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APPLICABILITY OF 2D RESISTIVITY TOMOGRAPHY, MICROBIAL AND GEOCHEMICAL INVESTIGATION IN AKURE LANDFILL SITE, SOUTHWEST, NIGERIA

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Abstract. *2-dimensional electrical resistivity tomography (ERT), microbial and geochemical methods were used as a tool in detection of groundwater contamination at Akure North municipal solid waste–disposal site in Igbatoro road, South Western Nigeria. Six (6) 2D resistivity profiles both around the perimeter and inside the dump were investigated with maximum length of 300 m. Results of the resistivity tomography delineated the leachate plume as low resistivity zones (6 - 33 ohm - m). Results of the physico-chemical analysis of water samples from existing borehole wells reported elevation in concentration of the measured parameters indicating contamination of the groundwater as a result of solid waste leachate accumulation, consequently, complimenting the geophysical data. The microbial analysis of water samples in the same borehole wells reported the presence of some toxic microorganisms such as staphylococcus sp, escherichia coli, streptococcus sp, basillus sp, clostridium sp, mycobacterium sp and micrococcus sp which implies that intake of this water may cause diseases like diarrhea, skin rashes, cancer, liver disease, kidney disease, etc. However, the effect of this dump site is felt on the borehole wells in the environment because of the accumulation and migration of the leachate plumes; therefore, it is advisable to relocate the dump site from its present location to another site where people have not been resided so as to minimize the environmental impact of this dump on humans and animals.*

Key word: *geophysical, leachate, landfill, geochemical, Igbatoro.*

1. INTRODUCTION

The environmental impact of municipal solid waste on health issues of the study area has been a global challenge over the decades (Adewumi, 2001) as well as uncontrolled growth and fast industrial development and production of toxic waste. Rural and urban waste materials majorly domestic garbage, are usually disposed of inadequately in waste disposal

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sites placing the groundwater resources at high risk. Groundwater pollution occurs majorly due to percolation of fluvial water and infiltration of leachates through the soil under waste disposal sites. Contamination takes place when the plume reaches the groundwater table, thereby affecting the potability of underground water and putting the community that make use of that natural resources under health risk.

Poor management of dumpsite has resulted to lots of disastrous effects of pollution, contamination, aesthetics and environmental hazards to a greater extent. More so, through infiltration and percolation of water in and around polluted landfill landscape. Components of water that are soluble; for instance, agriculture, industrial refuse, dry waste, sewage - migrate through the transportation of the fluid (leachates) to produce groundwater pollution, which will remain undetected until all the dug wells become polluted (Fang, 1995). Due to the heterogeneous nature of the organic-rich industrial and domestic waste, the distribution of settlement will be non-uniform and result to fracturing of the top seal of the dumpsite cover. Decades of chemical and physical processes (hydration, hydrolysis, carbonation, and oxidation) and microbial degradation result to the dissolution of landfill materials, gas generation (methane) and production of leachate. Leachate is rich in bacteria, inorganic salts, fungi and organic matter, water and dissolved organic wastes and organic fluids, or simply organic acids as a result of the presence of solvent and solute in the leachate mass (Farquhar, 1989)

Advantages of multidimensional non-invasive and scale variable monitoring, high density electrical resistivity tomography (ERT) is well established for detection and mapping of landfills, contaminant plumes, engineering, environmental and subsurface hydrology (Zhou et al., 2001, Daily and Ramirez, 2000). Understanding the subsurface geological lithology and surface require application of earth resistivity to characterize the landfill site and finite variations of earth resistivity to delineate chemical and physical processes (Singha and Gorelick 2006, Binley et al., 2002, Yang and Lagmanson, 2003, Manheim et.al 2004).

The dispersing leachate extends horizontally and vertically as it sinks towards the bottom of the substrate forming a 3-dimensional contaminant plume often found dipping steeply. With high rate of groundwater flowage due to dilution and dispersion of leachates in highly permeable geological formation, the plume may enhance the mineralization of groundwater; (Meju, 2000; Okpoli, 2013). The physicochemical parameters have a profound influence on the transport and bioavailability and chemical fractionation of landfill posed a hazardous assessment of human health and ecological risks associated with the landfill.

The thrust of this research is to determine the applicability of 2D resistivity tomography in mapping out the leachate plumes using geophysical technique which will be aided by laboratory analysis of water samples within the study area. This becomes necessary as the inhabitants of Igbatoro in Akure rely majorly on groundwater for their daily water demands.

Site description

The municipal solid waste is located in Igbatoro road in Akure north local government area of Ondo-State Southwestern Nigeria (Figure 1). The area of study lies within longitude 50141E - 50171E and latitude 70121N -70141N. The area of study is readily accessible; it is connected by motorable road.

The study area is underlain by the Precambrian Basement Complex Rocks of southwestern Nigeria. The rock units include migmatite gneiss, quartzite, granite gneiss and granitic rocks. The structural trend is north-south and which is typical of the Nigerian Basement Complex rocks (Rahaman, 1976).

Migmatite gneiss is the predominant rock unit that underlies the waste dumpsites. In basement complex area, groundwater is contained within the weathered and or fractured/jointed basement columns. The unconfined nature and the near-surface occurrence of the aquifer system make it vulnerable to surface/near surface pollutants such as leachate from a waste dump.

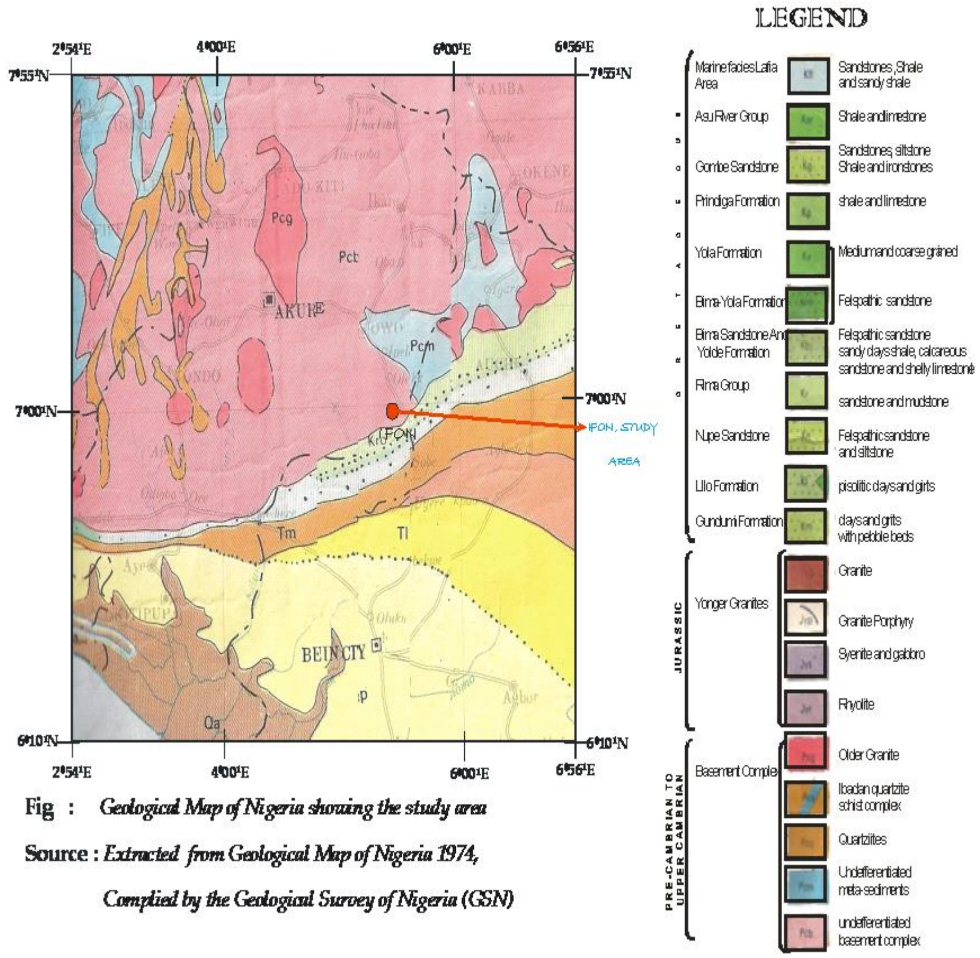


Fig. 1 Geological map Nigeria showing the study area (extracted from Geological map of Nigeria 1974, compiled by National Geological Survey Agency (NGSA)).

2. Materials and Methods

Data acquisition and processing

The geophysical survey of the municipal solid waste was based on the use of electrical resistivity tomography (ERT), geochemical and microbial results were used to attain the set objectives:

- Six ERT measurements around the perimeter of the landfill to get good result of the electrical response.
- Identify the leachate pathways
- Map the subsurface lithology of the site
- Define the heterogeneity of the geometry of the landfill
- Outline the environmental impact assessment for the health risks of the individuals residing in the study area

The 2D ERT data were processed and inverted using the RES2DINV. This program generates resistivity depth for each traverse line based on the iterative L- norm (smoothness constrained) least squares inversion algorithm after deGroot-Hedlin and Constable (1990) and Loke et al.,(2003), the regularized least square optimization approach (Loke and Barker, 1995, 1996) owing to this equation.

This minimizes the sum of the squares, as it provides significant better results for topographies with sharp boundaries.

Where I is the number of iterations, J is the Jacobian matrix of partial derivatives, λ is the damping factor, C is the roughness filter matrix, ρ is the perturbation vector to the model parameter, g is the discrepancy (data misfit) vector that consist of the differential logarithm of the measured and calculated apparent resistivity values an Rd and rm (Wolke and Schwetlick, 1988) are weighting matrices that are included so that diverse elements of the discrepancy and roughness model vectors are given equal weights during the inversion process. A measure of this difference is given by the root mean square error (RMS %). However, lower RMS errors are disregarded because of the unrealistic variations in the model resistivity values and inconsistence with geological model.

Microbial analysis

The method undergone in this analysis is the serial dilutions and pore plate technique according to the method of pore plate technique. Each of the water samples was serially diluted and plated. The cultures were incubated at 370C for 24hrs. After incubation, the colonies were enumerated as shown below to now the colony forming unit (cfu/ml) per unit of the water samples

2.1. Procedure for the anion

Cl- concentration was determined using 100ml of the sample was pipette into a chemical flask and 1.0ml K_2O_4 (Potassium Chromate) solution indicator was added, it was then titrated with constant stirring with 0.028M $AgHO_3$ until the suspension becomes pink. The pinkish colour shows the end point from which the concentration of Cl- can be determined.

CO_3- concentration was determined using 40ml of the sample was pipette into the conical flask and it was analyzed with 3.5ml of Bacl2 gelatine reagent and left for 30 seconds for colour development. The absorbent was read at 45mm calorimeter. The result was matched with standard calibrated graph where the corresponding value of 45mm on the horizontal.

2.2. Procedure for cation

Atomic Absorption Spectrometer (AAS) was used for the determination of the cations. The AAS entails the aspiration of samples into flames, where it becomes atomized. A light beam if the flame is directed through the flame into a monochromatic and unto a detector. The detector then measures the intensity of light absorbed by the atomized element in the flame thus the amount of the concentration of the element in the sample.

The cathode lamp of the elements is put in position and the instrument characteristics wavelength selector. Standard solution of the element to be determined is first prepared and the absorbance measured at the selected wavelength against the concentration of the standard to obtain a calibration graph. The absorbance has linear calibration with the concentration. The absorbance of the sample is then obtained and compared with the calibration curve so that the sample concentration can be determined.

2.3. Procedures for physical parameters

Electronic Ph meter (Digital) mode, Exner GMBH, D4040 NEUSSI was used. It has a combined electrode and it was standardized using buffer solutions of Ph 4 and 9 and the electrode was rinsed dish- led water and it was dipped into the sample and the value was recorded.

TDS was obtained using a clean crucible dish of suitable size which was placed in an oven at temperature of 103-150^{o}C until constant weight was noted. 100ml of the water sample was poured into the dish after shaking thoroughly and evaporate at temperature between 103-150^{o}C and was cooled to room temperature and weighed. It was returned into the oven dried further for 10-20 mins. Weighed after cooling to room temperature, this was repeated until constant weight was obtained.

Turbidity was determined using a meter which was rinsed with the portion of the water to be tested and later emptied and replaced the cover rotated knob until slides touch while it did not observe last visible light spot and was read direct off scale for turbidity unit.

Temperature was determined with a thermometer having a reading of 0.00^{o}C- 100^{o}C. The thermometer was placed vertically immersing the bulb containing the mercury in the water sample on the field immediately after collision. It was allowed to stand still and the temperature was taken and recorded.

3 Results and Discussion

Geophysical and physico-chemical result interpretation:

Leachates and waste is indicators that there are presences of hazardous waste to landfills. Majority of the substances recorded in landfill emissions have the capacity to act as environmental pollutants. It is essential as we recognise the contributions played by hazardous waste originating from domestic particularly in light of the growing and ever-changing variety of chemicals used in the home.

Figure 2-7 show the pseudosection model calculated from our laterally constrained inversion code. The model was obtained after 5 iterations using an initial damping factor of 0.2 and the root mean square error ranges from 1.16 - 5.0.

Figure 2 shows a highly conductive anomaly at depth of 3-20m and found migrating laterally and downward across the length of the study area. This anomaly appears to be connected to the landfill and relate to the feature associated with the landfill. Figure 3 shows a leachate plume at depth 1-9m and is seen migrating horizontally and vertically from 0-55m. The lower resistivity values associated with the inverted model shows the leachate migration and distinct demarcation into the underlying bedrock. Figure 4 indicates the presence of conductive plume at depth 0-12m and is seen migrating laterally and downward from 0-60m across the breadth. The blue coloured inverted pseudo-section indicates conductive region caused by the leachate plume and found persisting below the depth of 10 m. In figure 5 there are indications of migratory leachate plume at depth of 0-8m and starting initially from 18m and extend laterally downwards but the groundwater has been shielded by the overlying bedrock. It can be seen that the conductive region is in the upper section of the inverted model which runs laterally in the surveyed area while the lower section has resistive subsurface zone. Figure 6 shows the presence of conductive plume and pockets at depth 0-5m extending laterally from 0-30m and at 40-48m laterally respectively. Clay capping materials, sands with resistivity of less than 35 Ωm are filled with pore fluid conductivity (leachate) which exerts pockets influence in the subsurface. In figure 7 a highly conductive plume at depth 0-8m and found extending laterally and downward at initial spacing distance of 18m to the end of the traverse line. The study revealed that the landfill on the topsoil (sand) has been biodegraded to leachate plume at the top to eight meter depth downward.

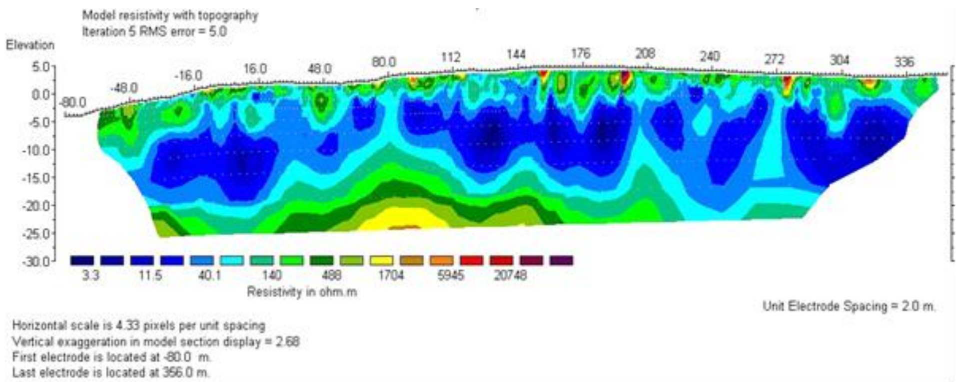


Fig. 2 Interpreted 2-D Pseudosection along a profile running across the length of the area of study

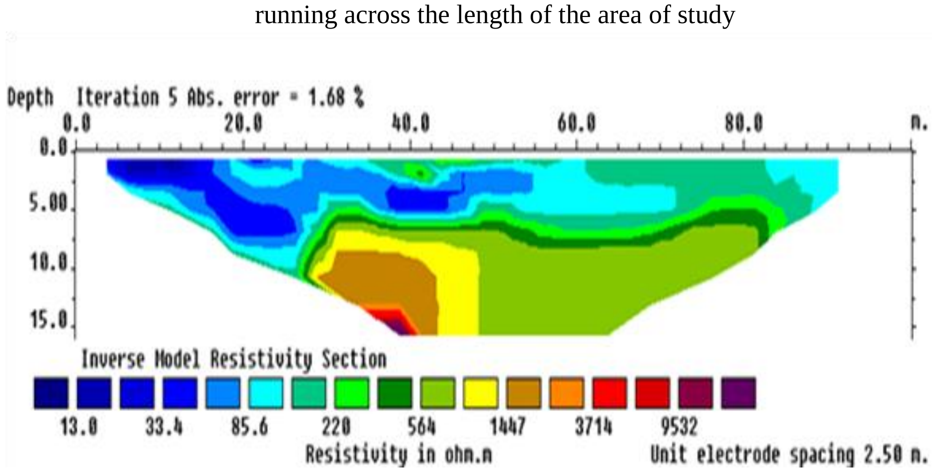


Fig. 3 Interpreted pseudo section along line across the breadth of the study area

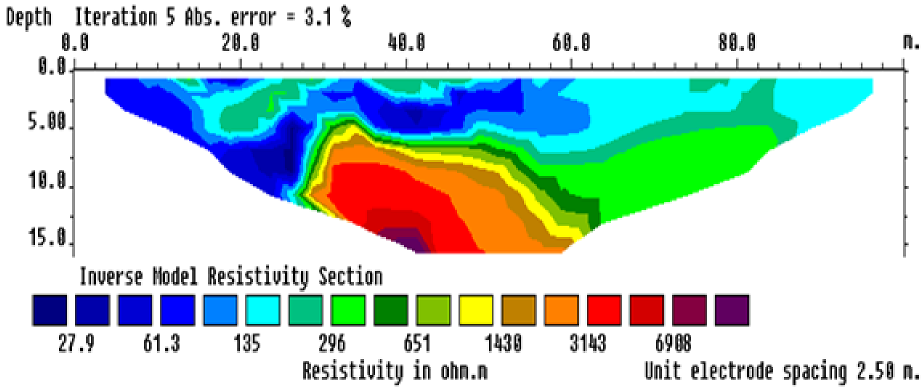


Fig. 4 Interpreted pseudo- section along line 2 across the breadth of the study area

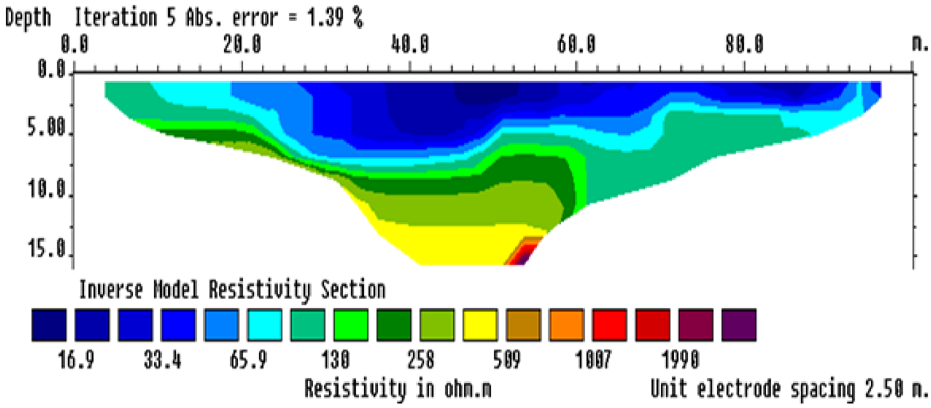


Fig. 5 Interpreted pseudo- section along line 3 across the breadth of the study area

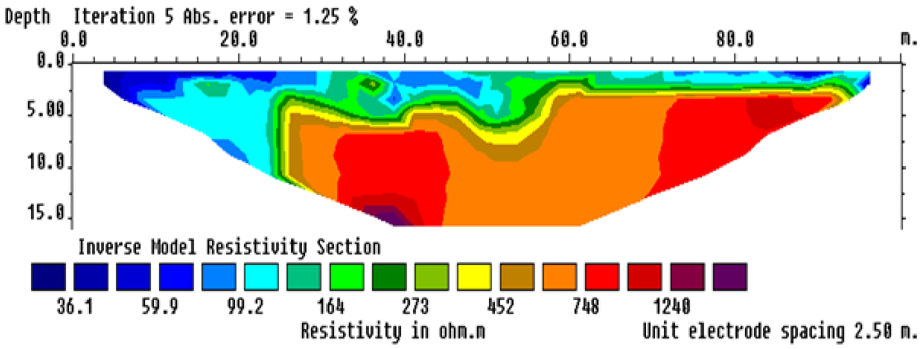


Fig. 6 Interpreted pseudo- section along line 4 across the breadth of the study area

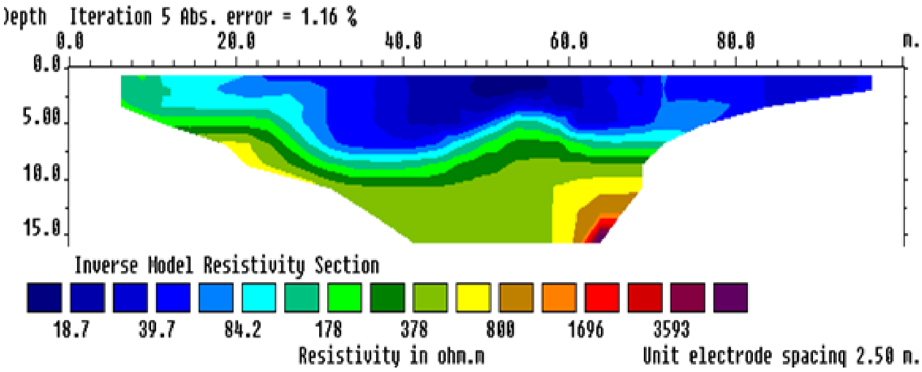


Fig. 7 Interpreted pseudo- section along line 5-9 across the breadth of the study area

3.1. Physico-chemical results:

Results of several studies shows that the range and amount of hazardous substances present in leachate that migrated to the boreholes (groundwater), which only a fraction of the total organic and inorganic content of leachate shows that it approaches the threshold limit of WHO drinking water standards.

Physical, anions and cations parameters concentration were measured from borehole/well water samples acquired from 30 locations within the study area, as shown in figure 8-10 Temperature of the water samples from borehole in the study area ranges from 30-310C, conductivity ranges from 132.3-284S/cm, pH ranges from 5.02-7.15, Total dissolved solids (TDS) ranges from 116.2-169.4mg/l, turbidity ranges from 0-7 and the anions- chlorides (Cl-) ranges from 5-16mg/l, Carbonates (CO3) ranges from 0-6mg/l while the cations-Lead (Pb) ranges from 0.001-0.012ppm, Arsenic(As) ranges from 0.002-0.088ppm, Cadmium (Cd) ranges from 0.002-0.006ppm, Mercury ranges from 0.0112-0.921ppm, Calcium (Ca) ranges from 9.088-20.512ppm, Magnesium (Mg) ranges from 5.198-19.884ppm, Potassium (K) ranges from 2.007-9.112ppm, Sodium (Na) ranges from 5.367-12.751ppm and Iron (Fe) ranges from 0.012-0.921ppm, respectively.

The study revealed that the groundwater in the study area is polluted because of some chemical concentrates exceeding the WHO threshold limit when is compared with the mean of the study area as shown in table 1. The ranges of physico-chemical results that exceed the maximum permissible level are: Arsenic =0.02ppm, Iron= 1.5ppm, Magnesium =11ppm, Conductivity =200S/cm, pH= 5-7 and temperature =310C; and their effects are potentially toxic such as- problems of circulatory systems and increase risk of cancer, rusting and cancer, gastrointestinal and kidney damage, anaemia and changes in blood, rusting and cancer, and bone disease respectively. The breakdown of excess organic matters in landfill does not only consume energy but also release several cations and anions into the groundwater.

The geochemical laboratory analysis water samples taken from the boreholes shows high conductivity and when compared with the 2-dimensional electrical resistivity tomography in the study area confirmed the result of the pseudosection as indicated in figure 4-9. Thus, is crystal clear that any good borehole for potable water should exceed 25m into the aquiferous system.

Table 1 Table showing the comparison of WHO drinkable water standard and the mean of the study area.

Parameter	WHO 2010 Max permissible level	Mean of the Study area
Temp	25	31
Turbidity	25	3
PH	6.5-8.5	5-7
TDS (Mg/L)	1500	144
conductivity S/cm	10	200
Mg (mg/L)	0.2	11
Ca (mg/L)	200	13
K (mg/L)	50	6
Na (mg/L)	200	8
Fe (mg/L)	0.03-0.1	1.5
Pb (mg/L)	0.01	0.005
Cd (mg/L)	0.003	0.02
As (Mg/l)	0.01	0.02
Cl	250	9

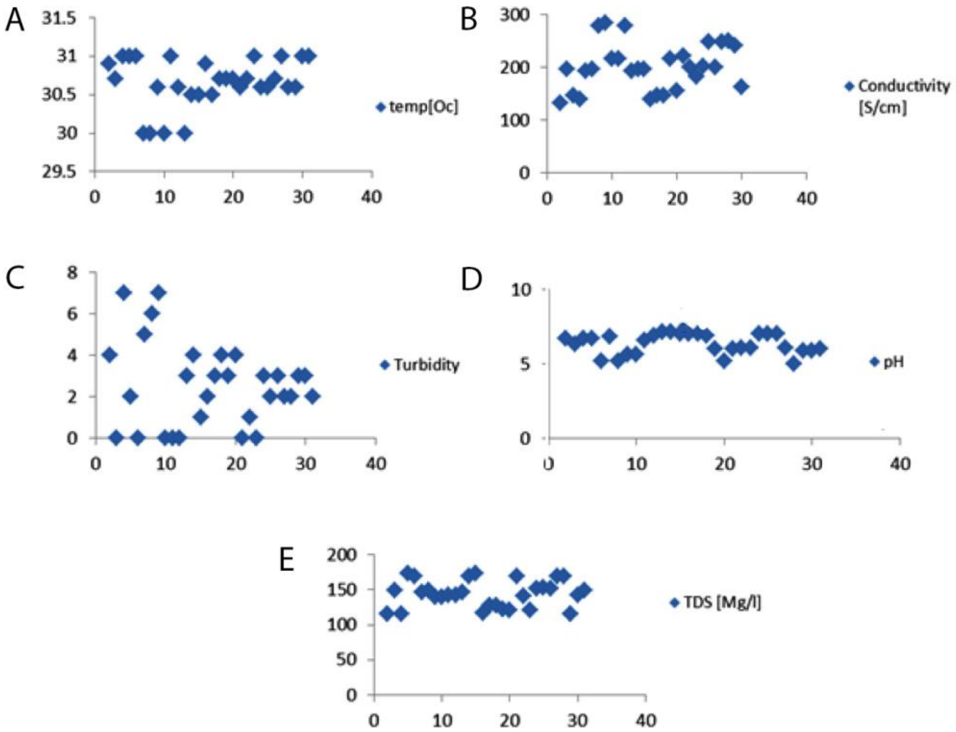


Fig. 8 Scatter plots of Physical parameters of 30 wells within the study area (A) Temperature, (B) Conductivity, (C) Turbidity, (D) Ph and (E) Total dissolved solids (TDS)

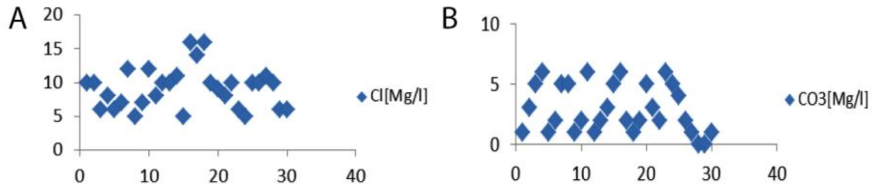
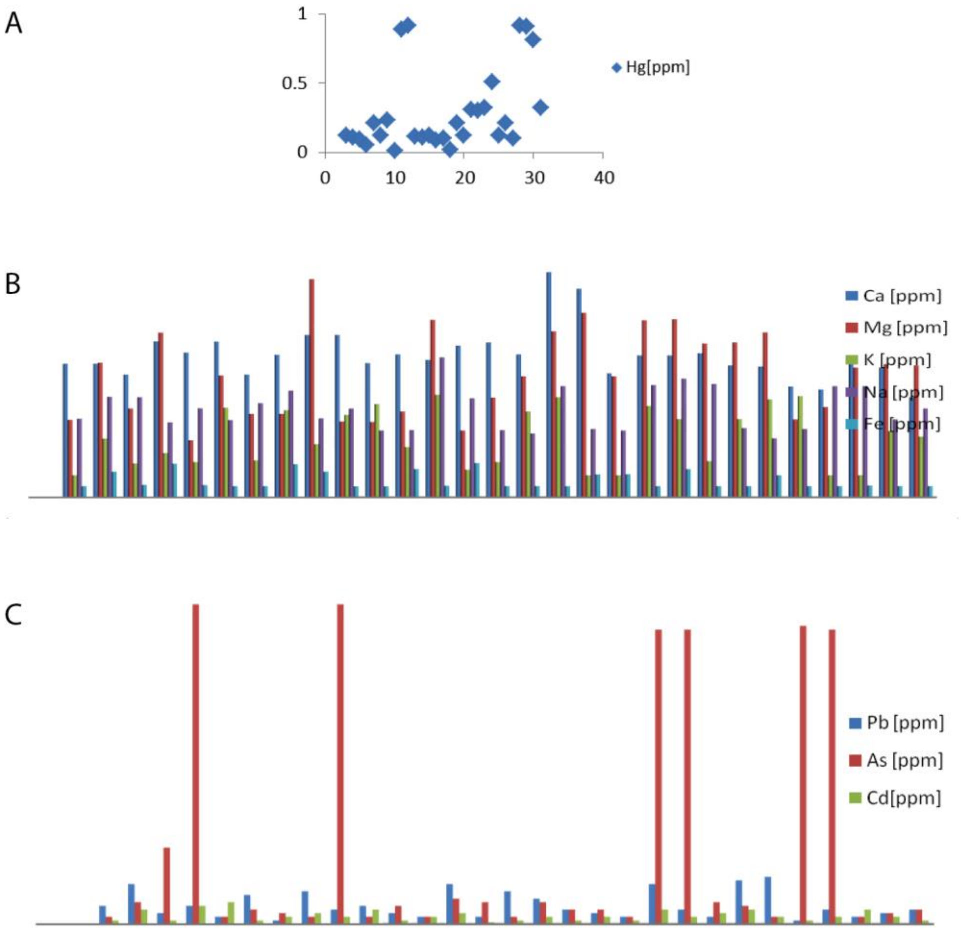


Fig. 9 Scatter plot of Anion of 30 wells within the study area (A) Chlorine and (B) Carbonate (CO_3)

C

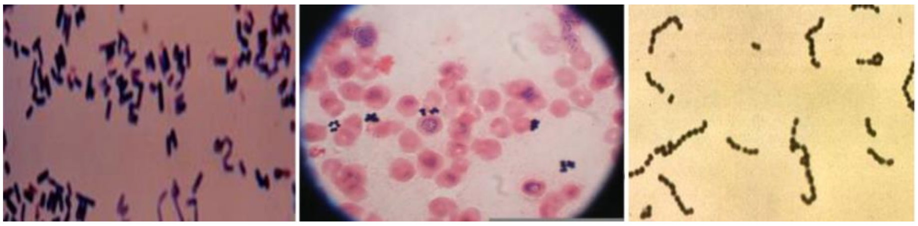


B

Fig. 10 Scatter plot of cations found in 30 wells within the study area (A)Mercury (Hg) and Bar charts of (B)Calcium, Magnesium, Sodium, Iron(C) Lead, Arsenic and Cadmiun

3.2. Microbial results

The results of microbial analysis which displayed some of the micro-organism found in the study area, as shown in figure 11, contain gram negative and gram positive bacterium which in case are poisonous to human life if the groundwater is consumed without undergoing WHO standard treatment and is used continuously in a day to day activity. For example, the following micro-organisms have been observed in the thirty water samples analysed: Bacillus is genus of Gram-positive, rod-shaped bacteria and a member of the phylum Firmicutes which causes kidney disease. Bacillus species can be obligate aerobes or facultative anaerobes, and test positive for the enzyme catalase as reported by Trochobanoglous et al., 1993. Thus, under stressful environmental conditions, the cells produce oval endospores that can stay dormant for extended periods (Xu and Cote, 2003).



Micrococcus sp *Staphylococci sp* *Streptococci sp*

Escherichia coli *Baccillus sp*

Fig. 11 Pictures showing the following micro-organisms: *Micrococcus sp, Staphylococci sp, Streptococci sp, Escherichia coli and Basillus sp* found in the water sample within the study area

Escherichia coli is a Gram-negative, rod-shaped bacterium that is commonly found in the lower intestine of warm-blooded organisms (endoderm's). The results from the microbial analysis of the water samples as shown in figure 11 revealed the presence of Escherichia coli. This micro-organism causes serious food poisoning.

*Streptococcu*s is a genus of spherical Gram-positive bacteria belonging to the phylum Firmicutes and the lactic acid bacteria group. The results from the laboratory analysis of sampled water indicate the availability of streptococcus sp, which is traceable to the contamination of the groundwater. Cellular division occurs along a single axis in these bacteria these microorganisms causes serious skin cancer.

The Staphylococcus genus includes at least 40 species. Of these, nine have two subspecies and one has three subspecies (Ryan and Ray 2004). Most are harmless and reside normally on the skin and mucous membranes of humans and other organisms. Found worldwide, they are a small component of soil microbial flora, Kloos (1980). The presence of Staphylococcus genus in the cultured media as found within the study area is caused by pollution of the groundwater. This organism causes severe reproductive problem.

Micrococcus spp. has been associated with various infections, including bacteria, continuous ambulatory peritoneal dialysis peritonitis, and infections associated with ventricular shunts and central venous catheters, Kocur et al. 2006. They have also been isolated from blood and surgical specimens in some patients with coronary and infectious conditions.

4. CONCLUSIONS

The field study has demonstrated the applicability and capacity of 2D electrical resistivity tomography and geochemical methods in capturing leachate plumes and groundwater accumulation within the study area. ERT allowed better imaging of lithologies found in the near-surface to subsurface. The consistency of the conductive anomaly in line with the landfill to depths well below the landfill base shows evidence of leachate invading the bedrock. The physico-chemical analysis of the water samples from the boreholes detected groundwater contamination due to the landfill in the study area.

The 2D resistivity model provides compelling evidence for leachate migration across the lateral and vertical extent of the contaminated regions in accompany by contaminant pathways due to fractures. The low resistivity zones below the landfill base shows evidence of leachate migration into the bedrock and contamination of groundwater, though further microbial and physico-chemical analyses confirm this hypothesis. Following the breakdown of much of the biodegradable mass with time while the decomposition of the organic constituents of the waste by rapid increase of microorganism activities, thus increasing the organic matter. The microbial result reveals the presence of some microorganisms such as Escherichia sp, Mycobacterium sp, Streptococcus sp, Basillus sp, Staphyloccus sp. Clostridium sp, and Micrococcus sp. These microorganisms in the water samples pose great infection like kidney disease, liver disease, diarrhoea, high blood pressure etcetera. The high concentration of detrimental substance in the physico-chemical results observed in the borehole water samples call for immediate action.

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PRIMENA 2D TOMOGRAFIJE, MIKROBIOLOŠKIH I GEOHEMIJSKIH ISPITIVANJA U AKURE DEPONIJI, SEVEROZAPADNA NIGERIJA

Dvo-dimenzionalna električna otpornost tomografija (ERT), mikrobiološka i geohemijska metoda su korišćene kao sredstvo za detekciju kontaminacije podzemnih voda na komunalnim deponijama Akure Sever za čvrst komunalni otpad, na Igbatoro putu, severozapadna Nigerija. Šest 2D profila koja se nalaze oko oboda i unutar deponije su ispitivana sa maksimalnom dužinom od 300 metara. Rezultati otpornosti tomografije pokazuju perjanicu procednih voda kao niske zone otpornosti (6 - 33 oma - m). Rezultati fizičko-hemijske analize uzoraka vode iz postojećih bušotina pokazuju povećanje koncentracije merenih parametara koje ukazuju na zagađenje podzemnih voda kao rezultat akumulacije procednih voda čvrstog otpada, čime dopunjuju rezultate geofizičkih podataka. Mikrobiološka analiza uzoraka vode u istim bušotina ukazuja na prisustvo nekih toksičnih mikroorganizama, kao što su staphilococcus sp, escherichia coli, streptococcus sp, basillus sp, clostridium sp, micobacterium sp i micrococcus sp što implicira da unos ove vode može izazvati bolesti poput diajreje, osip na koži, raka, bolesti jetre, bolesti bubrega, itd. Međutim, uviđen je uticaj ove deponije na okruženje zbog akumulacije i migracije procednih voda, stoga, preporučljivo je preseliti deponiju sa sadašnje lokacije na drugu lokaciju gde je naselejnost manja, kako bi se minimizirao uticaj ove deponije na ljude i životinje.

Ključne reči: *geofizika, podzemne vode, deponije, geohemija, Igbatoro.*