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MAPPING THE DEPTH TO GROUNDWATER USING GROUND PENETRATING RADAR (GPR) IN AN OIL PRODUCING COMMUNITY OF WESTERN NIGER DELTA

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The effectiveness of GPR in delineating the groundwater surface (GWS) was demonstrated in the study carried out in Ughievwen, an oil rich community of Niger Delta, Nigeria. A total of 456 line-meters of radar profiles were acquired. The GWS produces relatively strong reflections and distinct images in all the radargrams acquired within the survey site. The variation in the depth to the groundwater surface measured at the borehole point and the GPR measurement at the same location were is close agreement. The high degree of correlation in the estimated values obtained from the radar profiles and the actual values obtained in the borehole indicated that GPR is capable of defining accurately the GWS.

INTRODUCTION

This paper outlines the results of a study employing GPR to estimate the depth of the groundwater surface in a shallow freshwater groundwater system in Ughievwen community in the Niger delta area of Nigeria. The largest percentage of Nigeria oil and gas comes from Niger delta region. The region is considered as one of the most prolific oil producing regions of the world. It contributes about 90% of Nigeria foreign exchange earning and 25% of the GDP. Ughievwen and five other communities in Ughelli North, Ughelli South and Isoko South Local Government areas of Delta State have over 200 producing oil wells and four flow stations (Atakpo and Ayolabi 2009)

As a result of activities of various oil and gas companies located in the region, a considerable number of developments has occurred in the urban areas as rural development in the region is one of the topmost priorities of the Federal Government of Nigeria since the youths have laid down their arms and embraced amnesty. There is need to understand the influence the shallow groundwater system could have on the hydrogeologic environment as this will assist in proper design of facilities thereby preventing structural failures and environmental hazards.

An accurate definition of groundwater table in an area requires a good number of boreholes. This could be very expensive and time consuming. There is therefore the need for the use of geophysical methods which are non-invasive means of obtaining subsurface information. Various geophysical techniques such as direct current resistivity, time-domain electromagnetic (TEM), frequency-domain electromagnetics (FEM) etc have been adopted in the mapping of groundwater table (Barrett et al., 2002; Lenkey et al., 2005).

Several case studies have shown the effectiveness of GPR in hydrogeologic studies (Beres & Haeni, 1991) and mapping the groundwater surface (Al-Shuhail, 2006; Peterson et al., 2007), The Ground Penetrating Radar (GPR) method was adopted in this study based on its ability to image the shallow groundwater systems in real time with high resolution, lower costs and relative portability of the equipment.

GEOLOGY AND PHYSIOGRAPHY OF THE STUDY SITE

The area of investigation is located at Ughievwen community in Ughelli South local government area of the Delta State as defined by longitude 05°54’582’’E and latitude 05°31’381’’N (Figure 1). The terrain of the survey area is relatively flat with elevation of about 3 m above the sea level. The site is 40 m north of the Ekakpamre River. The vegetation is the rain forest type.

This GPR survey was conducted two months after the fire incidence of September, 2009, caused by the oil spills from the Rapelle oil pipeline buried about 1 m below the surface. The fire outbreak caused a serious environmental catastrophe in the area. There is still controversy between the host community and the oil firm on the probable causes of the fire outbreak. The study site is about 30 meters west of the fire outbreak area. However, the effect of the heat could be seen on some of the radargrams acquired in the area classified as ‘non affected area’.

The surficial sediments in the survey area are composed of medium to coarse-grained sands with variable clay admixtures. The sediments are underlain by Quaternary Sands belonging to the Sombreiro Deltaic Plain of the Niger Delta Basin. This formation directly overlies the Benin Formation and underlain by the Agbada and Akata Formations in succession (Short and Stauble, 1967; Weber and Daukoro, 1975). Various authors (Reijers et al., 1997) have extensively discussed the stratigraphy of the Niger Delta.

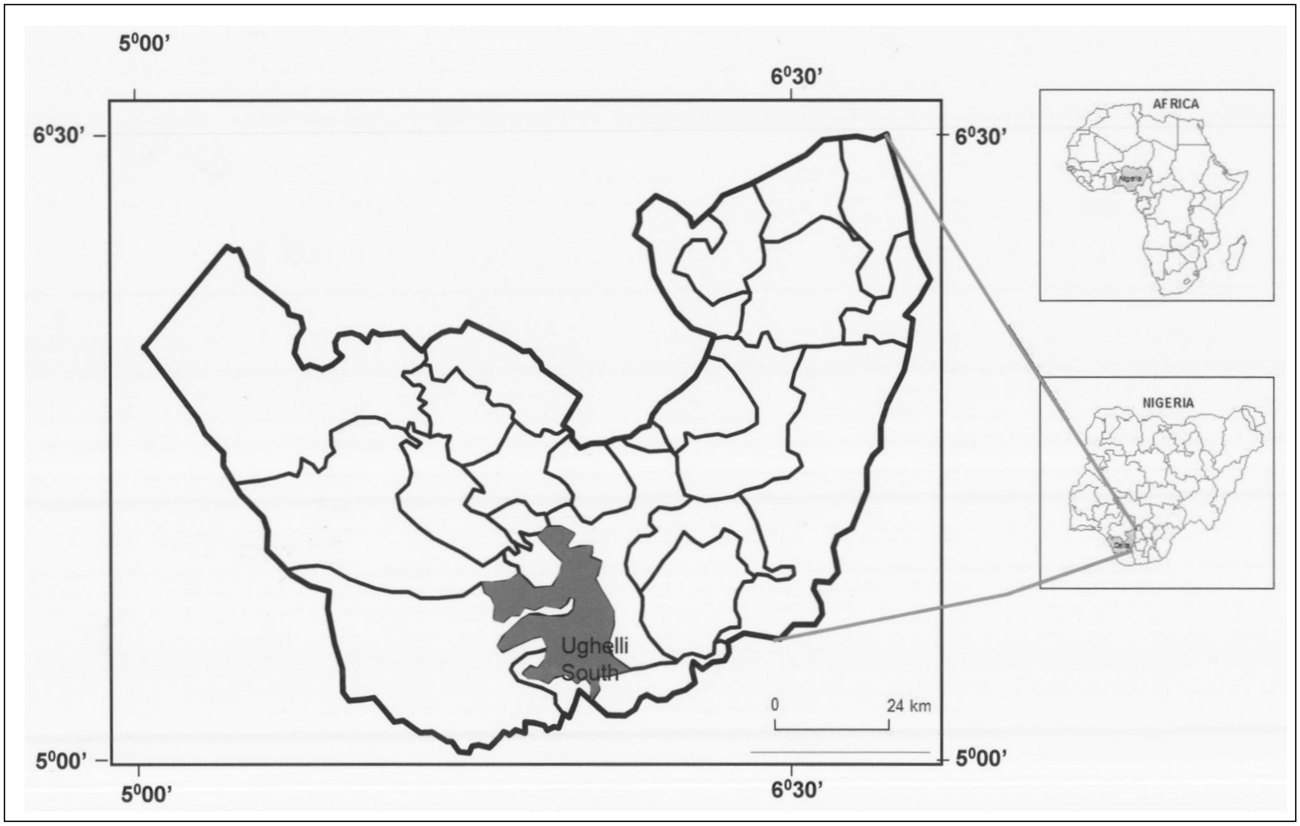

Figure 1. Map of Delta State showing the study area.

METHODS

Theory of Operation

Ground Penetrating Radar (GPR) uses transmitting electromagnetic waves that respond to changes in the electromagnetic properties of the shallow subsurface. A transmitting antenna generates electromagnetic wave which travels into the ground at the velocity determined primarily by the subsurface material’s electrical properties. If the waves hit an interface between materials with different dielectric properties some of the energy are reflected or scattered back to the surface while some are transmitted into the lower material. The reflected energy is captured by a receiving antenna. The time it takes for the wave to travel down to an interface and back to the surface is called the travel time (Daniel et al., 1995; Baker et al., 2007; Omolaiye & Ayolabi, 2010).

Data Acquisition

A total of 436 line-metres in length of GPR profiles (6 in number) were obtained in the relatively flat terrain; Five GPR profiles each 70 m long at intervals of 10 m and trending N-S including one N-S trending profile of 86 meters about 30 m east of the profile L5 were occupied in the study area (Figure 2). This line was acquired in the area affected by the fire disaster. The study was conducted two months after a fire incident in 2009. The GPR data were collected in digital format using the RAMAC X3M GPR equipment, manufactured by Mala Geoscience Ltd., Sweden.

GPR trial survey was conducted using two antenna frequencies (250 MHz and 500 MHz) over a borehole 200 m north of the survey site to determine the appropriate velocity and the frequency of the antenna to be adopted. The 500 MHz antenna has interpretable depth shallower than the target depth; therefore, 250 MHz antenna was deployed for this survey with the purpose of delineating

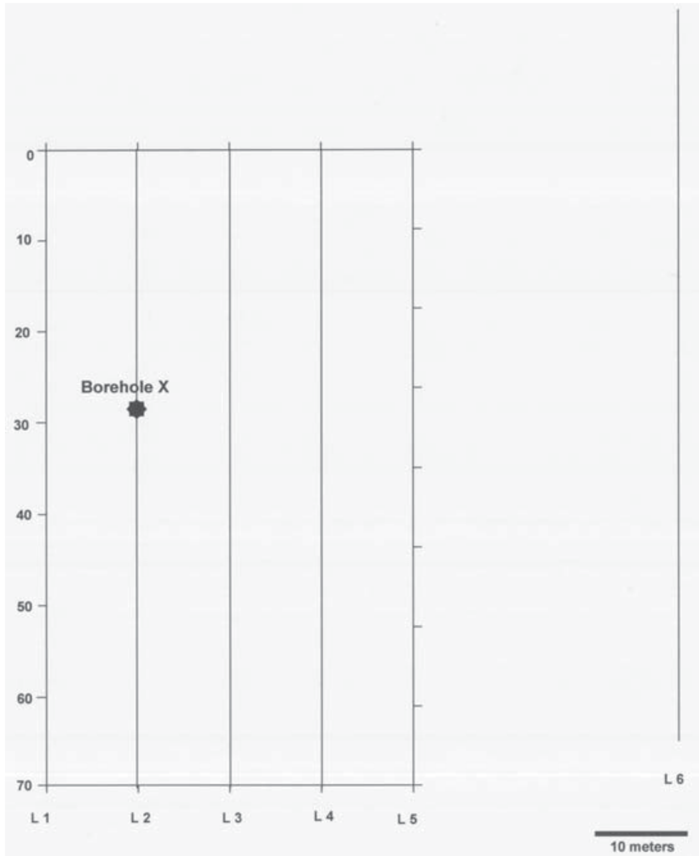

Figure 2. The survey area showing the layout of GPR lines.

the ground water surface and other subsurface features within the survey area.

The shielded 250 MHz antenna deployed has interpretable depth of 6.0 m. To effectively image the subsurface and also map the ground water surface (GWS) in the survey area, a regular interval of GPR profiles was maintained. Radar data were acquired by transmitting a single fold common offset line with sampling frequency of 2536 MHz, time window of 202 nanoseconds, trace interval of 0.1012 m and vertically stacked (20 stacks) to enhanced the signal to noise ratio.

A borehole was drilled directly on the GPR established lines within the survey site shortly after the GPR survey and the depth to the top of groundwater surface was measured. Data acquisition was completed in one day.

Data processing and analysis

The GPR data were initially edited using Ground Vision™ software; the edited data were processed and displayed in wiggle trace format using ReflexW software. Every data set was processed using the same set of parameters. The defined processing sequence is shown in Table 1. Static correction was not performed on the data because the terrain of the study area was approximately flat. The applied processing steps increased the interpretability of the GPR profiles by removing the random noise and enhancing the amplitude response of interest.

All measurements and borehole points were geo-referenced using a handheld *Garmin GPS 72* global positioning system (GPS).

Table 1. Processing steps / parameters adopted.

Subtract-mean (dewow)
Manual gain (y): 5 db – 40 db
Background removal: 10 ns
Stack traces: 10
Time to depth Conversion: Velocity approximation of 0.11 m/ns
Time cut Maximum range: 90 ns

RESULTS

Groundwater Surface Resolution

The results are presented as radargrams (Figures 3 and 4). The depth in meters is shown on the right vertical axis of the radargram, using the near-surface velocity of 0.11 m/ns (calibrated).

Adopting the Jol & Bristow (2003) method, the theoretical depth resolution of GPR reflections is approximately 1/4 – 1/2 of the wavelength;

Wavelength (λ) = V/F

V= velocity and F= frequency

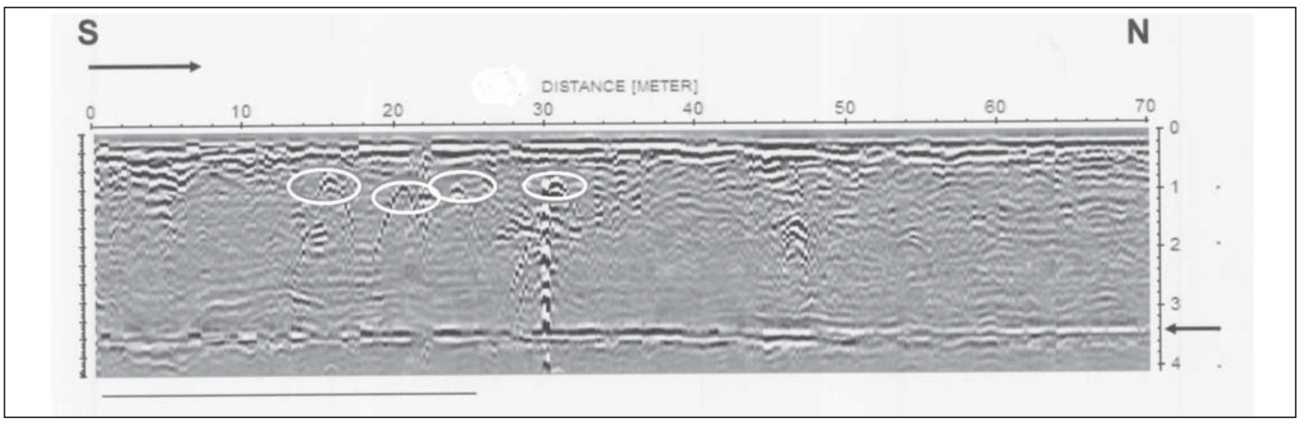

Figure 3. Typical GPR data exhibiting a reflection pattern similar to that of the groundwater surface and buried rapelle oil pipelines.

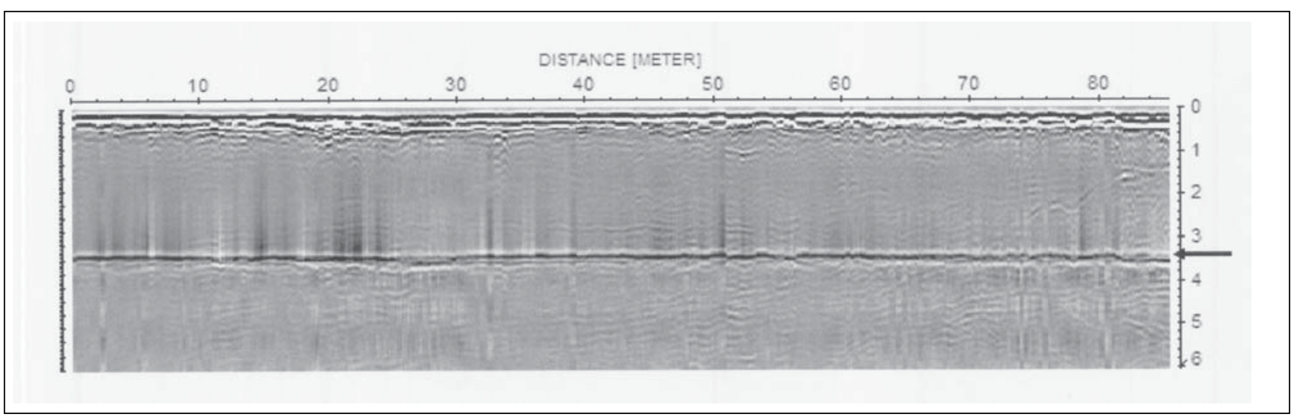

Figure 4. One of the GPR data acquired from the fire outbreak area exhibiting a reflection pattern similar to that of a groundwater surface.

The resolution for 250 MHz antenna and velocity = 0.11 m/ns is estimated to be 11 - 22 cm. Hence, the 250 MHz antenna can effectively resolve the GWS in this area.

The radargrams represent parallel vertical ‘slices’ through the ground to a depth of 6.0 meters (processed data) and 8.0 meters (raw data) below the ground surface. The 250 MHz antenna was able to delineate the GWS within the study area when compared with the result from the wellbore located in line 2 of the study area.

DISCUSSION

Radar signals/reflections typical of GWS could be a strong reflection on the radargrams based on the strong contrast in the dielectric properties between saturated and the unsaturated soils (Shih et al., 1986). A phase shift (reversal) could also be used to distinguish the GPR reflections (Daniel et al., 1995; Peterson et al., 2007). This approach was adopted in interpreting all the radar profiles.

The GWS produces relatively strong reflections and distinct images in all the radargrams acquired within the survey site; this is recognized as continuous horizontal and relatively high-amplitude reflection within the range of 3.4 - 3.52 m below the surface. The semi-discontinuous radar reflectivity and phase reversal (shift) observed on the profile L1 between 0.0 and 3.0 m may be as a result of the effect of diffractions caused by the Rapelle oil pipelines buried at a shallower depth (Figure 3).

Other subsurface features such as pipelines were also delineated in the study area, the diffraction of the radar reflection depicting pipes could be identified on some profiles (L1-L4). In Figure 3, radar signals typifying four Rapelle pipes (circled in white) on the profile at surface distance of 13, 20.5, 22 and 30.5 m buried at about 1.0 m with the orientation in the NE-SW direction could be identified.

The transparent package between 0.8 and 3.4 m in Figure 4 shows that the soils within the interval may be made up of the same materials; hence it shows little or no contrast in the dielectric properties. The medium grained soils that are dark in colour on Line 6 may be reworked materials which could be associated with the effect of intense continuous burning of the soil due to fire outbreak than the presence of some clay materials. Figure 4 (line 6) is the radar profile acquired in the affected area and this was used to interpret profiles 4 & 5 acquired within the survey area.

The groundwater surface was measured at a depth of 3.46 meters below the ground surface in borehole X. This result is in good agreement with the GPR interpretation that estimated the piezometric surface depth at the borehole location to be 3.43 meters. This shows a difference of 0.03 m and correlation coefficient of 0.9913 in the study area, which is an indication of a confidence of about 99 percent.

The groundwater surface was mapped in all the radar profiles and contoured to generate the potentiometric map of the study area. Figure 5 is the map of the top of the GWS obtained at the survey site; it shows that there is a depth increase in the GWS to the South. It indicates the flow direction of the groundwater towards the Ekakpamre River 40.0 m south of the survey area.

CONCLUSIONS

The results of the GPR technique have confirmed its importance in efficient, rapid and accurate mapping of the groundwater surface in the survey area. The groundwater map generated from GPR

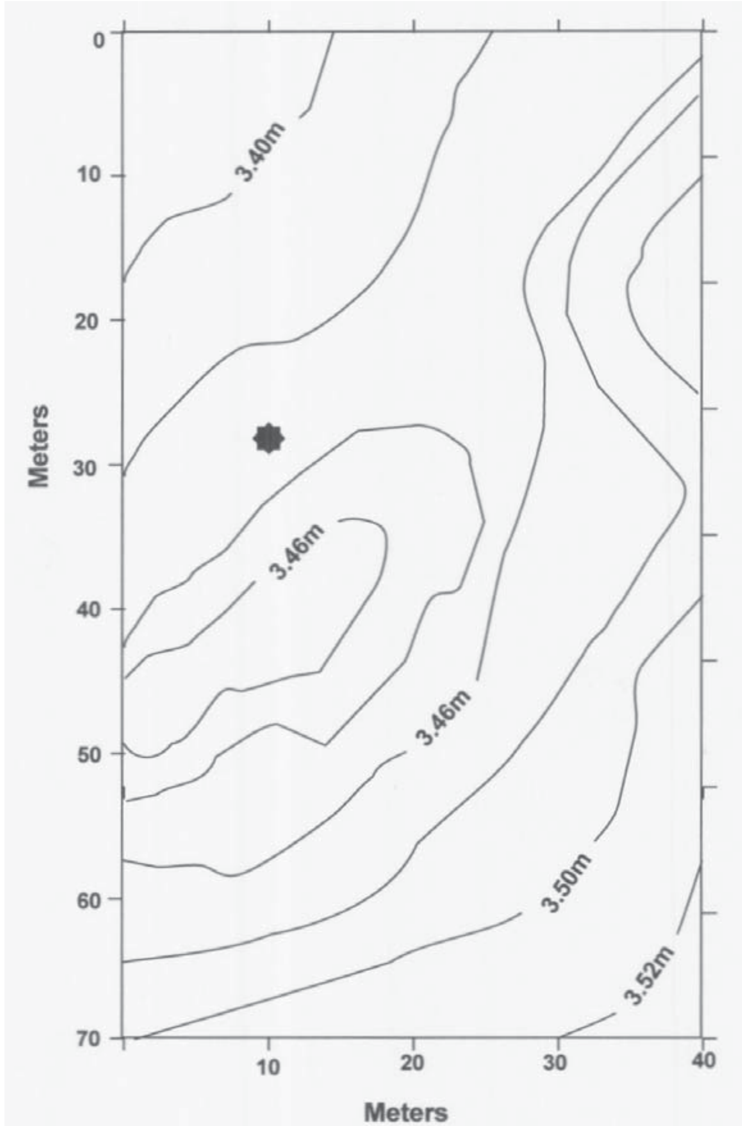

Figure 5. Map of the groundwater surface derived from the GPR data.

data could be easily used to determine the flow directions and the hydraulic gradients; this could help establish best possible locations for monitoring wells as well as improve groundwater modeling. The high degree of correlation in the estimated values obtained from the radar profiles and the actual values obtained in the borehole indicated that GPR can effectively define the top of GWS and delineate of some other subsurface features with a high degree of certainty.

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