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GEOPHYSICAL ASSESSMENT OF TWO COLLAPSED AND CONCEALED SEPTIC TANKS AT A RESIDENTIAL SITE IN ZARIA AREA, NORTH-WESTERN NIGERIA

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Abstract
A geophysical study was carried out in the vicinity of two collapsed and concealed septic tanks to delineate the structures responsible for their failure. Two-dimensional resistivity and seismic refraction tomography data were collected along a profile laid across the septic tanks. The data were collected using ABEM Terrameter SAS 4000, aided with LUND imaging equipment and seismograph, Terralloc MK6 respectively. The data were processed using REFLEX-W and RES2DINV software respectively. Pseudosections obtained show that the vicinity of the septic tanks is characterized by resistivity of 10–5200 Ωm and p-wave velocity of 320–2400 ms^{-1}. Results show that these ranges encompass those of clay and sandy clay at shallow depths, and granite and gneiss in a shallow and undulating basement. The zones where the tanks were apparently sited show very low p-wave velocity of < 600 ms^{-1} and on the contrary, very high electrical resistivity of >5000 Ωm which suggest the presence of trapped air column. Based on the interpreted results, the tanks are estimated to be with lateral extent of about 6.5 m and depth of about 2.9 m. The delineated clayey soils at shallow depths suggest that there could be seasonal soil swelling and shrinkages due to seasonal variation in moisture content of the clay. These most likely led to annual ground movements, cumulative soil creep and the subsequent collapse of the septic tanks.

Introduction
Empty, filled or buried sinkholes and tunnels, whether natural or artificial pose a geohazard to buildings, highway, bridges and dam construction as they may be subject to subsidence, soil piping and erosion. These features are often filled or obscured at the surface, requiring the use of geophysical techniques or remote sensing for their assessment. Some roads, buildings, landfills, unregulated dump sites, waste lagoons and septic systems have often been sited within or above unstable soils and rocks. In some places such as karstic environments, they may be ignorantly sited where cavities or sinkholes containing soil pipes exist. Such sinkholes are quickly filled with debris, such as weathered rocks, sandy or clayey soil, making them useless. Caves and sinkhole may collapse due to piping associated with leaking water and sewer lines. Soil instabilities under highways, streets, gutters, sidewalks and foundations may be caused by freeze-thaw swelling, clay swelling or in situations where there is networks of horizontal conduits, which give room for rapid lateral migration of contaminants, water or industrial effluents (Huntoon, 2006). Some important structures in most cities of the world are currently at high risk of collapse due to the presence of both natural and artificially buried structures at shallow depths in the subsurface (Tejero *et al,* 2002).

The siting of sewage tanks close to superstructures also could enhance hazard in semi-urban and urban areas.

The assessment of these structures is obviously a challenge to geophysicists because of the danger posed by the soil or rock type in the vicinity where they are already sited. It is also important to examine the existing subsurface structures around the site where new superstructures are intended. The underground targets, such as cavities and filled features, unrecorded buried structures, former mine workings, culverts, septic and soak away tanks, tunnels and landfill extents are easily characterized since their electrical resistivities and velocities differ from those of their host material. In most pars of the world, a number of surveys involving two-dimensional (2D) tomography have been used to examine sinkholes and the underlying weathered, or epikarstal bedrocks (McDowell, 1975; Carpenter and Ekberg, 2006). Similarly, in Zaria area, integrated geophysical investigation of foundation-based defects in some superstructures has been carried out using electrical resistivity and seismic refraction tomography (Egwuonwu, 2008).

In this study, integrated geophysical imaging comprising electrical resistivity and seismic refraction tomography were used to map abandoned, collapsed and buried or filled sewage tanks sited near a residential building site in Zaria, north-western Nigeria. However, the main thrust of this study is to map the partially concealed/buried septic tanks with the aim of delineating their lateral and depth extents and to investigate the probable causes of their failure. Figure 1 shows the photographs of the collapsed tanks partially shown on the ground surface. These findings will be highly needed for the architectural planning for the proposed building construction intended for the site.

Figure 1: Photographs of the collapsed tanks partially shown on the ground surface

The Study Area and Its Geology

Zaria area is located at approximately between latitude 11^0 03'N and 11^0 11'N, and between longitude 07^0 12'E and 07^0 47'E on an elevation of about 670 m above the mean sea level. It lies in a dissected portion of the Zaria–Kano plains developed on the crystalline rocks of the Nigerian Basement Complex. It is located within the region that has a tropical continental climate with distinct wet and dry seasons. The main lithological units in Zaria are granites and gneisses with other minor rock types such as schist and quartzites (Ike, 1988). The study site area is the premises of a bungalow located in one of the areas of the Ahmadu Bello University Staff quarters in Zaria (Figure 2). The building also show evidence of a foundation-based defect due to severe cracks observed on its walls. Previous works within the university quarters show that the area is mostly underlain by shallow gneissic and granitic bedrock and thin overburden. Also, lithologic inhomogeneity observed at some portions of the study area are few however, the Zaria area has high clay enrichment (Wright and McCurry, 1970 and Egwuonwu, 2008).

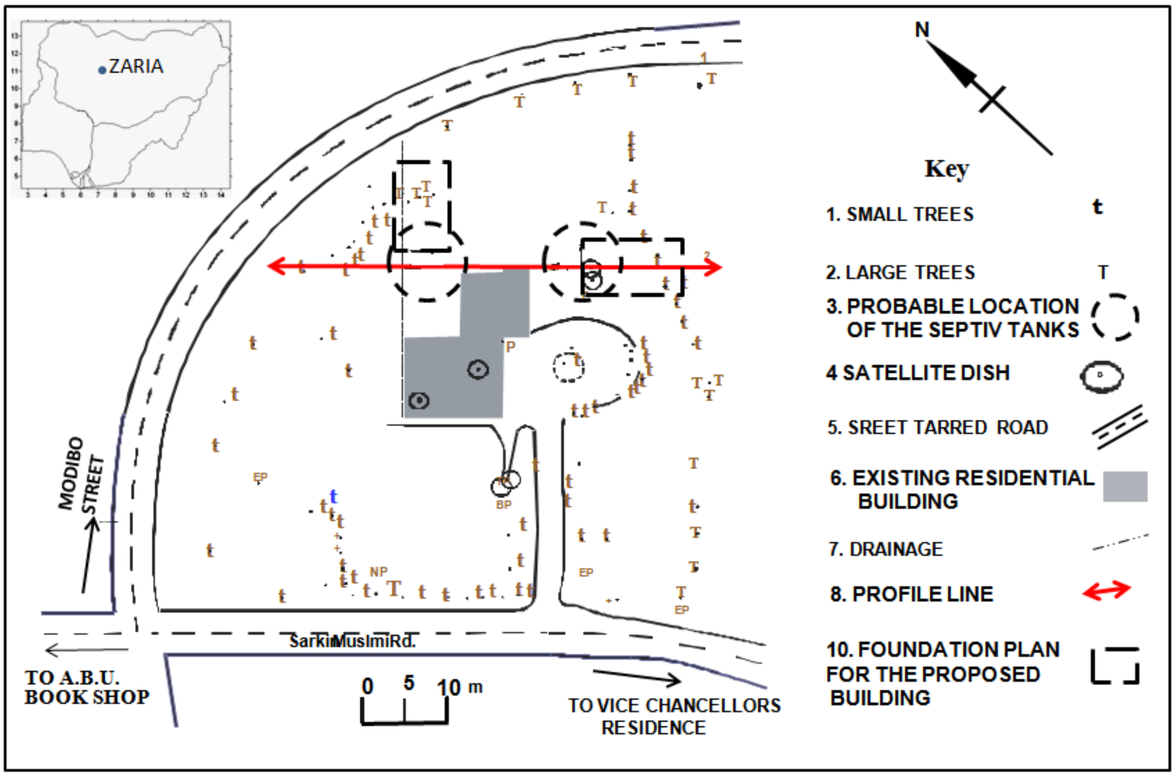

Figure 2: The Site Showing the Probable locations of the Septic Tanks and Survey Profile

Field Techniques

The electrical resistivity imaging is good at defining lateral variations of resistivity associated with structural anomalies such as caves, dykes, water contamination, and fractured zones among others (Tejero *et al*., 2002). The technique is considered vital in the geophysical assessment of both natural and artificial cavities for the mitigation of geohazards. This is because it is meant to map lateral and vertical variations in the electrical resistivity of the subsurface both in 2D and 3D studies. On the other hand, the seismic refraction tomography is good at mapping fractures, and deeper structures such as the basement. A 24 channel Seismograph namely ABEM Mk6 was used for collection in the seismic refraction method. In the electrical resistivity method, data collection was done using an automatic measuring Terrameter SAS 4000 aided by an electrode selector ES464 model. For high resolution, 1.0 m electrode spacing was used in the electrical resistivity imaging while geophone spacing of 1.5 m was used for the seismic data acquisition. It was ensured that these spacing were less than the length of the suspected septic tanks so that at least, the boundaries of the tanks could be mapped.

Data Processing and Results

The resistivity data was processed using a 2-dimensional inversion software RES2DINV which displays results as 2-dimensional colour images showing both vertical and lateral changes in subsurface resistivity. The measured apparent resistivity data were inverted to generate a resistivity model of the subsurface using iterative smoothness-constrained and Robust-constrained least squares (Loke and Barker, 1996). This scheme was used because it requires no previous knowledge of the subsurface; however, the initial-guess model is constructed directly from field measurements. The robust inversion was chosen because it better detects and delineates fractures and faults. It is also used for sharpening linear features such as faults, cavities, dikes, and contacts (Claerbout and Muir, 1973). The raw data acquired from the seismic refraction tomography were processed using REFLEX-W software (Sandmeire, 2003). The First arrival times were picked manually for every single shot of the spread. The picked data were loaded, assigned to layers and a model generated for the tomography inversion of the data.

Figure 3 shows a 2D resistivity inversion model of a NW-SE profile laid across the suspected collapsed septic tanks. This tomogram was obtained at the 5th iteration, with RMS error of 4.6%, showing good fits between the observed and the calculated data. There is no evidence of significant dipping in the subsurface layering along the profile as shown on the tomogram; however, undulating layers in are clearly noticeable vertically downward from the depth of about 5 m. The bedrock is partially shown on the tomogram. The electrical resistivity range which characterizes this section is 13 – 5239 Ωm. The region where the suspected septic tank was located on this model section shows relatively high resistivity values when compared with the rest of the regions in the section. This suggests a probable occurrence of an air–filled column which has very low conductivity or concrete which has very high resistivity. The shallower parts of the pseudosection showing electrical resistivity <1000 Ωm may be interpreted to consist of clay (1-100 Ωm), sand (10 – 1000 Ωm) and soil water (10 -1000 Ωm) respectively. These formations characterize the overburden of the model section. The weathered and fractured basements which are characterized by electrical resistivity range $>$ 1000 Ωm are slightly revealed at the base of the pseudosection and have minimum depth of about 11 m. Four zones of resistivity–high are clearly shown. Two of the anomalous zones are located at the topmost layer of the section whereas the other two are located at its base. The first anomaly, >1000 Ωm, occurs between 20 m and 34 m of the lateral distance and extends to maximum depth of about 5 m. The second >5000 Ωm occurs along this profile between 60 m and 70 m lateral distance having maximum depth of about 3.5 m. The resistivity high ($>$ 5000 Ωm) located at two zones A and B suggests the occurrence of air column comparatively or concrete. The resistivity high at the base of the section could be attributed to the resistivity of the granitic basement (4.5 x 10^3 Ωm (wet) – 3.6 x 10^6 Ωm (dry)) (Telford et al., 1976). Resistivity low at zones C and D (20 - 70 Ωm) is in the range of the resistivity of saturated clayey soil. This suggests that the soil which directly underlay the tanks is most likely saturated clayey soil. The basement which is partly mapped suggests that it could be an undulating. The rest of the tanks' vicinity which was mapped shows that the topsoil at the proposed building premises is characterized by clayey soils (1-100 Ωm).

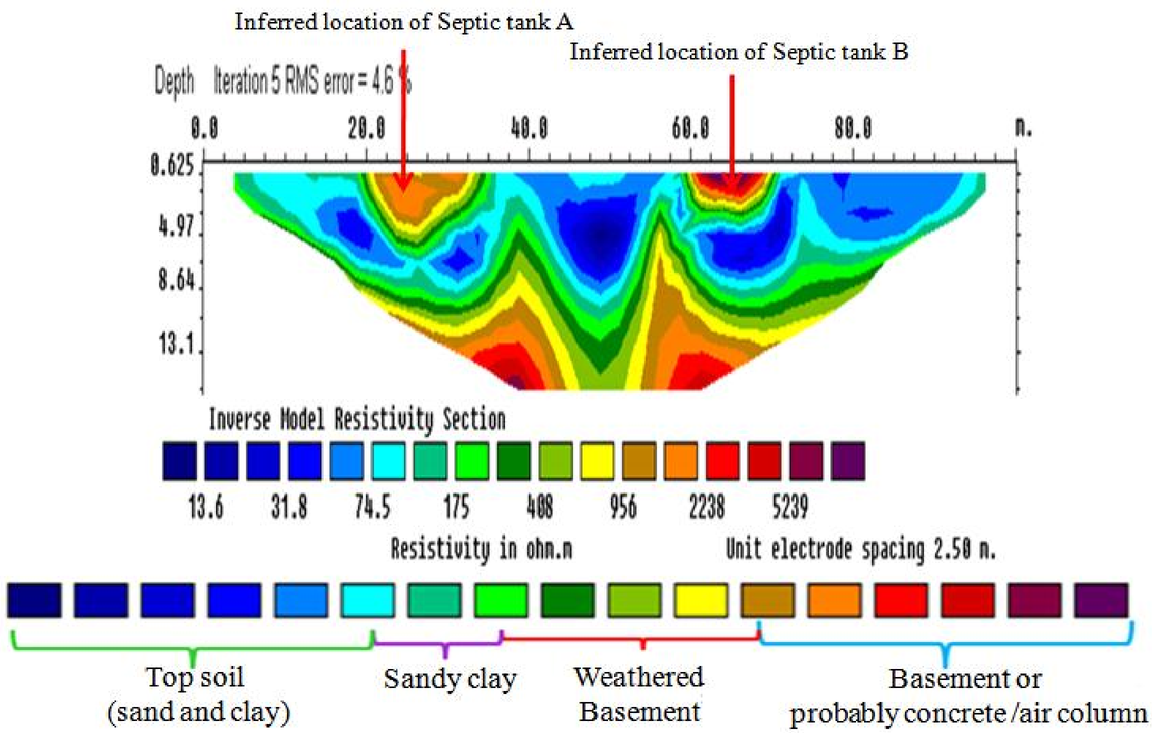

Figure 3: 2D Inversion Model Resistivity Section of Profile

Figure 4 shows the orthographic view of seismic refraction tomogram of the same profile. The tomogram also detects the zones of the collapsed septic tanks. These are shown at its lateral distances of 25 m and 47 m respectively. There is no evidence of a dipping layer across this profile however the basement also shown to be undulating just as shown on the electrical resistivity tomogram. The p-wave velocity range of this pseudosection spans between 200 m/s and 2000 m/s. The regions where the septic tanks are sited are shown to have lowest p-wave velocity values ($<$ 600 m/s) on the pseudosection. This also suggests a probable occurrence of an air-filled column (300-330 m/s) and sand (350 -1165 m/s) (Osemeikhan and Asokhia, 1994; Hugh, 1995; and Keary and Brooks, 1988). The zones C and D mapped and interpreted as saturated clayey soil in the resistivity section (Figure 4) is not shown at all in the seismic refraction tomogram. The depths around and below the location of the tanks is predominantly characterized by clayey soil which has p-wave velocity range of 1000-2500 m/s. Also, there could also be a probable occurrence of lateritic soil which has p-wave velocities between 1200 and 1500 m/s. The partly mapped granitic and gneissic basement (2000 – 7000 ms^{-1}) also clearly shows undulations just as shown in the electrical resistivity section with average depth of about 12 m (Figure 4).

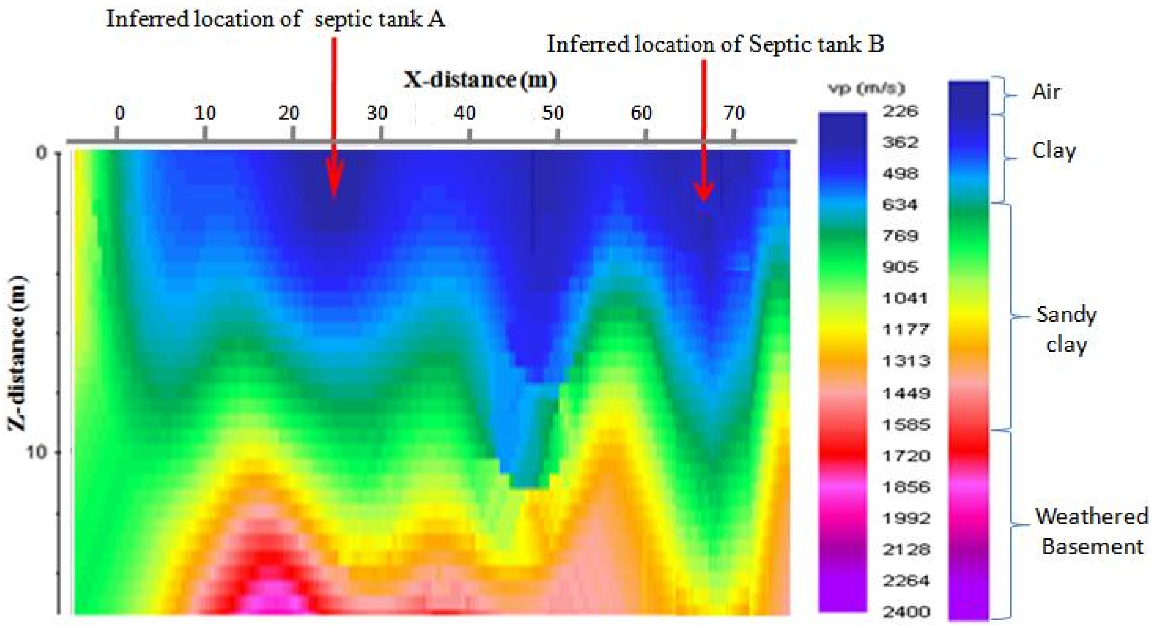

Figure 4: 2D Refraction Tomography Model Section of Profile

Discussion

The resistivity and seismic pseudosections show anomalies that are characteristic of void which most likely correspond with the locations of the septic tanks. They appear approximately at 25 m and 65 m horizontal distances on the pseudosections respectively. In the resistivity pseudosection, the maximum lateral and depth extents to which the tanks may have been sited are 6.0 m and 3.0 m which correspond to the dimensions of the high resistivity zones in the tomogram (Figure 4). Likewise, in the seismic refraction tomogram, the maximum lateral and depth extents to which they are probably sited are about 7.0 m and 2.8 m respectively (Figure 5). The results suggest that the tanks most likely have average lateral extent of about 6.5 m and average depth of about 2.9 m.

Thus it can be deduced that both the resistivity and seismic refraction tomography have delineated approximately the lateral extents and depth limits to which the inferred collapsed septic tanks (A and B) were sited based on the resistivity and p-wave velocity contrasts shown on the inverted model pseudosections. While the high resistivity ($>$ 1000 Ωm) is in the range of air-filled column and buried concrete slabs, the low velocity ($<$ 400 m/s) confirms the air-filled column which probably was trapped during the collapse of the tanks. The low resistivity zones (20-200 Ωm) which are shown and interpreted as saturated clayey zones directly underlying the two tanks and probably due to leakages at the base of the septic tanks are not show in the seismic section. Both the seismic refraction and resistivity pseudosections are shown to be generally characterized by a very shallow undulating basement with average minimum depth of 11.5 m. The collapse of the tanks could be solely attributed to presence of the expansive clayey soils at shallow depths in its vicinity. Few months after the study, an evidence of the clayey soil was clearly shown (Figure 5) as two new septic tanks about 2.5 m deep were sited to replace the collapsed/abandoned ones.

Figure 5: Photographs taken during the construction of new septic tanks showing the evidence of clayey soil at shallow depths.

Conclusion

Two collapsed and partially buried septic tanks were imaged geophysically to delineate the structures responsible for their failure. The information obtained is imperative because the site is intended for a building construction. Integrated geophysical techniques involving two dimensional electrical resistivity and seismic tomography were used for the study. The choice of these techniques was based on their ability to delineate minor variation in subsurface lithology at shallow depths. The tomography data were collected along a profile which was laid across the two septic tanks. The data collected were tomographically inverted. The interpreted results showed that the subsurface in the vicinity of the tanks is characterized by a resistivity range of about 10-5200 q m and a p-wave velocity range of about 320-2400 m/s. The resistivity range of about 1-100 q m and p-wave velocity of < 1000 m/s suggests that the formations at shallow depths (0-8 m) are predominantly clay and sandy clay. The resistivity high (> 5000 Ωm) located at the two inferred locations of the septic tanks suggests the occurrence of air column comparatively. This result is supported by an extremely low p-wave velocity in the range of 300-330 m/s. The results suggest that the tanks most likely have average lateral and depth extents of about 6.5 m and 2.9 m, respectively. The basement at vicinity of tanks is shallow and undulated with average depth of about 11.5 m.

The delineated clayey soils at shallow depths suggest that seasonal clay swellings and shrinkages due to seasonal variations in moisture contents of the clay are most likely responsible for the collapse of the septic tanks. The variation in moisture contents must have led to annual ground movement, cumulative soil creep and the subsequent failure of the septic tanks.

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