ABUAD INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES
ISSN: 2955-1021; e-ISSN: 1115-5892
AIJNAS Volume 4, Issue 1, 2024 pp 27-32
https://doi.org/10.53982/aijnas.2024.0401.04-j

https://journals.abuad.edu.ng/index.php/aijnas

Remote Detection of Leakages from a Compromised Buried Water Supply Pipe through Geophysical Measurements

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Abstract

The continuous drastic loss of stored water at a private household presumed to be caused by leakage(s) was subjected to geophysical investigations with a view to delineating the source(s) of the leakage(s). The Spontaneous Potential (SP) and Electrical Resistivity (ER) methods were deployed for the study. Measurements were taken along four (4) traverses at two intervals – firstly when the water supply valve from the overhead storage tank was closed and secondly when it was opened. The Total Field array was adopted for SP measurements with constant station separation of 0.5 m. ER measurements were taken via the Wenner array with electrode spacing (a) varied with an interval of 0.5 m from 0.5 m to 1.5 m. SP data were presented as profiles and maps while ER data were presented as 3-D resistivity depth stacks. SP values varied from -100 mV to 350 mV during the two measurement periods. ER values also varied from 100 ohm.m to 1200 ohm.m during the closed valve period and 100 ohm.m to 900 ohm.m during the opened valve period. During the closed valve period, pipeline routes were interpreted as manifesting oval-shaped high potential anomalies with central linear trend on the SP map; and as linearly-trending high resistivity intrusion within low resistivities on resistivity maps. The disparities between the results of closed valve and opened valve measurements were pointers to leakage-induced inhomogeneity in the subsurface. The diminished high potential SP anomaly and the anomalously low resistivity specks within linearly-trending high resistivity values were regarded as the source of leakage.

***Keywords**: loss of stored water; leakage(s); disparities; high potential SP anomaly; anomalously low resistivity specks.*

INTRODUCTION

The overhead water storage tank of a private residence in Ilupeju-Ekiti, southwestern Nigeria has been witnessing incessant drastic reduction and eventual loss of stored water for some time. The mysterious draining of 4000 litres of stored water even when all faucets were locked became a serious source of concern to the household. Due to the widespread dampness of the concrete/screeded floor and the rapid growth of the lush grass in the backyard of the building, uncontrolled water discharge/anomalous seepage were suspected in that vicinity (Plate 1). However, due to the irregularity and trendless nature of the dampness observed on the concrete floor, the exact point of leakage could not be pinpointed. Since the reticulation from the overhead tank and corresponding distribution within the household are also conduit, tracing leakages would involve too many failure-prone speculations. In order to avoid unnecessary excavation with attendant destruction of the concrete floor while embarking on a wildcat search for leakage(s), it was important to investigate the subsurface phenomena through geophysical means. This was with a view of identifying the possible point(s) of leakage(s) in more precise manners in order to guide the inevitable corrective excavation.

Geophysical methods have been indispensably adopted in studies involving leakages and/or anomalous seepages (McLean and Gribble, 1979; Olorunfemi *et al*, 2000; Olorunfemi, 2004; Eluwole and Olorunfemi, 2012; Fatoba *et al*, 2018). The most prominent geophysical methods that have found use in leakage mapping are the Electrical Resistivity (ER) and Spontaneous Potential (SP) methods (Olorunfemi *et al*, 2004; Eluwole and Olorunfemi, 2012; and Fatoba *et al*, 2018). It has been severally demonstrated that zones associated with leakages are usually identifiable on SP and ER profiles, maps and pseudo-sections. This is because leakages induce noticeable contrasts in their vicinities of occurrence. The successes reported on the use of the geophysical methods in related studies prompted their use in the present study.

Plate 1: Photo of the Building Backyard

Description of the Study Area

The house is situated at New Odo-ogan street, Ilupeju Ekiti, southwestern Nigeria. The geographic coordinates of the center of the premises are 7.813N and 5.352E decimal degrees (Figure 1). The topography of the site is relatively flat and it falls within the tropical rain forest of southwestern Nigeria with a mean monthly of about 28°C and annual rainfall of about 1300 mm (NIMET, 2007). In terms of local geology, the site and its surroundings are underlain by the Basement Complex of southwestern Nigeria (Rahaman, 1988) with the main rock unit being charnockite (Figure 1). While there are a few low-lying outcrops scattered around, the rock unit is concealed within the premises. The topsoil is predominantly lateritic.

METHODOLOGY

The backyard of the house where investigations were carried out is divided into two portions, namely; the Screeded/Paved portion covered by cement concrete and the Lush Grass/Garden portion made up of soil upon which grass and plants are cultivated (Plate 1 and Figure 2). The SP and the ER methods were used for the study. The SP method is a natural field method which measures the potential arising from electrofiltration or streaming potential, electrokinetic, thermoelectric, pressure gradient and bio-electric processes. The electrofiltration or streaming potential of the SP method is relevant to this study because it is derived from the interaction between the ions of a fluid and the wall of a capillary which oftentimes could be a seepage path (Fatoba *et al*., 2018). The principle of this phenomenon consists in unequal mobility of anions and cations transferred by the liquid medium through the porous material. This inequality generates measureable negative potential at the point of infiltration and positive potential at the point of outflow (Sentenac *et al*., 2018). SP measurements entail measuring natural earth potential through two non-polarizing electrodes. There are two electrode arrays used in SP measurements, these include the gradient array and the total field array.

The Electrical Resistivity (ER) method on the other hand is associated with the measurement of the resistance to current flow through four electrodes arranged along a line on the soil surface at determined distances between the electrodes. The potential difference is estimated between a pair of inner electrodes while electrical current is made to flow through the soil between a pair of outer electrodes (Eluwole *et al.,* 2018)*,* The resistivity measurement obtained is a bulk value representing a continuous volume of the subsurface beneath the four-electrode array (Allred *et al.,* 2008). There are several modes of measurement in ER method, that is the Horizontal Profiling (HP), Vertical Electrical Sounding (VES) and Combined Horizontal Profiling and Vertical Electrical Sounding (HP+VES) modes. The HP+VES mode is also referred to as Electrical Resistivity Imaging (ERI).

Four traverses of 1 m separation and 18 m length were established (Figure 2). SP measurements were taken via the Total Field Array (Figure 3) at 0.5 m interval across the four traverses. The Horizontal Profiling technique in conjunction with the Wenner electrode array (Figure 4) was used for ER measurements. In order to map different depth levels, three electrode spacing (a) regimes were adopted viz: a = 0.5 m; a = 1.0 m and a = 1.5 m. SP and ER measurements were taken in two phases. The first phase which hereafter is referred to as closed valve was the period when measurements were taken after the main supply valve from the overhead storage tank had been closed for one hundred and twenty (120) hours/ five (5) days. This was done with an assumption that possible leakage zones would have been deactivated thereby returning the subsurface to a somewhat state of equilibrium. The second measurement phase (opened valve) was the period when measurements were taken after the main supply valve had been partially opened for twelve (12) hours /half of a day and left in the same mode during measurements. The idea was to allow the stored water to drip without completely draining to achieve systematic saturation and to ensure the activation of the possible leakage zones during measurements. SP data were filtered using the three period moving average algorithm and were plotted as profiles with Microsoft Excel®. The SP data were also converted to maps using the Kriging interpolation method on the Surfer 8.0 of the Golden Software™. SP profiles and maps were interpreted semi-quantitatively by visual inspection to identify signatures/patterns diagnostic of the target while also estimating the position of the same. ER data were presented as 3-D depth stack maps and were also interpreted semi-quantitatively.

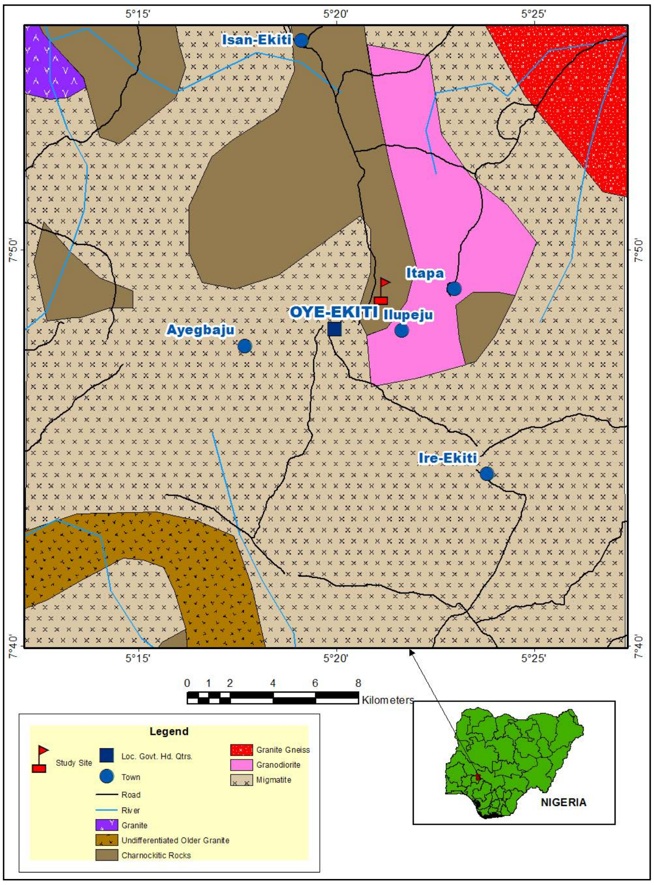

Figure 1: Geological Map of the area around the study site

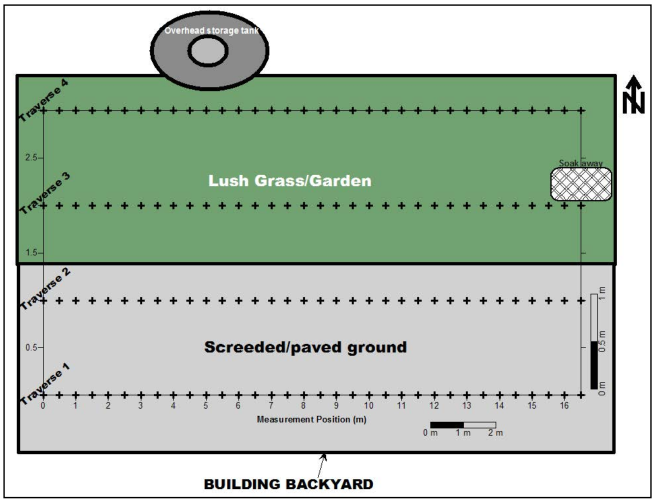

Figure 2: Geophysical Data Acquisition Map

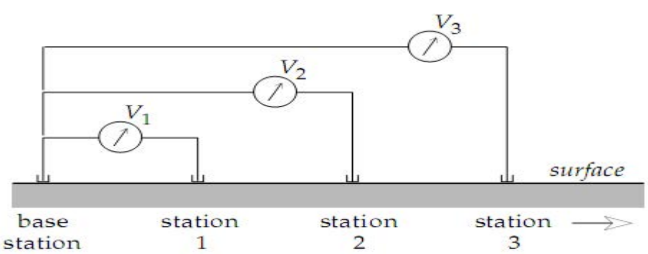

Figure 3: The Total Field Array (Lowrie, 2007)

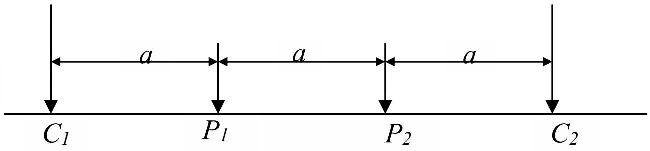

Figure 4: Wenner Electrode Array

RESULTS AND DISCUSSION

SP Profiles

The SP profiles obtained from Traverse 1 (Figure 5a) show the contrasts that exist between the closed valve and opened valve periods. A kind of potential reversal is observable in which locations with SP troughs during the closed valve period returned as superposed W-shaped peak positive amplitude and potential trough anomalies during the opened valve period. These are present at distance 2 – 6 m and 9 – 15 m in Figure 3a. In a similar reversed manner at distance 7 – 10 m and 15 – 18 m, peak positive amplitude anomalies correspond to SP troughs during the closed and opened valve periods respectively. Typical scenario plays out at specific portions of Traverse 2 (Figure 5b) with the most prominent reversal present between distance 6 and 10 m. Except for distance 10 – 18 m, the positions of observed anomaly reversal on Traverse 2 are the same as that of Traverse 1.

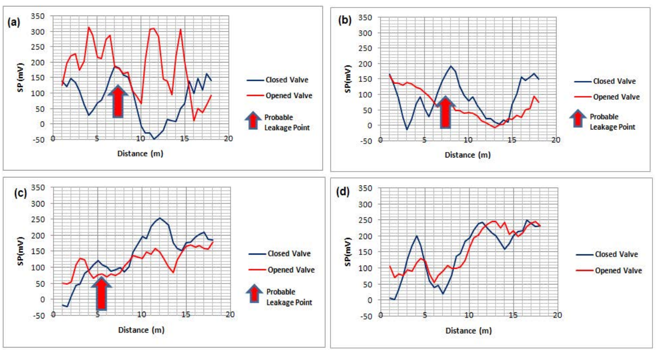

Figure 5: SP Profiles. (a) Traverse 1 (b) Traverse 2 (c) Traverse 3 (d) Traverse 4

On Traverse 3 and Traverse 4 (Figure 5 c and d), apart from the mild potential attenuation during the opened valve period, the shapes and patterns of anomalies obtained during the two periods of measurement have appreciable similarity indices. The only noticeable potential reversal is that present at distance 4 – 6 m on Traverse 3 (Figure 5 c) which could be likened to a displaced remnant of those previously identified in preceding traverses. The variations in spontaneous potential (especially reversal) during the two periods of measurements are indications of the differences in subsurface phenomena during the two periods. Positive SP troughs or peak positive amplitude anomalies have been attributed to streaming potential arising from the movement of fluids within capillaries with close relationship to anomalous seepages emanating from containment structures such as dams (Olorunfemi *et al*, 2000; Olorunfemi, 2004; Eluwole and Olorunfemi, 2012; Fatoba *et al*, 2018). In the same vein, potential reversals in which positive troughs during opened valve coincides with peak positive amplitude anomalies during closed valve were selected as probable leakage points in this study. These points are present at 6 – 10 m on Traverse 1 and 2 and distance 4 – 6 m on Traverse 3.

SP Maps

The SP map obtained during the closed valve period (Figure 6a) gives a spatial feel of the spontaneous potential across the four traverses. The map indicates a predominance of high to very high SP values ranging from 40 – 320 mV. Very low SP values range between – 100 and 20 mV. The first segment of the map comprising Traverse 1 and Traverse 2 located on the screeded/paved ground hosts the very low SP regime in abundance. While the other segment with lush grass/garden comprising Traverse 3 and 4 posed most of the high to very high SP values. The high to very high values may be attributed to potential due to immobile ions occasioned by plant activities (Golovko *et al*., 2007 and Urdea and Tambris, 2014). On the other hand, areas on the map associated with low SP values may be revealing high moisture content with corresponding mobile ions. Meanwhile the oval shaped high potential closures with a central linear trend and adjoining low potential anomalies straddling Traverse 1 and 2 (blocked out in Figure 4a) calls for particular attention.

During the opened valve measurement (Figure 6b), the second segment of the map retains its high potential characteristics with a good semblance with that of Figure 4a. However, the first segment appears to have undergone some anomalous episodes during this period. Because, unlike the closed valve map, some portions of the western flank of the first segment which hitherto manifested low potential now manifest high potential. A similar phenomenon is observed in parts of the eastern flank of the same segment. The time-lapse polarity switch may be attributable to pronounced streaming potential due to increased moisture content and/or saturation with commensurate mobile ions. The high potential linear closure observed during the closed valve period (Figure 4a) appears to have diminished both in dimensions and magnitude during the opened valve period (Figure 4b) and therefore only noticeable on Traverse 2. The substantial disparities between the maps of the two measurement periods are testaments of the inhomogenous subsurface conditions suspected to have been caused by leakages.

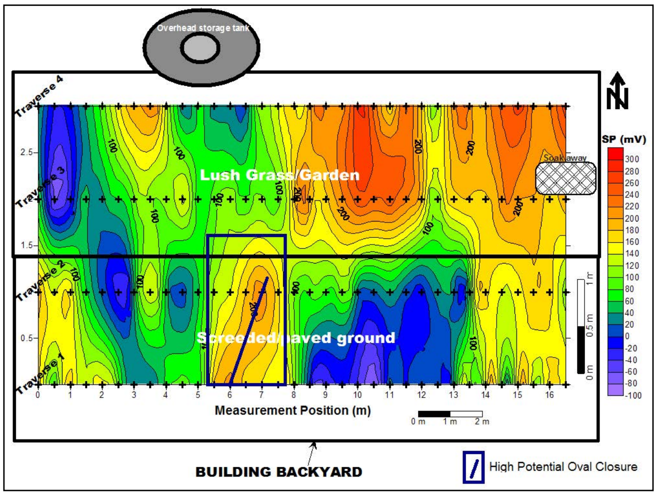

Figure 6a: SP Map during Closed Valve Measurement Period

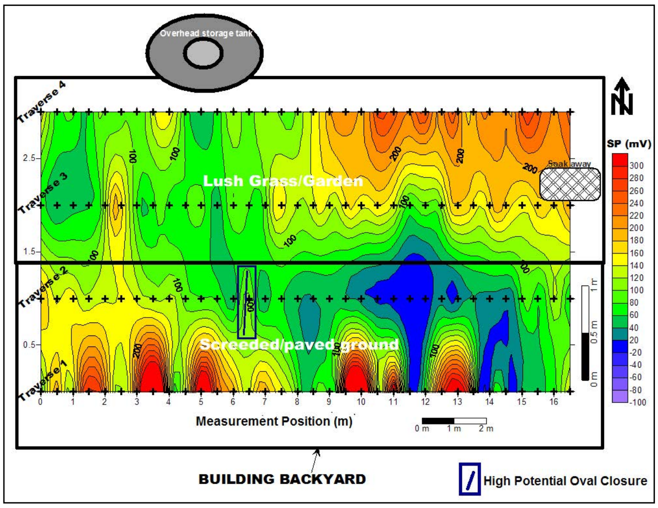

Figure 6b: SP Map during Opened Valve Measurement Period

3-D Resistivity Depth Stacks

Resistance values obtained from the resistivity meter were multiplied by the geometric factor (k) of the Wenner array to obtain the apparent resistivity values.

Figure 7 is the 3-D depth stack of the resistivity maps obtained from the three electrode spacings adopted (i.e. a = 0.5 m; 1.0 m and 1.5 m) during the closed valve measurement period. The depths of investigation of the electrode spacings are estimated at 0.17 m, 0.33 m and 0.50 m respectively (Roy and Apparao, 1971). The resistivity distribution across the three depth levels show that the segment with screeded/paved ground is predominantly associated with lower resistivity (<400 ohm.m) regimes, while the other segment with lush grass/garden is associated with higher resistivity values (400 – 1200 ohm.m). A reverse of the resistivity dichotomy would ordinarily have been expected between the two segments, that is, the paved segment is supposed to have higher resistivity than the lush grass segment with bare soil, since it has been sealed with concrete and prevented from surface induced moisture/percolation from precipitation. The lower resistivity observed in the paved segment therefore could be a manifestation of the trapped moisture induced by subsurface leakage(s). However, the intruding relatively high resistivity contours identified by blue arrows within the western and eastern flanks of the paved segment exhibiting relatively linear attitudes are suspected to be pipeline routes due to the nature of the pipe which is PVC. These are observed on all the depth levels but are clearest on the basal depth slice (0.5 m). The first arrow points towards the position of the overhead water storage tank, while the other arrow points in the direction of the underground waste water soak away.

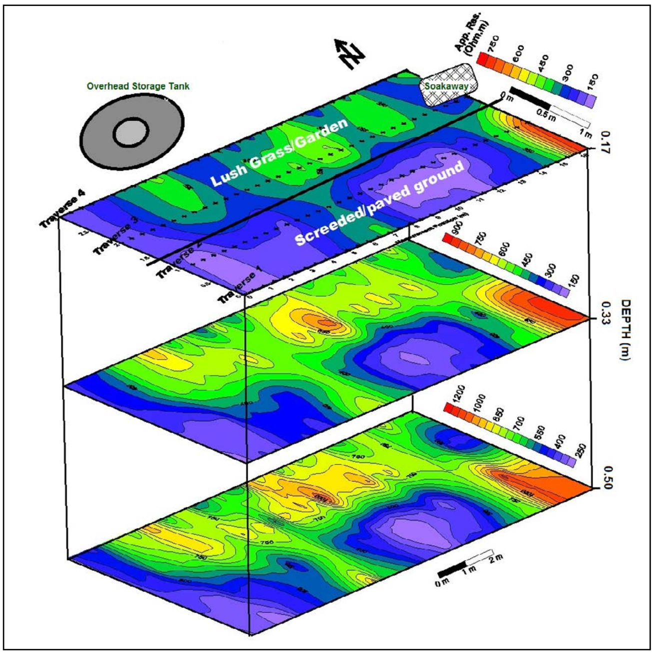

Figure 7: 3-D Resistivity Depth Stack during Closed Valve Measurement Period

From Figure 8, during the opened valve resistivity measurement session, the lush grass segment witnessed a general drop in resistivity values (<1200 ohm.m) especially in the topmost layer (0.17 m). The mid and basal depth slices (0.33 and 0.50 m) retained their spatial resistivity patterns in that segment as in the closed valve period. However, the linearly trending high resistivity intrusion previously observed in the western flank of the paved segment is now found to be discontinuous with low resistivity midway as identified by a red ring on Traverse 2 in the topmost layer and dimly continuous with low resistivity specks (identified by red rings and arrows) on the mid and basal layers. Meanwhile the eastern high resistivity intrusion with arrow pointing towards the soak away witnessed no discontinuity in its trend. The discontinuity and low resistivity specks are attributable to responses from a leaking pipe.

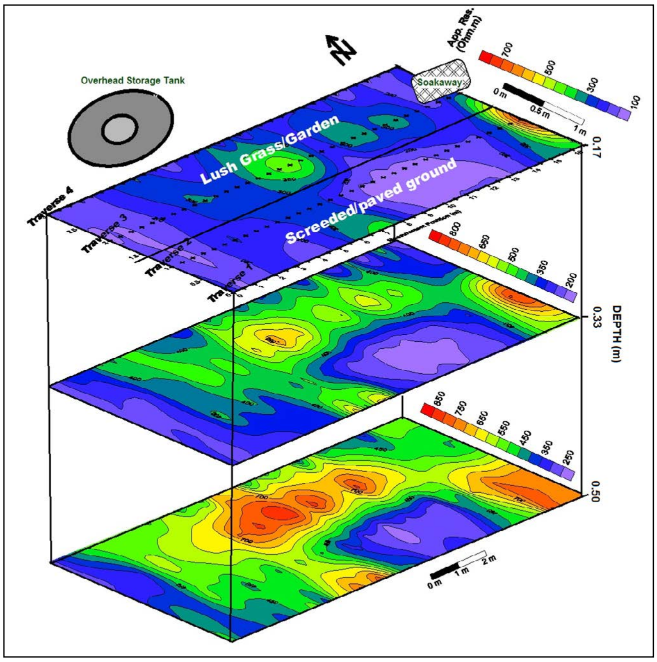

Figure 8: 3-D Resistivity Depth Stack during Opened Valve Measurement Period. It will be recalled that similar discontinuous/ diminishing effect was observed on the erstwhile linearly-trending high SP closures (see Figure 6b) during similar measurement conditions in the same vicinity.

The synchrony between the nature and positioning of SP and resistivity anomalies attributable to leakage/seepage affirms the possibility of the identified zone being the point where the buried water pipe is compromised with attendant leakage. In more specific terms, the low resistivity speck within the identified pipeline route in the mid and basal resistivity depth slices in Figure 8 could be said to be the actual point of the leakage.

CONCLUSION

The cause of the uncontrolled draining of stored water in a private household in Ilupeju-Ekiti has been investigated using the Spontaneous Potential and Electrical Resistivity methods of geophysical prospecting. For the purpose of comparison of results, measurements were taken during closed valve and opened valve periods. The linearly-trending high potential oval closures with adjoining lower potential anomalies; and high resistivity intrusions within low resistivities were attributed to responses from the water pipeline route during the closed valve period. There were disparities in the SP and resistivity results obtained during the opened valve measurements. These disparities especially the distortions observed on the linearly-trending SP and resistivity anomalies were believed to be due to leakages arising from the buried water supply pipe.

DECLARATIONS

- **Ethics approval and consent to participate:** Not applicable
- **Consent for publication:** Not applicable
- **Competing interests:** Not applicable
- **Funding:** This research was funded by the authors
- **Authors' contributions:** Akinola Bolaji Eluwole conceptualized and supervised the research; Odunayo Emmanule Bamidele and Akindeji Opeyemi Fajana co-supervised the research; Oludeji Akinbobose carried out the research; Leke Sunday Adebiyi, Naheem Banji Salawu and Temitope Emmanuel Olasupo participated in the data acquisition and processing; Adebayo Oluwaseun Adeyeye in the data processing and interpretation.
- **Acknowledgements:** The authors are grateful to Pastor and Mrs Peter Oni, the owners of the investigated property. Thanks are also due to Mr. Adebayo Olalekan and Miss Dada Janet for their roles in data acquisition.

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