam failure can be caused by structural flaws, lack of maintenance, aging, differential settlement, seepage, overtopping, and rockslides, among other things. Dam failures are uncommon, but when they do happen, they can cause significant damage and death (Ezugwu, 2013). Available records also indicate that some dams are constructed with little or no foundation created.

investigations before construction. As a solution to these problems, geological and geotechnical investigations of a dam site chosen for detailed evaluation are directed toward determining geological structures, faulting, foliation and groundwater conditions at the 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, determining appropriate mitigation methods, and also protecting the dam investments.

### 1.1 Study Area

The study area is in southwestern Nigeria's basement complex region. The dam under investigation is Asa, which is located in Ilorin, Kwara State, Nigeria. The research region (Figure 1) is located at $8^0 26' 24.55'' N$ and $4^0 33' 15.28'' E$. The research region is easily accessible through pedestrian, minor and main roads, particularly the Asa Dam Road in Ilorin. Footpaths and unpaved roads, some of which were freshly developed, provided access to the various sample locations. Thick vegetation, marshy and swampy places, and rivers, especially near the dam axis and reservoir sections, made access difficult.




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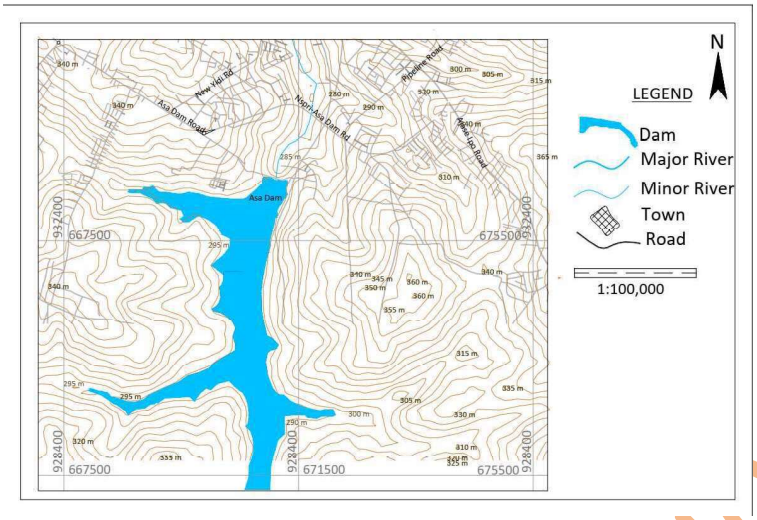



Fig 1: Location of Asa dam

### 1.2 Geological Setting

The studied area is located within the Migmatite-gneiss Complex of the Nigeria basement complex of southwestern Nigeria. Due to the widespread presence of Migmatite-gneiss Complex in the Nigeria basement complex rock, it is usually considered to represent the basement complex sensu stricto (Rahaman, 1998; Dada, 2006). Migmatite-gneiss, porphyritic-granite, and quartz veins are among the lithologies recognized from the research area's geologic map (Figure 2).

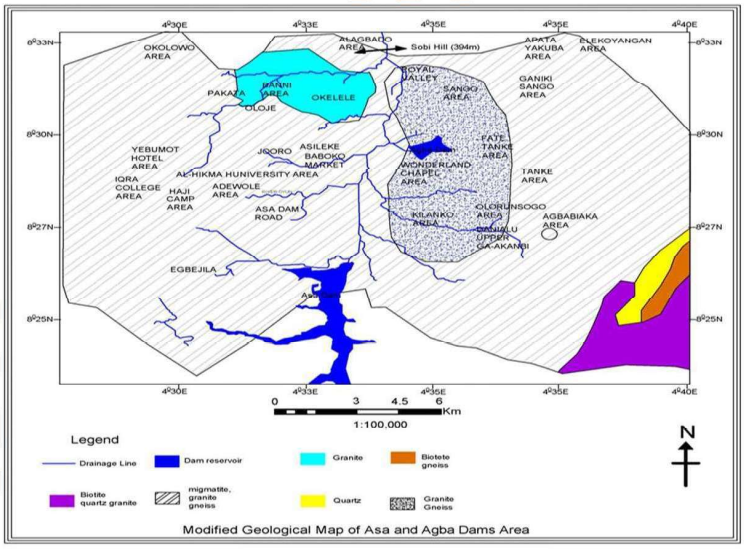



Fig 2: Geological map of the study area (Modified after NGSA, 2017)

### 2.0 MATERIALS AND METHODS

The Nigeria Geological Survey Agency provided high-resolution aeromagnetic data captured with a Scintrex CS3 Cesium Vapour Magnetometer and analyzed by Fugro Airborne in 2019 (MMSD, 2019). The data were systematically obtained using a Scintrex CS3 Cesium Vapor magnetometer, which is highly sensitive and measures in the range of pT (1 pT = 0.001 nT) in a 1 Hz measuring bandwidth, with sensitivity that does not decline when the detected ambient field drops. This magnetometer has a range of 15,000 nT to 100,000 nT. Fixed-wing (Cessna) aircraft carried out the aeromagnetic survey, which covered a total of 235,000-line kilometers with a

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flight spacing of 200 meters and terrain clearance of 80 meters. The flying direction was NW-SE (135), with a 200-meter flight-line spacing and a NE-SW tie-line direction (45).

In the World Geodetic System of 1984 (WGS84) inside UTM Zone 36S and using the Clark 1880/Arc 1960 coordinate system, a recording interval of 0.1 seconds and a grid mesh size of 50 meters were used. The aeromagnetic data set were processed using *ENVI 5.1* image processing and analysis software. The intensity of the processed airborne magnetic field was increased by removing the International Geomagnetic Reference Field (IGRF) from the area. This was eventually used in the production of an aeromagnetic map. The aeromagnetic intensity data set of the area around Asa dam (Sheet 202) was processed using *Geosoft Oasis Montaj*™ version 6.4.2 (HJ) software.

Surfer TM Version 12 and ArcGIS version 10.2 were utilized for data analysis and integration, respectively. To reduce near-surface noise and amplify magnetic anomalies over the research area, the aeromagnetic data set was extended upward to a height of roughly 100 m. Reduction to Equator (RTE), decidualization, Total Horizontal derivative, and Euler Deconvolution are some of the other data augmentation techniques used, as well as adding several structural indices to the magnetic anomaly map. The RTE was used to eliminate the magnetic inclination effect that is common in low-latitude areas. To eliminate the effect of deep-seated sources, residualization was used. To estimate the depth to the magnetic basement (DMB), a spectral analysis using the Fast Fourier Transform (FFT) method was used. The Source Edge Detection (SED) function was utilized to find edges, i.e. geological contacts or peaks using potential field data. Using the Cordell and Grauch technique of 1987, SED was used to predict the position of abrupt lateral changes in magnetization and find maxima on a grid of horizontal gradient magnitudes.

Electrical resistivity readings are linked to different depths depending on the distance between the current and potential electrodes in the survey, and they can be interpreted in terms of a lithologic and/or geo-hydrologic model of the subsurface (Keany, 1984). Resistivity (the inverse of conductivity) is occasionally used to determine water saturation and pore space connectivity. When it comes to filling voids, air, which has a naturally high resistance, has the opposite effect as water. Whereas the presence of water reduces subsurface resistivity, the presence of air in voids increases it (Omatsola et al., 1981). In electrical prospecting, the use of the Electrical resistivity tomography technique (dipole-dipole array) has become prevalent. It is one of the most practical approaches in terms of field logistics, especially for vast spacing. The current and potential electrode spacing in a dipole-dipole array is the same and the spacing between them is an integral multiple. As a result, the apparent resistivity is given by this formula:

$$\frac{V}{I}\pi an(n+1)(n+2)$$

The dipole-dipole array is used to determine the curvature of the potential field and is particularly sensitive to changes in resistivity between the electrodes in each electrode pair. A dipole is a pair of oppositely charged electrodes that are sufficiently close together that the electric field seems to be a single field rather than a field made up of multiple electric poles. The dipole-dipole array, which consists of a current electrode pair A and B and a potential electrode pair M and N, allows raw data to be plotted to create an image of the earth's cross-section. It calculates the apparent resistivity, which is a weighted average of the resistivities measured across the four electrodes. In a pseudo-section, the result is plotted. For each measurement, the apparent resistivity data is plotted at depths half the distance between the two dipoles and at themed point between the two dipoles.

The investigation's data were contoured and colorized to provide a crude representation of the subsurface. Although the data points obtained from these measurements do not produce an image of the ground, they do provide an image of the earth's cross-section. Two traverses were achieved for each dam location during this research work RTM 1 and RTM 2 for traverse 1 and traverse 2 respectively. Traverse 1 was done closer to the embankment and Traverse 2 along with the downstream of the dam embankment farther away from Traverse 1 which trends NW-SE direction of the dam.

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## 3.0 RESULTS AND DISCUSSION

### 3.1 Residual Magnetic Intensity (RMI)

The RMI image obtained from the software shows areas with high magnetic susceptible indicated by low magnetic values (blue) while areas with less magnetic susceptible are indicated with high magnetic values (pink color). Only the analytical signal image and its reduction to the pole image reveal high magnetic vulnerable locations with high anomaly values. The residual magnetic intensity map for Asa dam (Figure 3) shows that the magnetic intensity values ranged from high (132.3 nT) to low (-79.2 nT). Negative magnetic anomalies were observed in the area, which may be due to the presence of low magnetic rocks like shale, sandstone, limestone which are noted for low magnetic signatures. Removal of the regional magnetic anomaly from the measured anomaly gives negative RMI values.

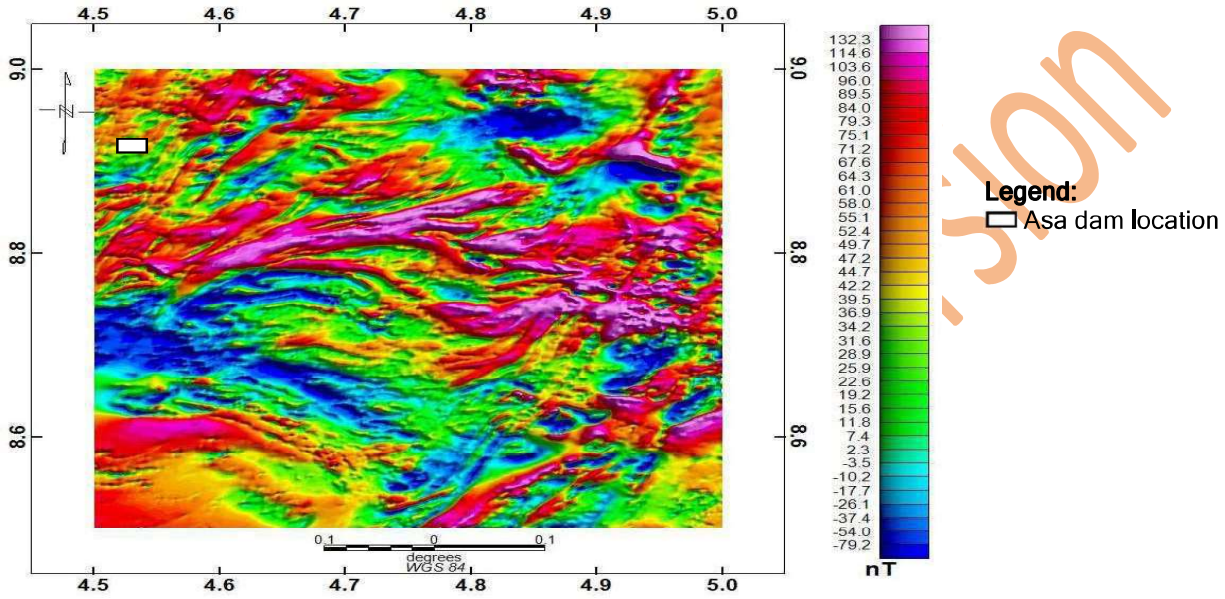



**Figure 3: The Residual Magnetic Intensity map of sheet 202**

### 3.2 Reduction to pole (RTP)

Figure 4 shows the RTP map of Asa dam area which depicts the frequency variations present in the magnetized rocks of the area. The RTP overlays residual magnetic field anomalies on top of the magnetic field produced by the causative rocks. The areas that were displayed as high and low magnetic anomaly zones in the RMI maps are now shown as low and high magnetic anomaly zone respectively in the RTP maps. 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. The majority of low magnetic signatures come from rocks with less magnetic minerals, whereas the high magnetic signature comes from rocks with a lot of magnetic minerals. The study region is located within Nigeria's basement complex, which is characterized by rocks of varied 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 around the central part of the study area. The basement rocks have been folded during several phases of deformation and these had allowed the magnetic minerals that are present in such rocks to also reshape themselves in the manner that the host rocks have done. The southwestern area of the RTP map (Figure 4) shows moderate magnetic signature with little or no structures when compared to the rest of the area. The map's orientation is NE-SW, which corresponds to structural tendencies that have been recorded physically on field outcrops and described by numerous researchers on the Nigerian basement complex.

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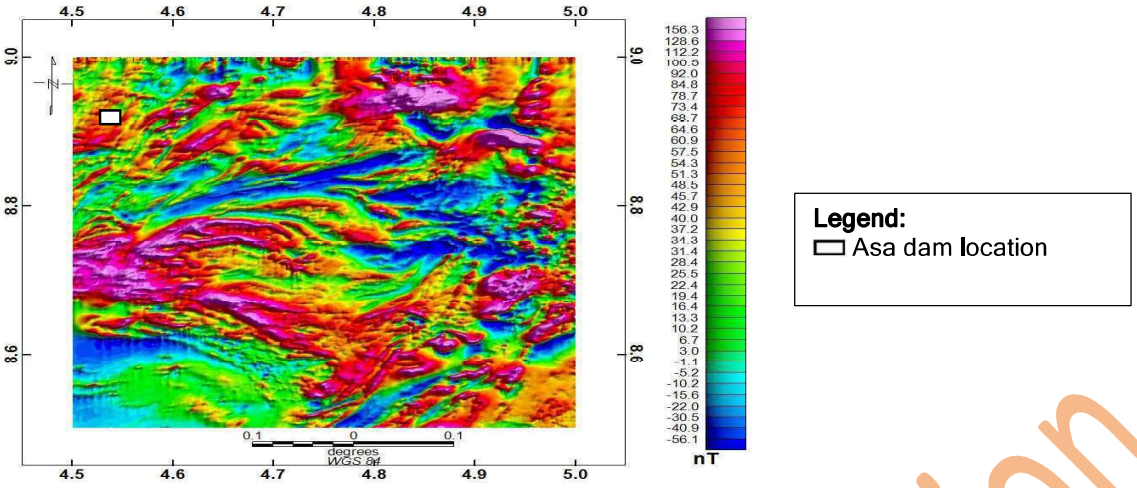



**Figure 4: The Reduced to pole map of sheet 202**

### 3.3 First vertical derivative (FVD)

Figure 5 shows the first vertical derivative map of the study area. The FVD grid was upwardly continued to a hundred meters to subvert the effects of deep source magnetic features and to enhance shallow source magnetic features that are associated with geological structures. Figure 5 shows lineaments, which are structural deformations associated with geological phenomena such as arching zones and even geological contacts. Magnetic minerals are concentrated along or aligned with certain structures, and lineaments were defined by noticing the sudden change in positive and negative magnetic anomalies. This gives a rough understanding of the research area's structure and lithologic deformations.

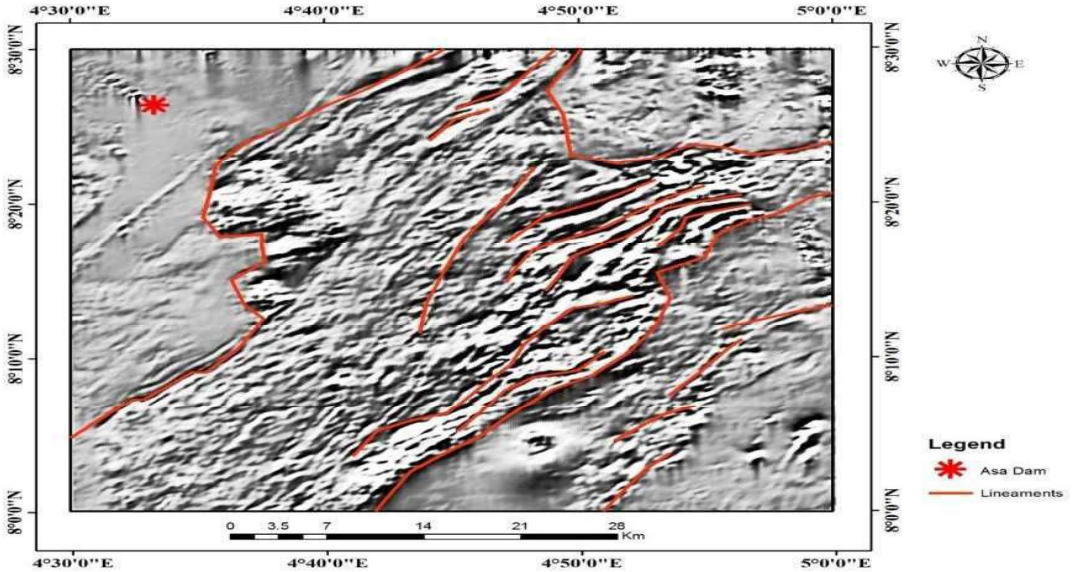



**Figure 5: The First Vertical Derivative map, showing lineaments in Asa dam area**

### 3.4 Asa dam 2-D resistivity Tomography

The first ERT profile was taken along the downstream sides of the dam around 15 meters from the center, while the second ERT profile was taken near the dam's core. The two ERT profiles are laid out in a SW-NE direction, beginning at the dam's embankment and ending at the spillway (Figure 6). To acquire better results from noisy data, the obtained ERT data were inverted using the least-squares method, which included smoothing of model resistivity.

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**Figure 6: Asa dam Resistivity Tomography Profile**

The 2D inversion of the ERT field data yielded results that were interpreted to characterize the subsurface structure within the research depth. The difference between the measured and computed apparent resistivity values must be reduced for this method to be optimized. The root mean squared (RMS) error is used to express this difference. The ERT field data was obtained along the profiles of traverse 1 and traverse 2. Dipro 4.0 computer software was used to invert the data.

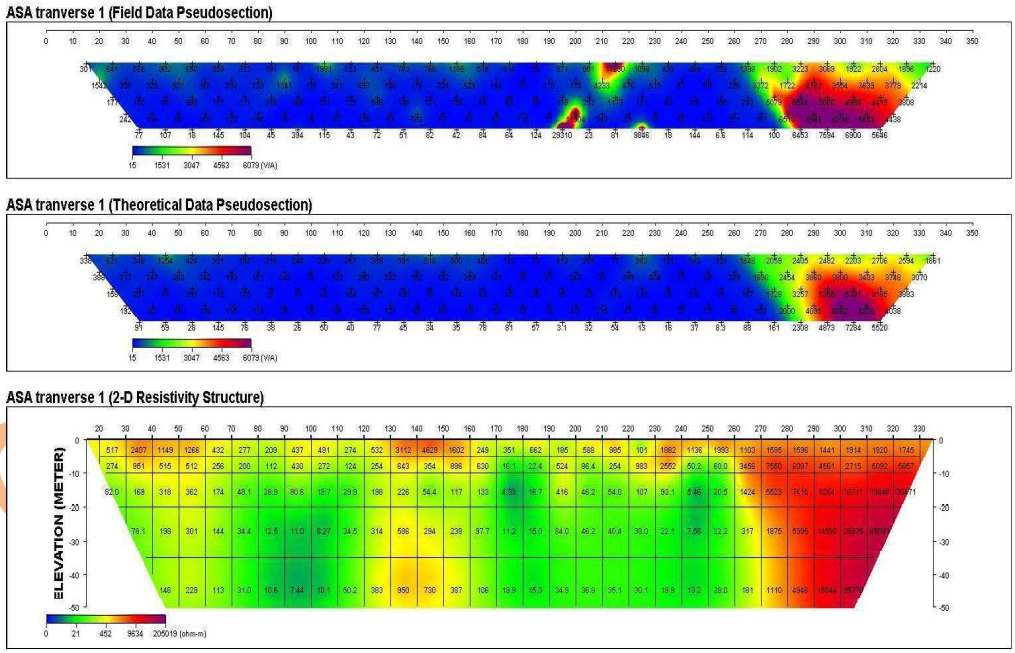



**Figure 7: Interpreted geo-electrical section of RTM 1 profile of Asa earth embankment**

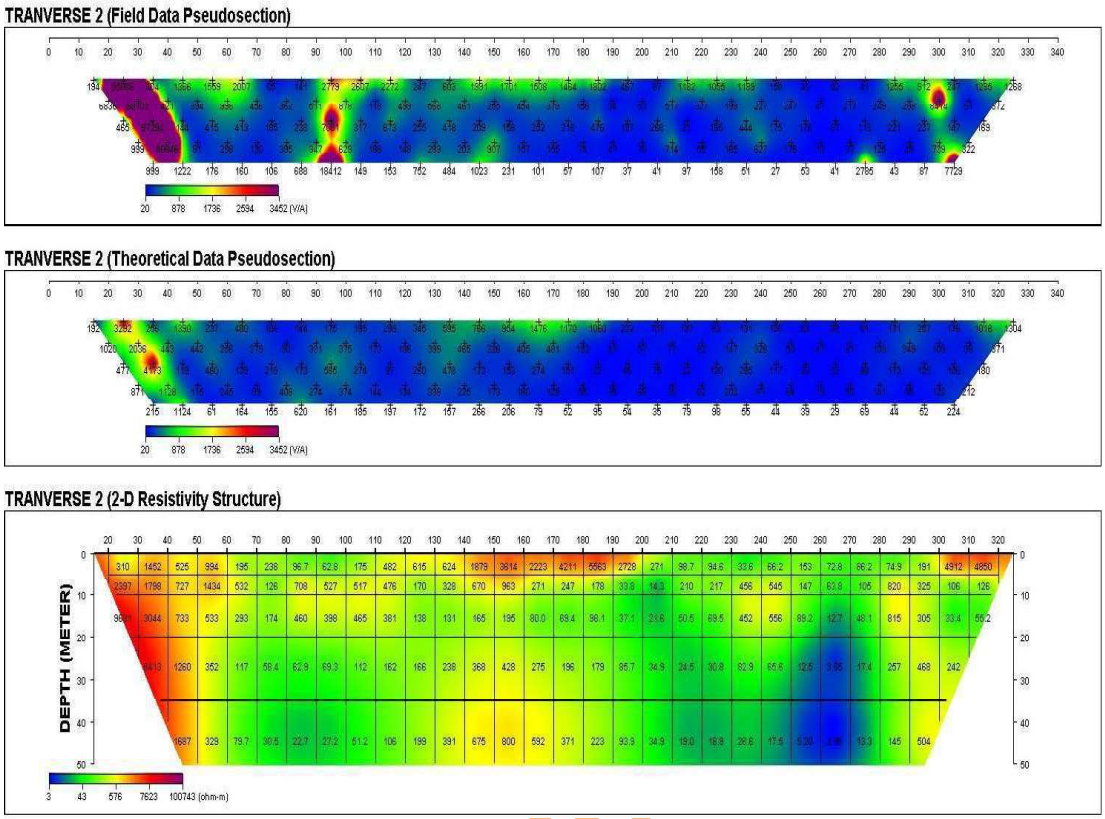
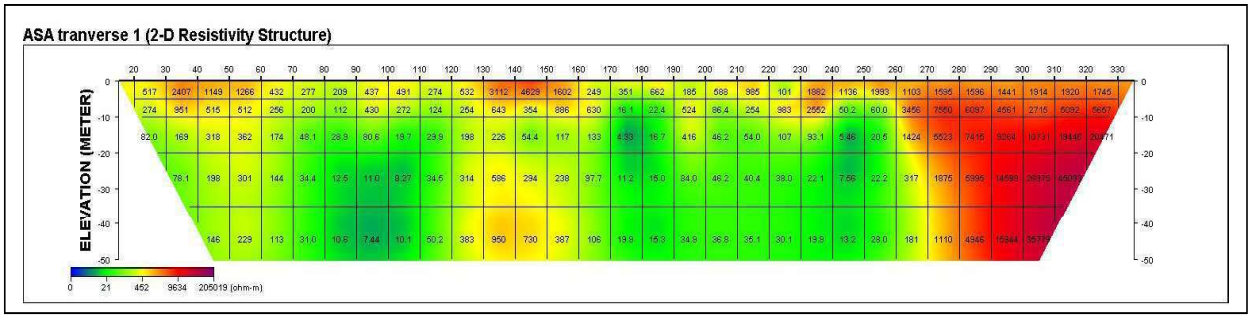



**Figure 8: Interpreted geo-electrical section of RTM 2 profile of Asa earth embankment**

Figures 7 and 8 shows traverse 1 and traverse 2 pseudo-section of the Asa dam established along the dam embankment. It shows both the theoretical, field sections, and resistivity structures. It further shows the cross-section of RTM 1 and RTM 2 profile of the subsurface up to a depth of 50 m. RTM 1 is along with the downstream of the dam embankment while RTM 2 is along the center of the dam embankment. The 2-D resistivity image shows three major resistivity zones; very low resistivity indicated by the blue coloration (depicting overburden and/or seepage zones or water-bearing soils), medium-range resistivity indicated by the green to yellow coloration (depicting lateritic soils, weathered basements, and indurated soil that is relatively impermeable to water), and the high range resistivity indicated by orange to purple coloration (depicting the fresh basement/highly competent rocks).

Figure 9 correlates the resistivity of RTM1 and RTM2 of the Asa earth embankment. The dam is well compacted at the surface which shows high resistivity values from the surface and relatively throughout the dam embankment. A relatively low resistivity zone is observed around chainage 250 to 270 commencing from around 15 m depth indicating weakness and or water-bearing zone. This location is observed to be the sand filter zone which is used in collecting the excessive underground water and water percolation in the semi-permeable zone of the composite earth dam. This does not affect the integrity but enhances the stability of the dam embankment and foundation. It could be observed that this is only noticed at the downstream section (RTM 1) of the earth embankment whereas the center (RTM 2) of the dam embankment at this section is highly indurated with no visible sign of water.

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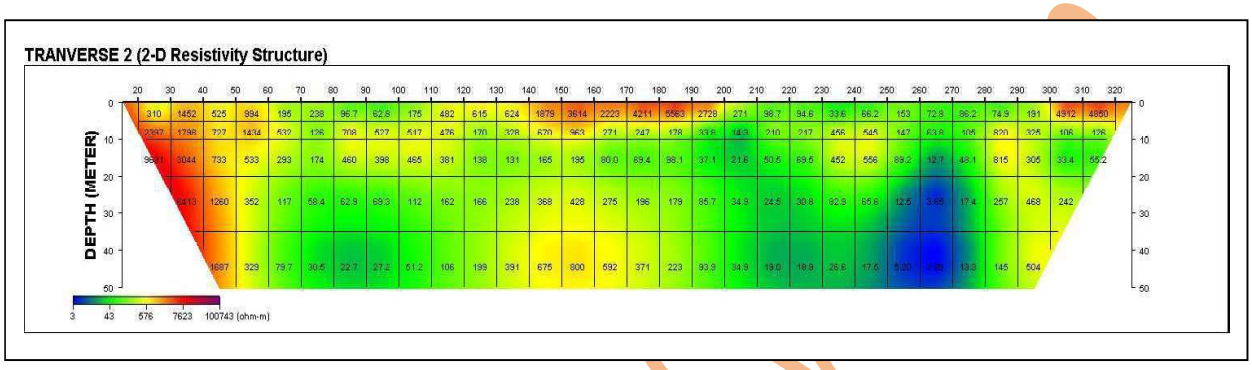




**Figure 9 Correlation of RTM1 and RTM2 of Asa earth dam embankment**

## 4.0 DISCUSSION AND CONCLUSION

The area of study falls within the basement complex of Nigeria that has undergone several episodes of deformation (polycyclic) according to Rahman, 1984. The patterns of folding and faulting observed on the FVD map (Figures 5) 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 themselves in the manner that the host rocks have done.

Before 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 a dam will increase significantly the construction cost, technicalities required for its construction and may also lead to failure of the dam in the long run which may affect lives and properties situated around the dam area especially the downstream. As seen in Figure 5, most of the lineaments are concentrated in the mid-part of the area of study and trends in a NE-SW direction. Shearing is also taking place in the middle part of the area of study. The style of folding and faulting in the area of the study suggests this area could be a shear zone i.e. places where several shearing is taking place, and as such is not suitable for dam emplacement without proper foundation treatment. This would however make dam construction in such areas more challenging and expensive. The northwestern part of the Asa dam study area (Figure 5) shows little or no sign of faulting and appears to be more stable than the other area of the map. It is not surprising that the Asa dam had been emplaced in such an area. The area is fairly stable structurally. We could therefore deduce from the above that the Asa dam is located in less structurally active zones and could likely have a functional failure rather than structural because there are no visible geological structures near the dam area.

Characterization of the Asa dam subsurface for seepage appraisal using resistivity tomography technique on the other hand revealed that the dam is well compacted and highly indurated at the surface and at depth, which shows high resistivity

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values from the surface and relatively throughout the dam embankment.

Conclusively, Asa earth dam is situated in a geologically stable environment as deduced from the aeromagnetic study and its earth embarkment is well compacted and highly indurated with no sign of seepage as obtained from the electrical resistivity tomography techniques of investigations.

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