

## ARTICLE

# The Application of Geophysical Techniques in Tracking Leachate Plumes Migration in a Typical Cemetery within the Sandy formation in Benin City, Nigeria

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### ABSTRACT

The survey aim is to track leachate plumes within the sandy formation which is below the surface laterite layer. It investigates the presence and migration of leachate plumes in the sandy region in a typical cemetery (Third Cemetery), in Benin City, Nigeria. The research engaged Vertical Electrical Sounding (VES), 2-Dimensional computation of migration in both the vertical and horizontal directions. The electrical resistivity data collected in parallel equidistant lines was processed to obtain geoelectric models using Res2dinv. The leachate plumes in the cemetery migrate vertically and horizontally at different rates. The maximum and minimum rates of vertical migration are 4.1 and 0.2 cm/day respectively, while the maximum and minimum rates of horizontal migration are 32.8 and 1.7 cm/day respectively. Volumetric analysis of the plume zones indicates that of the 75,231m<sup>3</sup> of the subsurface imaged, 6,322 m<sup>3</sup> is the zone contaminated by leachate plume, that is, 8.4 % of the earth volume investigated contained leachate plume. The research also showed that repeated ERT surveys can track movement of leachate plume emanating from decomposed dead bodies over time in active cemetery. The average travel time for a leachate plume to transverse a vertical distance of 6.6 m in coarse sand is 366.7 days at constant migration speed of 1.8 cm/day.

## 1. Introduction

Interment of bodies in cemeteries remains a widespread practice and the only alternative endpoint to dead bodies in Nigeria. In Benin City and Nigeria in general, the major cemeteries are located close to human residential areas and virtually all the populace within this locality depends on groundwater as the primary water source for various domestic purposes<sup>[1]</sup>

Many countries do not have appropriate legal regula-

tions with regards to location of cemeteries. If not appropriately located or not sufficiently protected, cemeteries pose a significant health problem for the people<sup>[2]</sup>. Health concern about possible impact of the cemeteries in Nigeria on the water supply has prompted this research. According to DOC<sup>[3]</sup>, cemetery sites/graveyards have the potential to result in impact on the local water environment and in particular, the groundwater underlying such sites. Multiples of studies elsewhere in the world have been devoted to impact of interment of bodies in cemeteries to

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the groundwater quality [4-11]. Toxic chemicals that may be released into groundwater include substances that were used in embalming and burial practices as well as varnishes, sealers and preservatives and metal component of ornaments used on wooden coffins [12]. Wood preservatives and paints used in coffin construction contain compounds such as copper, naphthalene and ammoniac or chromated copper arsenate [13]. Paints contain lead, mercury, cadmium, and chromium; arsenic is used as a pigment, wood preservative and anti-fouling ingredient while barium is used as a pigment and a corrosion inhibitor [14,15].

Studies on the impact of cemeteries on the quality of groundwater in unsaturated and saturated zones are usually conducted within or at some distance from the cemeteries [16]. Over 40% of cemeteries in South Africa contaminate water resources. Local authorities seem oblivious of the problem. Both legal regulation and the determination to act in a way which would limit the threat are lacking [17].

## 2. Study Area

This study was conducted in Benin City located in south-south geopolitical zone of Nigeria. Benin City is bounded by latitudes 06° 06' N, 06° 30' N and longitudes 005° 30' E, 005° 45' E and an area of about 500 square kilometers [18]. The city is located within the rain forest ecological zone with annual mean temperature of 27.5 °C [19] and an annual mean rain fall of about 2095 mm [20]. Three cemeteries namely First, Second and Third cemeteries are located within this city. The Third cemetery which has existed for over 50 year was considered for this study because of its proximity to human residents. The cemetery which is the biggest among the cemeteries in Benin City covers an area of about 5.167 ha [21].

Geological sitting of Benin City is underlain by sedimentary formation described by [22]. The formation is made up of top reddish clayey sand capping highly porous fresh water bearing loose pebbly sands, and sandstone with local thin clays and shale interbeds.

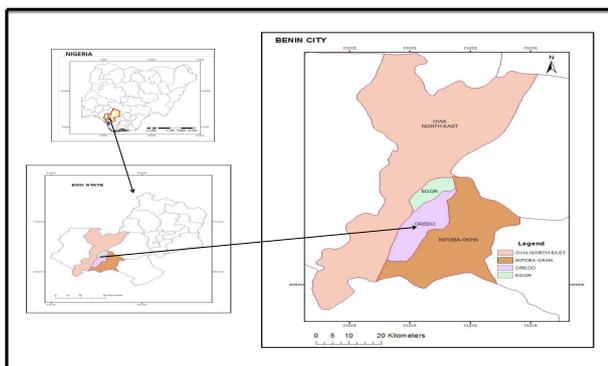


Figure 1. Study Area Map Showing Benin City with Four Local Government Areas

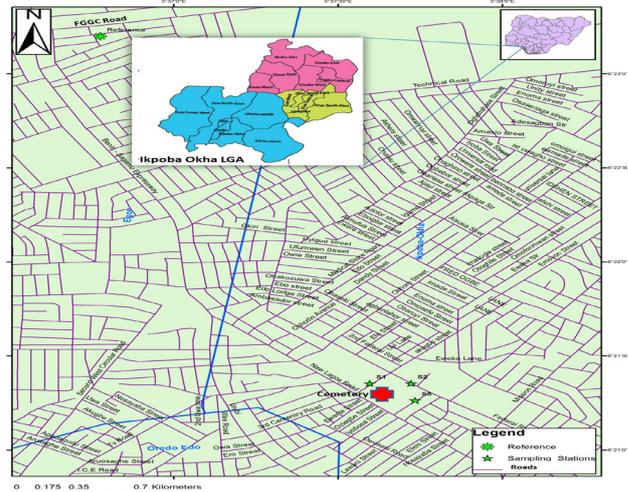


Figure 2. Map of Study Area (Third Cemetery). [23]

## 3. Methodology

Electrical resistivity imaging data was acquired twice using Pasi Earth Resistivity Meter. The second data set was acquired six months after the first one. The data coverage was made over an area defined by rectangular loop measuring 30m by 230m in the first survey while in the second survey was 30m by 200m. The resistance values were read from the measuring instrument using Wenner-Schlumberger array. This array is moderately sensitive to both horizontal structure and vertical structures [24].

In first survey, in each line location, electrodes numbered 0- 23 were placed into the ground at intervals of 10m along the line, while in the second survey, electrodes numbered 0-40 at 5m interval was planted into the ground. Each time measurement was to be taken, array of four electrodes are selected manually and connected to the Petrozenith earth resistivity meter via single core cable.

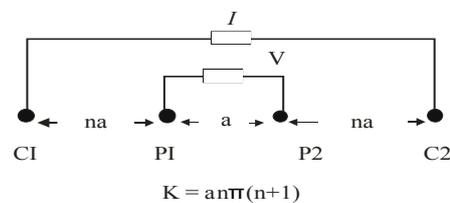


Figure 3. Wenner-Schlumberger Array [25]

$$K = a\pi(n + 1) \tag{1}$$

$$\rho = KR \tag{2}$$

## 4. Data Processing and Interpretation

The electrical resistivity data was processed to obtain geo-

electric models using Res2dinv and the second -survey data set was also merged and inverted as a single 3-D data set using Res3Dinv software, which is then visualized in detail using Voxler 4.0. The processed data depicted clearly the locations of low resistivity (blue) which occur at depths below 5.19m and 2.60m in the first and second surveys (subsurface data collection started at these depths) that are most likely to indicate accumulation of leachate plumes.

### 5. Discussion of Geophysical Tomography

The survey aim is to track leachate plumes within the sandy formation which is below the surface laterite layer. The sandy formation is a graded sand bed as seen from lithology log obtained from an existing borehole in vicinity. The water table likely occurs between the very coarse sand and medium sand. As leachate plume is detected in the medium sand, water in the well sorted coarse sand will be contaminated. If this shallow aquifer is polluted, there is high probability that the nearby deep confined, coarse sand aquifer at depth of 60 m (200 ft) is at risk. The geoelectric models obtained for the first and second surveys displayed leachate plumes starting from the laterite (the burial environment) down to the sandy formation (the regional water supply source). The leachate plumes presence in the sand bed are modeled and described as shown in the 2-D and 3-D displays, (Figure 4 to Figure 9) and Table 1.

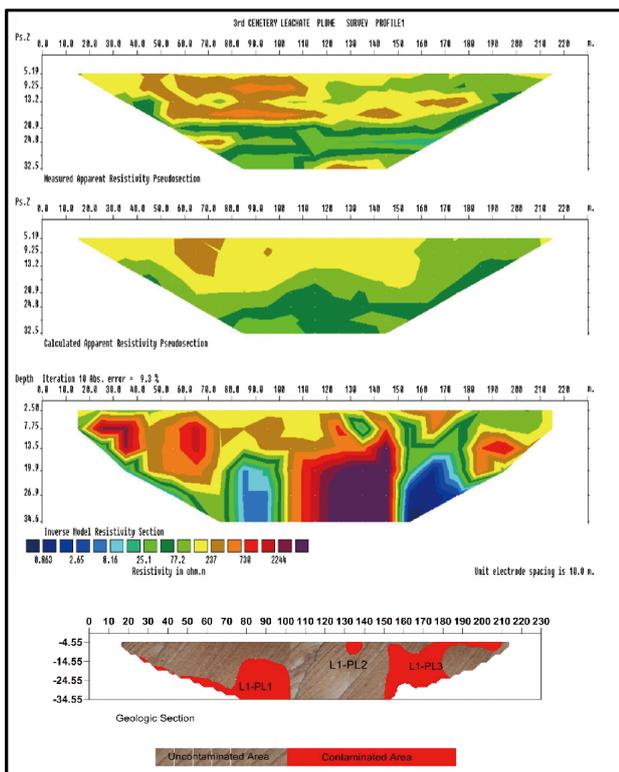


Figure 4. First Survey Profile 1

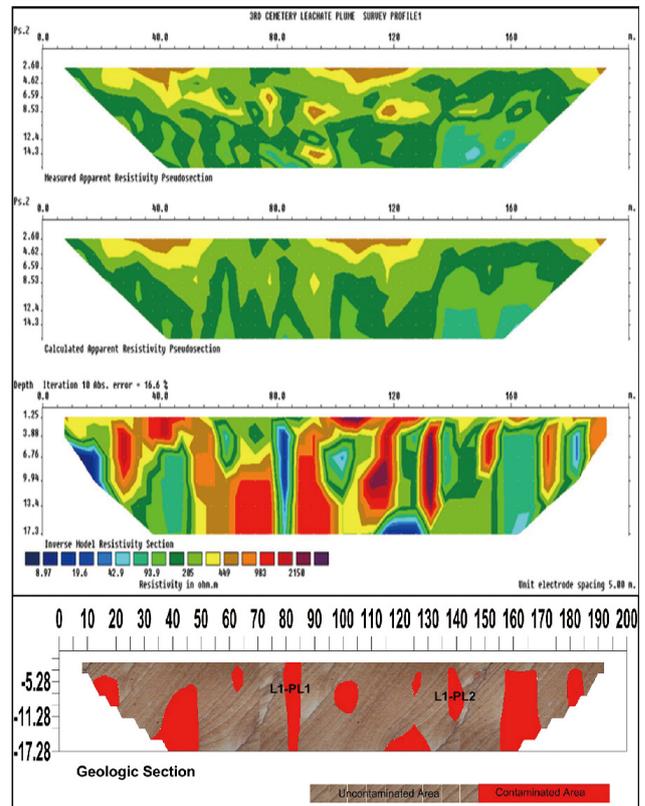


Figure 5. Second Survey Profile 1

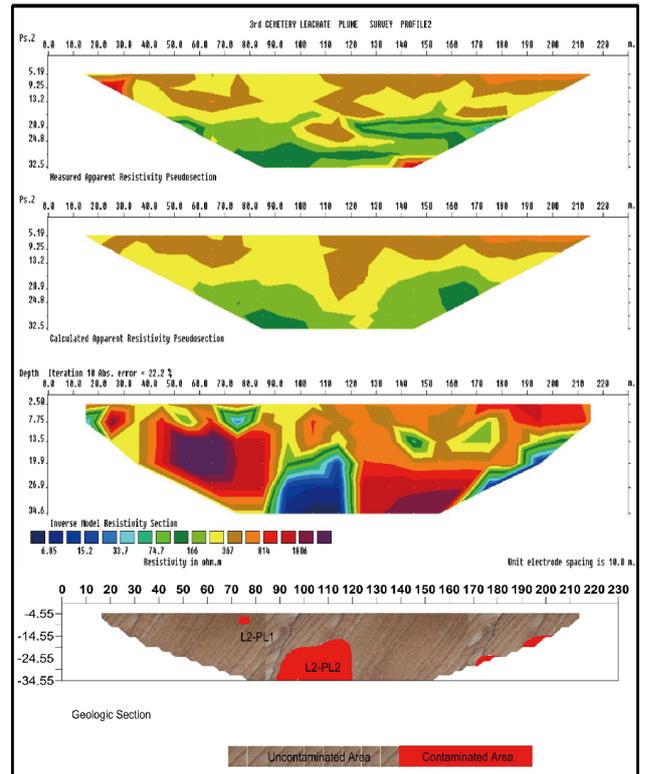


Figure 6. First Survey Profile 2

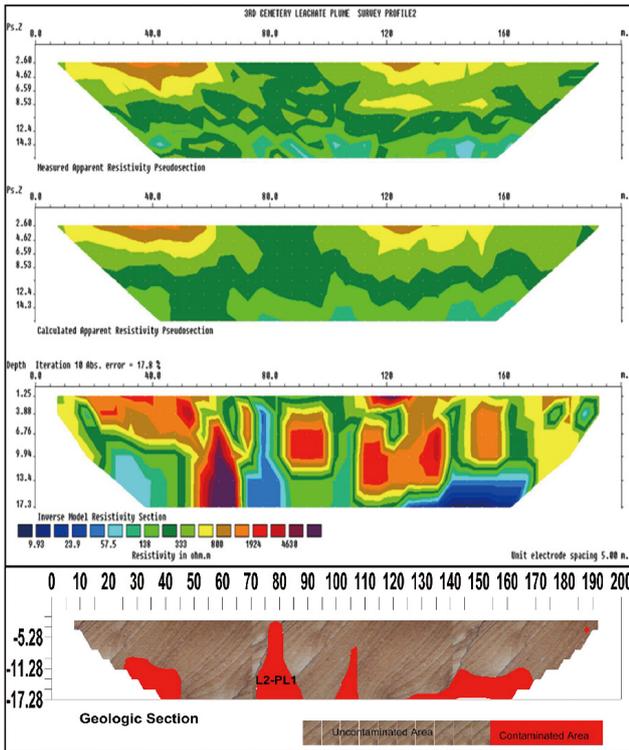


Figure 7. Second Survey Profile 2

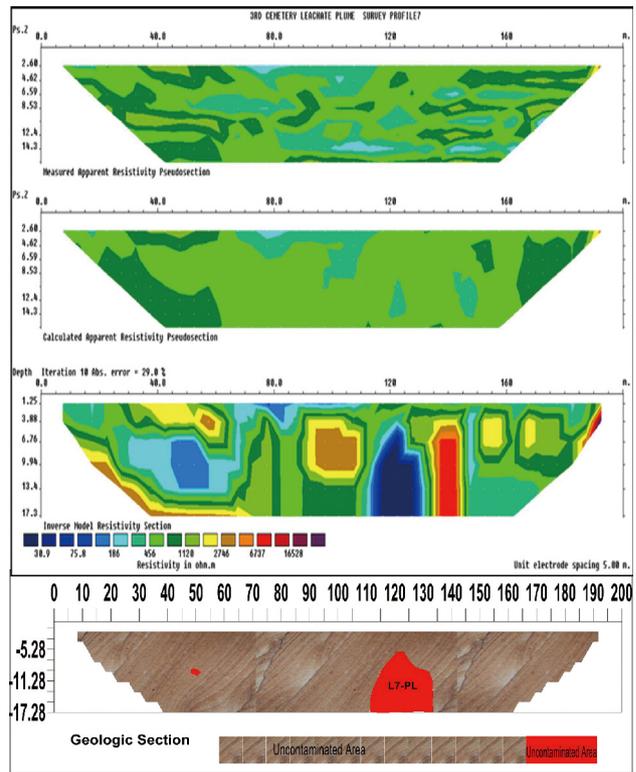


Figure 9. Second Survey Profile 7

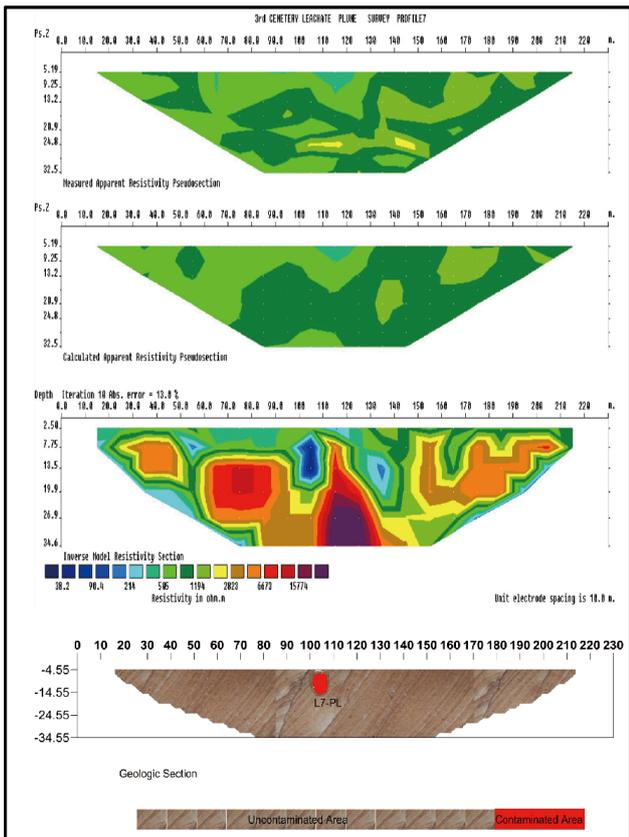


Figure 8. First Survey Profile 7

## 6. Discussion of Time Lapse

The field works were conducted in two sessions with a time interval of six (6) months. The first ERT survey was conducted in June 2017 (early period of rainy season) and the second ERT survey was conducted in December 2017 (early period of dry season) when the plumes must have been diluted with excess infiltrating water and move faster in the vertical and horizontal directions. The rate of migration depends on the permeability of the soil, incline topography, depressions created by decomposed corpses and collapsed burial materials. All these aid infiltration into the subsurface.

The rate of migration in the horizontal direction is higher than the rate of migration in the vertical direction as shown in Table 1. The maximum rate of migration in the vertical direction is 4.1 cm/day while the maximum rate of migration in the horizontal direction is 32.8 cm/day. From the Table 1, it is observed that horizontal migration is higher than the corresponding vertical migration. The plume flows vertically and outwardly into the ground, and the horizontal permeability of sediment is found to be higher than the vertical permeability except in vertical solution fractures [26].

**Table 1.** Time Lapss Analysis

June, 2017			Dec. 2017			Vert. Shift (m)	Horiz Shift (m)	Vert. Migrat. Rate (cm/day)	Horiz. Migrat. Rate (cm/day)		
Plume	Average Resist. (Ωm)	Bottom Depth (m)	Horiz Extent (m)	Plume	Average Resist. (Ωm)	Bottom Depth (m)	Horiz. Extent. (m)				
L1-PL2	61	10	10	L1-PL2	94	12	13	2.0	3	1.1	1.7
L2-PL1	51	10	3	L2-PL1	73	17.3	20	7.3	17	4.1	9.4
L3-PL1	76	14.5	10	L3-PL1	52	17.3	20	2.8	10	1.6	5.6
L3-PL2	89	17	1	L3-PL2	79	17.3	60	0.3	59	0.2	32.8
L4-PL4	97	14	5	L4-PL	63	13.6	25	0.4	20	0.2	11.1
L7-PL	64	14	4	L7-PL	31	17.3	25	3.3	21	1.8	11.7

Plume, L2-PL1 has the highest vertical migration rate (4.1cm/day), and found in the very coarse sand bed as seen from the nearby borehole lithology log. This could however enhance the migration rate by virtue of the sediment high porosity and permeability. Water producing borehole within or close to this sand unit is probably at the point of contamination.

The borehole lithology log made at vicinity of the cemetery revealed that very coarse sand occurs at the depth range 32 ft (9.6 m) to 72 ft (21.6 m). The plume, PL7-PL has the highest migration rate (1.8 cm/day) and depth to the bottom is 17.3 m (58 ft). The sand bed is graded one: porosity and permeability differ, and hence fluid flow rate differ. Assuming the flow of Plume, PL7-PL within the environment of occurrence (very coarse sand) is at constant speed, and then the migration can be modeled in the form:

$$H=1.8T \tag{3}$$

$$T = H/1.8 \tag{4}$$

H= Distance traveled. T= Time taken.

The plume occurs at 22 ft (6.6 m) or 660 cm away from bottom of the very coarse sand. The time it may take the plume to transverse a distance of 6.6 m within the sand is

$$T = 660/1.8 = 366.7 \text{ days (approx. year).}$$

The leachate plumes interpreted from the 2-D vertical display were located in the 3-D distribution plot using their depths of occurrence and lateral locations on the 2-D survey profiles. The volumetric analysis (carried out at the Voxler4.0 window) of the plume zones indicate that, out of 75,231 m<sup>3</sup> of the subsurface visualized, 6,322 m<sup>3</sup> is the zone contaminated by leachate plume, that is, 8.4% of the earth volume investigated contain leachate plume<sup>[27]</sup>.

## 7. Conclusion

The survey aim is to track leachate plumes within the sandy formation which is below the surface laterite layer. Un-

der favourable hydrological and geological conditions, the plumes delineated from the Electrical Resistivity Imaging will slowly migrate into the groundwater. The maximum migration rates in the vertical and horizontal directions are 4.1 and 32.8 cm/day respectively.

Geophysical Methods employed in the investigations of leachate plume migration in Third Cemetery showed that the arrival time of the plumes to the next layer (within the sandy layer) of distance 6.6 m is 366.7 days, assuming the time rate is constant.

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