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Geophysical Exploration of Gold Mineralization Zones using Induced Polarization and Electrical Resistivity Imaging Methods at Itagunmodi Area of Ilesha, Osun State, Southwest Nigeria

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ABSTRACT

Gold is a valuable and economically solid mineral due to its unique physical and chemical properties. However, this research investigated the potential zones of gold mineralization at Itagunmodi in Atakunmosa West Local Government Area of Ilesha, Osun State, Nigeria, through the generation of subsurface 2D resistivity and induced polarization models that provide helpful information in determining the depths and lateral distances of suspected gold deposits. The time domain-induced polarization and electrical resistivity imaging (ERI) measurements were carried out along six traverses using dipole-dipole configurations with electrode separations of 5.0 m and profile lengths ranging from 128.0-315.0 m. The apparent resistivity and chargeability data were used to generate 2D subsurface models using RES2DINV software to accurately and effectively interpret the location of gold mineralization potential zones. The results from the 2D ERI and chargeability models along traverses 1 and 2 revealed low resistivity zones ranging from 16.3-669.0 Ωm corresponding to high chargeability zones ranging from 288 to 444 msec on the 2D chargeability section, which were identified at lateral distances of 82.5-102.5, 167.0-187.5, 164.0-260, 95.0-110.0, and 55.0-75.0 m from approximated depths 9.94-26.20, 6.76-36.98, 11.0-23.0, and 6.0-12.0 m beneath the subsurface. These anomalous zones along these traverses weresuspected to harbour minerals such as goldsince they can also be attributed to quartz veins and fractures that may likely be filled with conductive materials like gold and associated base metals. This research has revealed the efficacy of electrical resistivity and induced polarization methods in delineating the suspected regions of gold mineralization.

Keywords:
Electrical resistivity imaging,
Gold mineralization,
High chargeability,
Induced polarization,
Low resistivity.

INTRODUCTION

Gold is a valuable and profitable metal that provides substantial financial gains because of its unique physical and chemical properties. The rush for gold in Itagunmodi, Ilesha, is a result of the high demand and rising price of this precious metal, where low-skilled local miners, especially from the northern part of Nigeria, have settled to extract the mineral and other associated base metals from a mineralized quartz vein (Osinowo and Falufosi, 2018). Gold deposits in the Ilesha area are primarily associated with the younger metasediments, particularly the schist belts. Significant deposits can be identified at the Itagunmodi, Iperindo, and Ibodilocations. Other occurrences are found at Ifewara, Ibokun, Ijana and Idoka. These deposits manifest in two main forms: primary and alluvial. The primary deposits predominantly comprise tiny auriferous quartz veins and strings that have intruded sheared zones within granite gneiss at Iperindo and in amphibolites at Itagunmodi and Ibodi.

On the other hand, alluvial gold deposits result from the erosion of primary deposits within the surrounding country rocks. The eroded gold concentrates within the channel of tributaries flowing into the Osun and Owena rivers in the Ilesha district (Adekoya *et al.,* 2003). The primary deposits are persistent and low-grade, while the alluvial deposits are richer and widely spread. The latter thus constitutes the primary source of gold exploited in the Ilesha area. The primary gold in Itagunmodi and Iperindo areas exhibits varying grades, ranging from 5.3 grams per tonne to 62.2 grams per tonne with an average of 20.2 grams per tonne (Adekoya *et al.,* 2003).Mineral resources provide a significant source of national wealth. However, before they can be used, the prospecting, exploitation and processing stages must be fully completed (Adekoya, 2003; Aigbedion, 2007; and Idowu, 2013). Nigeria's solid minerals have a substantial commercial value, with over seventy percentage hidden underground in the northern part of the country (Nasir *et al.,* 2018). Nigeria must prioritize exploring, exploiting, and adequately utilizing these abundant mineral resources to drive economic growth and ensure sustainability. By doing so, the nation can create opportunities for establishing small-scale industries, significantly reducing unemployment. Currently, much of the exploitation is carried out informally and often illegally, using crude methods that disregard environmental and human health concerns (Nasir *et al.,* 2018).

The non-invasive geophysical technique ERI can effectively estimate the 2D subsurface electrical resistivity distribution (Ojo *et al*., 2022). It depends on how the electrical resistivity characteristics of the targeted zones and the host rock differ (Telford *et al*., 1990). Porosity, clay content, saturation level, pore fluid conductivity, and pore fluid temperature significantly impact the subsurface electrical resistivity characteristics (Levy *et al*., 2018). For years, resistivity methods have been utilized in various rock formations to characterize the subsurface. The technique was thought to be highly laborious in earlier applications, but introducing multi-electrode surveys has dramatically reduced this drawback (Ewusi, 2006).

In numerous locations worldwide, the Induced Polarization (IP) approach is quite effective in mineral exploration in various subsurface settings (Yuval and Oldenburg, 1996; Ayman *et al*., 2018). Exploring dispersed mineralization can be accomplished using the (IP) approach. According to Maman (2014), this measurement shows the extent of specific mineralization in the rock and offers a way to find and map conductive mineralization and alteration. Its capacity to identify even minute concentrations of metallic minerals under favourable conditions is the main benefit of the IP approach (Maman, 2014).

Electrical resistivity imaging has been deployed in Ilesha area for the purpose of gold exploration. In 2020, Osinowo *et al.* employed electrical resistivity tomography to map the potential for gold mineralization in Iperindo, southwest Nigeria's Ilesha schist belt. Some of the delineated low resistivity zones from their results have sharp, vertical edges, which are probably due to the vertical faults flanking the zones. These zones' low resistivity may be explained by the presence of conductive materials, such as gold and related base metals, which are most likely found in the pegmatite veins that run through them. Kazeem *et al*. (2021) used electrical resistivity imaging and induced polarization method to investigate the mode of occurrence of mineralization in part of Ilesha Schist Belt, Southwest Nigeria. Their result revealed that the areas with low resistivity are suspected to be fault/fractured zones, which agree with high chargeability zones, indicating disseminated mineral deposits within the fractured/fault zones.Moreover, the Electrical Resistivity Imaging (ERI) and Induced Polarization (IP) techniques, due to their efficacy in mineral exploration, were fully deployed at the Itagunmodi area of the Ilesha schist belt to delineate the potential zones of gold mineralization due to the challenges of failed targets occasionally encountered by the local miners.

MATERIALS AND METHODS

Location and Geology of the Study Area

Itagunmodi, which falls within Atakunmosa West Local Government Area of Ilesha, Osun State (Figure 1), is located between latitude 070 28' 12"N to 070 33' 00"N and longitude 040 37' 12"E to 040 42' 00"E. It is a typical rural community where the number of migrants working in minefields is significant. Agriculture makes up most of the land use, particularly the production of food crops like fruits, yams, and cassava, as well as cash crops like cocoa, kola nuts, oil palm, and plantains. Many farmlands have holes in them that were excavated while searching for gold. The weather is described by two distinct seasons: the tropical wet season, which runs from April to October, and the dry season, which runs from November to March (Awoyemi *et al*., 2005). The study area is in the Nigeria Basement Complex (Figure 2). The main rock groups in the Ilesha region are a component of Nigeria's Proterozoic schist belts, which are primarily found in the western part of the country (Julius and Adekunle, 2015; Rahaman, 1976).

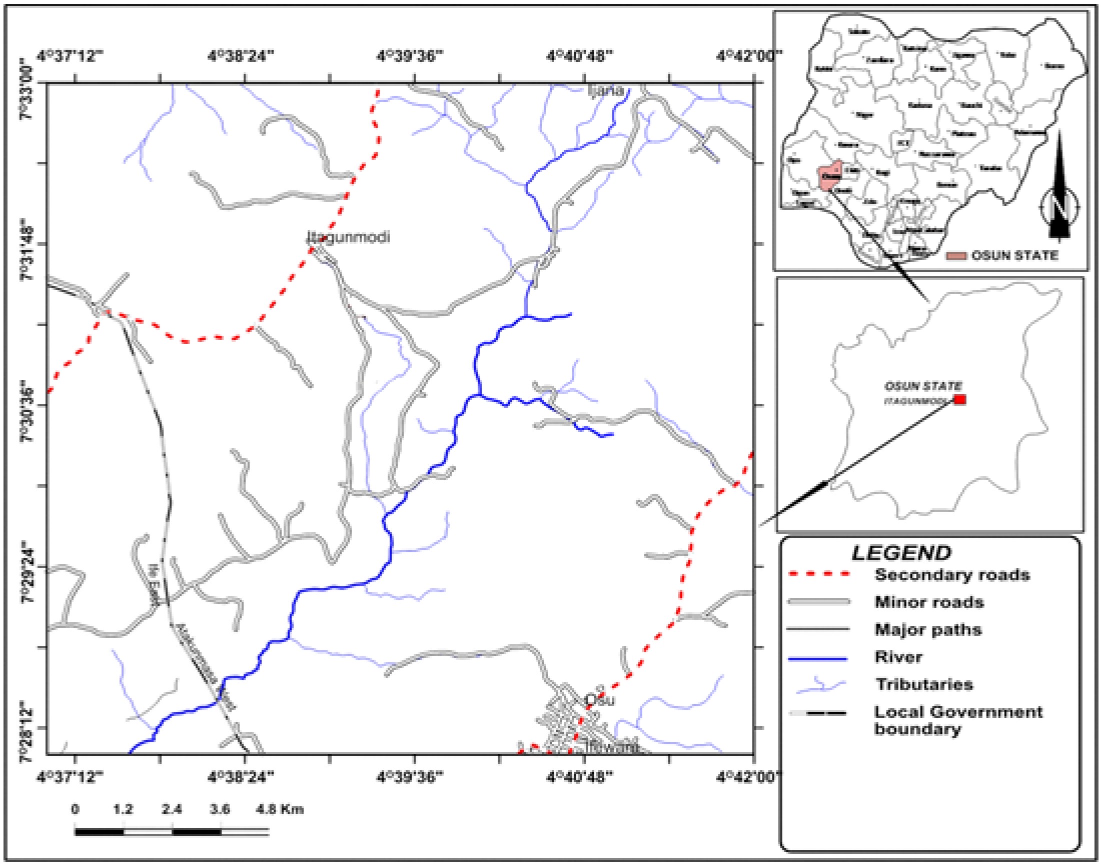

Figure 1: Location map of the study area

The Nigerian schist belts' structural characteristics, lithology, and mineralization bear significant resemblance to the Achaean Green Stone Belts. But in the latter case, the proportions of mafic and ultramafic rocks and lower metamorphic grade assemblages are frequently substantially higher (Olusegun *et al.,* 1995; Rahaman, 1976; Julius and Adekunle, 2015). The Iwaraja faults in the eastern portion and the Ifewara faults in the western part are two critical fracture zones that structurally split the rocks in the Ilesha Schist - Belt regions into two main segments (Julius and Adekunle, 2015; Folami, 1992; Elueze, 1986). Meta-ultramafites, meta-pelites, amphibole schist, and amphibolites comprise most of the fault's western section. The eastern portion is made up of large psammitic units with little meta-pelite. These are found as quartz schist and quartzites. These assemblages are all cut by a range of granitic rock formations and are linked to migmatitic gneisses (Julius and Adekunle, 2015; Olusegun et al., 1995; Rahaman, 1976).

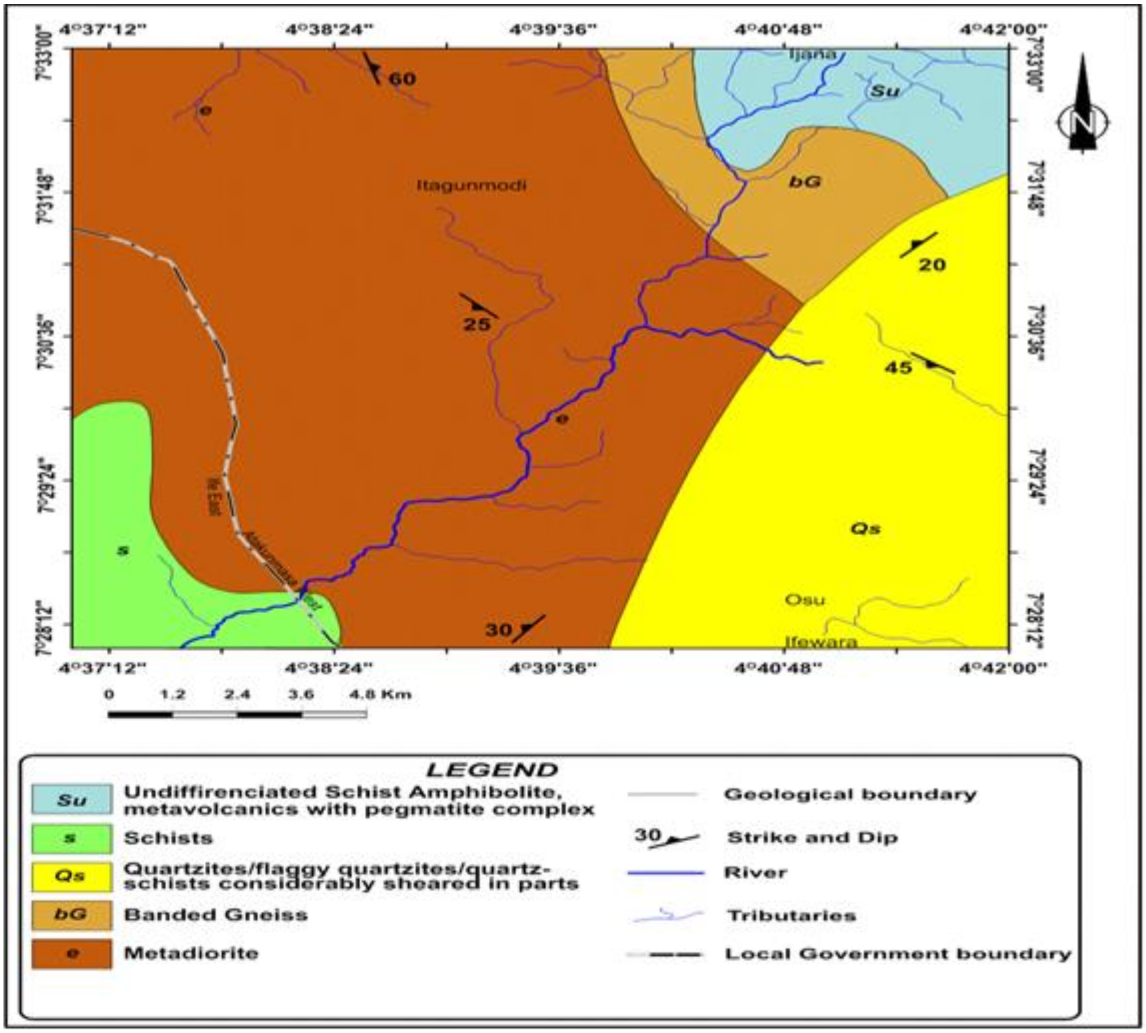

Figure 2: Geological map of the study areas

Data Acquisition and Processing Method

In order to prevent or reduce failed targets occasionally encountered at times by the local miners in the study area, time domain Induced Polarization (IP) and Electrical Resistivity Imaging (ERI) techniques were used to investigate the potential gold mineralization zones using dipole-dipole electrode configuration as arranged in Figure 3.

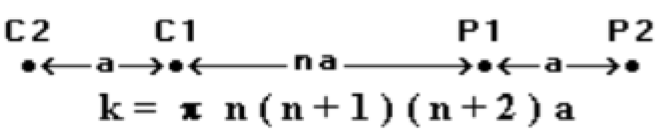

Figure 3: Dipole-Dipole electrode configuration(Loke, 2011)

In this study, the time domain IP and ERI measurementswere undertaken simultaneously. The method involves injecting a known current intensity intothe ground via a pair of stainless-steel electrodes and measuring the electric potential generated between two other non-polarizable electrodes. With the injected current and the measuredpotential, the apparent electrical resistivity of the subsurface can be calculated using equation (1) (Ewusi, 2006).

$$\rho_a = \frac{K\Delta V}{I} \qquad (1)$$

Where K is the geometric factor which depends on the arrangement of current and potential electrodes, V is the potential difference in volts, and I is the current in amperes.

However, for time domain IP measurements, the voltage decay between a pair of non-polarizable electrodes is measured after the current is cut off. As soon as the current is activated, an induced potential is generated across the potential electrodes. The initial voltage (V_o) is measured shortly after a charge-up effect to calculate the DC electrical resistivity right before the current is cut off. The voltage falls to a secondary level following the current interruption, and it decays over a limited and observable amount of time during the relaxation period. Equation (2) yields the calculated parameter of the subsurface materials, known as the chargeability M, which is expressed in milliseconds as explained by Reynold, 1997.

$$M = \frac{1}{V_o}\int_{t1}^{t2} V_p(t)dt \qquad (2)$$

Where $V_p(t)$ is the secondary potential integrated over a time frame between t_1 and t_2. Different minerals can typically be identified by their characteristic chargeability (Kearey and Brooks, 1991).

The data acquisition was carried out along six established traverses whose profile length ranges from 128-315 m using Abem multi-electrode resistivity meter which is capable of measuring both the resistance and chargeability of materials in the subsurface simultaneously. Traverses 1-4 were established in NW-SE direction with 30 m inter traverse separation. Likewise traverses 5 and 6 were also established in SW-NE direction with 50 m inter traverse separation which cuts across traverses one to four (Figure 4). Sixty-four (64) electrodes were laid and hammered to the ground along the traverses and cables were connected to each of the electrodes through which current was injected into the ground.Dipole-Dipole electrode configuration with electrode separation 5.0 m was employed.The resistivity meter was set to four cycles of stacking with a standard measurement error of 5%. The data were automatically calculated at each measurement, stored in memory in a format compatible with RES2DINV software, and later retrieved for processing.

The apparent resistivity and chargeability data for all the six traverses were processed and jointly inverted to obtain the 2D resistivity and chargeability models of the subsurface of the study area using RES2DINV software.The software uses nonlinear optimization method and several inversion settings to automatically calculate the true resistivity and chargeability of the subsurface for the input data. The details of the inversion routine by Ojo et al. (2022) were adopted in the study. Moreover, for better observation of conductive and resistive zones, the inverted resistivity and chargeability models were displayed as 2D pseudo-sections which are comparable to a geological cross-section revealing the true depth and true resistivity/chargeability formation.

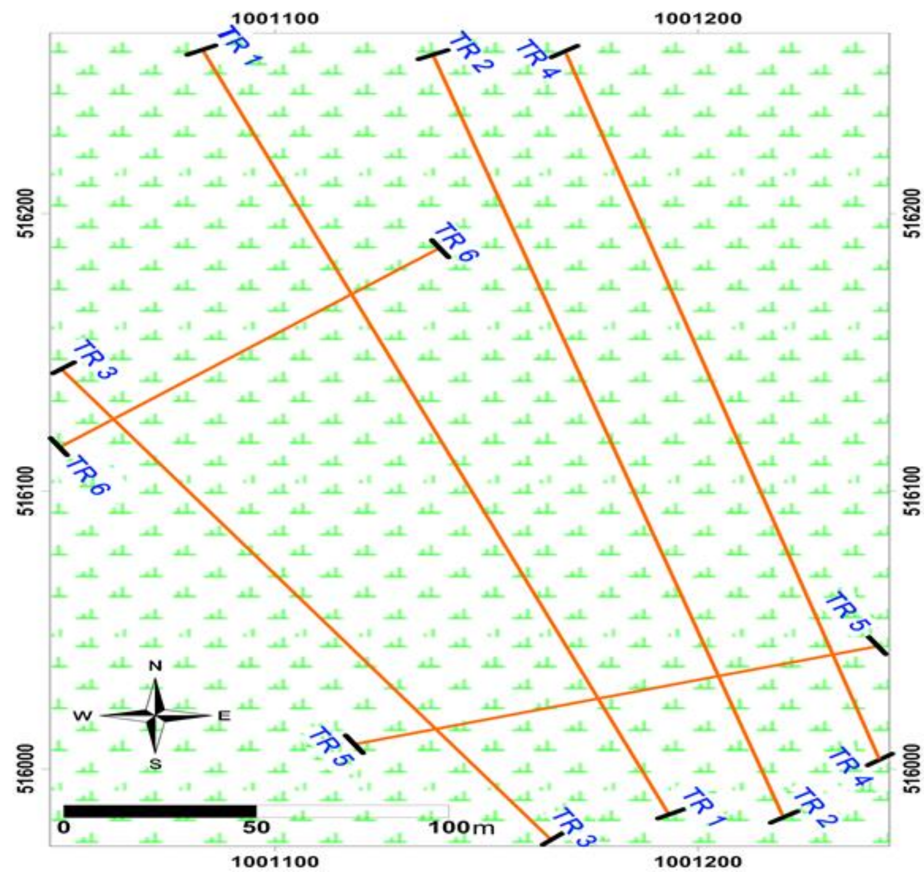

Figure 4: IP and ERI data acquisition map

RESULTS AND DISCUSSION

The 2D resistivity and chargeability inversion sections were presented in Figures 5-10. The results showed resistivity and chargeability sections varying in shape due to heterogeneous nature of the subsurface, probably as a result of different mineralization at different depths. In addition, the 2D inverted models also showed a qualitative idea of resistivity and chargeability distribution in thesubsurface.The primary gold deposits in the study area were associated with auriferous quartz veins and have invaded sheared zones in amphibolites, which are characterized by low resistivity and corresponding with high chargeability according to Ideozu*et al.*(2023).However, Figures 7, 8, 9, and 10 indicated the subsurface resistivity and chargeability distribution along traverses 3, 4, 5, and 6, respectively, whose resistivity values ranged from 30.8-1018632, 13.3-312562, 19.1-284863, and 1.76-71346Ωm and with correspondingchargeability values ranging from 0.0-683, 0.0-834, 0.0-869, and 0.0-641 msec penetrating to a depth of about 49.9 m beneath the earth surface. The 2D resistivity models revealed regions withlow resistivity values but the corresponding chargeability plots showed very low potential for gold mineralization.

The 2D resistivity model and chargeabilityplot of traverse 1 (Figure 5)revealed low resistivity zones (16.3-64.5 Ωm) and denoted as zones C and D on the inverted section corresponding to high chargeability regions (288-432 msec) on the 2D chargeabilityplot identified at lateral distances82.5-102.5 and 167-187.5 m at depths ranging from 9.94-26.2 m. Likewise, a massive anomalous and pocket of low resistivity zones (76.8-669Ωm)corresponding to high chargeability regions (333-444 msec) on the 2D chargeabilityplots wereidentified at approximated lateral distances164-260, 95-110, and 55-75 m from depthsrange of about 6.76-36.98, 11.00-23.00 and 6.00-12.40 m beneath the earth surface ontraverse 2 (Figure 6).The low resistivity with corresponding high chargeability zones along these traverses are regarded as the suspected regions of gold mineralization since they might contain several smaller sets of fractures and quartz veins that may likely be filled with conductive materials such as gold and associated base metals (Arifin et al., 2019; Naskar et al., 2018). The fractures can also serve as conduit for groundwater accumulation (Idowu and Ojo, 2024; Ojo et al., 2022).The 2D resistivity and chargeability models results from the survey only showed two promising traverses in Figures5 and 6, that could be exploited for economic purposes.

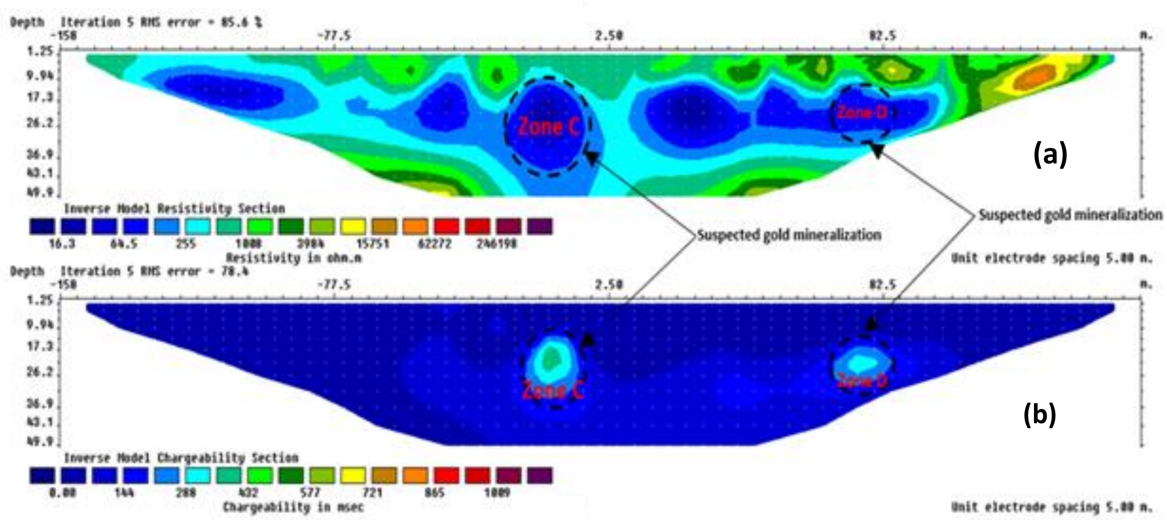

Figure 5: 2D inverted resistivity and chargeability sections along traverse 1

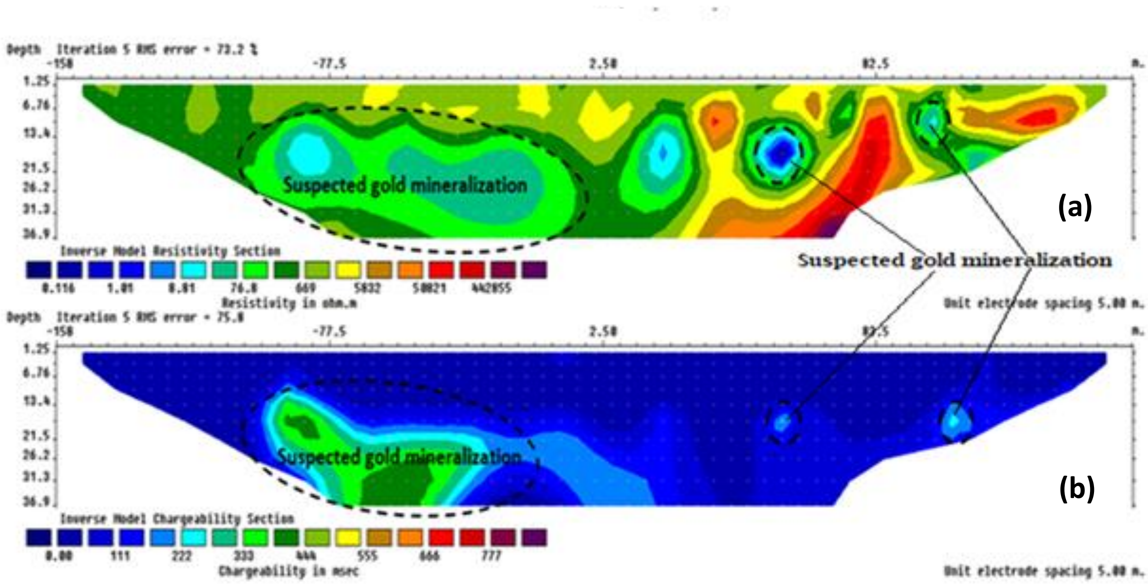

Figure 6: 2D inverted resistivity and chargeability sections along traverse 2

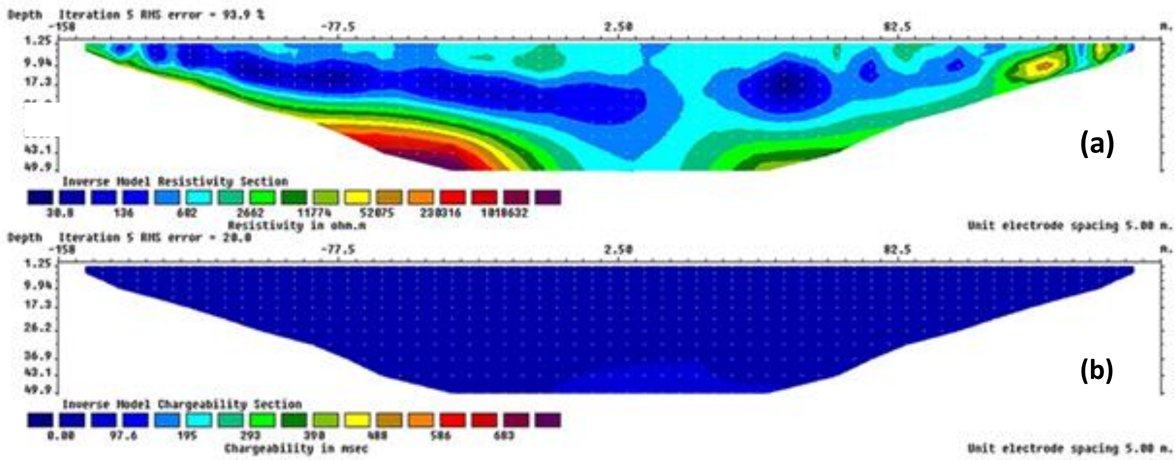

Figure 7: 2D inverted resistivity and chargeability sections along traverse 3

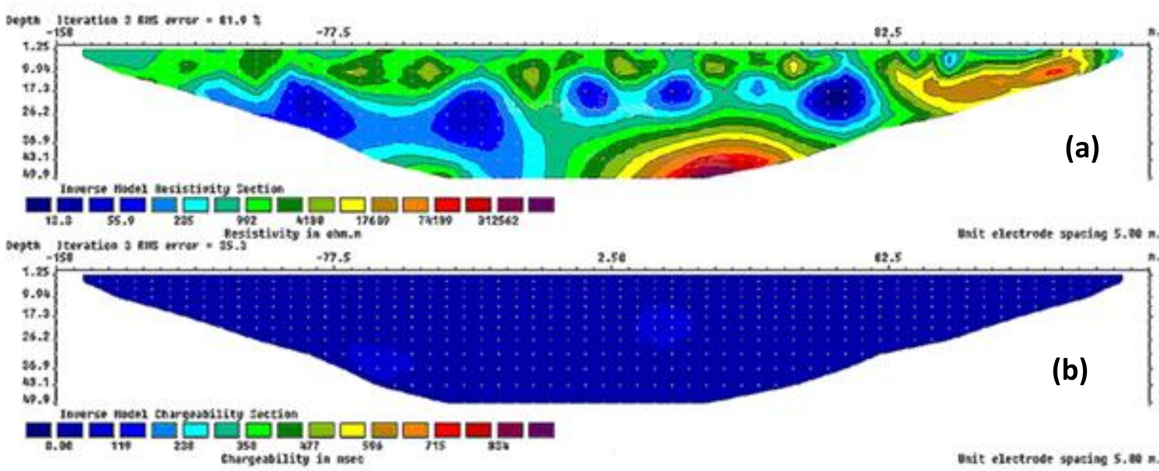

Figure 8: 2D inverted resistivity and chargeability sections along traverse 4

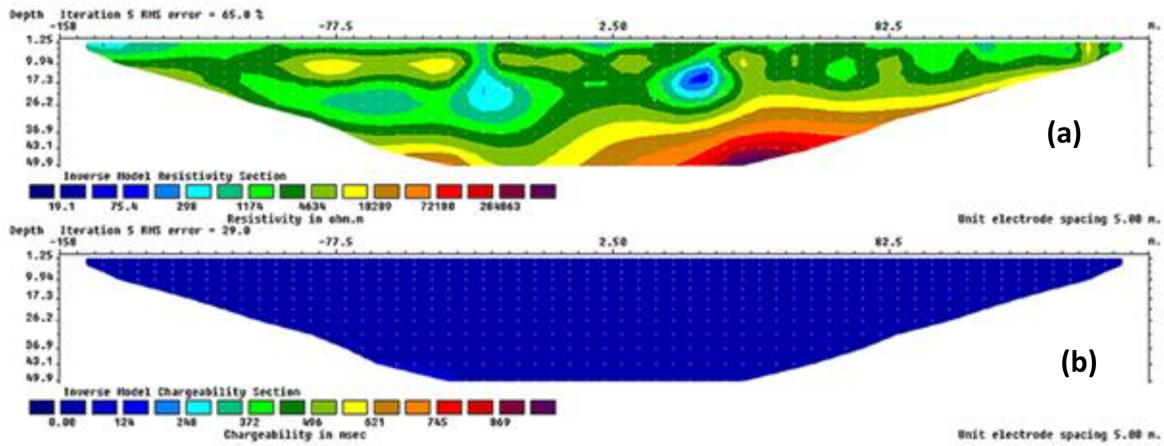

Figure 9:2D inverted resistivity and chargeability sections along traverse 5

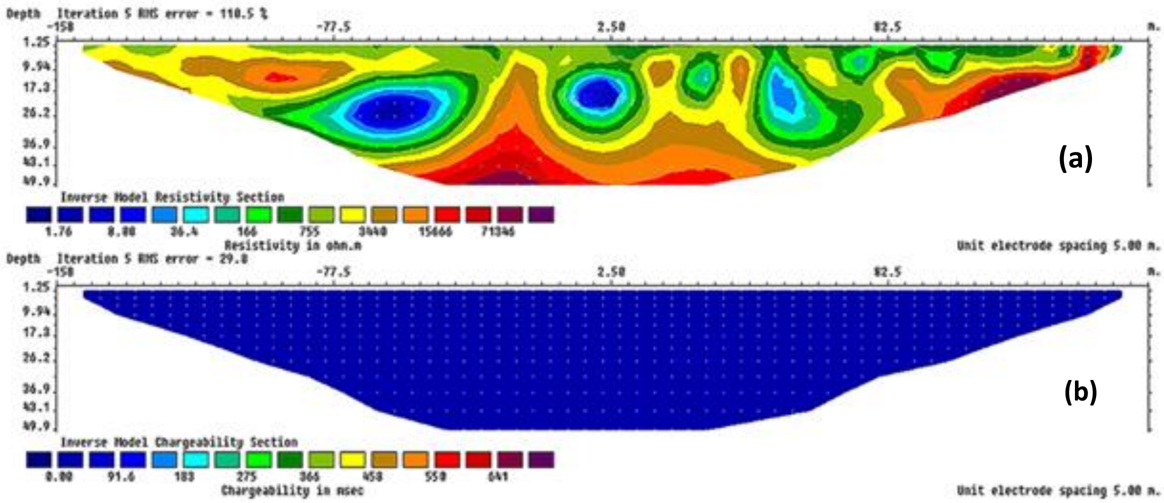

Figure 10: 2D inverted resistivity and chargeability section along traverse 6

CONCLUSION

Geophysical exploration was carried out at Itagunmodi in Atakunmosa west local government area of Ilesha to determine the potential zones of gold mineralization within the area using induced polarization and electrical resistivity methods. The results from the2D resistivity and chargeabilitysections showed clearly the heterogeneous nature of mineralization within the zones of low resistivity and high chargeability that may represent suspected gold bearing zones. Also, the results from the 2D inverted resistivity and chargeability models along traverses 1 and 2 revealed low resistivity zones ranging from 16.3-669.0 Ωm,corresponding to high chargeability zones with values ranging from 288-444 msec on the 2D chargeability section, which were identified at lateral distances of 82.5 m – 102.5 m, 167.0 m – 187.5 m, 164.0 m – 260 m, 95 m – 110 mand 55 m – 75 m from depth of about 9.94 m – 26.2 m, 6.76 m – 36.98 m, 11.0 m – 23.0 m, and 6.0 m – 12.0 m beneath the surface. The 2D electrical resistivity and induced polarization techniques have been effectively used to determine the lateral distances and vertical depths of suspected gold mineralization zones in the study areas which could be of economic values for the development of the country. This research has clearly revealed the efficacy of the adopted methods in delineating the suspected regions of gold mineralization.

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