

1                   **GROUNDWATER CONTAMINANTS INVESTIGATION IN A**  
2                   **BASEMENT AREA OF NIGERIA USING 2D ELECTRICAL**  
3                   **SURVEYING METHODS**

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9                   **ABSTRACT**

Some of the common methods of monitoring and mapping groundwater contaminants is by extracting and analyzing samples of the groundwater obtained from wells within the expected investigation area, although lots of limitations are encountered in this type of investigation technique (point wise method) due to the nature of most subsurface layers, which are heterogeneous and anisotropic in nature and acquiring information using this method is comparatively difficult due to the few points acquired for investigation. Common and most recent method used to overcome such type of limitation and improve ground monitoring cost-effectively, is the use of Direct Current Resistivity measurements. This method gives a comprehensive characterization of the electrical properties of the subsurface layers (volume) needed. This paper investigates the usability and advantages of the resistivity method as a better method technique in monitoring groundwater contaminants in basement area or terrains under different seasons, in monitoring programmes. The work comprises field investigations at several sanitary landfills around the basement area of Ado-Odo town, in Ogun State, Nigeria, using Wenner array configuration (tomography) technique. From the results obtained, the level/degree of contaminants are easily identified and evaluated within the subsurface layers. We therefore concluded that the use of resistivity survey method gives an improved, better and appropriate information, generally suitable for mapping and monitoring of conductive groundwater contaminants in basement area.

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11                   *Keywords: Contaminants, Groundwater, Monitoring, Wenner, Configuration,*  
12                   *Tomography*

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14                   **1. INTRODUCTION**

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16                   Geophysical methods and Hydrogeological techniques are commonly used to  
17                   investigate or assess the potential of groundwater in any given area, although  
18                   geophysical investigations give more quick, improved and effective means of obtaining  
19                   the distributed information of the subsurface hydrogeology (Kearey and Brooks, 1991).  
20                   The techniques of groundwater resource mapping and evaluation of water quality using  
21                   geophysical methods has generally increased astronomically within the last decade due  
22                   to the use of enhanced and rapid electronic devices with advanced technology as well  
23                   as the development of new modeling solution system (Olayinka, 1991; Metwaly *et al.*,  
24                   2009; Ndlovu *et al.*, 2010). The use of different hydro-geophysical techniques are

25 common and available, electrical resistivity method remains the most popular  
26 techniques due to its low cost of execution, simple operation technique and its high  
27 efficiency ratio in areas with high resistivity contrast, such as overburden weathered  
28 layers and bedrocks (Telford and Sheriff, 1990). The use of electrical methods is  
29 particularly suitable for groundwater studies due to difference contrasts in hydrogeologic  
30 properties, such as permeability and porosity, which can easily be correlated with  
31 electrical resistivity values of the subsurface layers. Geo-electrical techniques are  
32 basically concerned with obtaining measurement of electrical resistivity of subsurface  
33 layers, which often gives information of the various geological layers, the structures and  
34 possible groundwater presences (Van Overmeeren, 1989; Dahlin *et al.*, 1999; Nowroozi  
35 *et al.*, 1999; Meju, 2005). Resistivity of subsurface layers is related to various geological  
36 properties, such as the porosity, permeability, fluid and mineral contents, and level of  
37 water saturation.

38 Some limitations are often encountered when investigating subsurface  
39 contamination using tracer tests techniques in order to obtain a clearer and  
40 enhanced picture of the groundwater flow patterns and their corresponding  
41 velocities. A major critical point in tracer tests technique is the distance of the  
42 observation wells and points of infiltration, as tracer pulses or signal s can be lost in  
43 the formation between observatory wells, due to heterogeneous flow pattern.  
44 Overcoming such limitation of tracer tests or point investigations, in a cost  
45 effective way, is the use of a Direct Current (DC) resistivity method, which are  
46 very useful in characterization of the subsurface layers physical properties, both  
47 vertically and laterally, covering large volume of the ground, thereby improving  
48 the monitoring technique. The Direct Current resistivity method is one of oldest  
49 known geophysical methods, which have been used over time for investigating  
50 presence of leachates in landfill environs and studying of other environmental  
51 challenges. The use of resistivity methods for investigating the presence of  
52 contaminants in subsurface formations is based on the knowledge that the resistivity  
53 of the saturated soil basically depends on the groundwater resistivity and properties  
54 of the porous matrix, thus creating the ability and potential of detecting leachate  
55 present, resulting in changing the resistivity of the subsurface layers due to changes  
56 in the concentration of contaminants (dissolved ions) in the groundwater. The  
57 resistivity method is most effective and suitable for relative measurement, and  
58 monitoring of leachate flow in the subsurface (Benson *et al.*, 1988).

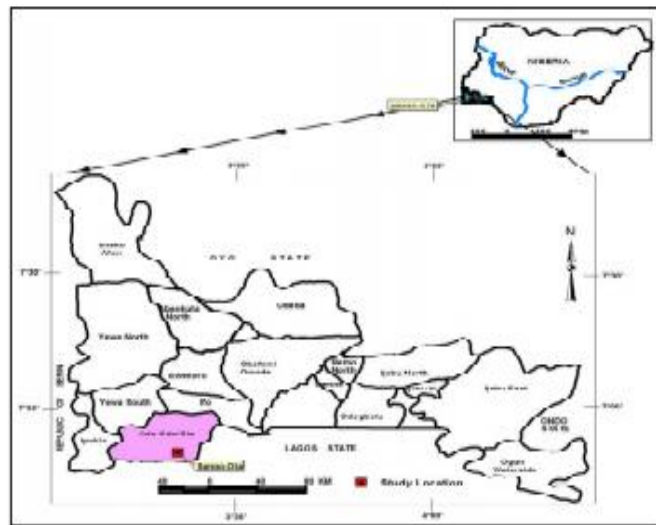
59 In complex hydrogeology area, monitoring of contaminants flow is assess by the use  
60 of high density systems and for area with very high fluctuating groundwater table,  
61 which will enable the system to give a vertical cross-section of the concerned area.  
62 While low-density systems are effective for hydrogeological environments with fewer  
63 and shallow layers but with stable groundwater table, or area with less detailed  
64 information (both in time and space). The use of Continuous Vertical Electrical Sounding  
65 (CVES) system is generally preferable for tracer tests and commonly recommended,  
66 because of the density of measurements required and the ability for automatic  
67 measurement. Major precaution require in the use of tracer tests in resistivity  
68 measurements, is in the estimation of the needed amount of tracers based on the  
69 size and depth of the aquifer, as well as the estimated groundwater flow. The use of  
70 high concentration of tracers will give detectable resistivity changes even in deep  
71 aquifers, while too high concentration tracers may cause unwanted differential flows.

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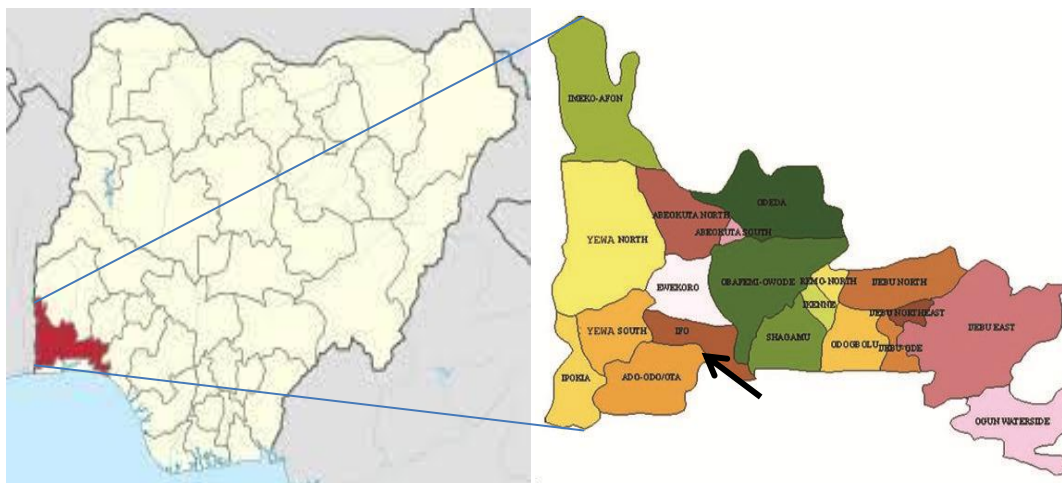
## 73 **2. THE STUDY AREA**

74 The survey was conducted in Ado-Odo/Ota town, a borders town between Ogun  
75 State and metropolitan Lagos State (Figure 1). The local government area is the  
76 second largest in Ogun State, with its headquarter at Ota main town with  
77 coordinates 60°41'00"N 30°41'00"E and at Latitude/Longitude 6°37'25" N/ 3°5'11" E

78 (Figure 2), with a total landmass area of about 878 sq-km. Ota main town possesses the  
 79 same geologic characteristics with many other parts of the state, with basement complex  
 80 rock and the pre-Cambrian age basically made up of the older and younger granites (Figure  
 81 3) especially in the northern part of the state, while the younger and older sedimentary rock  
 82 of tertiary and secondary ages are common in the southern parts (Iloeje, 1981). The region  
 83 possesses a typical climate of tropical rain-forest with two main climatic conditions namely;  
 84 the rainy season (commonly from April to October, with little a month interruption), and the  
 85 dry season (Running through November till February). The rainfall duration usually runs for  
 86 more 90 days, resulting in a humid climate due to the high level of rainfall, which often  
 87 amount to about 250cm<sup>3</sup> in a year (Ufoegbune *et al.*, 2016)  
 88 Groundwater flows generally follows the topography nature of the area surface with  
 89 seasonal variations in water levels, usually characterized by rising (Increasing) water  
 90 levels between November and March (Wet season), while between May and September  
 91 (Dry season), there is reducing (Declining) water levels. The red circles indicate the 4  
 92 locations where field investigations were carried out in the study area (Figure 4).  
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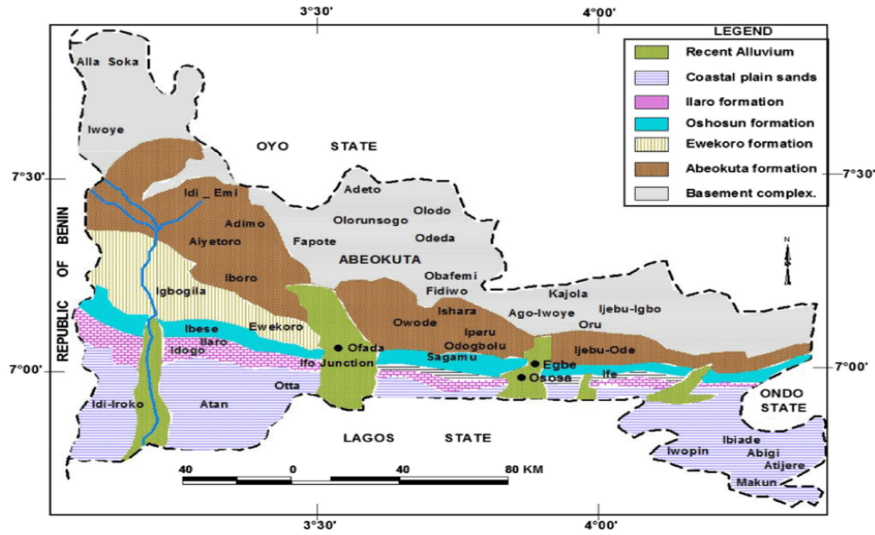
94  
 95 Figure 1: Map of Ogun State showing the Study Area of Ado-Odo/Ota (Ufoegbune *et al.*, 2016)  
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Figure 2: Map of Nigeria insert with map of Ogun State showing Ado-Odo/Ota Local Government Area (Wikipedia.org)



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Figure 3: Geological content map of Ogun State showing different formations

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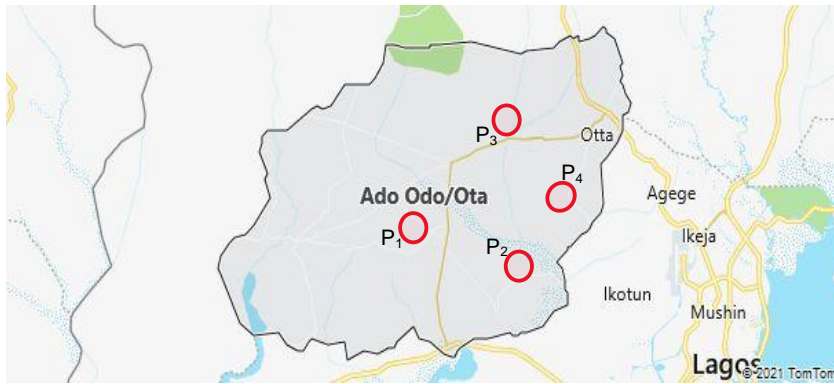


Figure 4: Map of Study Area showing the four locations (P<sub>1</sub>, P<sub>2</sub>, P<sub>3</sub> and P<sub>4</sub>) of Study in Ado-Odo/Ota Metropolitan

### 3. MATERIAL AND METHODS

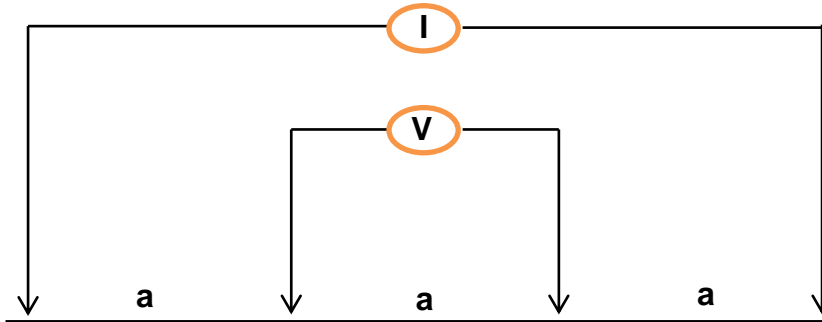
#### 3.1. MATERIALS

The following materials were used for the study, this include Electrical Resistivity meter, Garmin-Global Positioning System (GPS), Compass, Processing softwares (mainly Res2Dinv and WinRes).

#### 3.2. METHODS

The Wenner array was used to determine the presence of lateral variation of the leachates. The Wenner array configuration used (Figure 5) was designed to monitor the presence of leachate/contaminants in the subsurface using the lateral variation of the level of the leachate/contaminants through monitoring of the electrical conductivity anomaly.

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Figure 5: Wenner array configuration

Where the resistivity values is obtained using

$$\rho_a = 2\pi a \frac{V}{I}$$

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146 For the 2-dimensional imaging, the Wenner array method was conducted along four profiles,  
147 namely Profile 1, 2, 3 and 4. The technique used involved injecting direct current into the  
148 subsurface layers (ground) through a pair of current electrodes (AB), while the potential  
149 difference was measured via another set of potential electrode pair (MN) as shown in Figure  
150 5. A constant electrode spacing of  $na$ , (where  $n = 1,2,3,4$  and  $5$  respectively) were used for  
151 each of the current and potential electrodes spacing sequentially for each of the profile.

152 For the first electrode spacing of  $1a$ , the spacing distance of both the current and potential  
153 electrodes are made equal, while subsequent measurement was done by shifting the  
154 electrodes at equal distance for successive measurement readings along a total spread of  
155 100 m. This procedure was repeated for each of the electrode spacing of  $2a$ ,  $3a$ ,  $4a$ , and  $5a$ ,  
156 respectively and separately. The electrode spacing 'a' used for the field work is equal to 3m.  
157 After acquiring the data, the data were quality-checked an inverse modelling technique was  
158 used to obtain and interpret the variation in the resistivity values of the leachate plume, while  
159 the data obtained from the Wenner configuration measurements was uploaded into the  
160 available software (Res2Dinv) to process and obtained the 2D tomographic section. After the  
161 standard processing and interpretation procedure performed, the final result obtained are  
162 displayed.

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## 165 4. RESULTS AND DISCUSSION

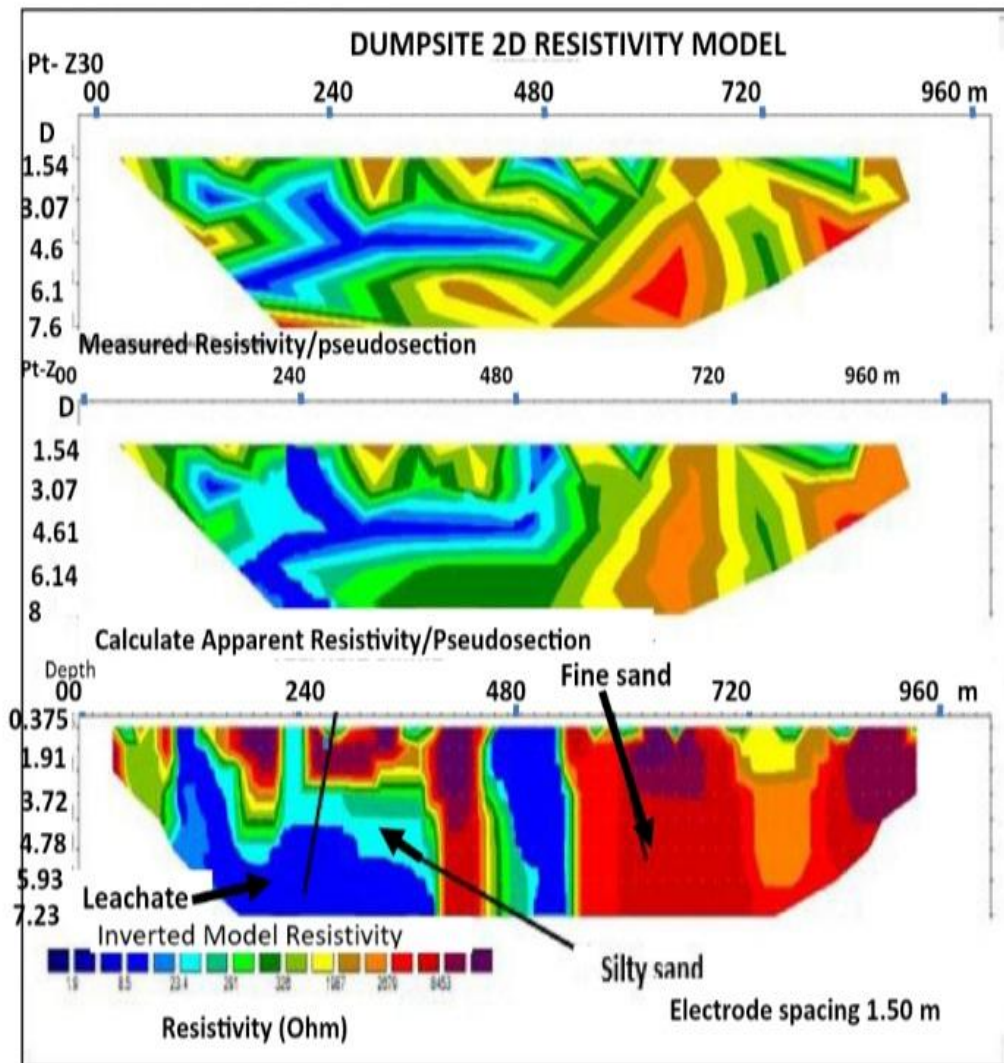
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### 167 4.1. RESULTS

168 The results obtained from the inversion of the Wenner-array data obtained along the  
169 individual profiles 1, 2, 3 and 4 are shown in Figures 6, 7, 8, and 9 respectively.  
170 Profile 1 was acquired in a SW- SS trend across the dumpsite (Study Area), while  
171 Profile 2 is located at the southeastern end of the study area, measuring 100 m in  
172 length. Profile 3 was acquired in a NE–SW trend direction of Profile 2; the Profile is  
173 located at the southwestern end of the study area, also measuring 100 m in length.  
174 While Profile 4 is located at the eastern end, 1 km away from the dumpsite, with an  
175 100m measurement in length. The inverted resistivity models obtained for the  
176 respective profiles are shown as follows.

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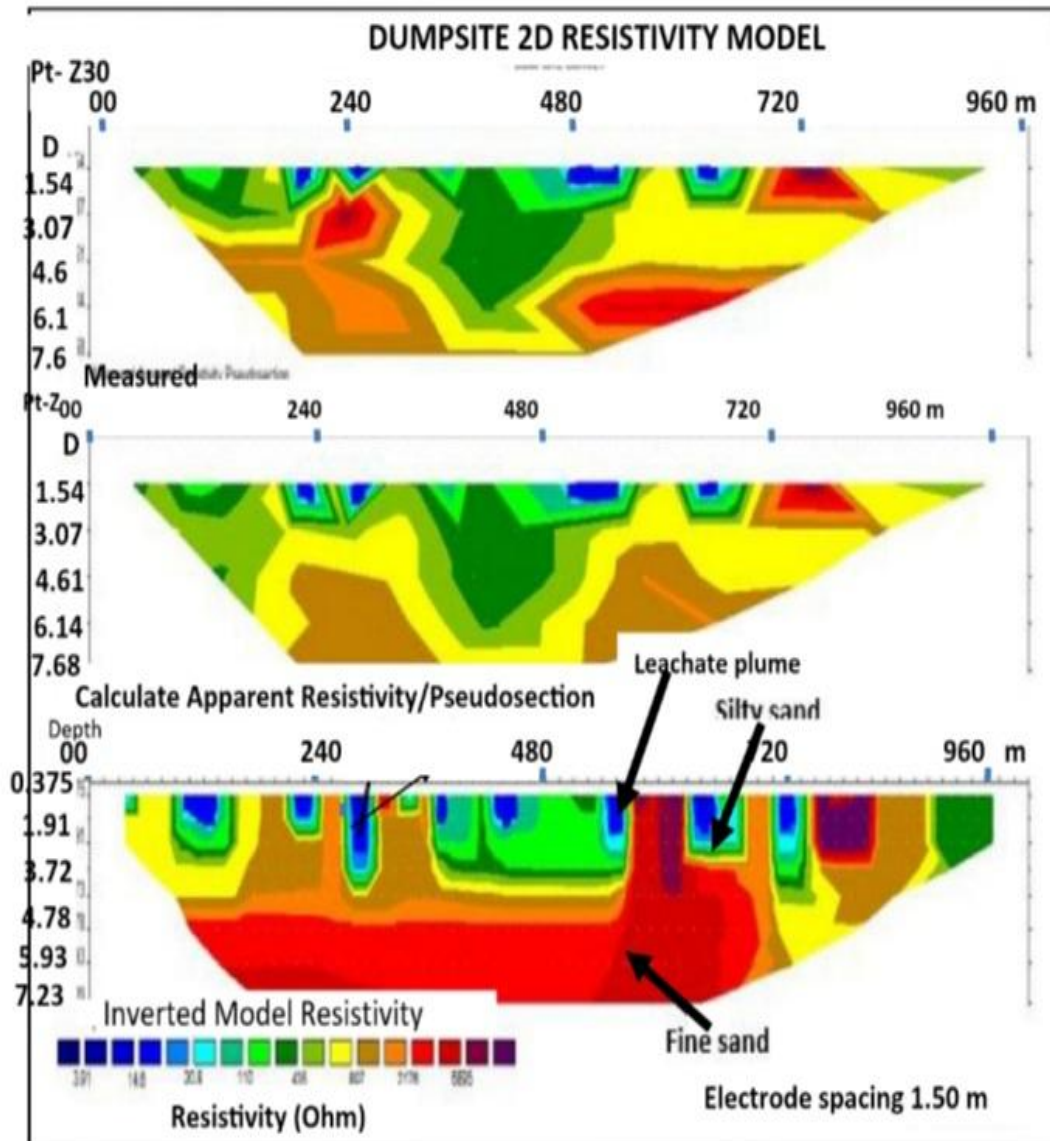
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Figure 6: The 2D inversion of the Wenner-array data obtained along profile 1, showing the variation in resistivity of the subsurface layers. The section with red colors shows subsurface area with high resistivity zone, while blue colors represent area with least resistivity zone.



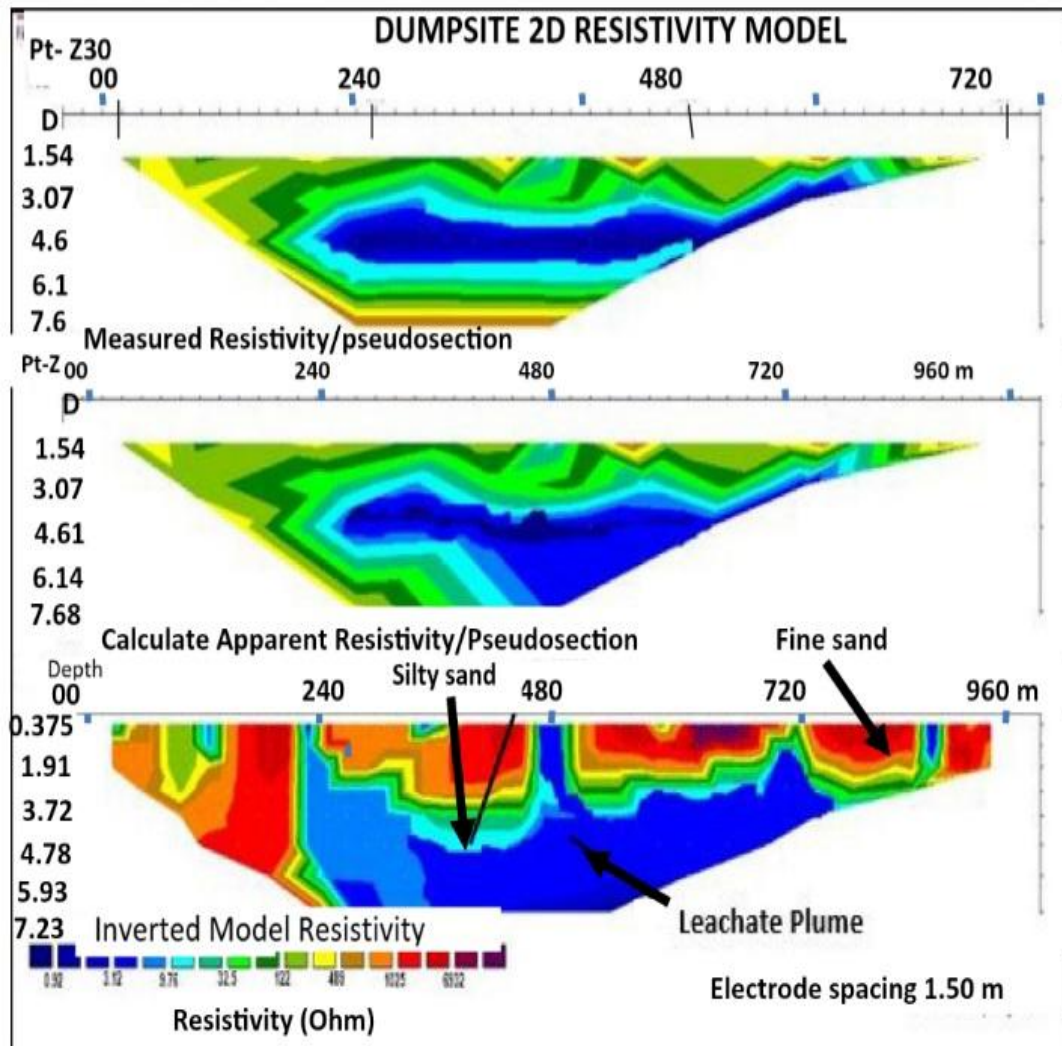
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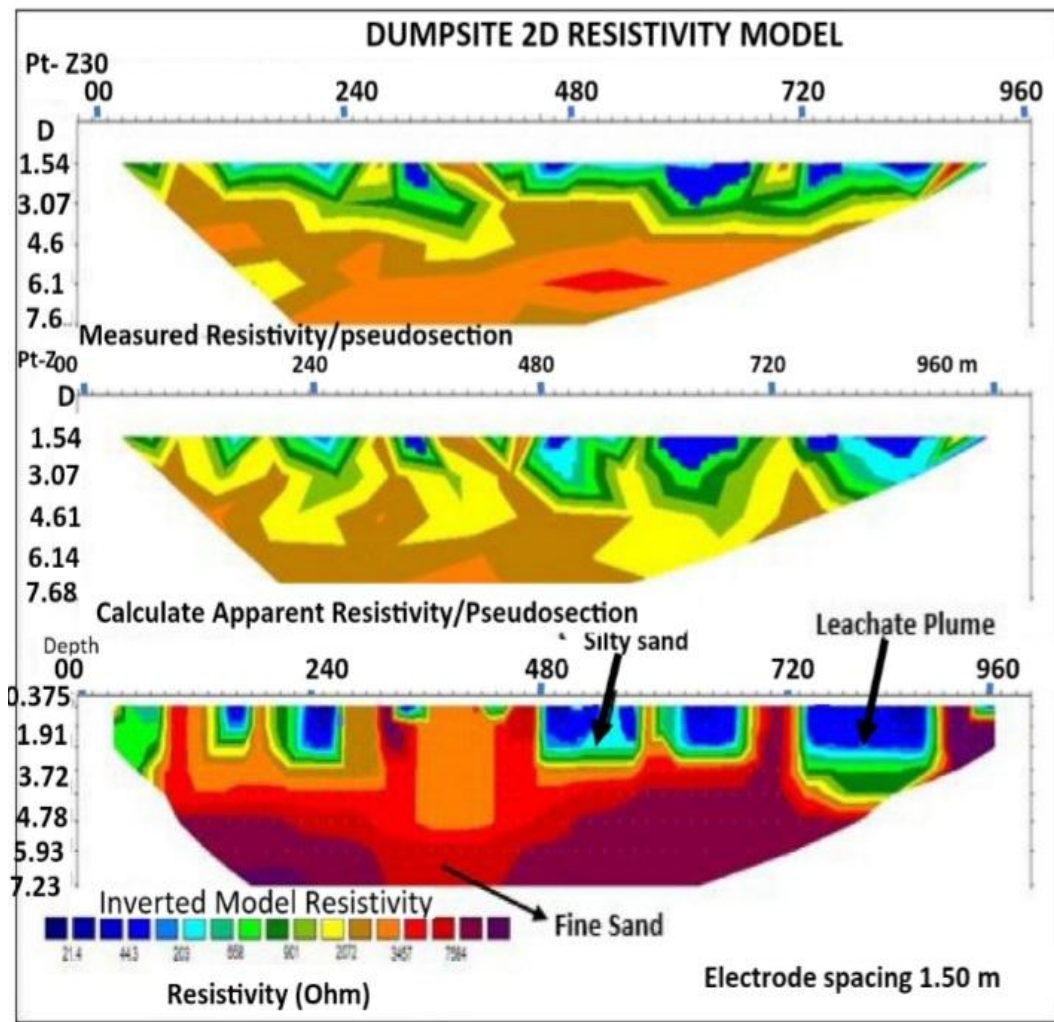
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Figure 7: The 2D inversion of the Wenner-array data obtained along profile 2, showing the variation in resistivity of the subsurface layers. The section with red colors shows subsurface area with high resistivity zone, while blue colors represent area with least resistivity zone.



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188 Figure 8: The 2D inversion of the Wenner-array data obtained along profile 3, showing the  
 189 variation in resistivity of the subsurface layers. The section with red colors shows subsurface  
 190 area with high resistivity zone, while blue colors represent area with least resistivity zone.



191  
 192 Figure 9: The 2D inversion of the Wenner-array data obtained along profile 4, showing the  
 193 variation in resistivity of the subsurface layers. The section with red colors shows subsurface  
 194 area with high resistivity zone, while blue colors represent area with least resistivity zone.  
 195

196 **4.2. DISCUSSION**

197 Profile 1: 2D section from the resistivity inversion obtained after 30 iterations with a  
 198 5.4% Root Mean Square (RMS) error is shown as a pseudo section in Figure 6. The  
 199 apparent resistivity, measured in ohm-meter ( $\Omega m$ ), is plotted against the pseudo-  
 200 depth (in metres). A zone with low resistivity value of  $>8.7 \Omega m$ , shown in dark blue  
 201 colour, is observed near the surface at the South Western part of the section, with  
 202 depth ranges from 0.375m to 7.20 m. This value indicates that the leachate plume  
 203 had penetrated the subsurface layer and polluted the groundwater presence in this  
 204 zone, when calibrated against the surrounding areas. While at the Northern and  
 205 Western part of the section, A high resistivity zone of  $>8453 \Omega m$  is observed near  
 206 the surface with depth ranging from 0.375m to 4.21 m. This high resistive zone near  
 207 the surface represents the uninvaded zone by the leachate. While the zone, coded

208 in red color, with a high resistivity value of  $>8453 \Omega\text{m}$ , is essentially interpreted as  
209 basically composed of fine sands. From a depth of 0.375m–7.20 m, the zone with  
210 resistivity values ranging  $>23.4 \Omega\text{m}$ , and coded in light blue colour is interpreted as  
211 being underlain by silty sand.

212

213 Profile 2: The 2D pseudo-section from the inversion obtained after 30 iterations, with  
214 a 7.9% RMS error is shown in Figure 7. A zone with low resistivity value of  
215  $>14.6 \Omega\text{m}$ , coded as dark blue color, identified close to the surface at depth ranging  
216 from 0.375m to 3.1 m, indicates zone already invaded by leachate plume, showing  
217 that the topsoil has been contaminated. While the zone with high resistivity value of  
218  $>2176 \Omega\text{m}$ , and coded red colour, near the top surface with depth ranging from  
219 0.375m to 3.7 m to the West and East of the section, shows that the zone is polluted  
220 as a result of the presence of high resistive chemical compounds. The migration  
221 near the surface is an indication that it is less dense, thus the lithology can be  
222 inferred as fine sands. The zone with low resistivity value of  $>20.8 \Omega\text{m}$ , and coded  
223 as light blue color, identified close to the surface, indicates the presence of silty  
224 sand, which probably hindered the further penetration of the leachate into the  
225 subsurface.

226

227 Profile 3: The pseudo section shows the resistivity inversion results obtained after  
228 30 iterations, with 8.5% RMS error as shown in Figure 8. The zone with low  
229 resistivity value of  $>3.12 \Omega\text{m}$  and coded in dark blue color, close to the surface with  
230 depth ranging from 0.375m to 7.2 m, indicates that the leachate plume has  
231 penetrated beyond the topsoil, directly into the subsurface layers, thus polluting the  
232 underground formations. While the zone with high resistivity value of  $>1025 \Omega\text{m}$ ,  
233 and coded red color, which occurs near the surface with depth ranging from 0.375m  
234 to 5.3 m at the eastern part of the section, shows that the zone is (being interpreted  
235 as being high resistive zone near the surface), is less dense and, thus interpreted as  
236 fine sands. At a depth ranges from 0.375m to 5.1 m, a resistivity zone with resistivity  
237 value of about  $9.76 \Omega\text{m}$ , and color-coded light blue, indicates zone of silty sand, thus  
238 showing a highly contaminated environment as a result of the leachate plume  
239 infiltration.

240

241 Profile 4: The inverted pseudo section (Figure 9) shows the resistivity inversion  
242 results after 30 iterations with 29.6% RMS error. From the pseudo section result, the  
243 zone with low resistivity value of  $>44.3 \Omega\text{m}$ , coded blue in colour, isolated close to  
244 the surface with depth ranging from 0.375m to 3.3m, indicates area of the topsoil  
245 that the leachate plume has contaminated. While the zone with high resistivity value  
246 of  $> 7584 \Omega\text{m}$ , coded purple colour, existing near the surface and also occupied the  
247 bottom of the section with depth ranging from 0.375m to 7.20 m from South to  
248 Eastern part of the section, indicates the presence of a denser material with the  
249 leachate displacing them as they penetrated downwards in the dominantly clayey  
250 sandstone layers. The light blue coloured zone seen around a depth of 1.91m along  
251 the top layers indicates silty sand; which generally impedes the migration of the  
252 leachate plume, thus the subsurface groundwater area is not yet affected by the  
253 presence of the leachate plume in this area. The red-coloured zone found at the  
254 bottom indicates an unpolluted zone of fine sand lithology.

255

#### 256 **4. CONCLUSION**

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258 The study has shown effective use of electrical surveying methods in investigating the  
259 presence and effects of contaminants on ground water in a basement environment. The  
260 method deployed is an effective, simple and low cost technique of monitoring the presence

261 of lateral contaminants in underground water. This resistivity method of investigating or  
262 monitoring the presence of leachate plume in groundwater shows that it is a valuable and  
263 effective complement to groundwater sampling using tracer tests. The result obtained can  
264 also be used to estimate flow pattern and flow velocity of the aquifers, as well as the  
265 subsurface geological conditions of the environs.

266

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272 .

## 273 **COMPETING INTERESTS**

274

275 "All Authors declared that no competing interests exist.".

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## 278 **AUTHORS' CONTRIBUTIONS**

279

280 'Author A' designed the study, performed the statistical analysis, wrote the protocol, and  
281 wrote the first draft of the manuscript. 'Author B' managed the analyses of the study and  
282 managed the literature searches..... All authors read and approved the final manuscript."

283

## 284 **ETHICAL APPROVAL:**

285

286 AS PER INTERNATIONAL STANDARD OR UNIVERSITY STANDARD WRITTEN  
287 ETHICAL APPROVAL HAS BEEN COLLECTED AND PRESERVED BY THE  
288 AUTHOR(S).

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## 291 **CONSENT (WHERE EVER APPLICABLE)**

292

293 "All authors declare that 'written informed consent was obtained for publication of this case  
294 report and accompanying images. A copy of the written consent is available for review by the  
295 Editorial office/Chief Editor/Editorial Board members of this journal."

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