

Archaeo-Geophysical Investigation of Simulated Settlement: Case Study in a Part of Basement Complex of Nigeria

Saminu Olatunji and Isaac Onimisi Lawal*

*Department of Geophysics, University of Ilorin, PMB 1515, Ilorin, Nigeria,
Email: sam61ng@gmail.com.

ABSTRACT: We have used the 2D Vertical Electrical Sounding method and Electrical Resistivity Tomography (ERT) method to map buried artifacts in a simulated settlement, and have shown how the geographical information system could aid future research. Stones, bones, metals, cement bricks, and cement-and-sand mixtures were locally constructed to fit into an African-archaeological setting. Parameters such as the materials' composition, width, electrical resistivity, height, age, and depth of burial were taken into account before this investigation. The integrated methods employed collected data over the study area along with a pre-calculated dense network of parallel profiles. A total of eight (8) VES points and six (6) ERT profiles were obtained. The analysis and interpretation revealed that the VES yielded poor resolution for small-scale archaeological anomalies and could only be used fractionally for prospection whilst the ERT results were more suitable for delineation due to the high spatial resolution they provided. The field values correlated with other literature values. This research suggests that rapid significant prospection information, of any area under investigation, can easily be obtained from Google Earth time-lapse images and that its results will serve as a thorough reconnaissance in the search of prehistoric activities.

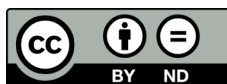
Keywords: GIS; Vertical Electrical Sounding; Tomography; Archaeology

التحقيق الأركيولوجي الجيوفيزيائي لتسوية المحاكاة: دراسة حالة في جزء من مجمع الطابق السفلي في نيجيريا

سامينو أولاتونجي و إسحاق أونيميسي لاوال

الملخص: لقد استخدمنا طريقة السبر الكهربائي العمودي ثنائي الأبعاد وطريقة التصوير المقطعي بالمقاومة الكهربائية (ERT) لرسم خرائط للقطع الأثرية المدفونة في مستوطنة محاكاة ، وأظهرنا كيف يمكن لنظام المعلومات الجغرافية أن يساعد الأبحاث المستقبلية. تم بناء الأحجار والعظام والمعادن وطوب الأسمنت ومخاليط الأسمنت والرمل محليًا لتناسب البيئة الأثرية الأفريقية. تم أخذ معالم مثل تكوين المواد وعرضها ومقاومتها الكهربائية وطولها وعمرها وعمق الدفن في الاعتبار قبل هذا التحقيق. جمعت الطرق المتكاملة المستخدمة البيانات عبر منطقة الدراسة على طول شبكة كثيفة محسوبة مسبقًا من الملامح المتوازية. تم الحصول على ما مجموعه ثمانية (8) نقاط VES وستة (6) ملفات تعريف ERT. كشف التحليل والتفسير أن VES أسفرت عن دقة منخفضة للشذوذات الأثرية الصغيرة الحجم ولا يمكن استخدامها إلا بشكل جزئي للتنقيب بينما كانت نتائج ERT أكثر ملاءمة لتحديد الحدود بسبب الدقة المكانية العالية التي قدمتها. ارتبطت قيم المجال بقيم الأدبيات الأخرى. يشير هذا البحث إلى أنه يمكن الحصول بسهولة على معلومات التنقيب المهمة والسريعة ، في أي منطقة قيد التحقيق ، من صور الفاصل الزمني لبرنامج Google Earth وستكون نتائجها بمثابة استطلاع شامل في البحث عن أنشطة ما قبل التاريخ

الكلمات المفتاحية: السبر، الكهربائي العمودي، الأشعة المقطعية؛ علم الآثار.



1. Introduction

The application of geophysical principles and techniques to locate concealed archaeology can be traced back many years before Archaeometry was published [1]. The first of such significant surveys took place at the prehistoric ditches of Dorchester in 1946 using a resistivity meter, and through the decades, several advancements have been made to provide portable instruments capable of taking simultaneous readings [2, 3].

Many corporate and public bodies have invested time and resources in the development of a well-structured discipline which, when superimposed with the educational, cultural and historical pillars, will encourage visitors, researchers, students and the entire public to participate in their historical heritage [4].

Archaeology is undoubtedly the solution and it remains the most precise proof of existence. A wise thought stated that “Evidence doesn’t lie, history may be accurate, but archaeology is precise” [5]. Also, the great scholars, James Hutton and Charles Lyell summarized this fact when they said: “the present is the key to the past” [6]. Archaeology is therefore a tool for unveiling present remains which when studied, can tell precise stories of our past existence.

Archaeology remains crippled and ineffective. It lacks the strength to precisely locate the remains of civilizations buried meters beneath the earth, lost in the sea, stratified in rocks, dissolved in volcano-genetic earth processes or well exposed in the desert. It is with respect to this problem that the power of geophysics is acknowledged as man’s greatest invention to accurately unravel the past, elucidate the present and, to a great extent, predict the future.

Geophysics has been successfully used in many archaeological areas of research, [7, 8, 9, and 10]. Yet, few geoarchaeological expeditions have been carried out in Africa and, more locally, Nigeria. One existing work carried out in Nigeria was in mapping the extent of the area of the remains of a Stone Age settlement of Zilum [11]. Records from internet open sources only present a few such explorations, none of which has made any remarkable breakthrough [11]. Owing to inadequate funding, inaccessibility to heritage sites, poor documentation, among numerous other impediments, archaeological geophysics has been little practiced in this part of the world.

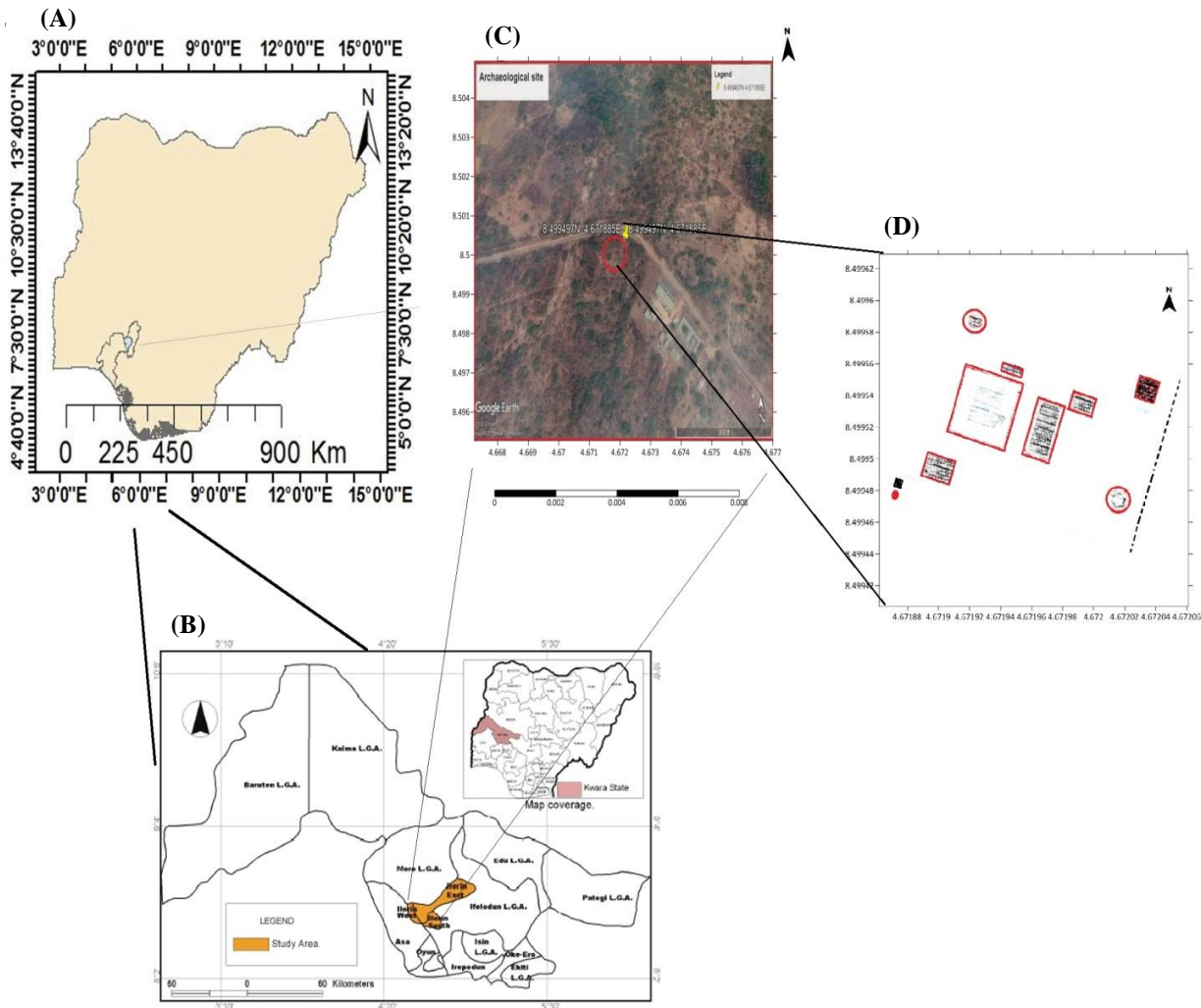


Figure 1. (A) shows the map of Nigeria and its coordinates, (B) shows the map of Kwara State, (C) shows the map of the study area generated from Google Earth, and (D) shows the base map of the area generated by Windows Surfer

ARCHAEO-GEOPHYSICAL INVESTIGATION

This project seeks to establish and define some variables necessary to facilitate future practices for archaeological research in Nigeria as well as to provide future researchers with a minimum of information on various archaeological signatures and subsurface indications. Through the earth resistance method, great advances can be achieved which will help to determine the various signatures from buried artifacts qualitatively, and will quantitatively characterize the dimensions of various features in a bid to reconstruct a model of what the culture was.

Above all, through a simulated approach, this study will provide insight into the challenges that future generations of geoarchaeologists will face in answering archaeological questions.

1.1. Local geology of the study area

The study area (Figure 1D) is a highly vegetated field bounded by two major roads in the north-eastern part of the University of Ilorin's main campus (Figure 1C). The campus (Figure 1B and 1A) is situated in the southern region of Ilorin, Kwara State which is primarily composed of Precambrian basement complex rock with very rich loamy soil. Owing to the leaching of minerals and nutrients from the soil, lateritic soil tends to form the soil types in Ilorin as a result of the heavy seasonal rainfall combined with the high temperature [12].

The region is bounded by the Sobi hill, which rises to 394 meters above sea level, and the western environs, which range from 273 to 333 meters. The Asa River has a dendritic drainage system that runs from Ilorin's southern to northern sections [12].

With the help of geoarchaeological research on time-lapse data, a hypothetical weather map has been postulated by [13] to guide archaeological geophysicists in their expected outcomes. With the aid of the resistivity contrast formula, anomaly contrast can easily be monitored. The research area is characterized by two major climatic conditions; the tropical wet and dry climate and Aw under the Koppen-Geiger classification. The survey was executed in March which has an average temperature of 26.2 °C (79.1°F) and average precipitation of 1185 mm (see Figure 2).

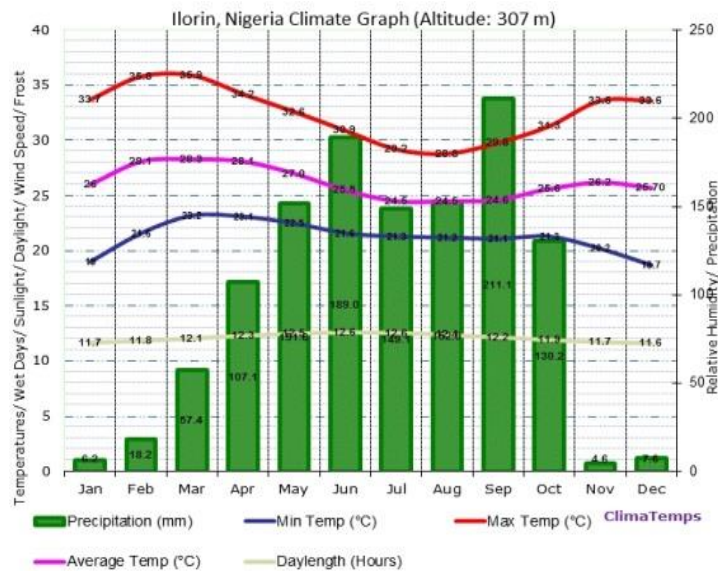


Figure 2. The Climate of Ilorin throughout the year [14].

2. Methodology

The simulated archaeological materials buried at the site consist of foundation walls, debris, ditches, a well henge, a metallic chest, and installations depicting a market area whose physical property (resistivity) is shown in Table 1. Having studied the resistivity of the items and installations, we can predict their detectability by the methods employed, and their contrast from background geological lithologies [15].

Sixteen (16) VES points and Six (6) ERT profiles were carried out at the study area (Figure 3).

2.1 Google Earth

The use of the Google Earth is supported by many researchers and though it was not directly used in this survey, it has been closely examined to aid future research. It offers quick and rapid coverage of plausible archaeological sites, providing data (such as aerial photographs) which when compared with survey data could yield better interpretative results [21].

The following are some steps taken during the analysis of a Google Earth image, but they are not exhaustive: land capabilities, geology, visible archaeological features, landforms, altitude, settlement patterns, vegetative cover and

changes, time-lapse events [22, 23, 24] etc. With the above done, three major methods are employed in determining the type of archaeological feature present in a Google Earth image as given by [22];

- Checking for anomalous features and changes using historical time-lapse images.
- Cross-referencing images with images from well-known archaeological sites.
- Comparing similarities between images and actual archaeological artefacts. One example is comparing a picture to a visible stone henge.

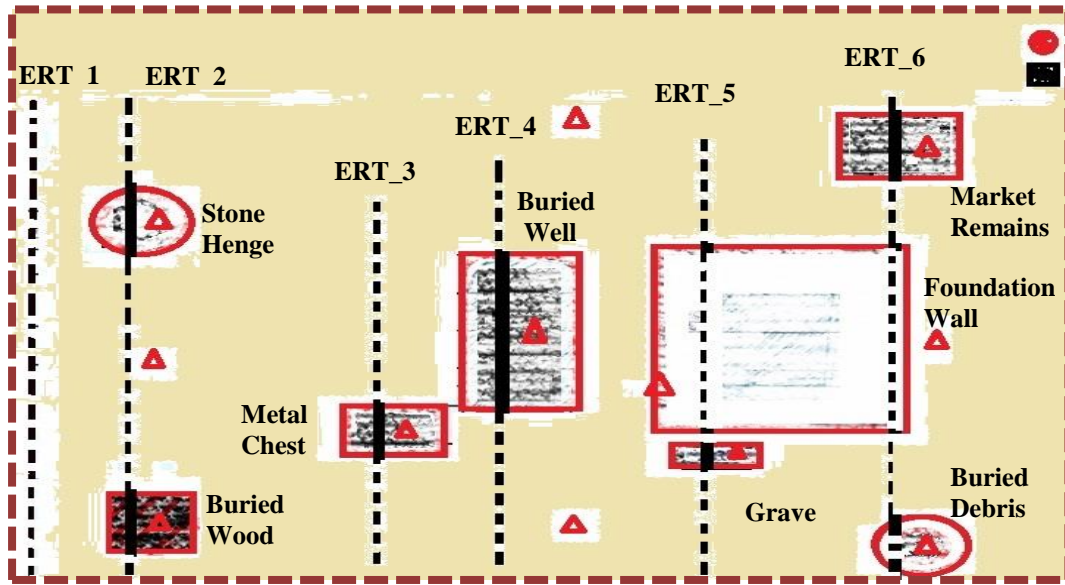


Figure 3. shows the base map generated for the study, the burial positions, the ERT lines and the VES points (denoted by the red-triangles).

Table 1. The dimensions and resistivities of each buried object.

S/N	Archaeological Connotation	Materials used	Parameters ($l \times b \times h$)m depth(m)	Resistivities (Ωm)
1.	King's market (A Ditch)	Cement Sand Water	($2 \times 2 \times 0.04$) 0.5	244.1-677.99 [16] 278 – 285 [17]
2.	Foundation of King's Palace	Cement Blocks	($5 \times 5 \times 0.3$) 0.3	244.1-677.99 [16]
i.	Debris (A Ditch)	Refuse Materials	($0.5 \times 0.4 \times 0.1$)	244.1-677.99 [16]
i.	Carpenter's shop (A Ditch)	Old woods	($0.5 \times 0.3 \times 0.02$) 0.5	4 - 1000 [18]
i.	Metal Chest	19 th - century Metal Box	($0.5 \times 0.4 \times 0.1$) 0.4	Depending on the coat, resistive if resistive and conductive if conductive
i.	Grave Site (A Ditch)	Cow, Bones Bricks	($1.3 \times 0.5 \times 0.2$) 0.4	244.1-677.99 [16]
j.	Stone Henge	Stones Cement Plaster	($0.3 \times 0.3 \times 0.2$) 0.4	180-1500 [19]
k.	Tree root	Tree	-	$990 - 10^6$ [20]

A Digital Elevation Model (DEM) is a multi-dimensional facility that enables visualization of surface characteristics, features and elevation arrays at regular intervals [25]. It plays a vital role in studying and analyzing various landscapes that existed [26], it helps reveal both natural and human-driven processes affecting the land and shows the social affordance of the area [27] and can be generated using the Google Earth Pro software in conjunction with the T and X Converter software.

2.2 Geophysical Methods

2.2.1 Earth Resistance Methods

Earth resistance surveys are based on the idea that subsurface buried artefacts and features alter electrical current flow injected into the ground through electrodes [13]. Because the integrity of results obtained depends more on the difference between the anomaly and the surrounding matrix rather than on the Apparent Resistivity of the feature [28, 29], weather, geologic, and soil conditions were incorporated in comprehending the signatures from buried artefacts. The resistivity of geological materials have one of the broadest ranges of all physical properties (from $1.6 \times 10^{-8} \Omega\text{m}$ for native sulfur to $10^{13} \Omega\text{m}$ for pure Sulphur) and in addition, resistivity surveys have the advantage of being less affected by above-ground material [29]; this has greatly facilitated its use. Thus, earth resistance surveys have stood for decades as the second leading geoarchaeological method [30].

The resistivity contrast formula (equation 1 and equation 2), helps to better understand the above statements

$$K = \frac{\rho_2 - \rho_1}{2\rho_2 + \rho_1} \quad (1)$$

$$\Delta\rho = \rho_{feature} - \rho_{background} \quad (2)$$

Also, a hypothetical weather map has been postulated by [13] to guide archaeological geophysicists in their expected outcomes (Figure 4).

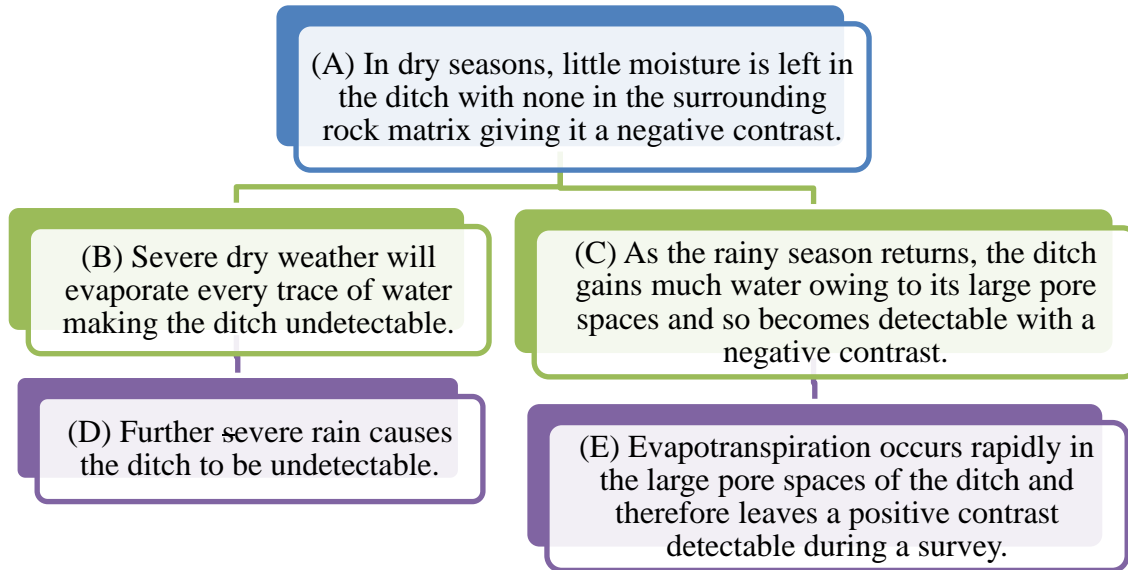


Figure 4. Hypothetical weather sequence.

Sixteen (16) VES data were obtained at various locations on the various burial locations using the Schlumberger array which possesses a high vertical resolution and moderate signal to noise ratio [31]. The *Winresist* software, which is based on the algorithm of [32] and [33], was used for the calculation of true resistivity and estimation of layer depth from the data.

The Wenner array, which is one of the most popular and simplest electrode configurations [34,35,36] has been reconfigured to form a 160 electrode ERT of high sensitivity (figure 5), thus enabling depth sections to be generated, high visualization of “buried features at particular depths” [21] and the ability to map areas possessing complex geology [37]. Six (6) profiles trending north-east and longitudinal to the burial positions were acquired. The Res2DInv software package, developed by Loke [20], which uses the inversion routine based on the smoothness-constrained least-squares method described by equation 13 [16, 19] and shown in Figure 5, was used to process the data.

$$(J^T J + \lambda F) \Delta q_k = J^T g - \lambda F q_k \quad (3)$$

where

$F = \alpha_x C_x^T C_x + \alpha_z C_z^T C_z$, C_x = horizontal roughness filters, C_z = vertical roughness filter, J = Jacobian matrix of partial derivatives, J^T = transpose of J , λ = damping factor, q = model change vector, g = data misfit vector.

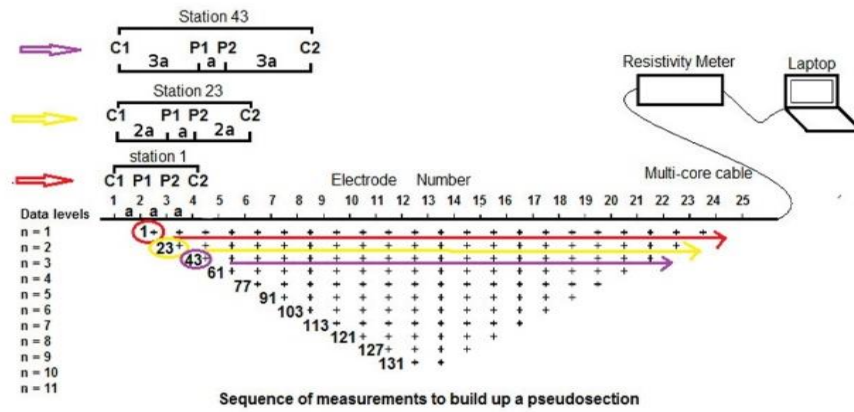


Figure 5. The data acquisition principle of the Electrical Resistivity Tomography (ERT) using four cultural electrodes [38].

The instruments for earth resistance measurement used were determined based on their sensitivity, site-specific factors, user familiarity and speed [39]. The instruments used in this survey are listed below:

1. Herojat Resistivity meter (A Nigerian made highly sensitive equipment)
 - a) Array: Schlumberger & Wenner (in ERT configuration)
 - b) Electrode Spacing: 0.5 m – 1 m
 - c) Software used: Winresist, Res2DInv.
2. Global positioning system (GPS)
3. Clips, paper tapes, water jar

The Schlumberger array was chosen for the prospection of anomalies and the ERT exploration method for careful delineation and partial characterization. To minimize survey profiles, the direction of known features was taken into account bounded by a 20 m² area, which is the most practicable value. Also, a compromise of 0.5 – 1 m electrode separation common for depths up to 1 m [21], was chosen in this study.

3. Results

It has been said that the work of translating geophysical data into a readable and understandable archaeological coefficient is not in any way easy [15], hence the need for critical consideration and standards of comparison, before, during and after every research as shown in Table 1 above.

3.1 Google Earth Results

It should be noted that, whilst other geophysical methods employed in this work related to actual field data to solve the archaeological questions, the results from Google Earth used in this work have only been used hypothetically to show how it could be used as a tool for archaeological prospection in future surveys. The analysis of the results, in the context of geo-archaeology, has been summarized in Table 2.

Other features that could easily be spotted from the Google Earth images include but are not limited to: communal areas, farming areas, old ditches, graveyards, etc.

Table 2. A summary of the Google Earth images.

S/N	Features	Old Image Figure 6B (2017)	New Image Figure 6A (2021)	Inferences
1.	Abandoned road (<i>trending Eastward in figures 6A & 6B</i>)	Partially submerged (Red Arrow)	Totally submerged (Red Arrow)	The road network that existed in the vicinity before it was abandoned for a new road can still be noticed
2.	Academic facilities	Not yet Built (White circle)	Built-Up (White circle)	Changes in structural buildup over the years could be used to trace submerged features or demolished archaeological structures.
3.	New Road (<i>trending Eastward in the figures 6A & 6B</i>)	Under Completion	Completed	
4.	Vegetative cover	Not Visible	Heavily Present with Tall Tress	

ARCHAEO-GEOPHYSICAL INVESTIGATION

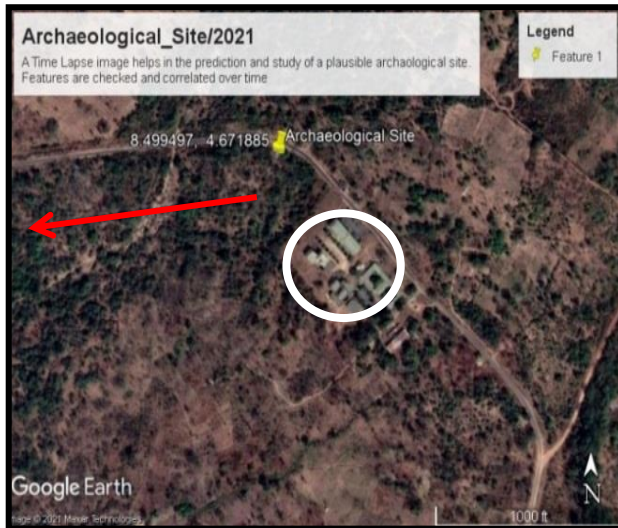


Figure 6A. The Google Earth image showing a submerged road and a built-up facility.



Figure 6B. Google Earth image of the submerged road and a built-up facility from 2016.

The advantages of Google Earth cannot be overstated. The availability of high-resolution images, which can be accessed at any time and from any location through the internet, is a very useful function of Google Earth. Google Earth avoids the high costs of commercial satellite imagery or aerial photography by providing free access to data through portable Internet devices. By increasing the speed of surveying, Google Earth saves time. The time-lapse is the most useful feature of Google Earth in the historical imagery slider as used in this research, and is the best and most useful innovation in Google Earth.

3.1.1 Digital Elevation Model

The DEM was derived from Google Earth Software as a plausible prospection tool and utilized to facilitate this project. The DEM derived for the area, shown in Figure 7 (the study area marked by a white circle), shows the elevation distribution of the area, the topography, and the gradient of the land. These variables obtained could indicate a reconstruction of the area due to possible submergence of structures and rise in topography due to secondary deposition, which could aid prospection, and survey planning.

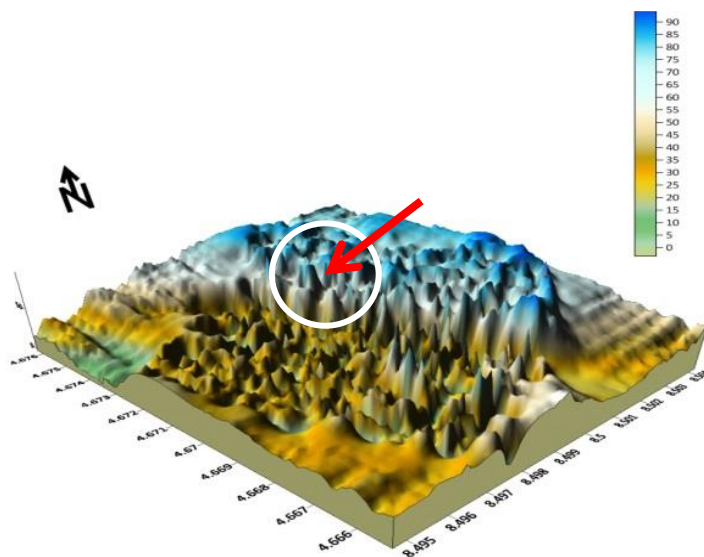


Figure 7. Digital Elevation Model obtained from Windows Surfer 16.

3.2 Vertical Electrical Mapping

The final values obtained after thorough manual curve matching assisted by the WINRESIST software (Figures 8A and 8B) as shown in Table 2 were visually interpreted using Windows Surfer 16 to create a colour scale resistivity contour map of the first layer only (Figure 8) since most anomalies were buried at shallow depths.

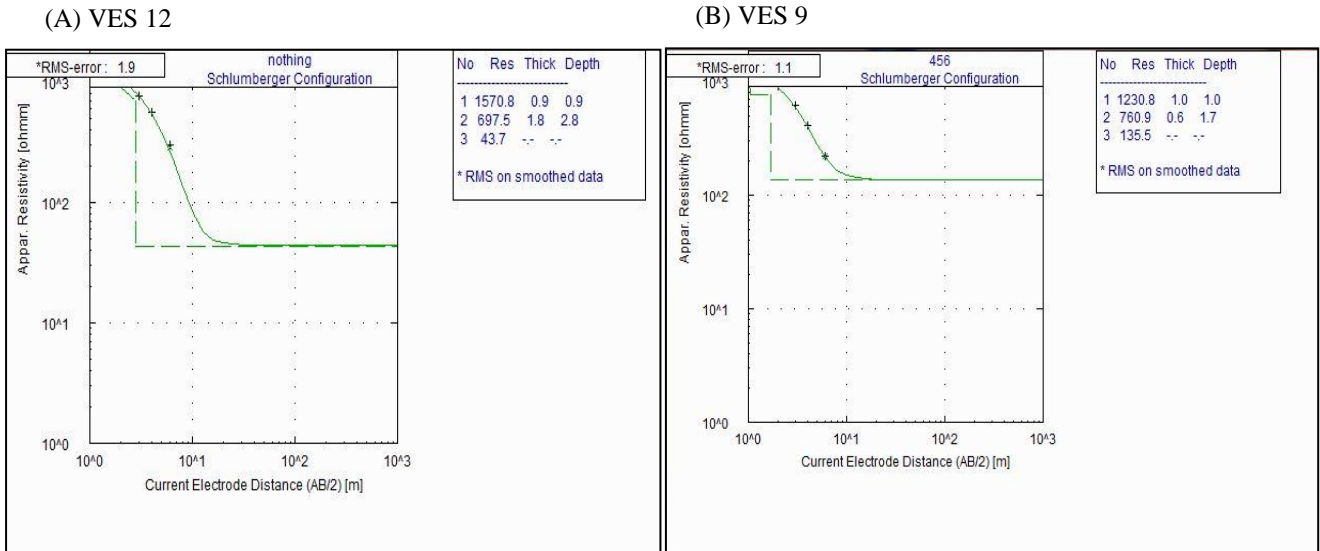


Figure 8A and 8B. Sample VES field curves, plotted using the WINRESIST Software after thorough curve matching.

Table 3. The resistivity of the buried objects layer.

VES. No.	Thickness of Layer (<i>h</i>)	Resistivity of Layer (Ωm)	Latitude (Dec.)	Longitude (Dec.)	Status
1.	1	1230.8	8.499497	4.671885	King’s market
2.	0.9	1680.5	8.499526	4.671862	Foundation
3.	0.7	1320.3	8.499579	4.671896	Foundation
4.	0.8	1059.7	8.499629	4.671913	Debris
5.	0.8	1016.1	8.499600	4.671873	-
6.	1.1	842.5	8.499552	4.672033	-
7.	1.2	868.3	8.499565	4.672061	Wood shop
8.	0.8	804.8	8.499486	4.671999	-
9.	1.0	577.3	8.499575	4.671966	Metal Chest
10.	1.8	1165.9	8.499529	4.671953	Grave Site
11.	0.8	1853.8	8.499524	4.671905	Foundation
12.	0.9	1102.1	8.499440	4.671977	Stone Henge

Contour plots were used as an approximate method of viewing the VES data obtained within the first layer (i.e. from 0 m – 1.5 m) using a sequence of contour lines to show the points where the magnitudes of the geophysical quantity being measured coincide with *a priori* information, thereby signifying some anomalous presence [21].

The iso-resistivity map was derived from 16 VES data points to show the variations in resistivity across the lithology. All points of burial are superimposed on the resistivity map shown in Figure 9 below. The results would have demonstrated the limitations of this technology more strikingly if the VES data points had been denser. The map shows a strong distribution of highly resistive overburden, typical of the topsoil in the soil horizon (sandy-loamy soils to clay soils); this is due to its low water retention capacity and its unconsolidated nature, highly resistive in the south-western part of the area, slightly resistive at the north-eastern part and moderately resistive in the middle.

There is a qualitative change in the contour values as the burial positions are approached; very noticeable is Position WH (*Well Stone Henge*), where resistivity sharply rises from the eastern part and then, just as it reaches the feature, decreases by a few tens of resistivity (1550 Ωm to between 1100 Ωm and 1050 Ωm); further ERT survey results, confirmed this to coincide with the position of the well henge. Points GS (*Grave Site*) and DB (*Debris*) have similar explanations; the anomalies are not strongly visible, but a gradual fade-in value could suggest their presence. The three other displayed burial positions largely represent their anomalies with closing resistivity contour values, and can easily be distinguished. Point MC (*Metal chest*) at the Northern location, KG (*King’s Market*) and FK (*King’s Foundation*) all show closing contours of 550 Ωm , 1050 Ωm and 1550 Ωm respectively. From further ERT results, these positions were confirmed to host buried materials.

ARCHAEO-GEOPHYSICAL INVESTIGATION

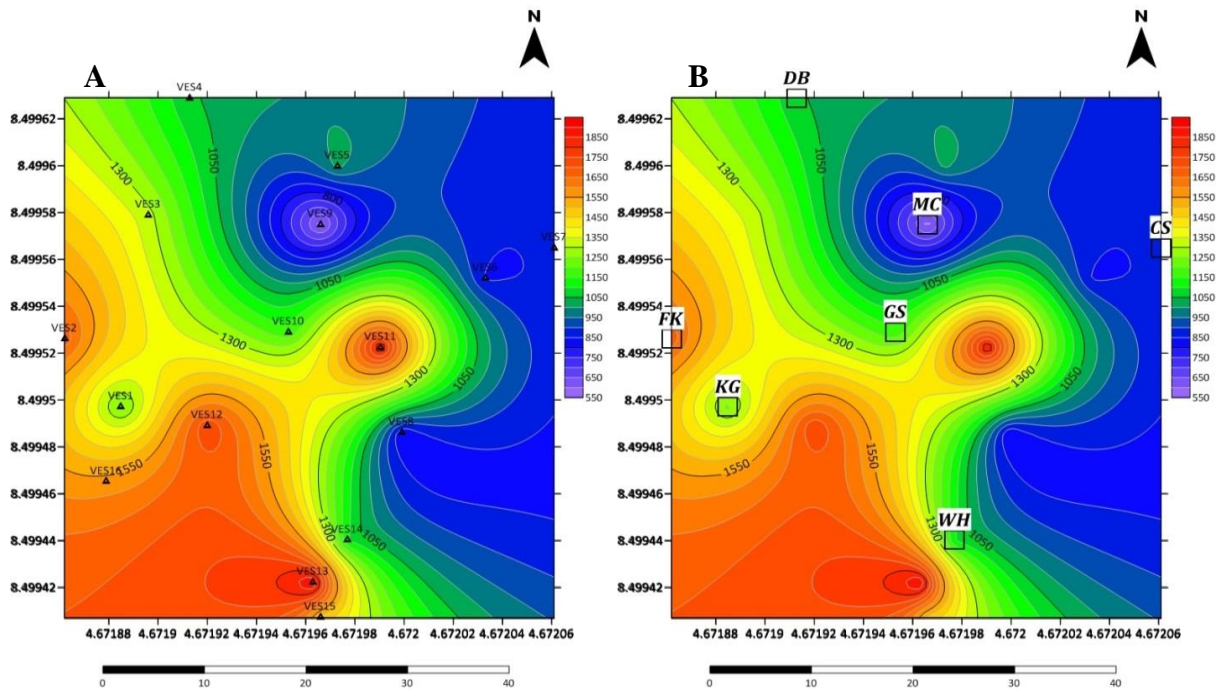


Figure 9A and 9B. Resistivity map of the area under investigation and each VES point (B) The resistivity map of the area showing the burial locations: WH (Well Stone Henge), GS (Grave Site), DB (Debris), MC (Metal chest), KG (King's Market) and FK (King's Foundation).

The 3D resistivity model shows the resistivity variations with depth in Figure 10 below. The Location marked A at Latitude 8.499440° and Longitude 4.671977° shows the buried well stone henge; C is situated on the King's Market (Latitude 8.499497° , Longitude 4.671885°); The location marked B (Latitude 8.499529° , Longitude 4.671953°), shows the gravesite; E (Latitude 8.499579° , Longitude 4.671896°), the buried metal chest and D (Latitude 8.499579° , Longitude 4.671896°) is situated within the foundation wall area.

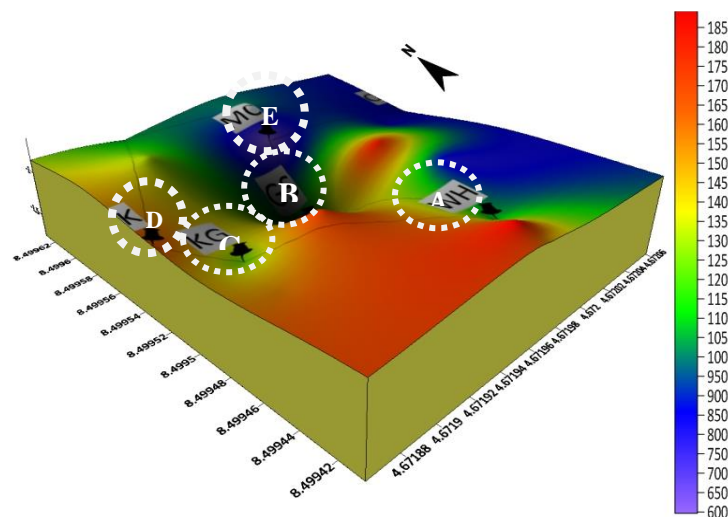


Figure 10. A 3D Resistivity Model of the study area showing resistivity distribution and burial points.

3.3 Electrical Resistivity Tomography (ERT).

The processed results show the presence of anomalous bodies. The weather simulations given by [13] have also guided our interpretations, by providing explanations for the poor contrast zones, which would have yielded low detectability in the models. The control resistivity data set acquired on a clean line (Figure 11A) was taken at regular stations (0.5 m apart) and an electrode spacing of 0.5 m with an expansion factor (n) of 5. A background study shows that the area has been engaged in a secondary deposition during the road construction nearby, giving the top layer its high resistivity values of between $900 \Omega\text{m} - 1300 \Omega\text{m}$.

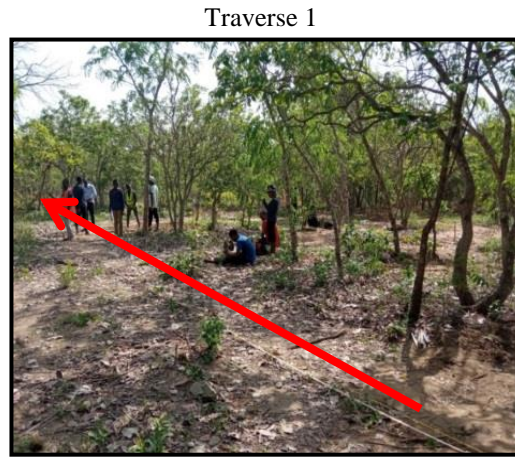


Figure 11 A. The data acquisition line for the first profile (traverse 1) at the archaeological site.

Subsequent inversion models obtained from each traverse were compared to the test data (figure 11B) and slight contrast from the background values were interpreted as anomalies, either positive (buried artifacts) or negative (caused by noise). The topmost layer has a varying resistivity range of 526 Ωm - 1000 Ωm which is consistent with data for sandy-loamy soil [17]. The slightly low resistive extremes in the data profile (<500 Ωm) is due to the scant precipitation during the survey period.

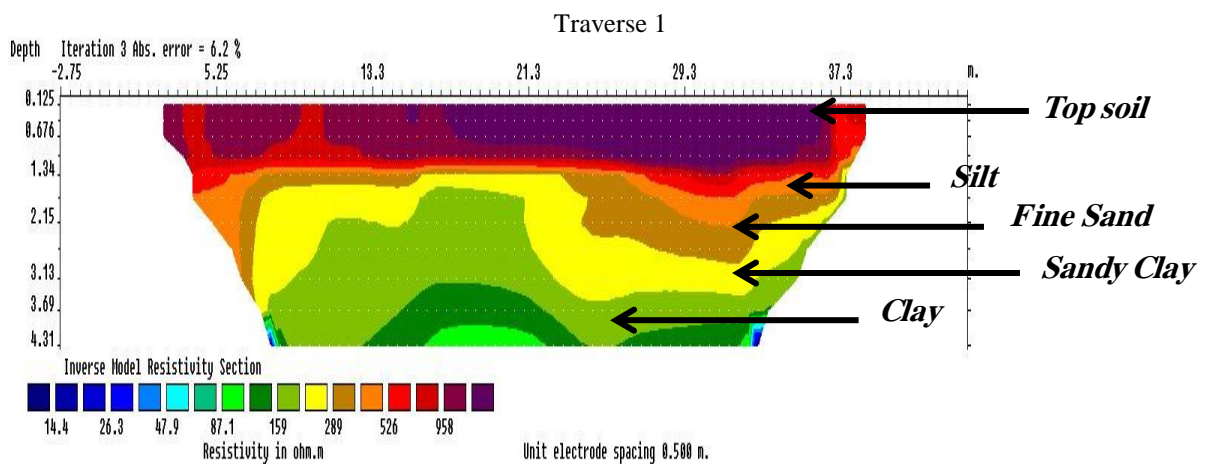


Figure 11B. The 2D apparent resistivity pseudo-section of the control data.

On further comparison between the values for the ditches and those recorded in the literature, we can deduce that the 2nd layer coloured red, with a resistivity range of 526 Ωm - 958 Ωm is a Siliciclastic layer or silt. The layer marked yellow, with a resistivity range of 160 Ωm - 260 Ωm denotes the presence of fine sand [17], beneath (the green layer) is a sandy-clayey soil with a resistivity range of 159 Ωm - 189 Ωm , and lastly in light green (between 87.1 Ωm - 149 Ωm), clay. With this established, it is possible to deduce, through comparison, occurrences of anomalous zones.

On traverse 2 (Figure 12A), the observed anomaly on the inversion model is immediately spotted on the measured apparent resistivity pseudo-section, with a low-resistive square-shaped depression showing different values from the background located between 16 m – 17 m on the profile (Figure 12B). In contrast to the highly resistive 511 Ωm - 805 Ωm background value of that layer, the depression has a resistivity value ranging from 130 Ωm - 324 Ωm and is consistent with the buried well stone henge. The position and resistivity correspond with field data and literature findings respectively. The Stone henge was buried at the exact location and with the same width as the anomaly.

Traverse 3 (Figure 13A) contained a metal chest buried at a depth of 0.4 m. The profile was taken along the burial location of the metal chest which represents storage for artifacts and relics. The background resistivity value proves this fact with a visible contrast from this value in this location. In Figure 13 B, the black marker shows the buried metal chest buried at 0.4 m depth., with a width of 0.3 m and a length of 0.6 m; the anomalous signatures can be seen on the depth pseudo-section (Figure 13B). The resistivity value from the model corresponds precisely with some internet sources [18] and lies between 500 Ωm to 700 Ωm .

ARCHAEO-GEOPHYSICAL INVESTIGATION



Figure 12A. The submerged stone henge of a well.

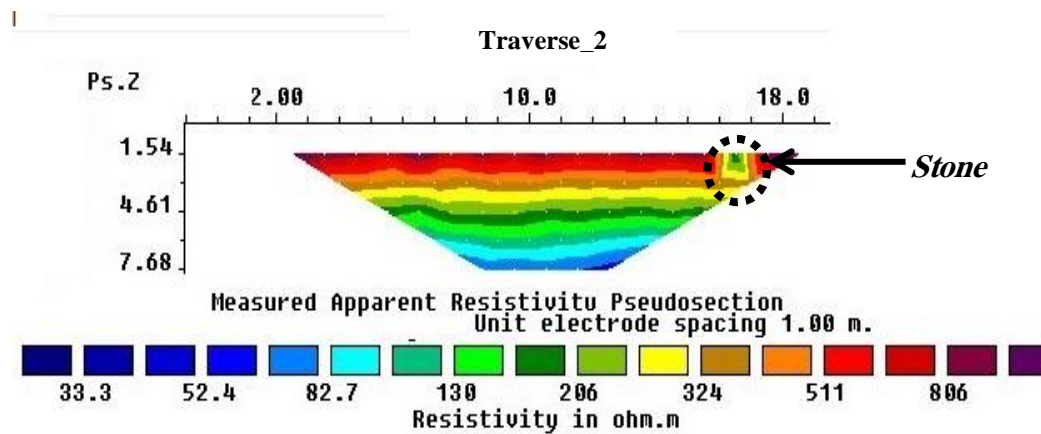


Figure 12B. The 2D model derived from the apparent resistivity response from the buried stone henge.



Figure 13A. The burial spot and depth of the metal chest.

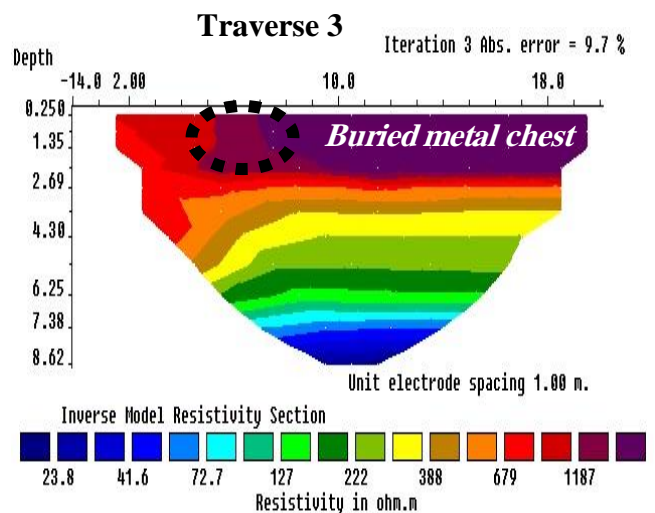


Figure 13B. 2D Pseudosection showing the burial spot and depth of the metal chest.

Traverse 4 (Figure 14A) contains a buried ditch. The anomaly displayed between 7 m to 11 m on the measured apparent pseudo-section as shown in Figure 14B corresponds with an unconsolidated soil that must have filled the ditch, and thus archaeologically signifies an area where the living prints of the inhabitants, through submergence, have been buried. The resistivity range of this anomalous zone varies from 1000 Ω m to 1200 Ω m. This highly resistive zone must have been a result of poorly consolidated soil, filling a previous ditch. An explanation for this phenomenon is examined by [13], which results from the rapid evaporation of water from the ditch due to the looseness of the soil fill,

causing it to be more resistive in contrast with the lithology. The profile was taken longitudinally with the ditch which explains the length of the anomaly (*about 4 m*). The anomaly measures about 4 m in length in contrast to the 2 m actual length of the ditch and a depth very close to the subsurface. This abnormal lengthening is due to the electrode separation effect; the greater the electrode spacing, the greater the size of the anomaly displayed.

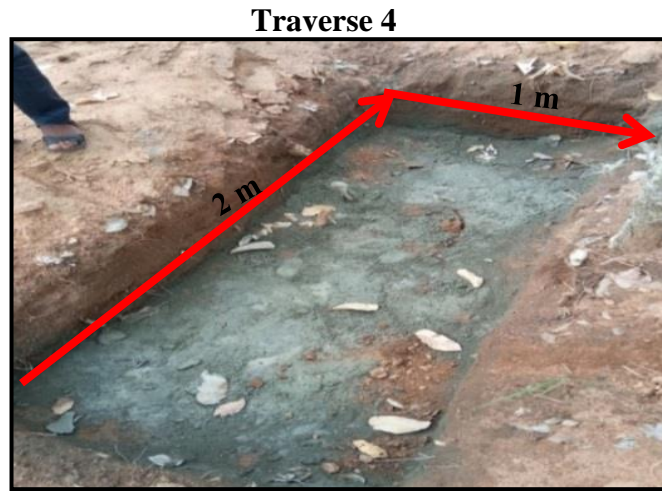


Figure 14A. Photo of a dug ditch with a hardened base, made using cement aggregates.

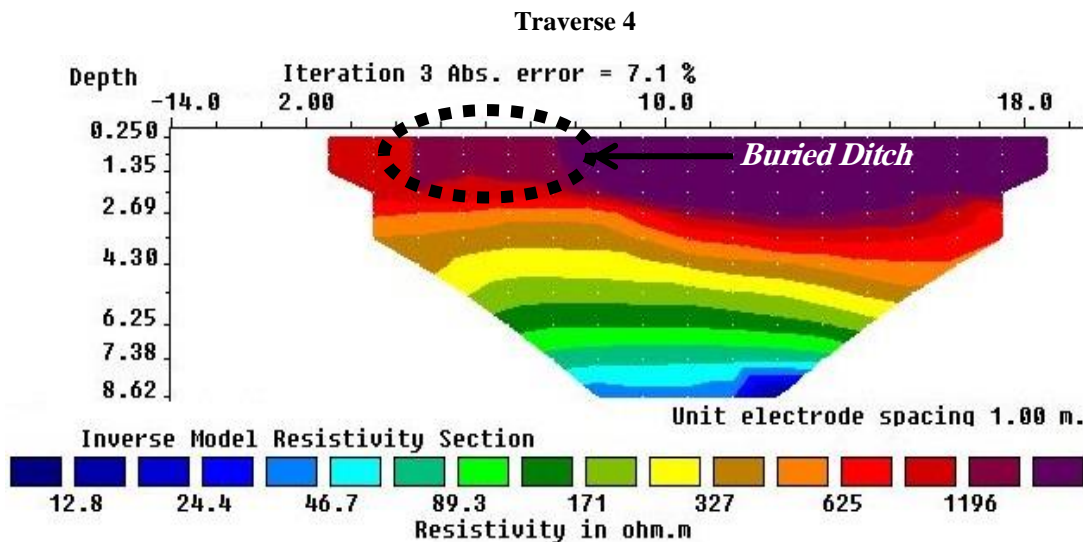


Figure 14B. The 2D model derived from the apparent resistivity response on Traverse 4, showing the Buried Ditch.

Traverse 5 represents a grave (Figure 15A). The grave in the traverse is easily seen as a highly resistive anomaly in the range of $900 \Omega\text{m} - 1000 \Omega\text{m}$ at the black marker (Figure 15B). This value is consistent with shallow graves that have undergone a high level of lithification and compaction, so that the wooden components have collapsed and decayed and the section absorbs water very slowly, giving it a high resistivity value. The dimensions and shape can be approximated to a limited extent, the bulk of which remains indeterminate from the 2D section presented here, due to the low resolving power of the methods to very shallow buried artifacts. The anomaly at point 18 m, the blue marker, is the root of a tree that was noted during the survey.

Traverse 6 (Figure 16A and B) contains the supposed remains of the king's palace and market. The expected anomaly is not visible on this traverse, although the layer resistivity contrast is high, yet no reasonable anomaly is evident on the pseudo-depth section at the anomalous points (Figure 16C). The positions of the foundation and the market are denoted at arrow points 7.5 m and 12 m and shown by the broken arrow. The reason for this near failure is almost certainly due to the very shallow depth of the foundation walls (<0.5 m) leaving the electrode separation insufficient to map the feature, even with the high resolution of the Wenner Array.

ARCHAEO-GEOPHYSICAL INVESTIGATION

The king's market remains are not evident on the measured pseudo-section (Figure 16C). The ditch representing the remains is characterized by its looseness, fast evaporation, and transpiration, and has no conductive moisture, giving it a resistivity that closely matches the resistivity of the surrounding matrix.

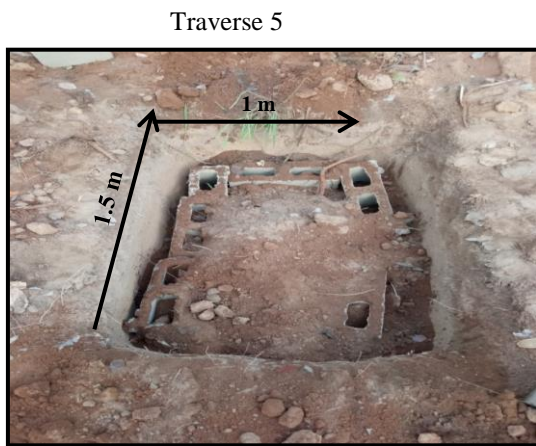


Figure 15A. The burial location of cow bones, depicting a collapsed grave.

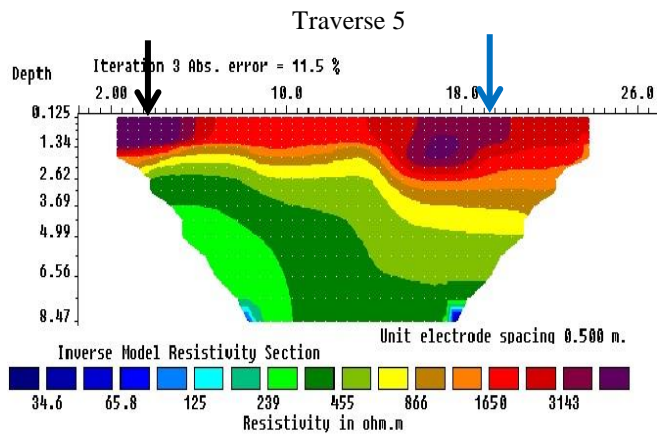


Figure 15B. The 2D model derived from the apparent resistivity response, showing the buried bones and a tree root.



Figure 16A. The buried cement blocks, depicting remains of a king's palace foundation.



Figure 16B. A ditch depicting the remains of the king's market.

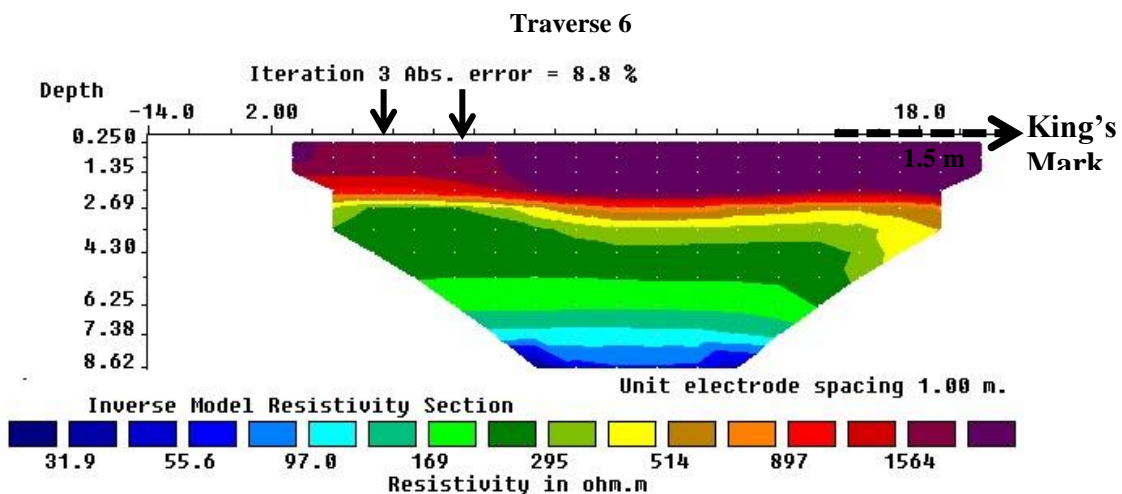


Figure 16C. The 2D model derived from the resistivity response, showing the king's market remains.

4. General Discussion

The success of any geophysical survey depends on the degree of coherency and correlation of methods used. Thus, there is a need for critical assessments based on comparison from the Google Earth results, the vertical electrical sounding results, and the electrical resistivity data to guide this procedure.

Table 5. Summary of results obtained from all the three methods.

S/N	Buried Artefacts <ul style="list-style-type: none"> ✓ Visible ● Not Visible ○ Based on Inferences 	Google Images	Vertical Electrical Sounding [VES]	Electrical Resistivity Tomography [ERT]
1.	King's market (A Ditch)	○	✓	●
2.	Foundation of King's Palace	○	✓	✓
3.	Debris (A Ditch)	○	✓	●
4.	Carpenter's shop (A Ditch)	○	●	●
5.	Metal Chest	○	✓	✓
6.	Grave Site (A Ditch)	○	✓	✓
7.	Well stone Hedge	○	✓	✓
8.	Palace's Square (A Ditch)	○	●	✓
9.	Total Tests (T)		8	8
10.	Total successes (Ts)		6	5
11.	Total Failures (Tf)		2	2
12.	Percentage successes (Ts/T *100%)		75%	62.5%

Table 6. The contrast factors of each electrode array, based on weather factors.

S/N	Next Layer	Array	Features	Anomaly Type	Contrast Factor [K]
1.	Lateritic Soil	Wenner/ Schlumberger	Test Data	-	17.7% 29.4%
2.	Clay	Wenner/ Schlumberger	King's market (A Ditch)	Low	18% -17%
3.	Lateritic Soil	Wenner/ Schlumberger	Foundation of King's Palace	High	-23.0% -4.5%
4.	Lateritic Soil	Wenner	Debris (A Ditch)	Low	18.0%
5.	Lateritic Soil	Wenner	Carpenter's shop (A Ditch)	Low	16.0%
6.	Lateritic Soil	Wenner/ Schlumberger	Metal Chest	High	16.0% 28%
7.	Lateritic Soil	Wenner/ Schlumberger	Grave Site (A Ditch)	High	-23.0% 23%
8.	Lateritic Soil	Wenner/ Schlumberger	Well stone Hedge	High	16.0% 29%
9.	Lateritic Soil	Wenner	Palace's Square (A Ditch)	Low	19.0%

There have been attempts in the field of archaeological geophysics to define a successful geophysical survey. The definition of Gaffney and Gater has earned global acceptability and defines geophysical survey success as “A survey that can identify the presence of an ancient site” [40]. This definition has been employed in assessing the methods used in this research and has been summarized in Table 5.

Based on the previous results obtained, a critical study can be done to ascertain the individual capabilities of each method from the contrast factors. The contrast factor is obtained by comparing two distinct lithological units of known resistivity using the contrast formula provided by [31] is shown in Table 6.

The contrast factors are solid proofs of the presence of buried objects in the location's vicinity. Table 6 reveals areas of positive contrast which is a deviation from the general negative contrast trend from the results. Due to the decreasing resistivity with the depth of the subsurface layers as compared with vertical electrical sounding results, the resistivity contrast calculated should be negative from one geo-electric layer to another.

A positive contrast suggests a more resistive layer and it can be inferred that the negative contrast in the table signifies probable anomalies.

5. Conclusion and Recommendation

This work attempted to prove the usefulness of the Google Earth technology and also to exploit the capabilities of the Vertical Electrical Sounding Technique and the Electrical Resistivity Tomography Method to prove their usability and applicability in solving archaeological problems. The results from the VES displayed through contour plots proved very effective in revealing the distribution and signatures of the various buried objects. Of the sixteen VES points, eight (8) points were of great interest and were distinctly prospected, creating a premise for the ERT interpretation.

Through qualitative comparisons of knowledge and experience obtained from other authors and field data pseudo sections, it was possible to mark the specific location and characterize each anomaly on the ERT pseudo-sections; one of which was the well stone henge in Figure 12B.

Though the project models failed to resolve some anomalies such as the market remains, buried debris, and the buried foundations, partially due to the shallowness of the objects and the wide electrode spacing (0.5 m - 1 m), we advocate that future surveys should employ the multi-electrode systems with dense electrode arrangements, as this will aid better visibility of features.

Suggestions have also been made regarding the use of the Geographic Information System through the eye of Google Earth, to serve as a reconnaissance tool for predicting, locating, and studying the plausible occurrences of heritage sites in future research.

Critical and in-depth analysis of the various parameters needed to precisely locate burial sites should be carried out with care and thorough consultation before any survey; this will help to avoid any wastage of time and money.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgment

The authors are grateful to the management of the University of Ilorin for permitting the usage of the school's premises for this research. Special thanks also to Dr. Jamie Pringle of Keele University for supplying useful information that has improved the quality of this work.

References

- Gaffney, C. Detecting Trends in the Prediction of the Buried Past: A Review of Geophysical Techniques in Archaeology. *Archaeometry*, 2008, **50**, 313-336. <https://doi.org/10.1111/j.1475-4754.2008.00388.x>
- Greene, K. *Archaeology, and Introduction: The History, Principles, and Methods of Modern Archaeology*. Routledge, London, United Kindom. 1996.
- Overview - Archaeological Prospection. Wiley Online Library. <https://onlinelibrary.wiley.com/page/journal/10990763/homepage/productinformation.html> 2021.
- Everett M. E. *Near-Surface Applied Geophysics*. 1, Cambridge University Press. London, 2013.
- Schulte, B. Organized hunts for Civil War relics raise dust between participants, historians. SFGATE, 2020. <https://www.sfgate.com/news/article/Organized-hunts-for-Civil-War-relics-raise-dust-2536163.php>
- Brian.ricketts@xtra.co.nz. The present is the key to the past Archives. *Geological Digressions*. 11 December 2017 <https://www.geological-digressions.com/tag/the-present-is-the-key-to-the-past/>
- Rasheed, R. Top ten archaeological discoveries <https://www.thecompleteuniversityguide.co.uk/>, 2020 <https://www.google.com/amp/s/www.thecompleteuniversityguide.co.uk/student-advice/what-to-study/top-ten-archaeological-discoveries%3famp=true>
- Leucci, G., & Greco, F. 3D ERT Survey to Reconstruct Archaeological Features in the Subsoil of the "Spirito Santo" Church Ruins at the Site of Occhiola (Sicily, Italy). 2012, **1**, 1-6, <https://doi.org/10.5923/j.archaeology.20120101.01>.
- Hasek, V., and Kovarnik, J. Aerial and Geophysical Prospection in Archaeological Research of Prehistoric Circular Ditches in Moravia. *Archaeological Prospection*, 1999, **6**, 187-209, <https://ur.booksc.org/book/84590/8145de>.
- Amer, M. *Egyptian Underwater Heritage in Alexandria and Preservation Management*. Research Gate, Published, 2016. https://www.researchgate.net/publication/310843070_Egyptian_Underwater_Heritage_in_Alexandria_and_Preservation_Management/stats.
- Magnavita, C. Contributions of archaeological geophysics to field research in Sub-Saharan Africa: past, present, future. *Azania: Archaeological Research in Africa*, 2016, **51**, 115-141. <https://doi.org/10.1080/0067270x.2016.1150084>.
- Ajadi, B., Adaramola, M., Adeniyi, A., and Abubakar, M. Effect of effluents discharge on public health in Ilorin Metropolis, Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 2016, 389. <https://doi.org/10.4314/ejesm.v9i4.1>.

13. Schmidt, A. Earth Resistance for Archaeologists (Geophysical Methods for Archaeology. AltaMira Press, 2013.
14. Climatemps. Climate of Nigeria. [Http://Www.Nigeria.Climatemps.Com/](http://Www.Nigeria.Climatemps.Com/) 2017. <https://www.ilorin.climatemps.com>.
15. Sala, R., Garcia, E., and Tamb, R. Archaeological geophysics - from basics to new perspectives. archaeology, new approaches in theory and techniques, 2012, 133-150. <https://doi.org/10.5772/45619>.
16. Loke, M.H. Rapid 2-D Resistivity and IP inversion using the least-squares method. 2015 <https://www.geotomosoft.com>.
17. Hazreek, Z.A.M., Rosli, S., Chitral, W.D., Fauziah, A., Azhar, A.T.S., Aziman, M., and Y, B. Soil Identification using Field Electrical Resistivity Method. <https://Iopscience.Iop.Org/Article/10.1088/1742-6596/622/1/01203>, 2021. <https://iopscience.iop.org/article/10.1088/1742-6596/622/1/012030>.
18. A Table of Electrical Conductivity and Resistivity of Common Materials. Thought Co. <https://www.thoughtco.com/table-of-electrical-resistivity-conductivity-608499>.
19. Soupios, P.M., Loupasakis, C., and Vallianatos, F. Reconstructing former urban environments by combining geophysical electrical methods and geotechnical investigations-an example from Chania, Greece. *Journal of Geophysics and Engineering*, 2008, **5**, 186-194. <https://doi.org/10.1088/1742-2132/5/2/005>.
20. Day-Lewis, F.D., Johnson, C.D., Singha, K., and Lane, J.W.J. Best Practices in Electrical Resistivity Imaging: Data Collection and Processing, and Application to Data from Corinna, Maine. https://www.google.com/url?sa=t&source=web&rct=j&url=https://cluin.org/programs/21m2/projects/EPA_admin_report_02Dec2008_final.pdf&ved=2ahUKEwjxLT6z63wAhWiqHEKHW8HAJYQFjAAegQIBBAC&usg=AOvVaw0yzj9K1t4pALCbNFor66_x 2007.
21. Schmidt, A., Linford, P., Linford, N., David, A., and Gaffney, C. EAC Guidelines for the Use of Geophysics in Archaeology: Questions to Ask and Points to Consider (Spied.). Archaeolingua, 2016.
22. Jensen, M. The Application of Google Earth in Archaeology: A Survey of Northumberland. Durham University Department of Archaeology, 2013, https://www.academia.edu/11573538/The_Application_of_Google_Earth_in_Archaeology_A_Survey_of_Northumberland_UK.
23. Goldberg, P., Holliday, V.T., Mandel, R.D., Sternberg, R., and Gilbert, A.S. Encyclopedia of Geoarchaeology (Encyclopedia of Earth Sciences Series). Springer, 2016, 1.
24. Thakuria, T., Padhan, T., Mohanty, R.K., and Smith, M.L. Google Earth As An Archaeological Tool In The Developing World An Example From India. The SAA Archaeological Record, 2013. <https://www.researchgate.net/publication/263652922>.
25. USGS. What is a digital elevation model (DEM)?. <https://Www.Usgs.Gov/>.2021. https://www.usgs.gov/faqs/what-a-digital-elevation-model-dem?qt-news_science_products=0#qt-news_science_products.
26. Herzog, I., and Yépez, A. The impact of the DEM on archaeological GIS studies A case study in Ecuador. International Conference on Cultural Heritage and New Technologies, 2015 1-18. <https://www.semanticscholar.org/paper/The-impact-of-the-DEM-on-archaeological-GIS-studies-Herzog-Y%C3%A9pez/a9d879b1996c13d126a8e8eb7fabf91692198657#citing-papers>.
27. Skinner, T. Mapping the Landscape for Archaeological Detection, Preservation, and Interpretation: A Case Study in High-Resolution Location Modeling from the Blue Mountains of Northeastern Oregon. Ph.D. Thesis, University of Nevada, 2017. <https://doi.org/10.34917/11889753>.
28. Schmidt, A., Dabas, M., and Sarris, A. Dreaming of Perfect Data: Characterizing Noise in Archaeo-Geophysical Measurements. *Geosciences*, 2020, **10**, 382. <https://doi.org/10.3390/geosciences10100382>.
29. Pringle, J., Ruffell, A., Jervis, J., Donnelly, L., McKinley, J., Hansen, J., Morgan, R., Pirrie, D., and Harrison, M. The use of geoscience methods for terrestrial forensic searches. *Earth Science Reviews*, 2012, **114**, 108-123. <https://doi.org/10.1016/j.earscirev.2012.05.006>.
30. Gaffney, C.F., Gater, J., Ovenden, S., and Institute of Field Archaeologists. The Use of Geophysical Techniques in Archaeological Evaluations. Institute of Field Archaeologists, 2002.
31. Reynolds, J.M. An Introduction to Applied and Environmental Geophysics (2nd ed.) Wiley, 2011.
32. Zohdy, A.A.R. A new method for automatic interpretation of Schlumberger and Wenner sounding curves. *GEOPHYSICS*, 1989, **54**, 245-253. <http://doi.org/10.1190/1.1442648>.
33. Loke, M., and Barker, R. Practical techniques for 3D resistivity surveys and data inversion1. *Geophysical Prospecting*, 1996, **44**, 499-523. <https://doi.org/10.1111/j.1365-2478.1996.tb00162.x>
34. Milsom, J., and Eriksen, A. Field Geophysics. John Wiley and Sons. Published. 2011. <http://doi.org/10.1002/9780470972311>.
35. Herman, R. An introduction to electrical resistivity in geophysics”, *American Journal of Physics*, 2001, **69**, 943-952. <https://doi.org/10.1119/1.1378013>.
36. Telford, W.M., Geldart, L.P., and Sheriff, R.E. Applied Geophysics (2nd ed.). Cambridge University Press, 1990.
37. Loke, M.H., Wilkinson, P.B., Uhlemann, S.S., Chambers, J.E., and Oxby, L.S. Computation of optimized arrays for 3-D electrical imaging surveys. *Geophysical Journal International*, 2014, **199**, 1751-1764. <https://doi.org/10.1093/gji/ggu357>.

ARCHAEO-GEOPHYSICAL INVESTIGATION

38. Loke, M.H. Electrical Imaging Surveys for Environmental and Engineering Studies 1999, 1-61. https://www.researchgate.net/publication/273337531_Electrical_Imaging_Surveys_for_Environmental_and_Engineering_Studies.
 39. Zonge, K., Wynn, J., and Urquhart, S. 9. Resistivity, Induced Polarization, and Complex Resistivity. Near-Surface Geophysics, 2005, 265-300. <https://doi.org/10.1190/1.9781560801719.ch9>.
 40. Bonsall, J., Gaffney, C., and Armit, I. You Know It's Summer in Ireland When the Rain Gets Warmer: Analysing Repetitive Time-Lapse Earth Resistance Data to Determine 'Optimal' Survey Climate Conditions, 2015, **53**, 5-29. https://www.researchgate.net/publication/282184728_You_know_it's_summer_in_ireland_when_the_rain_gets_warmer_analysing_repetitive_time-lapse_earth_resistance_data_to_determine_'optimal'_survey_climate_condition.
-

Received 12 July 2021

Accepted 23 December 2021