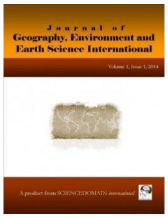

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Subsurface Imaging of Leachate Plume in Some Communities of Esan North East Local Government Area, Edo State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Groundwater being one of the most valuable drinking water resources is often fresh and cold, since it is filtered through the ground, it is often fresh and cold and usually cleaner than surface water. Unfortunately, the over dependence on groundwater came as a result of lack of pipe borne water. Portable water does not contain chemical substances or microorganisms which could cause hazards to health. However, the quality of groundwater is under intense stress form increasing demand and withdrawer, climate change and anthropogenic activities and this demands consideration because the people of the study area have no means of judging the quality and safety of water themselves.

To image the subsurface in the area, the Wenner-Schlumberger array method utilizing the

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Petrozenith resistivity metre was employed to delineate leachate plume. The global positioning system device was used to obtain the geographic co-ordinate (longitude and latitude) and altitude in metres of beginning and ending of survey lines. The ZondRes2D and Surfer 11 software were used for the interpretation of data. Groundwater samples were collected in Eguare (January 2013 and December 2014) and Unuwazi (January 2013) and subjected to physical and chemical analysis after which was compared using World Health Organisation (W.H.O) drinking water benchmark.
The result from the laboratory analysis revealed evidence of pollution from physical and chemical sources in Eguare and Unuwazi of Esan North East Local Government Area, Uromi, Edo State. The hand dug well in Unuwazi was not functioning as at time of survey in December 2014 and therefore water sample was not taken. The geoelectric survey delineated leachate plume in Eguare which corroborates with the result of laboratory analysis of groundwater sample taken from the survey location. However, Unuwazi inferred to be clay, lateritic clay and laterite revealed absence of resistivity anomaly due to few numbers of resistivity values within the defining range of (1.5-20) Ωm and (6.5-20) Ωm

Keywords: Groundwater; leachate plume; electrical tomography; geometry; contamination; pH; nitrite.

1. INTRODUCTION

Portable water is a fresh water body that is unpolluted, suitable for drinking, odourless and tasteless [1]. Such water boils at 100°C, freezes at 0°C, is neutral to litmus and has an atmospheric pressure of 760 mmHg [2]. The usefulness of water depends on whether such waters are timely, quantitatively and qualitatively available. Over 71% of the universe is covered with water, it is a renewable resource due to the interplay of the components of the Hydrologic cycle and constitutes about the most single resource available to mankind. Groundwater is commonly understood to mean water occupying all the voids within a geologic stratum [3]. It is not usually static but flows through the rock [4]. Consequently, the electrical resistivity of leachate is often very much lower than natural groundwater. Pollutants or contaminants released into the environment rarely remains at the point of discharge [5]. Leachate is generally associated with high ion concentrations and hence results in very low resistivity of the rock formations containing them. [6]. This makes geoelectrical techniques most adequate for mapping the extent of leachate contamination [7]. Geoelectrical surveys have been carried out by numerous researchers on leachate contamination of soil and groundwater. The Electrical resistivity tomography has proven to be very useful in mapping of groundwater contamination [8], mapping of subsurface hydrocarbon contamination [9], imaging and detecting underground contaminant in Landfill sites [10] just to mention a few. However, maintaining a portable ground water supply that is free from microbial and chemical contaminants is far from reality due to poor waste disposal and management practices [11]. The work aims at delineating the geometry of the leachate plume, locate and model the subsurface sources evidence of the physicochemical analysis of hand dug well water sample taken from the survey locations.

2. LOCATION OF STUDY AREA

The city of Uromi which lies in north-eastern Esan of Edo State, Nigeria, is located on longitude 3°24`E and latitude 6°27`N respectively. Almost, the whole of the city is covered with land [12]. Uromi, originally known as ‘Uronmun’, is the largest and most populated area in Esanland. The Esanland is divided into two groups. The first group comprises of the earliest kingdoms in Esan, located on the waterless plateau [13] and the second group is made up of those on the low lands rich in water and luscious vegetation [14]. However, Uromi falls on first group. Among the Esan plateau dwellers, Uromi stands topmost on the plateau sitting at about 1000 feet (300 metres) above sea level, [15] with the village of Ivue occupying the highest point on the Ishan plateau with about 1,490 feet (447 metres) above sea level [13].

3. METHODOLOGY

3.1 Geochemical Survey

Water samples were collected in clean polyethylene bottles from hand dug wells in

Eguare and Unuwazi, esan north east local government area, Uromi, Edo State. The samples were treated with H_2SO_4 and nitric acid, stored at 4°C before it was transferred to the laboratory, this was done to ensure quality assurance. The samples were analyzed for different parameters such as pH, Total Dissolved Solids (TDS), Electric Conductivity (EC), Total Suspended Solids (TSS), Hardness, Colour, Turbidity, Alkalinity, Nitrate (NO_2), Nitrite (NO_3), Phosphate (PO_4), Zinc (Zn), Lead (Pb), Iron (Fe), Magnesium (Mg), and Manganese (Mn), their concentration were established using standard laboratory procedures: pH meter, EC meter, TDS meter, Turbidity meter, Titrometric method, Atomic Absorption Spectrophotometer (AAS), and UV Spectrophotometer each parameter was compared with the World Health Organisation (W.H.O [16]) drinking water benchmark.

4. FIELD OPERATION

4.1 Equipment and Materials

Wenner Schlumberger array method which is oriented vertically and laterally and employing the Petrozenith earth resistivity metre was used for the acquisition of data. Other essential accessories were the hammer, cutlass, measuring tape, electrodes, wires and the global positioning device which was used to obtain geographic coordinates of (longitude and latitude) and altitude in metres of starting and ending of survey line.

4.2 Survey Location Base Map Construction

The survey location base map for Eguare and Unuwazi was acquired using Google Earth map software, this was done by gridding the area that enclosed the survey profiles, and then determined geographic coordinates of the grid lines intersections, the ground elevations obtained from the entire grids were contoured, the survey area topographic map construction with water shed map and the 3D elevation model of the survey locations were also displayed using the Surfer 11 mapping software. The survey location base map construction as shown in Figs. 1 and 2 displays the survey profiles, hand dug wells and surface topography which comprise of the surface water flow and the contour map of the area.

The surface water flow was superimposed into the 3-D elevation model as shown in Figs. 3 and 4. Which displays a three dimensional view of the survey location, showing the surface structure and also the flow of water from a higher elevation to a lower area.

5. RESULTS AND DISCUSSION

The Table below shows the description of water samples collected form hand dug wells in Eguare and Unuwazi respectively between December 2013 and December 2014.

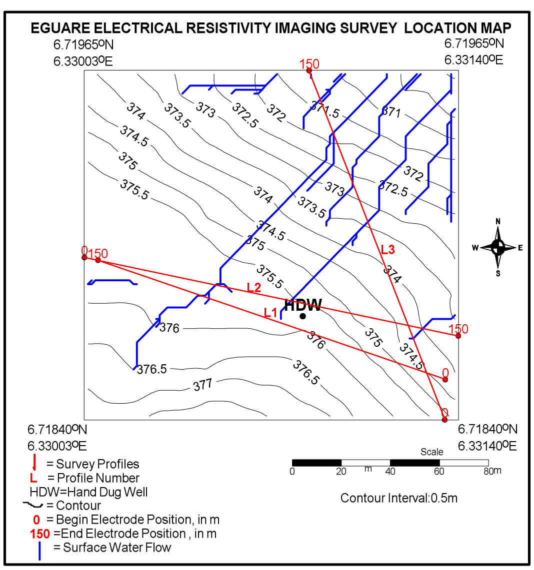

Fig. 1. Electrical imaging survey location map for eguare

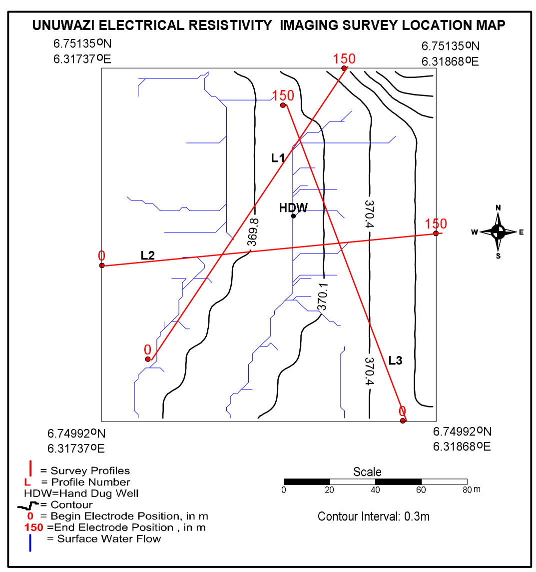

Fig. 2. Electrical imaging survey location map for unuwazi

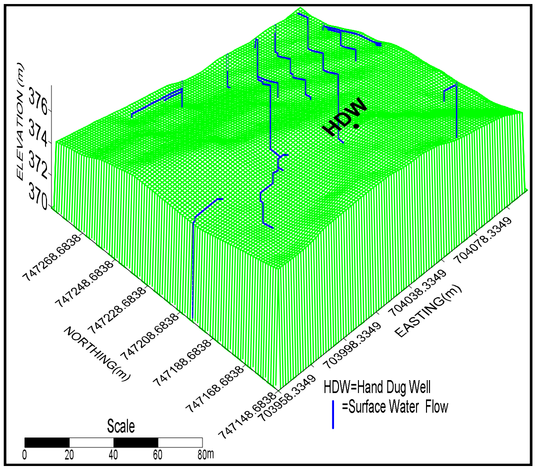

Fig. 3. 3D elevation model of electrical imaging survey location for eguare

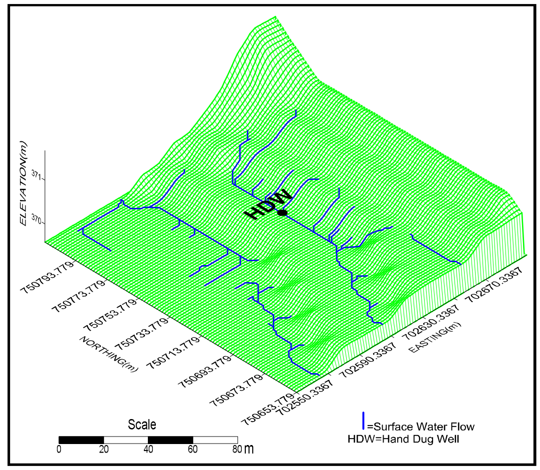

Fig. 4. 3D elevation model of electrical imaging survey location for unuwazi

The result from Table 1 indicates that most of the parameters analysed for groundwater were within the benchmark recommended by World Health Organisation apart from pH in Unuwazi with a value of 5.17 as against World Health Organisation drinking water benchmark of 6.5 – 8.5 making the water acidic with little trace of phosphate 0.18 mg/l at Eguare in 2014 and also nitrite with values of 4.44 mg/l, 4.96 mg/l and 3.13 mg/l for Egaure (2013 and 2014) and Unuwazi (2013) respectively as against 3.0 mg/l World Health Organisation drinking water benchmark. The result indicated the highest value of nitrite at Eguare in 2014 with 4.96 mg/l.

It was observed that the hand-dug well was cited in a cluster of septic tanks and also few meters away from a dumpsite. It was also observed that the diameter of the hand-dug wells is 1.5 meters allowing the well to be susceptible to pollution both surface and subsurface. Offodile [17] explained that latrines discharge waste water into the subsurface and the pollutants can migrate into the aquifer if it is located along its flow path and therefore, causing adverse effect on the quality of water in the wells. However the hand dug well in Unuwazi was not functioning as at time of survey in 2014. This is probably due to the shallow nature of the well (perched aquifer).

Table 1. Results of physical and chemical properties of hand dug well water samples

Parameters	Units	Eguare 2013	Eguare 2014	Unuwazi 2013	Unuwazi 2014	WHO limit
pH		6.80	6.93	5.17	N/A	6.5-8.5
EC	$\mu S/cm$	80.50	85.60	34.20	N/A	1000
TDS	mg/l	57.10	56.30	25.50	N/A	1000
TSS	mg/l	BDL	BDL	BDL	N/A	N/A
Total hardness	mg/l	2.69	4.80	1.80	N/A	100-500
Turbidity	FAU	2.00	1.00	2.00	N/A	5.00
Colour	Pt/Co	2.00	2.00	1.00	N/A	5.00
Alkalinity	mg/l	73.00	68.00	81.00	N/A	500
Fe	mg/l	BDL	0.03	BDL	N/A	0.3
Zn	mg/l	0.21	0.02	0.15	N/A	5.00
Mg	mg/l	BDL	0.39	BDL	N/A	50.00
Mn	mg/l	0.02	BDL	BDL	N/A	0.10
Cu	mg/l	BDL	BDL	BDL	N/A	1.00
Ca	mg/l	BDL	1.28	BDL	N/A	75.00
NO_2	mg/l	4.44	4.96	3.12	N/A	3.00
NO_3	mg/l	BDL	0.05	BDL	N/A	10.00
Pb	mg/l	BDL	BDL	BDL	N/A	0.05
PO_4	mg/l	BDL	0.18	BDL	N/A	N/A

BDL -Below detectable limit, N/A –Not available, FAU –Formazin attenuation unit, mg/l –milligram per litre, Pt/Co –Platinum Cobalt scale, µS/cm – Micro Siemens per centimeter

6. GEOELECTRIC INTERPRETATION

The ZondRes2D software was used for the interpretation of data. The apparent resistivity data obtained during the survey were entered into a text file compatible with the ZondRes2D software running on a computer. The software produces a pseudosection of the subsurface by contouring and smoothening the apparent resistivity values from the geophysical survey which produces three images such as the observed and calculated apparent resistivity and the inverse model resistivity. The observed and calculated apparent resistivity are pseudosection which are distorted or approximate picture of the true subsurface resistivity distribution while the inverse model resistivity presents the subsurface geology. To convert the resistivity picture into a geological one it requires some knowledge of the typical resistivity values for the different types of subsurface materials and geology of the surveyed area [18].

The maximum imaging survey depth was 14.48m as computed from maximum array length transformed to depth. Surface geology of the chosen locations and information from locally dug pits and holes in the area up to the depth, 14.48m indicates lateritic profile.

The lateritic profile of the locations was characterized geo-physically using resistivity ranges of laterite, (800 – 1500)Ωm, lateritic soil, (120 -750)Ωm, clay, (1 -100)Ωm and leachate (1.5-20)Ωm by [19,20,21,22] and [23] for subsurface pollution studies and this resistivity ranges for the various geoelectric materials where adopted in this work.

6.1 Eguare Data Interpretation

Four different colour shades, blue, green, yellow and red are seen in the resistivity block model section. The blue is within the range of about (1.0 - 6.5)Ωm, (on the average 4 Ωm), green, about (6.5 – 66) Ωm, (on the average 36Ωm), yellow, about (66 – 316) Ωm, (on the average 191 Ωm), and red, about (316 – 1500) Ωm (on the average 908 Ωm). This probably implies four different geoelectric materials. The geological interpretation of the resistivity anomalies are shown in the form of geologic section, in Fig. 6.

The average resistivities of about 43Ωm, 191Ωm and 908Ωm were inferred to be clay, lateritic clay and laterite. Two resistivity anomalies, labeled PL1 and PL2 lie between 1.5 Ωm and 20 Ωm (on the average 11 Ωm) indicating leachate plume is observed. PL1 which is conical in cross section is 1.7 metres by 2.9 metres and is laterally located between 43 metres and 46 metres marks, and extends vertically to a depth of about 5.4 metres. PL2 is 2.0 meters by 2.6 metres in cross section, which is laterally located between 102 metres and 105 metres marks, and extends vertically to a depth of about 5.8 metres. The plumes are separated by a distance of about 56 metres.

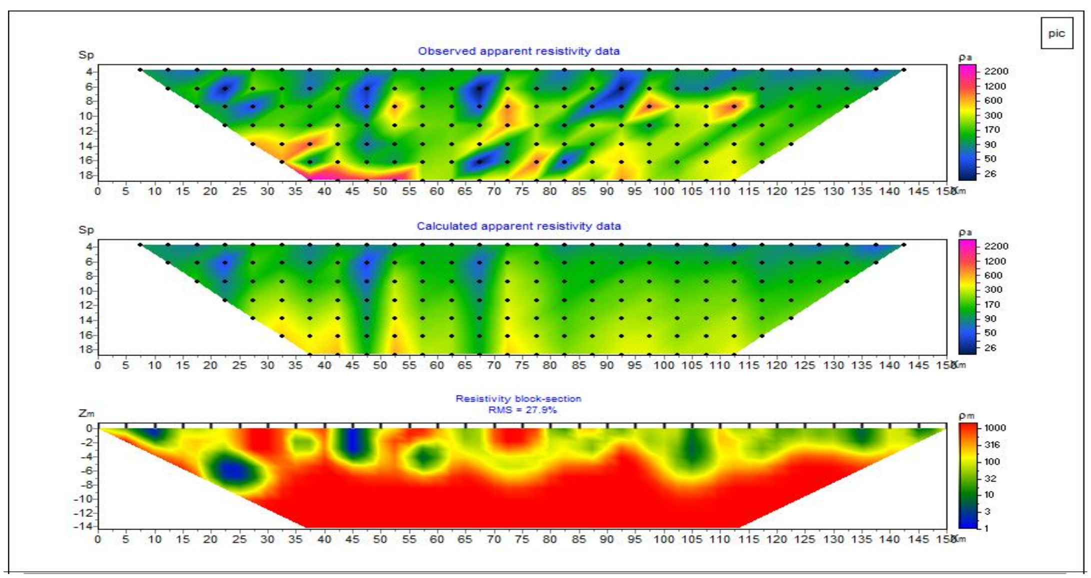

Fig. 5. Geoelectric image of survey profile line (l1) at eguare

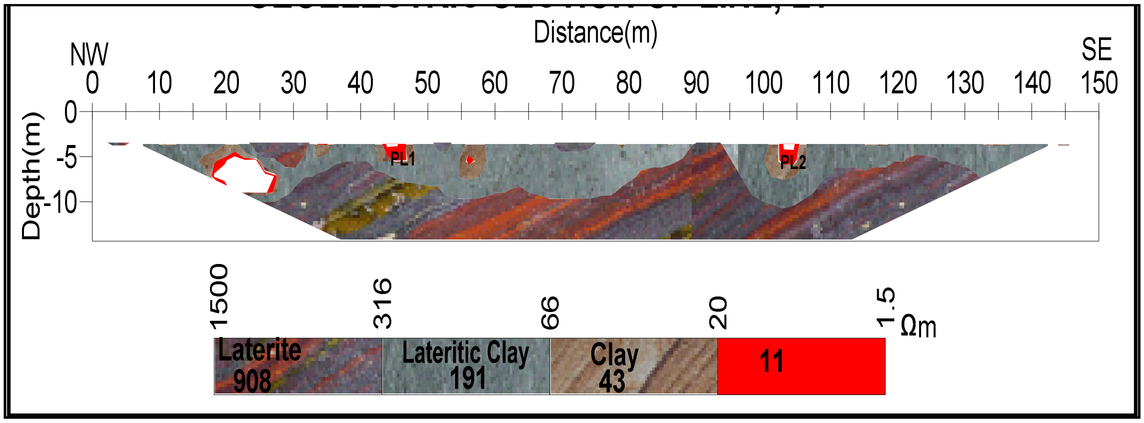

Fig. 6. Geologic section of survey profile line (l1) at eguare

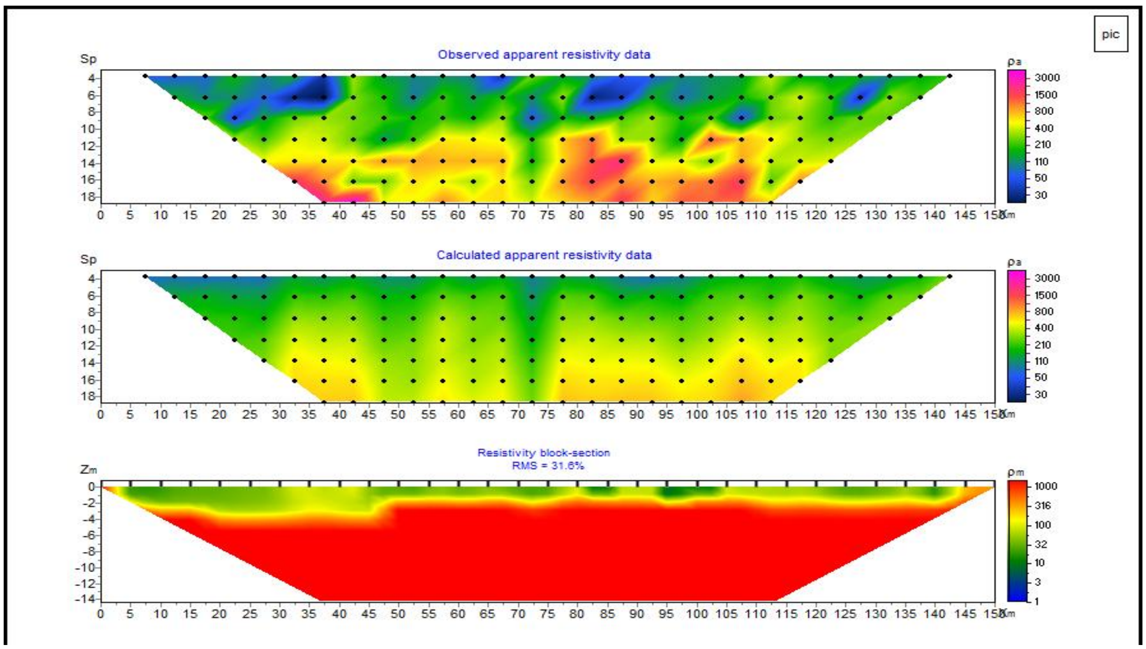

Fig. 7. Geoelectric image of survey profile line (l2) at eguare

Three different colour shades, green, yellow and red are seen in the resistivity block model section. The green is about (6.5 – 66) Ωm, (on the average 36 Ωm), yellow, about (66 – 658)Ωm, (on the average 362 Ωm) and red, about (658 – 1500) Ωm, (on the average 1079 Ωm). This probably indicates three different geoelectric materials. The geological interpretation of the resistivity anomalies are shown in the form of geologic section, in Fig. 8.

The average resistivities of about 43 Ωm, 362 Ωm and 1079 Ωm were inferred to be clay, lateritic clay and laterite. The red colour shade indicating leachate plume was not captured on the geoelectric section due to few numbers of resistivity values within the range of about (6.5 - 20) Ωm.

Three different colour shades, green, yellow and red are seen in the resistivity block model section. The green is about (6.5 – 66) Ωm (on the average 36 Ωm), yellow, about (66 – 658) Ωm (on the average 362 Ωm) and red, about (658 – 1500) Ωm (on the average 1079 Ωm). This probably indicates three different geoelectric materials. The geological interpretation of the resistivity anomalies are shown in the form of geologic section, in Fig. 10.

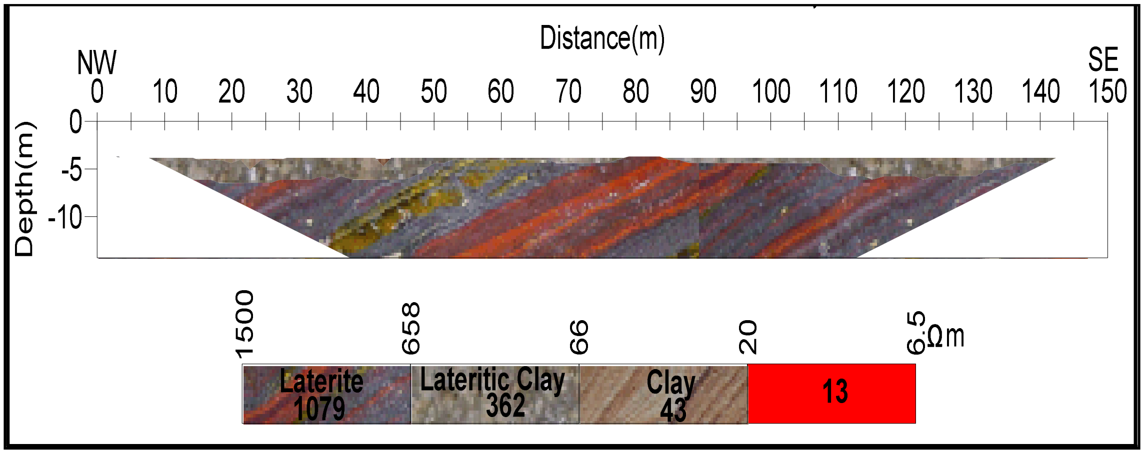

Fig. 8. Geologic section of survey profile line (l2) at eguare

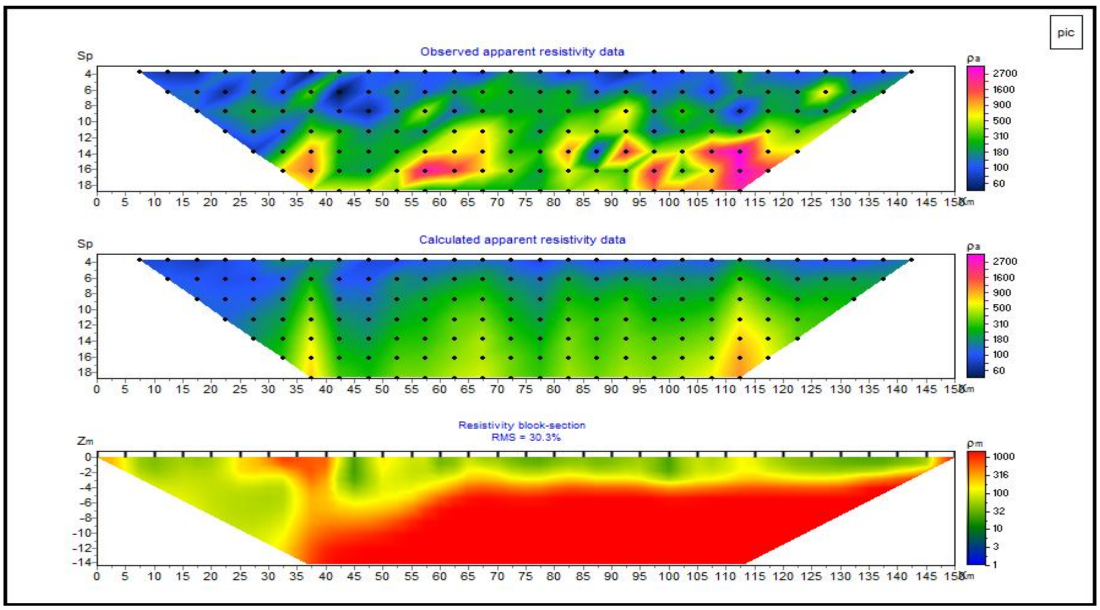

Fig. 9. Geoelectric image of survey profile line (l3) at eguare

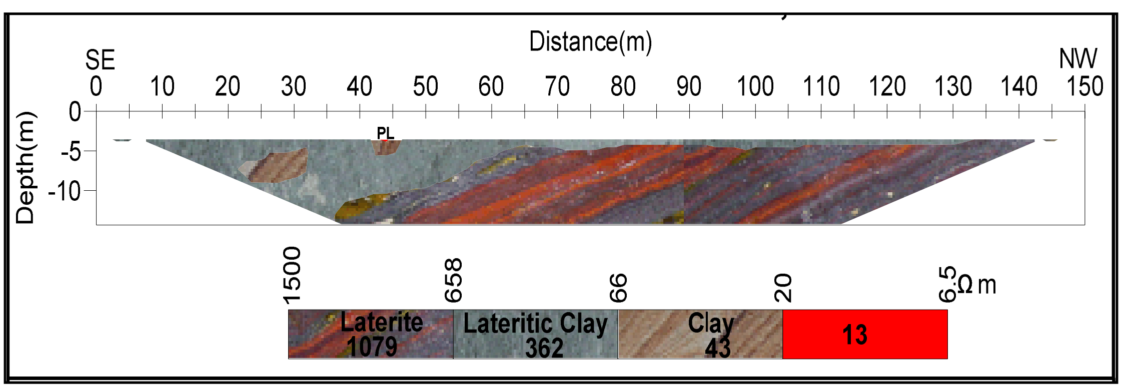

Fig. 10. Geologic section of profile (3) at eguare

The average resistivities of about 43 Ωm, 362 Ωm and 1079 Ωm were inferred to be clay, lateritic clay and laterite. Small resistivity anomaly, labeled PL lies between 6.5 Ωm and 20 Ωm (on the average 13 Ωm) indicating leachate plume was observed at 43 metres mark. The minute nature of the plume did not permit measurement of the geometry.

It is important to note that the topographical cross section drawn through the hand dug well and leachate plume provides a tie between the topographical information with the leachate plume i.e it helps to predict the direction of flow of plume. It also explains explicitly the factors that control the flow of a plume which is topographical setting and permeability.

The topographical cross section indicates that the plume, PL1 is located down elevation of the hand-dug well location, which is about 20 metres away from the plume location and is slopping towards the south east of the map as will be seen in Fig. 14. From this topographical setting, it could be suggested that lateral migration of the plume is away from the hand-dug well location, and if migration continues, region down gradient from it might be contaminated.

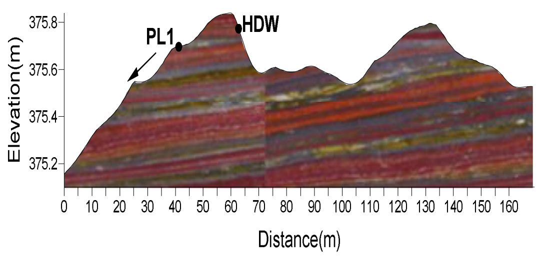

Fig. 11. Topographical cross section across plume, pl1 and hand dug well location at eguare

The topographical cross section indicated that the plume is located in a depressed area. The plume, PL2 is located down elevation of the hand-dug well location, which is about 42 metres away from the plume location. From this topographical setting, it could be suggested that lateral flow of the plume is towards the hand-dug well location, and flow to a region up elevation of the plume location might be very low. Thus, vertical migration might be well pronounced.

The topographical cross section indicates that the plume, PL is located down elevation of the hand-dug well location, which is about 41 metres away from the plume location and slopes towards the eastern area of the map as shown in Fig. 14. From this topographical setting, it could be suggested that lateral migration of the plume is away from the hand-dug well location, and if migration continues, region down gradient from it might be contaminated.

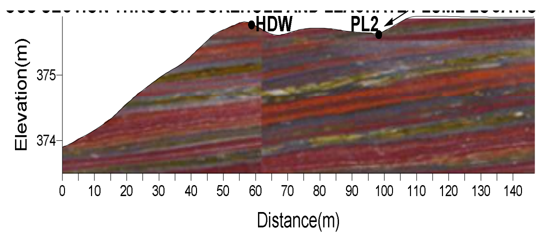

Fig. 12. Topographical cross section across plume, pl2 and hand dug well locations at eguare

Geographical analysis of Eguare survey location map shown in Fig. 14 indicates that the ground surface slopes towards the northern part of the map as seen from the contours. The surface water runoff is in this direction.

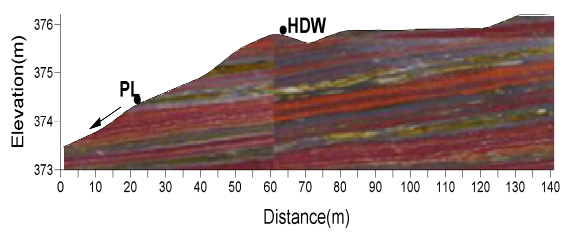

Fig. 13. Topographical cross section across plume, pl and hand dug well locations at eguare

6.2 Unuwazi Data Interpretation

Three different colour shades, green, yellow and red are seen in the resistivity block model section. The green is about (6.5 – 66) Ωm (on the average 36 Ωm), yellow, about (66 – 658) Ωm (on the average 362 Ωm) and red, about (658 – 1500) Ωm (on the average 1079 Ωm). This probably shows three different geoelectric materials. The geological interpretation of the resistivity anomalies are shown in the form of geologic section, in Fig. 17.

The average resistivity of about 362 Ωm and 1079 Ωm inferred to be lateritic clay and laterite. The red colour shade indicating leachate plume neither shown on legend bar nor on the geoelectric section was due to absence of resistivity anomaly within the defining range of about (1.5 – 20) Ωm.

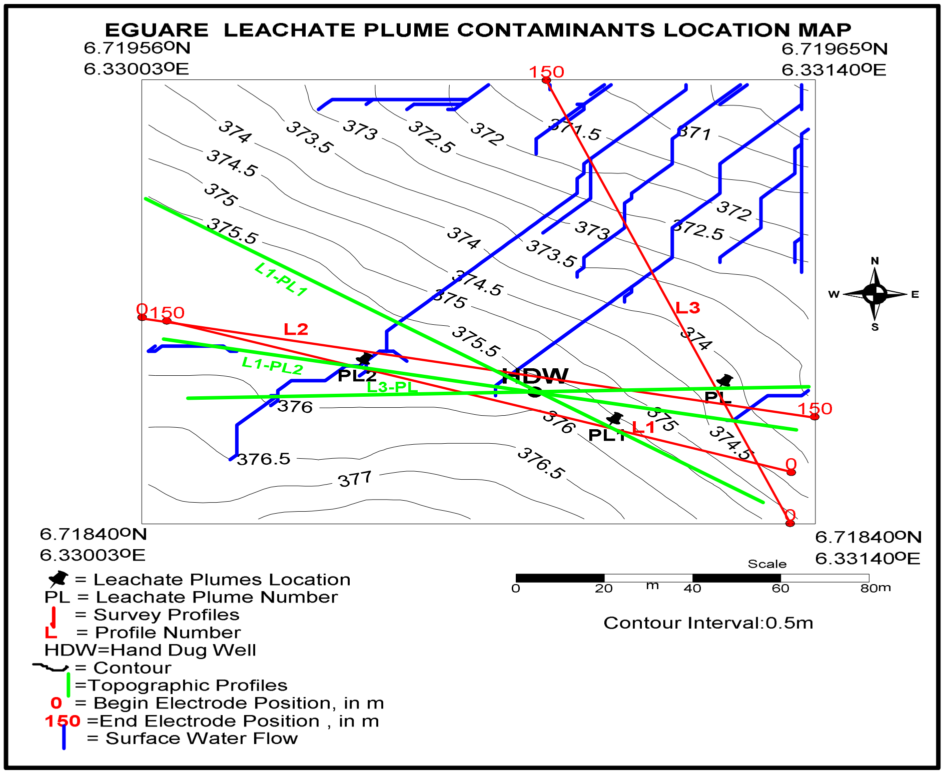

Fig. 14. Leachate plume contaminants location map at eguare

Three different colour shades, green, yellow and red are seen in the resistivity block model section. The green is about (6.5 – 66) Ωm (on the average 36 Ωm), yellow, about (66 – 658) Ωm (on the average 362 Ωm) and red, about (658 – 1500) Ωm (on the average 1079 Ωm). This probably indicates three different geoelectric materials. The geological interpretation of the resistivity anomalies are shown in the form of geologic section, in Fig. 19.

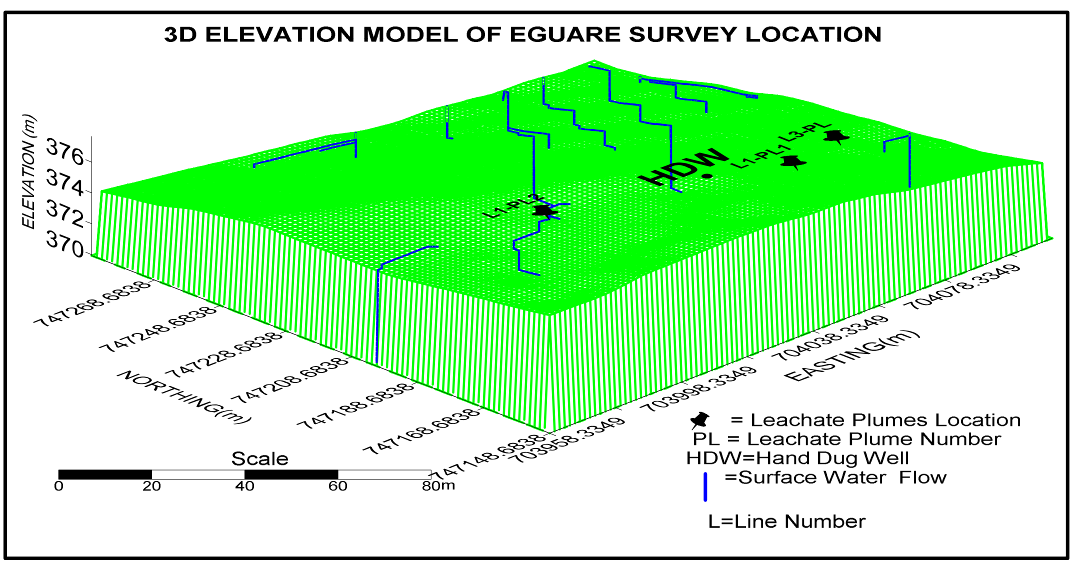

Fig. 15. 3D surface plot of leachate plumes locations at eguare

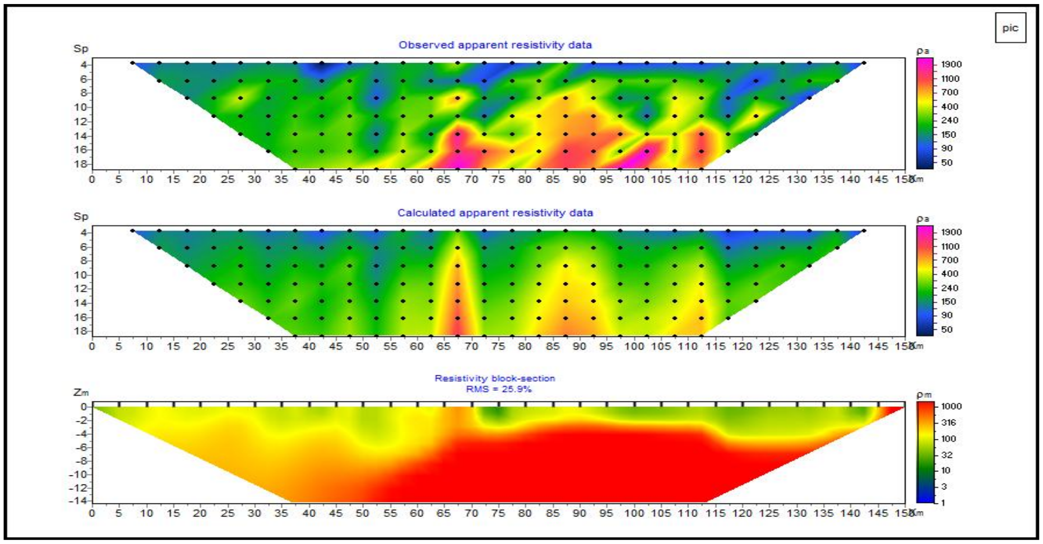

Fig. 16. Geoelectric image of survey profile line (l1) at unuwazi

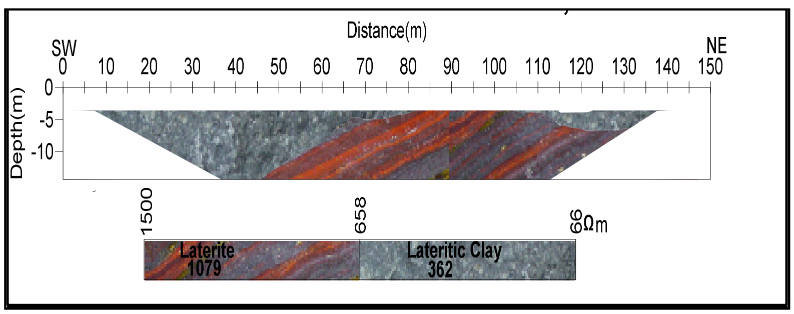

Fig. 17. Geologic section of survey profile line (l1) at unuwazi

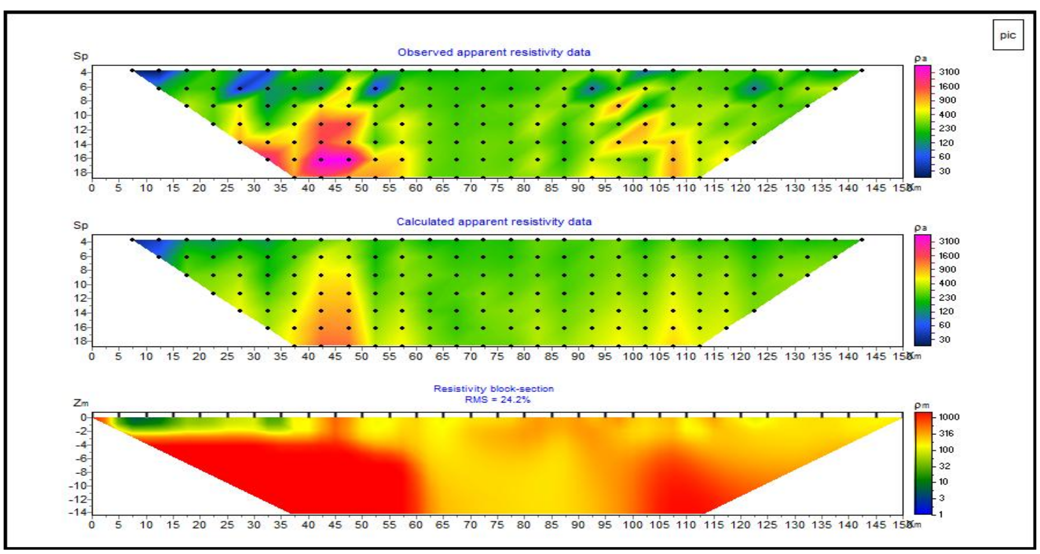

Fig. 18. Geoelectric image of survey profile line (l2) at unuwazi

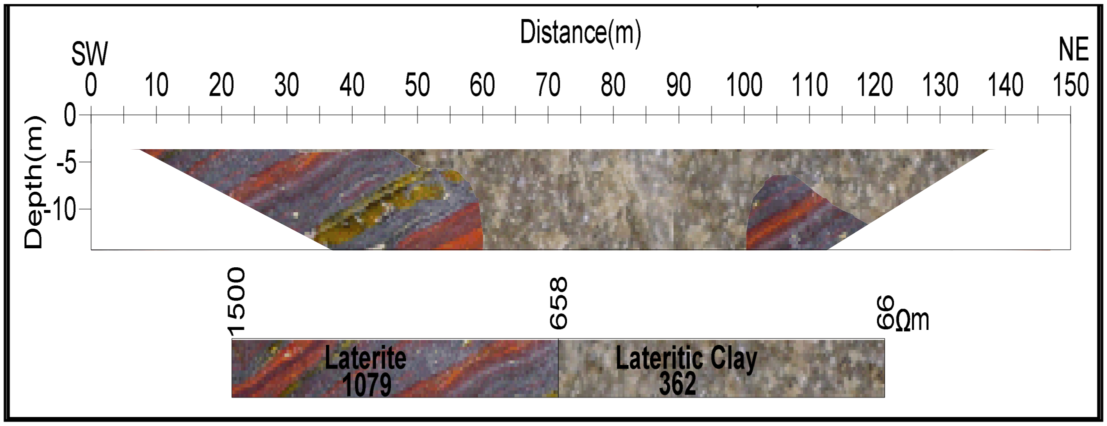

Fig. 19. Geologic section of survey profile line (I2) at unuwazi

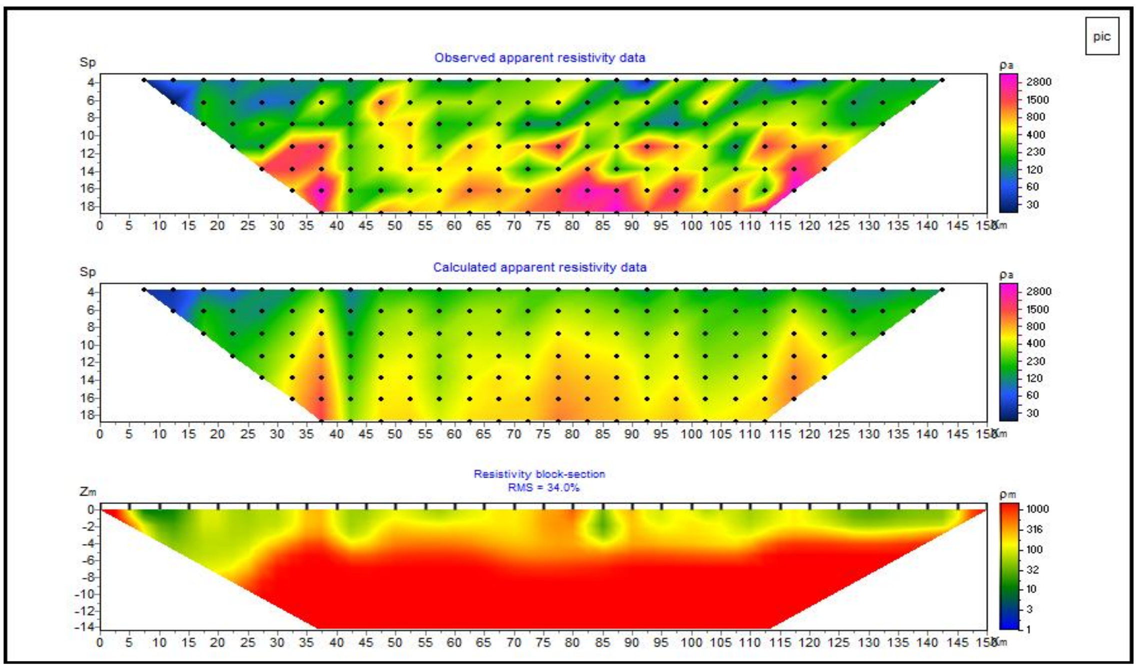

Fig. 20. Geoelectric image of survey profile line (I3) at unuwazi

The average resistivity of about 362 Ωm and 1079Ωm were inferred to be lateritic clay and laterite. The red colour shade indicating leachate plume neither shown on legend bar nor on the geoelectric section was due to absence of resistivity anomaly within the defining range of about (1.5-20) Ωm.

Three different colour shades, green, yellow and red are seen in the resistivity block model section. The green is within the range of about (6.5 -66) Ωm (on the average 36 Ωm), yellow, about (66-658) Ωm (on the average 362 Ωm) and red, about (658 -1500) Ωm (on the average 1079 Ωm). This probably shows three different geoelectric materials. The geological interpretation of the resistivity anomalies are shown in the form of geologic section, in Fig. 21.

The average resistivities of about 43 Ωm, 362 Ωm and 1079 Ωm were inferred to be clay, lateritic clay and laterite. The red colour shade indicating leachate plume is not visible on the geoelectric section due to few numbers of resistivity values within the range of about (6.5 – 20) Ωm.

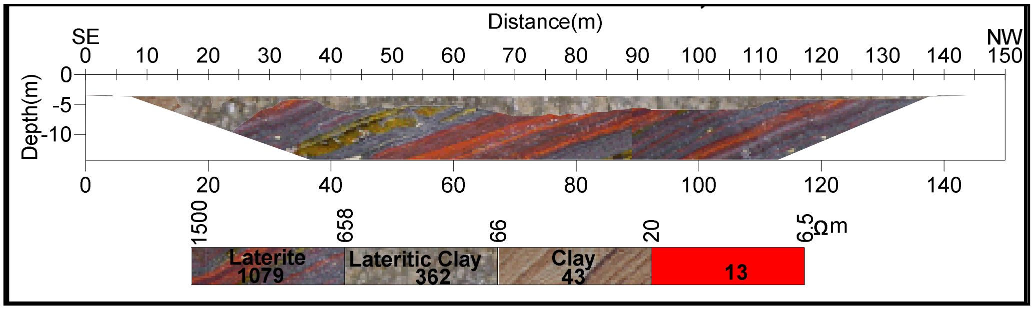

Fig. 21. Geologic section of survey profile line (I3) at Unuwazi

7. CONCLUSION

The non-invasive technique have been established as a tool for environmental investigation which is efficient in detecting mapping and characterizing the lateral and vertical extent of the leachate plume.

The low pH level of 5.17 and high nitrite concentration of 3.12-4.44 mg/l were above the drinking water benchmark recommended by World Health Organisation of 6.5-8.5 and 3.0 mg/l respectively. The high level of ion and nitrite is probably due to clusters of septic tanks and dumpsite in which the hand dug well was cited and this could adverse health implication.

The geoelectric data delineated leachate plume as low resistivity zones of (1.5-20) Ωm which agrees with the laboratory analysis of groundwater samples taken from hand dug well in Eguare and Unuwazi of Esan North East Local Government Area, Edo State. The global positioning device and the surfer 11 mapping software were useful tools in mapping the location of the hand dug well, survey and topogarphic profile respectively, surface topography and the spatial distribution of plume around the hand dug well location. Hence the triangular survey profile was adopted to track resistivity anomaly indicating leachate plume around the hand dug well location. This was to facilitate data ties for geophysical and geochemical interpretation. However, Unuwazi inferred to be clay, lateritic clay and laterite revealed absence of resistivity anomaly due to few numbers of resistivity values within the defining range of about (1.5-20) Ωm and (6.5-20) Ωm.

Conclusively, if economic condition dictates the construction of hand dug well, it should not be cited along the flow path of potential pollution sources, ion exchange, lime or sodium bicarbonate should be used to treat groundwater polluted with high nitrite and low pH levels.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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