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Near-Surface Investigation of Groundwater Contamination in the Regolith Aquifer of Palladan, Zaria using Borehole log and Tomography Techniques

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Abstract: Two geophysical Tomography techniques- Electrical resistivity and Seismic refraction were used to investigate the subsurface of a potentially polluted dumpsite in Palladan a densely populated area of Zaria, with a view to examining the possible subsurface distribution of groundwater contamination plume. The presence of domestic wells in the residences of the people which are distances 10.0 to 30.0 m from the dump facilitated analysis of water chemistry to enhance the geophysical interpretation. The groundwater level in the dumpsite site was found to be higher than the surrounding area, thereby creating a local deviation from the regional groundwater flow. Due to this the contaminants from the waste site spread out in the nearby soil and groundwater. The resistivity models clearly show a top layer of about 10.0 m thickness with low resistivity, whereas the resistivity has an inverse correlation with distance from the waste disposal site. Bore hole log shows that the top upper 10.0 m of soil consists of loose permeable laterite with high water content followed by a layer of degraded sand before the weathered basement which suggests the possibility of the contamination penetrating deeper into the regolith aquifer. This agrees with the result of the water chemistry analysis which shows elevation in concentration of contaminants above the WHO guidelines. The borehole log also indicated the presence of fracture basement at a depth of 23.0 m this correlated well with the Seismic refraction result. The study therefore suggests that these fractures also facilitate the migration of the contaminants. Based on the combined results, the contamination plume seems to have migrated not less than 500.0 m in the southern direction which is also the direction of hydraulic gradient

Key words: Contamination, electrical resistivity, groundwater, seismic refraction, tomography

INTRODUCTION

Groundwater is the primary source of drinking water for roughly a third of the world's people, but it has been found to be highly vulnerable to pollution (Payal, 2000). Because groundwater recharges with geological slowness, once an aquifer is excessively depleted or contaminated, the damage is essentially permanent and efforts to reduce the contamination are extremely costly. To preserve this valuable resource for future generations, we need to make systematic changes in the way we grow our food, manufacture goods, and dispose of waste.

In Nigeria and other developing countries, waste disposal management has become a major problem (Agunwamba, 1998; Ogwueleka, 2009). Large refuse dumpsites that need remediation are seen surrounded by residential quarters in our urban cities. In the majority of these dumpsites the contaminants are heavy metals; however the levels of contamination are often unknown (Ogwueleka, 2009). Pollution of groundwater under and near waste disposal site happens when rain falls and

passes through the waste dump and a waste fluid called leachate is formed which can infiltrate across the unsaturated zone and deliver contaminated water to the water table (Fig. 1). Every conceivable inorganic and organic material may be present in the leachate that can degrade the groundwater quality thereby putting the local community under serious health risk. One of the most frequent demands in metropolitan areas includes the detection of the location and extent of contamination patches in areas as small as dumpsites. In such a context, the integrated use of various geophysical methods provides an important tool for the evaluation and characterization of contaminants generated by urban residues (domestic and/or industrial).

In the last several decades geophysics has proved an invaluable tool as it has been used to isolate and clean up sites victimized by past industrial and human practices that have left soil and water supplies in some locations unfit for human use. Electrical Resistivity, Induced Polarization, Seismic Refraction tomography, electromagnetic, magnetic and ground penetrating radar

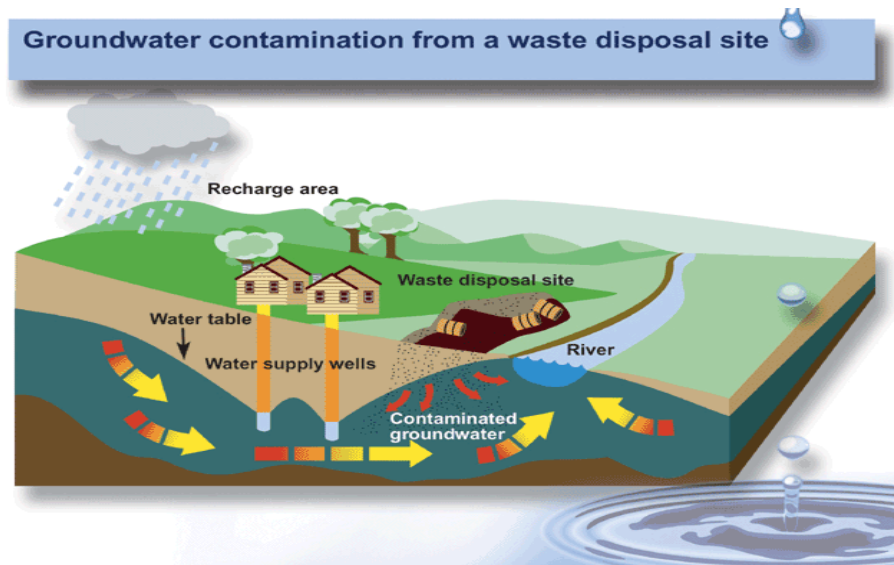


Fig 1: A modeled diagram showing how groundwater gets recharged and contaminated at waste disposal sites (courtesy: Porter and Stimmann, 1988).

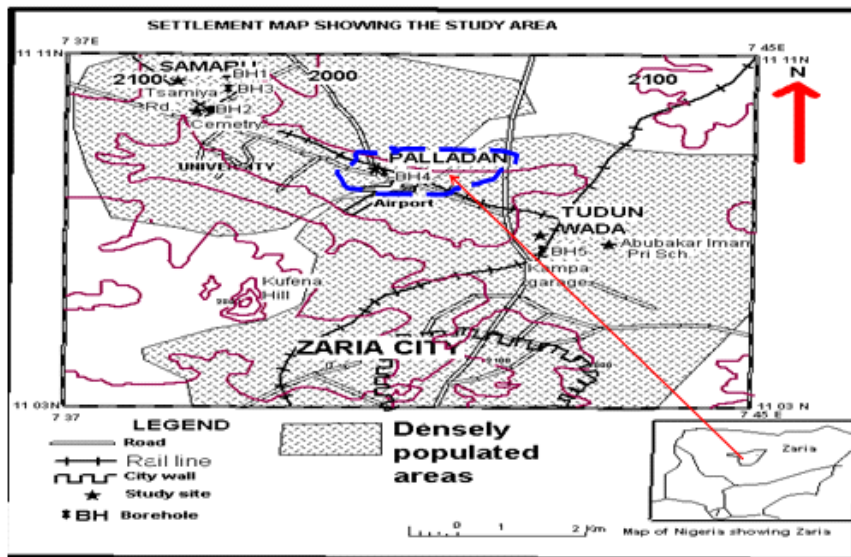


Fig. 2: Settlement map of Zaria showing the location of paladan

surveys are a particularly useful integrated techniques for examining the possible subsurface distribution of contamination plume because dissolved plume (leachate) can influence resistivity or conductivity, dielectric constant, chargeability, and magnetic susceptibility (Keary *et al.*, 2002). In this paper, electrical resistivity imaging technique was used to locate and monitor probable leachate plumes escaping from dumpsites. Since the electrical conductivity of leachate is so much higher than that of the natural groundwater, the plumes could also be detected (Soupios *et al.*, 2007). In such case, the unknown base of the dump can be outlined on the image

and the less resistive leachate can be seen extending beneath the base of the dump into the surrounding ground. For this research the location of fracture zones was critical to the subsurface investigation as the fracture zones represented preferential fluid migration paths with enhanced groundwater flow and the potential of transmitting contaminants at greater rates (Bates *et al.*, 1991). The refraction seismic tomography technique in correlation with borehole records were use to map the lithology and the fractures which could serve as possible pathways of the contaminant plumes into the aquifer body.

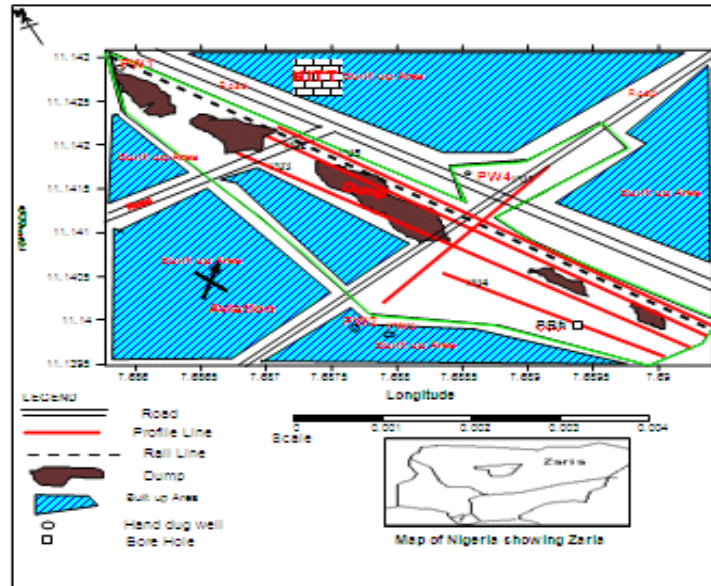


Fig. 3: Detail map of the open dumpsite and the profile orientation

MATERIALS AND METHODS



Fig.4 : Part of the paladan dumpsite

Location of study area: The open dumpsite is located in Palladan, a densely populated area opposite the Nigerian College of Aviation Technology and adjacent to the Nigerian institute of transport technology (NITT) in the Zaria basement complex. The Zaria basement complex lies between Latitudes $11^{\circ}03' N$ and Latitude $11^{\circ}11' N$ to Longitudes $07^{\circ}37' E$ and $07^{\circ}42' E$ (Fig. 2). The approximate average elevation is about 670m above mean sea level. It occurs in a dissected portion of the Zaria - Kano plains. The Zaria-Kano plains are an extensive peneplain developed on the crystalline rocks of the Northern Nigerian Basement Complex. Residual granite inselbergs, the largest of which is the Kufena Hill, provides the main relief. The co-ordinates of Palladan on a detail scale lies between Latitudes $11^{\circ}08' 22'' N$ and $11^{\circ} 08' 35'' N$ to Longitudes $07^{\circ}41' 10'' E$ and $07^{\circ}41' 24'' E$ (Fig. 3).



Fig. 5: Paladan bore hole showing some villagers lined-up fetch water. This is an evidence of high abstraction rate. (Jegade *et al.*, 2011)

The site characterization: The deposits of this site are known to consist of municipal and agricultural waste (Fig. 4). Heavily contaminated groundwater is present, in many cases reaching above regulatory levels. The major contaminants commonly discovered are organic anthropogenic materials and high levels of heavy metals as revealed by the groundwater sample analysis collected from hand dug wells and borehole close to the dumpsite. The water demand in the community is very high which result in the high abstraction on the only borehole in the community (Fig. 5). The maximum difference in elevation



Fig. 6: Thick overburden observed in the study area . (Jegede , 2009)

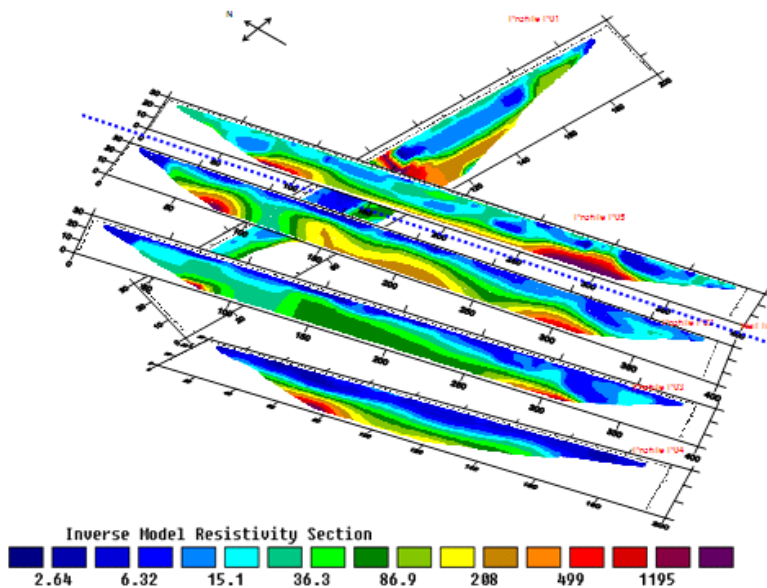


Fig .7 : Distribution turned of the resistivity pattern in the study area.

between the top of the solid waste and the surrounding area is about 6.0 m.

Geology and hydrogeology of the area: The survey area lies entirely within the Basement Complex of Northern Nigeria.

The bedrock consist of a series of granites, gneisses, migmatite, low-grade schist, quartzite and amphibolites which are overlaid by thick weathered (Adanu, 1987) overburden reaching up to 5-12 m thickness (Fig. 6). The top soil varies in composition, color and texture and at most places they are predominantly Laterite and quartz grains (deep brown or reddish brown soils). Geophysical investigation and borehole drilling reports have clearly established two major aquifers in Zaria. These are the overburden weathered (regolith) aquifer and the fractured

crystalline aquifer. The former holds a great quantity of groundwater and most hand dug wells are located in this shallow aquifer for domestic water supply. At some locations, these aquifers are interconnected and form single unconfined hydro geological unit

Geophysical survey: A combination of Seismic refraction tomography and Electrical resistivity tomography was used to investigate a potentially polluted waste disposal site. The resistivity surveying was carried out using the Abem Lund Imaging System, a computer controlled multi-electrode system. The data acquisition was carried out as a number of parallel continuous vertical electrical soundings (CVES). The Wenner- α array was used throughout, employing cables with 5 metres between each electrode take-out, 42 electrodes and the ES464

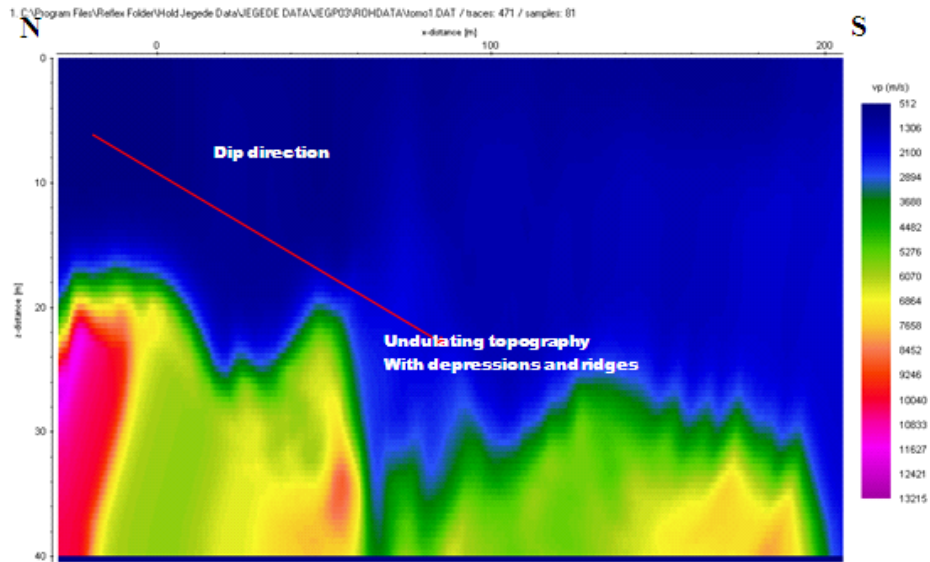


Fig.8 : SRT model for profile P03

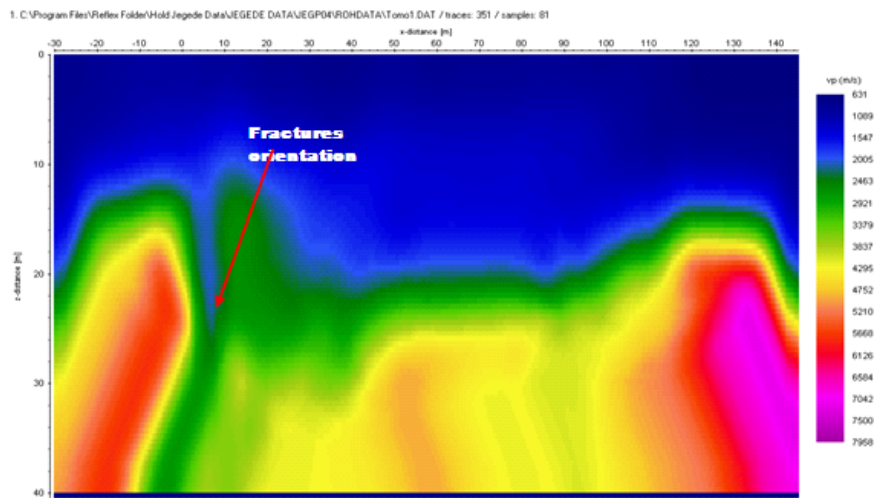


Fig. 9: SRT model for profile P04

electrode selector. The Wenner- α roll along technique was used. The profile length, range from 200m to 400m. Five (5) ERT and Two (2) SRT profiles were surveyed in March/ April 2007. The profiles were labeled P01, P02, P03, P04 and P05 for the ERT and P03 and P04 for the SRT. All the readings were taken with transmitted current ranging between 20 mA and 100 mA for the ERT (Abem, 2006). Figure 2 shows the orientation of the profile lines in the study area. The built up areas, the Railway line and the roads are also shown as constrains on the profile lengths. The Seismic refraction survey was carried out using the Abem MK6 system, a 24 channel Seismograph with vertically positioned geophones that are separated by a constant distance of 5.0 m giving rise to a profile length

of 120 m for a single spread. The roll along technique was also adopted to extend the profile length. The resulting seismic data acquired were processed and tomography data were interpreted using the ReflexW software (Sandmeier, 2003).

Processing and interpretation of ERT data: Processing and interpretation of ERT data was carried out using the 2-D computer Software, RES2DINV (Res2Dinv, 2006). The aim of the resistivity inversion algorithm is to recover a physically realistic set of model parameters that adequately reproduces the given set of field data (Aristedemou and Thomas-Betts, 2000). Data were filtered to eliminate bad datum points and in addition the

robust inversion constrained was applied on the model resistivity values. There are two inversion schemes built into the RES2DINV commercial imaging software, the robust inversion and the smoothness-constrained least squares. In groundwater pollution studies, it is important to determine the position of the boundary of the more conductive leachate plume in the saturation zone. Therefore the robust optimization method is usually better to generate the resistivity models in preference to the smoothness-constrained method. It provides significantly better results in situations where true subsurface resistivity consists of regions that are approximately homogenous internally and separated by sharp boundaries (Osazuwa and Abdullahi, 2008). According to Kalik and Kaya (2001), resistivity method can identify contaminant plume by low resistivity, observation of low resistivity zone will be considered sufficient to determine the spread of contamination that is expected to be in the direction of groundwater flow in the site in the absence of clay. In this survey, the unknown base of the dump was outlined on the models and the less resistive leachate was seen extending beneath the base of the dump into the surrounding ground.

Processing and interpretation of SRT data: The data collected were processed using the ReflexW software. Filtering were applied to the data to enhance its quality and deconvolution was carried out to counter the effect of filtering, first arrival times were picked and incorporated into a data file for each profile line. Each of the data file includes precise positions of each geophone and shot point and all the first arrival picks. The picked arrivals were assigned to layers and joint inversion of the travel time pick was carried out to generate model which was followed by ray tracing. The resulting model was then used to generate the tomography section. The results obtained were presented in tomography models. For the interpretation of the selected data sets each arrival time was corresponded to a layer where the deepest refraction of the seismic wave has been recorded. Thus the first arrivals (close to the seismic source) correspond to the direct waves which give information about the velocity of the first waves corresponding to the second layer. The same procedure was applied for deeper layer.

DISCUSSION OF RESULTS

The interpreted resistivity model sections were merged to form a pseudo- 3D dataset presented as vertical slices of the resistivity maps for the different horizontal interval in the study area. This arrangement of the resistivity model sections makes it possible to view the distribution trend of the resistivity pattern in the study

area (Fig. 7). Borehole logs from the surrounding and Previous resistivity survey in the study area (Chiemeke, 2005; Chii, 2001; Jegede, 2009; Jegede *et al.*, 2011) suggest that the weathered overburden is characterized by resistivities in the range of 50 to 200 Ohm-m, therefore in the neighborhood of the dumpsite, it is expected to occur as a relatively thick layer of contaminant zone, in that case, the resistivity of shallow regolith might be expected to be less than 50 Ohm-m. Since the water table is shallow and regolith is largely saturated, any resistivity much below 20-Ohm-m will indicate groundwater contamination, in the absence of clay materials.

The final interpretation of the profile (as far as p-waves are concerned) is based on the morphology of the discontinuities (refractors) and the velocities of the space waves. The tomography models Fig. 8 & 9 are painted in shades of different colours which correspond to specific velocities in the colour bar placed besides the models. The velocities range from 512m/s to 13215m/s and 631m/s to 7958m/s for profile P03 and P04 respectively. A comparison of the model velocities which represent the distribution of velocities within the subsurface with borehole records (Table 1) obtained from the Nigerian institute of transport technology shows good correlation. A comparison of the model velocity with standard velocity and their corresponding lithology is also shown in Table 1. The depths indicated by borehole records correlated well with the depth of the various layers delineated by tomography model.

The topography of the study area can be seen delineated from the tomography model of SRT Profiles P03 and P04 as well as the direction of dip. Figure 2 shows that the profiles were oriented N-S which implies that the topography of the subsurface is dipping down in a North - South directions, although some levels of undulation can also be observed in the tomography models. This implies that the direction of groundwater flow will be mainly in the north - south direction (Fig. 8 & 9). This fact is also confirmed by the ground surface elevation which slopes down from the north to the south.

The difference in elevation between the dumpsite and the surrounding ground shows that the groundwater level in the dumpsite is higher than the surrounding area thereby creating a local deviation from the regional groundwater flow. The tomography models show clear region of fractured basement. In profile P03 & P04, (Fig. 7) varied degree of fracture can be observed along the profile stretch. The low velocity regions penetrating into the fresh basement of high velocity is an indication of fractured basement. Besides the fact that this feature enhances the groundwater potential of the study area, they also serve as preferential migration pathways for the groundwater contaminants.

Table 1: A comparison of the model velocity with standard velocity with their corresponding lithology

Rock type	Std Vel(Osemeikhian & Asokhia 1994) (m/s)	Corresponding tomo Vel (m/s)	Tomo model depth (m)	Borehole depth (m)	Formation
Top soil	350-900	512-909	0-5.1m	0-6	Top soil
Sandy clay	975-1160	909-1306	5.1-14.8	6-15	Over burden
Granite	2,902-5600	2100-4483	22-25	27-46	Basement of various degree of fractures
Gneiss		4483-7215	>25	>46	Fresh basement

Table 2: Groundwater samples from area of study

S/N	Parameter	Unit	PW1	PW2	PW3	PW4	PBH1	WHO Limit (1992)
1	PH	-	7.41	6.76	6.38	6.77	6.60	6.5-8.5
2	EC	µs/cm	1660	740	1120	1538	280	-
3	TDS	mg/L	870	426	866	892	136	-
4	BOD	mg/L	0.8	1.1	1.2	1.4	2.0	<40
5	COD	mg/L	610	380	150	350	100	80.1
6	Zn	mg/L	0.650	0.700	0.600	0.600	0.750	-
7	Pb	mg/L	0.060	0.060	0.060	0.133	0.200	0.010
8	Cu	mg/L	0.125	0.083	0.125	0.250	0.167	2.000
9	Fe	mg/L	0.556	0.778	0.556	0.444	0.222	2.500
10	Mn	mg/L	0.125	0.150	0.150	0.200	0.075	0.500
11	Cd	mg/L	0.458	0.417	0.417	0.438	0.017	0.003
12	Cr	mg/L	0.017	0.033	0.167	0.167	0.017	0.050
13	Ni	mg/L	0.833	0.833	0.667	0.833	0.033	0.020

Quality of groundwater in the study area: In order to determine the quality of groundwater in the study area, water samples from four hand dug wells and one borehole close to the dumpsite were analysed for physicochemical parameters and heavy metal contents. Table 2 shows the result of the analysis which indicates various degrees of contaminations as some of the heavy metals show elevation in concentration above the WHO (1992) guidelines. The physicochemical parameters were analysed in the Laboratory of the Department of Water Resources Ahmadu Bello University, Zaria, while the heavy metal contents were analysed in the Laboratory of the National Animal Production Research Institute, Shika, Zaria. The results from both Laboratories correlated well.

CONCLUSION

The ERT Survey identified a general pattern of the electrical properties of the geological sequence within the investigation site, showing a zone with low resistivity roughly within the top 10.0 m (Fig. 7). However within the zone, there is also a positive correlation between the resistivity and distance from the site. Even though no profile was taken at much distance from the dump; the water sample result shows that the lowest resistivity in the soil correlated well with elevated groundwater conductivity. Profile P04 showed strong contamination based on the low resistivity that characterized the top soil (10.0 m).

SRT survey was able to clearly delineate the bedrock topography showing the dip in the N-S direction sloping towards profile P04. The refraction imaging also delineated the lithology giving a good correlation between refraction survey results and borehole results. Based on the refraction result the thickness of the overburden was

about 9.7m approximately 10 m. The depth of fractured basement from model was 22.9 m, while the borehole gave 23.0 m this is good correlation. The high velocity of the basement suggests granite-gneiss bedrock. The study shows that the regolith aquifer in the area of study is highly vulnerable to pollution from the refuse dumps.

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