TWO DIMENSIONAL GEOELECTRICAL RESISTIVITY IMAGING TO INVESTIGATE LEACHATE PLUME MIGRATION FROM CEMETERIES IN BENIN CITY, SOUTH-SOUTH NIGERIA

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ABSTRACT

Electrical Resistivity Tomography method (ERT) technique was used to detect and evaluate contaminant plume migration from three cemeteries in Benin-City, South-South Nigeria. The study is aimed at determining the risk to groundwater and soil in the study area and also putting a time lapse on leachate plume migration. The Electrical Resistivity Imaging survey conducted as seen in the subsurface images obtained shows some good traces of migration of plumes from the surface to the subsurface. Surface and subsurface soil investigation in the burial environment showed that it is purely laterite, which is impervious to fluid flow. Generally, many depressions were identified within the study area, although migration rate is low because the rate of flow is controlled mainly by subsurface geology. A time lapse study showed contaminant migration rates of 41.6 cm/month and 51.7 cm/month in the horizontal directions in the second and third cemeteries respectively and 19.2 cm/month in the vertical directions for both cemeteries. Also, the arrival time of migrating plumes in laterite layer under favorable hydrological and geological conditions was estimated to be 4 years.

KEY WORDS: *Plume, Tomography, Laterite, Subsurface, Contaminant.*

1. INTRODUCTION

Agriculture, industry and landfills are commonly believed to be major anthropogenic sources of environmental contamination. Little attention has been given to cemeteries as possible pollution sources. Research conducted on the latter has been limited to examining pollutants emanating from dead bodies (Borstel and Niquette, 2000).

However, cemeteries are not the final resting place for bodies only but also for coffins and caskets used for the interment of remains. The minerals that are used in Coffin-making may corrode or degrade releasing harmful toxic substances (Spongberg and Becks, 2000b). These may be transported from the graves through seepage and diffuse into surrounding soils. From there they may leach into groundwater and become a potential health risk to the residents in areas surrounding the cemetery (Jonker and Olivier, 2012; Engelbrecht, 2010; Dent and Knight, 1998; Kim et al, 2008; Williams et al, 2009;

Canninga and Szmigina, 2010) Most existing cemeteries were sited without thinking about potential risks to the local environment or community (WHO Nancy Project Report-TARGET 23, 2000).

The most common practice for disposal of dead bodies is inhumation in soil, which favours interactions with the surrounding environment and returns nutrients to the life cycle. However, when the burial ground is located where hydrogeological, geological and climatic conditions are not favourable to the process, contamination of soils and groundwater may occur, and decomposition may be inhibited, leading to social, economic and political problems. The most critical parameters when assessing the pollution potential of a burial ground are inhumation depth, geological formation, depth of the water table, density of inhumations, soil type and climate.

In 1998, the World Health Organization (WHO) published a short review of soil and groundwater contamination by cemeteries with the aim of evaluating its impacts on the environment and public health. The main conclusion is that buried corpses have different microbial organisms, and the materials used in funeral practices may be sources of chemical compounds and heavy metals. Nuclear waste from medical treatments or devices and prostheses may also be found. If the cemetery is on vulnerable soil or if the soil reaches its depurative limit, the pollution may reach the groundwater (Ucisik and Rushbrook, 1998).

In 1999, Young et al collected the information available at that time about the potential threats that burial sites may pose to the environment. Different reports on this subject confirm that decomposition forms a saline contamination plume when geological, hydrogeological and climatic factors are not taken into account when choosing the locations of new burial grounds.

Because of its viscosity and density in relation to water, the plume slowly spreads under the graves in the direction of the hydraulic gradient, and the dispersion depends on several factors including the infiltrating rainfall, the hydraulic conductivity, the water table and the characteristics of the contaminant source (Hudak, 1999). Assuming that the plume may percolate from the inner to the outer area of the burial ground, the main risk for public health is the dissemination of waterborne diseases by direct or indirect contact through contaminated water or disease vectors.

Thus, the primary physical environmental impacts from cemeteries are related to soil, surface water and groundwater contamination. When surface water is dynamic and oxygenated, the contamination risk is remote (Rodrigues, 2002).

Groundwater applications of near-surface geophysics include mapping the depth and thickness of aquifers, mapping aquitards or confining units, locating preferential fluid migration paths such as fracture and fault zones and mapping contamination to the groundwater such as that from saltwater intrusion (Benson et al, 1997; Kalik and Kaya, 2001).

Most geophysical techniques have been used for groundwater characterization but the electrical and electromagnetic methods have recorded greater success in directly mapping and monitoring contaminated and clean groundwater. This research work presents an indirect method and a cost effective way of assessing the impact of cemeteries on the soil and groundwater regime without resorting to drilling which is usually too expensive for the purpose.

2. LOCATION OF STUDY AREA

The study area is Benin City, the capital of Edo State. It is situated in the mid-western part of Nigeria (Figure 1). Edo State is bounded on the North by Kogi State, on the West by Ondo State and East and South by Delta State. Benin City lies between latitudes 6°20´ and 6°58´ North and between longitudes 5°35´ and 5°41´ East of the Greenwich Meridian. The area lies within the Sub Humid Tropical Region. Simply because of its location, Benin City has a temperature of about 27 °C and an annual rainfall of over 2000mm (Eseigbe *et al.*, 2007).

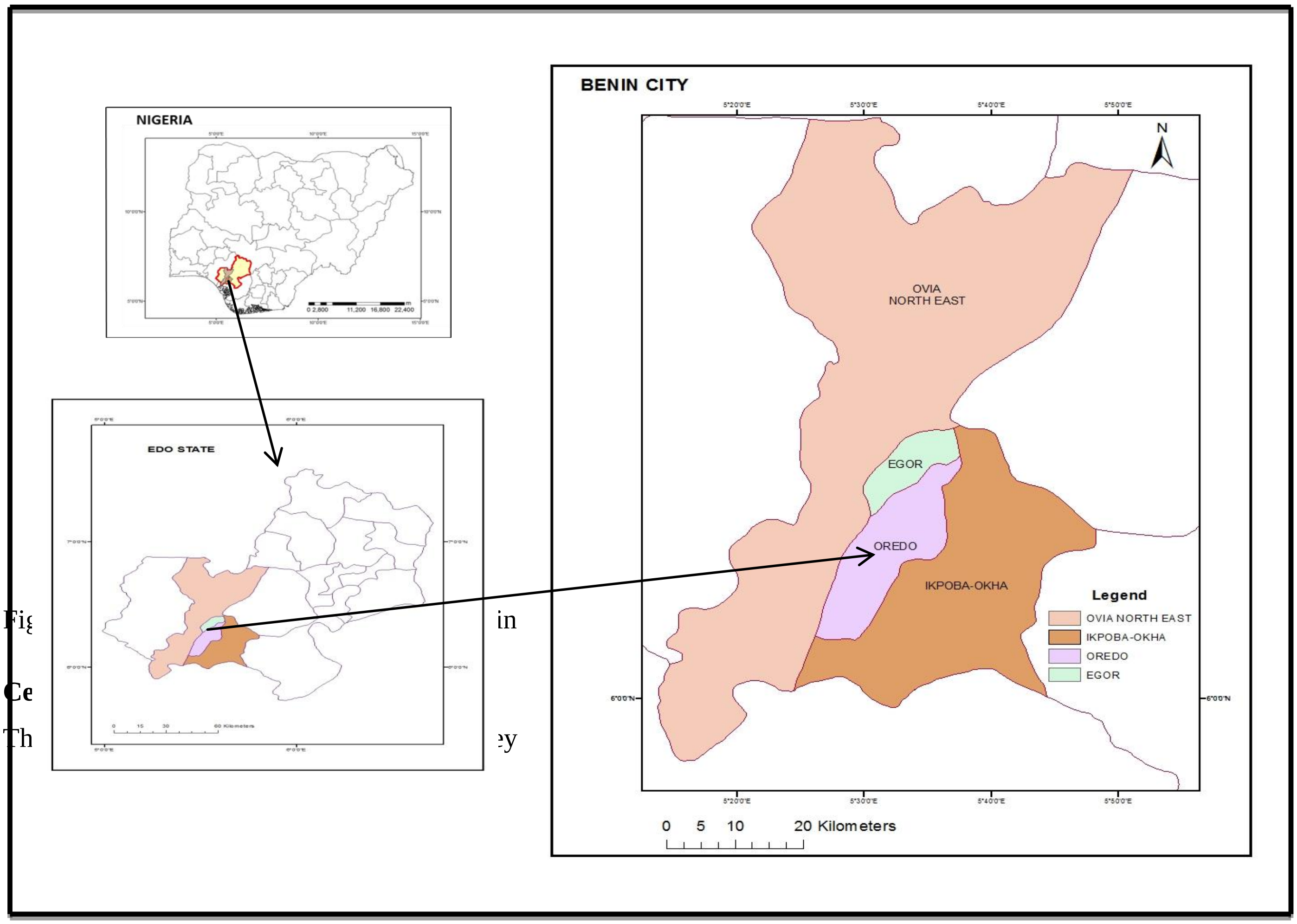

Figure 1: Map of the Study Area Showing Benin City with Four Local Government Areas.

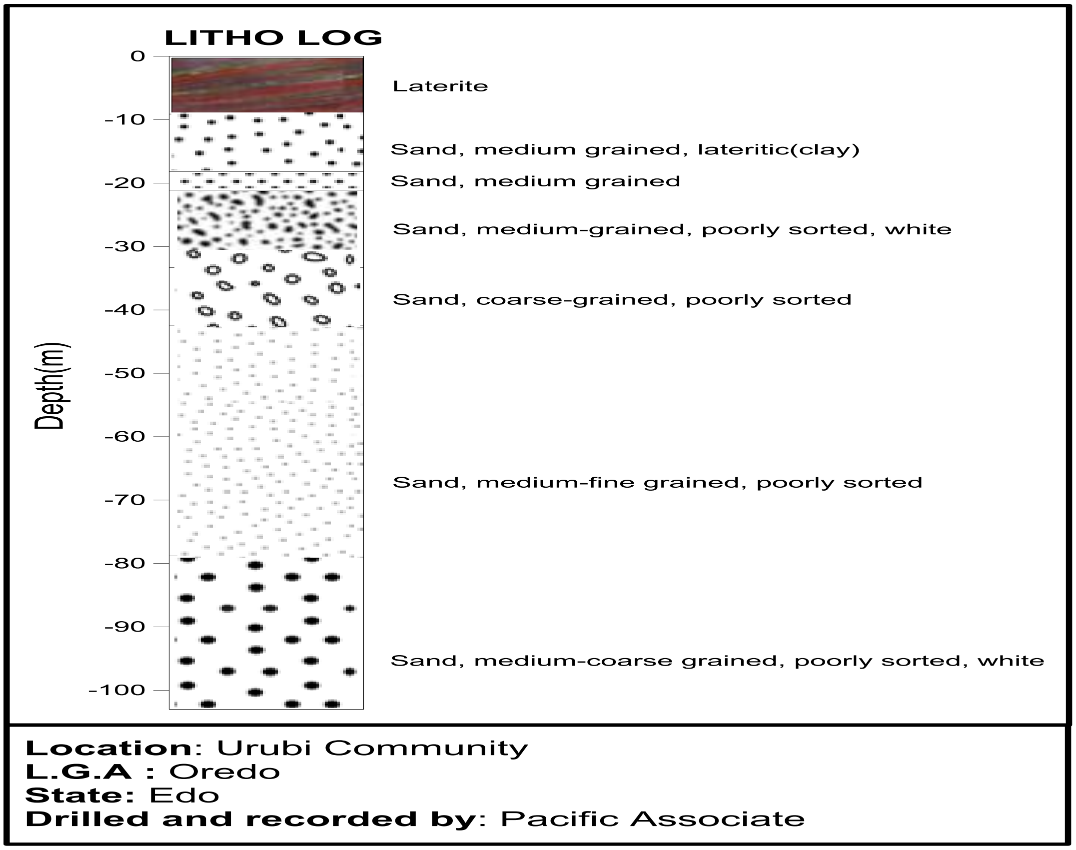

Figure 2: Borehole lithology log for survey area

(Source: Pacific Associate, Benin City, Edo State. Drilled on 13/02/2014).

(filled with pools of water during raining season) which must have been created by collapsed burial items. There is no rock outcrop in the sites, and report of borehole drilled (see Figure 2) within Oredo Local Government Area shows the presence of sediments from the surface to a depth of 103 m. The surface soil is laterite, reddish brown, sticky when wet and impervious to fluid with thickness of 9.1 m. The subsoil is composed of fine sand, medium sand and coarse sand up to the 103 m drilled.

3. MATERIALS AND METHOD

The array type used for the Electrical Resistivity Tomography (ERT) investigation is dipole-dipole configuration. This array type is most sensitive to resistivity changes between the electrodes in each dipole pair. The dipole-dipole array is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes in the resistivity (Loke, 2014).

The ERT survey was executed at two different times. The first was conducted in the month of August, 2014 while the second exactly one (1) year later. The first ERT survey was used to determine the actual nature, depths, vertical and horizontal extent of the conductors located by the VLF-EM Survey.

This first ERT survey data was acquired using Pasi Earth Resistivity Meter, with measurement profiles positioned on the locations of the corresponding VLF-EM profiles. The apparent resistivity data were inverted using Res2dinv software to obtain 2D model of the true subsurface resistivities.

Data Processing

The program Res2dinv was used for this processing. Models for 2D resistivity inversion program comprise rectangular blocks (cell). The bottom of a block corresponds to a data point which is approximately equal to its effective depth. The software computes, by inversion, the true resistivity of the subsurface that agrees with the measured apparent resistivity values from the survey. Apparent resistivity measurements recorded during the survey were entered into a text file in a format compatible with the Res2dinv and read into the computer with the software running. The software produces a pseudosection of the subsurface by contouring the apparent resistivity values from the geophysical survey and this is presented as the first image of the figure. The calculated apparent resistivity values was also contoured and presented as the second image of the same figure. An explanation of these steps is given in the appendix.

Pseudosection gives very approximate picture of the true subsurface resistivity distribution. However, the pseudosection gives a distorted picture of the subsurface because the shape of the contours depends on the type of array used and the true subsurface resistivity (Loke, 2014).

4. RESULT

Geological Interpretation

Resistivity is a fundamental electrical property of rocks that is closely related to rock lithology of which the main controlling factors are bulk rock porosity, pore structure, amount and salinity of water, temperature and the presence of clays. To convert the resistivity picture into a geological picture, one requires some knowledge of the typical resistivity values for the different types of subsurface materials and geology of the surveyed area (Thomas, 2002).

The resistivities of Laterite and lateritic soil are 120-750 Ωm and 800-1500 Ωm respectively (Reynolds, 1998), and for each of the cemeteries surface layers on which burial is being done is made of lateritic soil and laterite which is reddish, fined grained, sticky (when wet), and low permeability sediment. This is evident from surface observation, excavations and drilled holes within the cemeteries. Fluid flows slowly through laterite and lateritic soil by virtue of low permeability unlike sand and gravel. Leachate plumes in the cemeteries will probably start to migrate from bottom of burial trench (1.2 m). Leachate plume that contains mainly inorganic chemicals is electrically conductive, and when it flows through porous and permeable sediments can lower the resistivity at the migration path. In the absence of clay, electrically conductive plume is likely to be traced in soil with value within 1-120 Ωm.

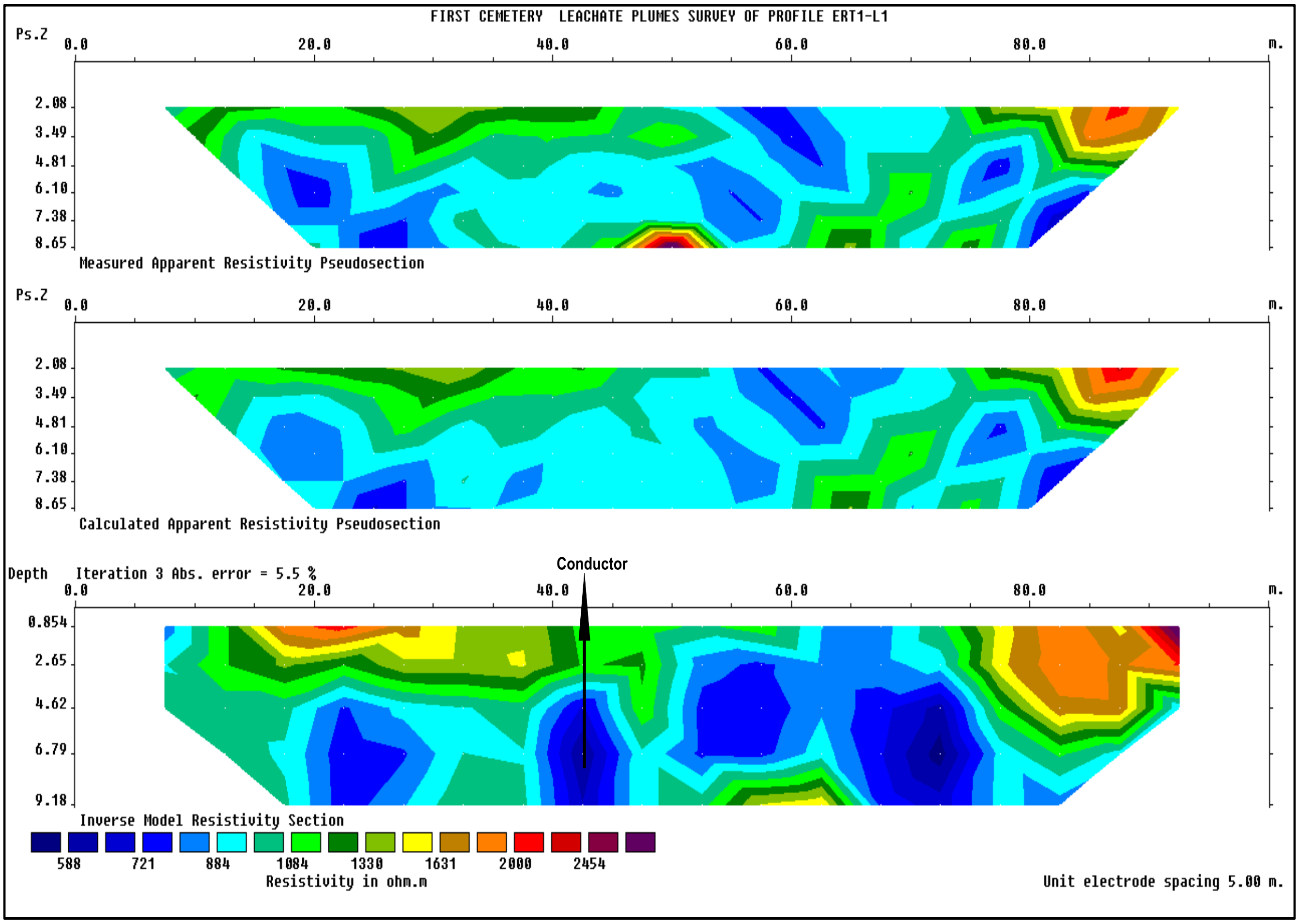

Figure 3: 2D Geo-electrical Image of First Cemetery, Profile ERT1-L1

The conductors are seen to be displayed between 40.0 m and 50.0 m marks on the ERT1-L1 model section. The electrical resistivity of the conductor is 588 Ωm, which is above the upper limit of the control value 1-120 Ωm, and is labeled as a conductor and is likely a non leachate plume.

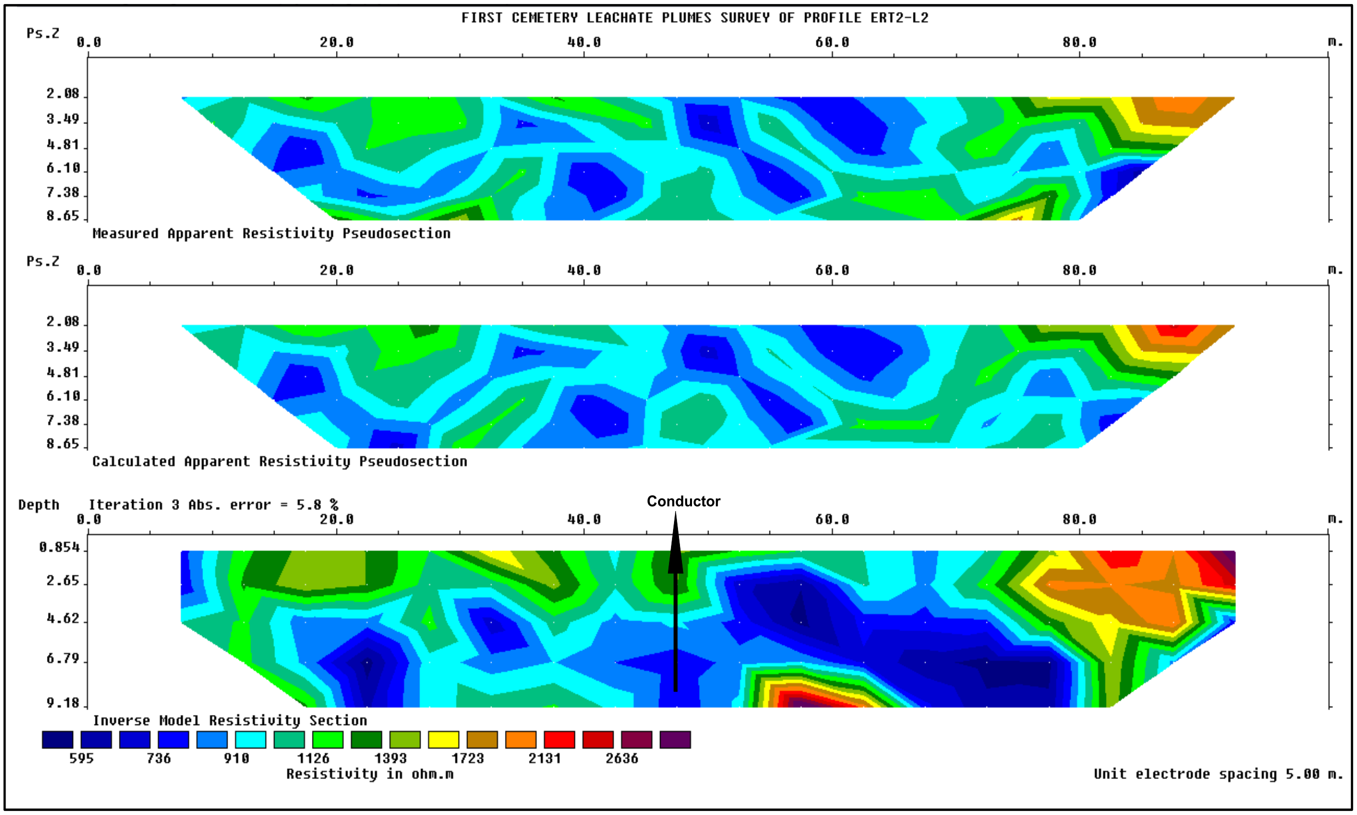

Figure 4: 2D Geo-electrical Image of First Cemetery, Profile ERT2-L2

The conductors are seen to be displayed between 42.5 m and 50.0 m marks on the ERT2-L2 model section. The electrical resistivity of the conductor is 666 Ωm, which is above the upper limit of the control value 1-120 Ωm, and is labeled conductor and is likely a non leachate plume.

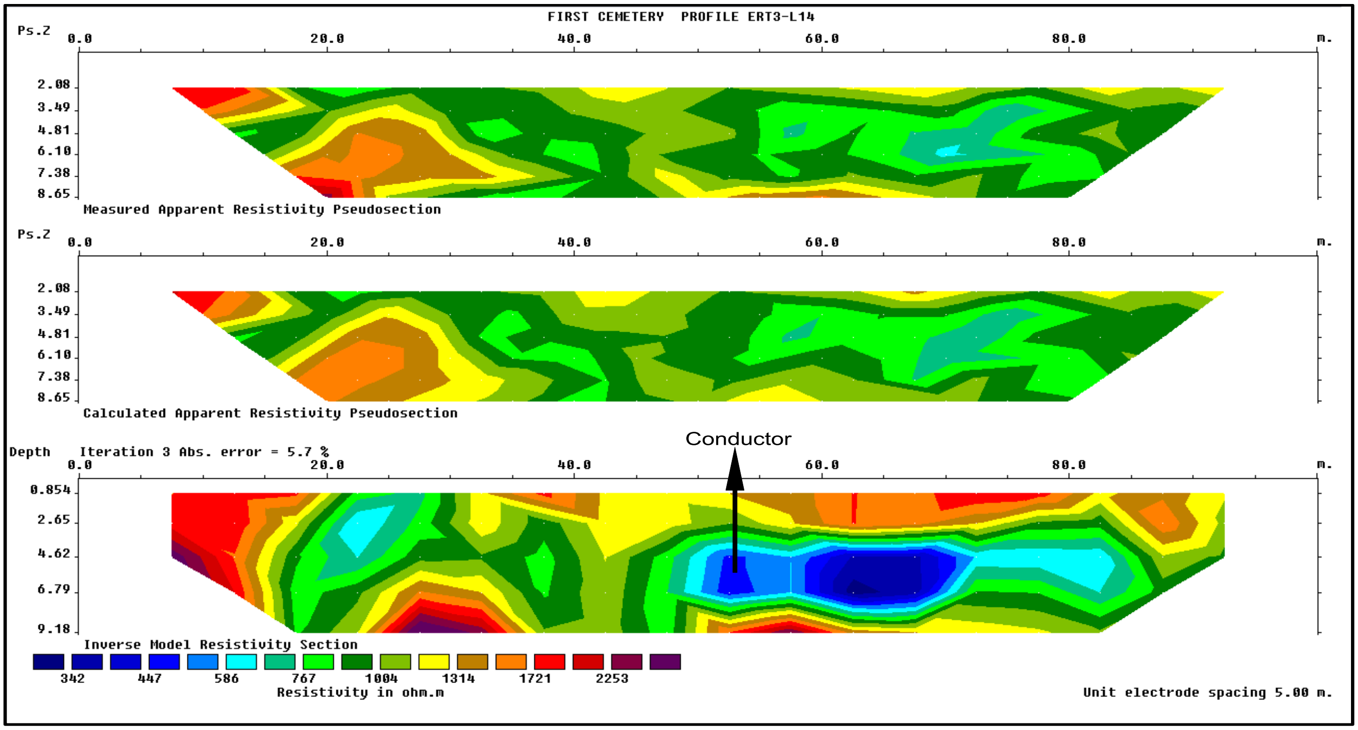

Figure 5: 2D Geo-electrical Image of First Cemetery, Profile ERT3-L14

The conductors are seen to be displayed between 52.5 m and 53.8 m marks on the ERT3-L14 model section. The electrical resistivity of the conductor is 447 Ωm, which is above the upper limit of the control value 1-120 Ωm, and is labeled conductor and is likely a non leachate plume.

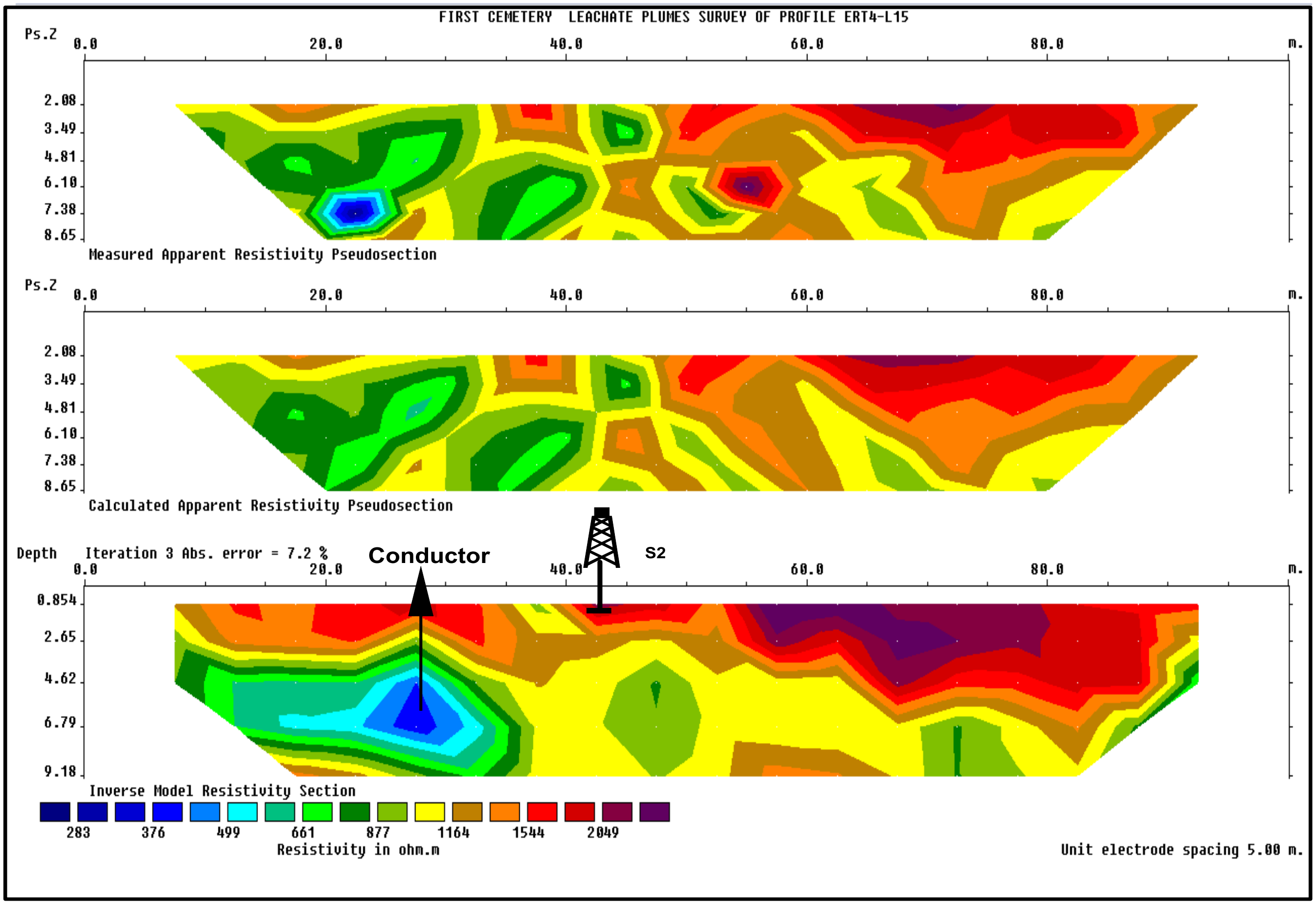

Figure 6: 2D Geo-electrical Image of First Cemetery, Profile ERT4-L15

The conductors are seen to be displayed between 26.3 m and 28.8 m marks on the ERT4-L15 model section. The electrical resistivity of the conductor is 376 Ωm, which is above the upper limit of the control value 1-120 Ωm, and is labeled conductor and is likely a non leachate plume.

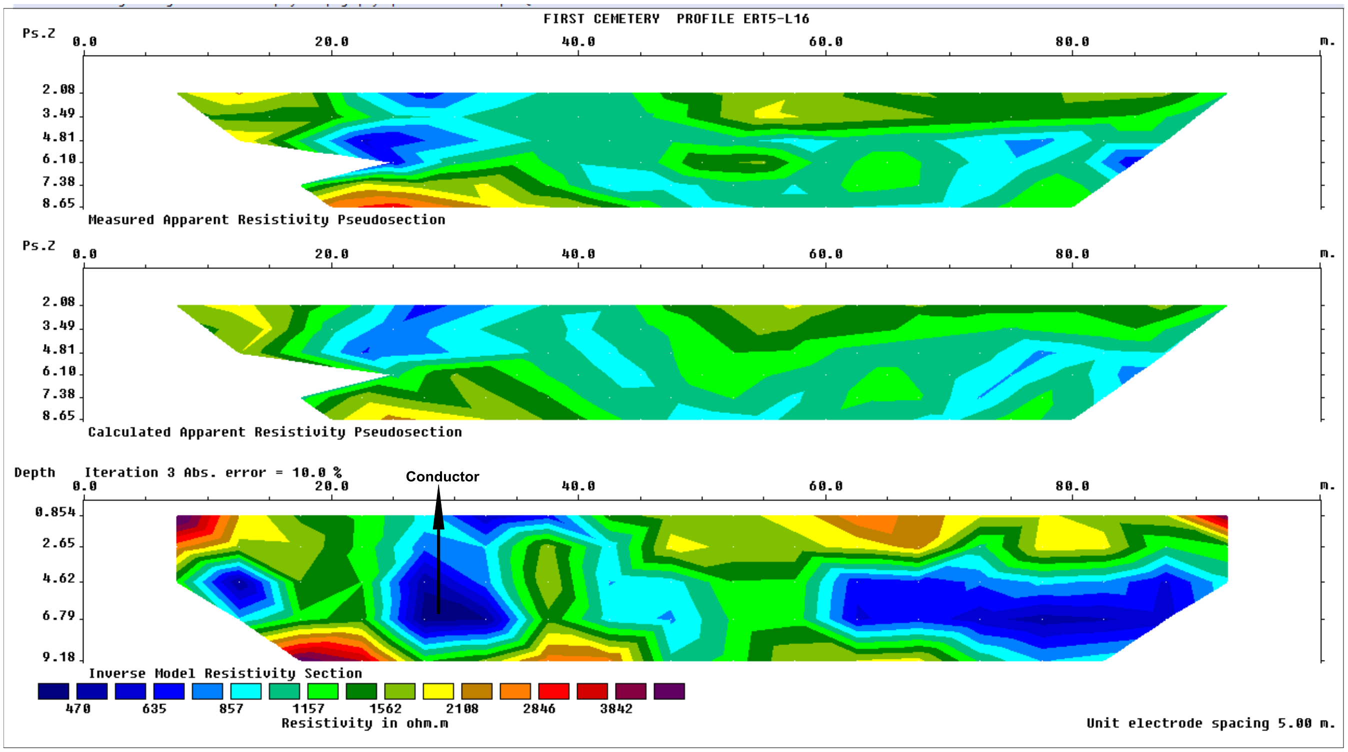

Figure 7: 2D Geo-electrical Image of First Cemetery, Profile ERT5-L16

The conductors are seen to be displayed between 26.3 m and 28.8 m marks on the ERT5-L16 model section. The electrical resistivity of the conductor is 470 Ωm, which is above the upper limit of the control value 1-120 Ωm, and is labeled conductor and is likely a non leachate plume.

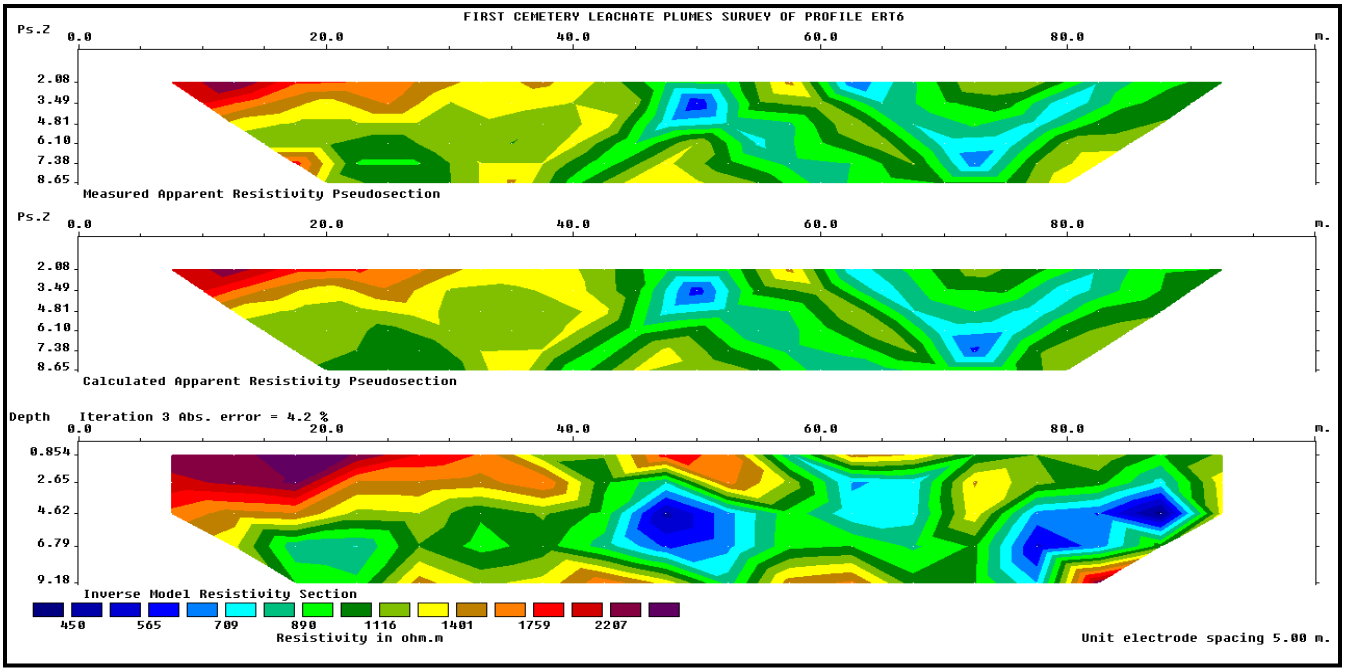

Figure 8: 2D Geo-electrical Image of First Cemetery, Profile ERT6

The electrical resistivity of the dark blue colour is 450 Ωm, which is above the upper limit of the control value 1-120 Ωm and is likely a non leachate plume.

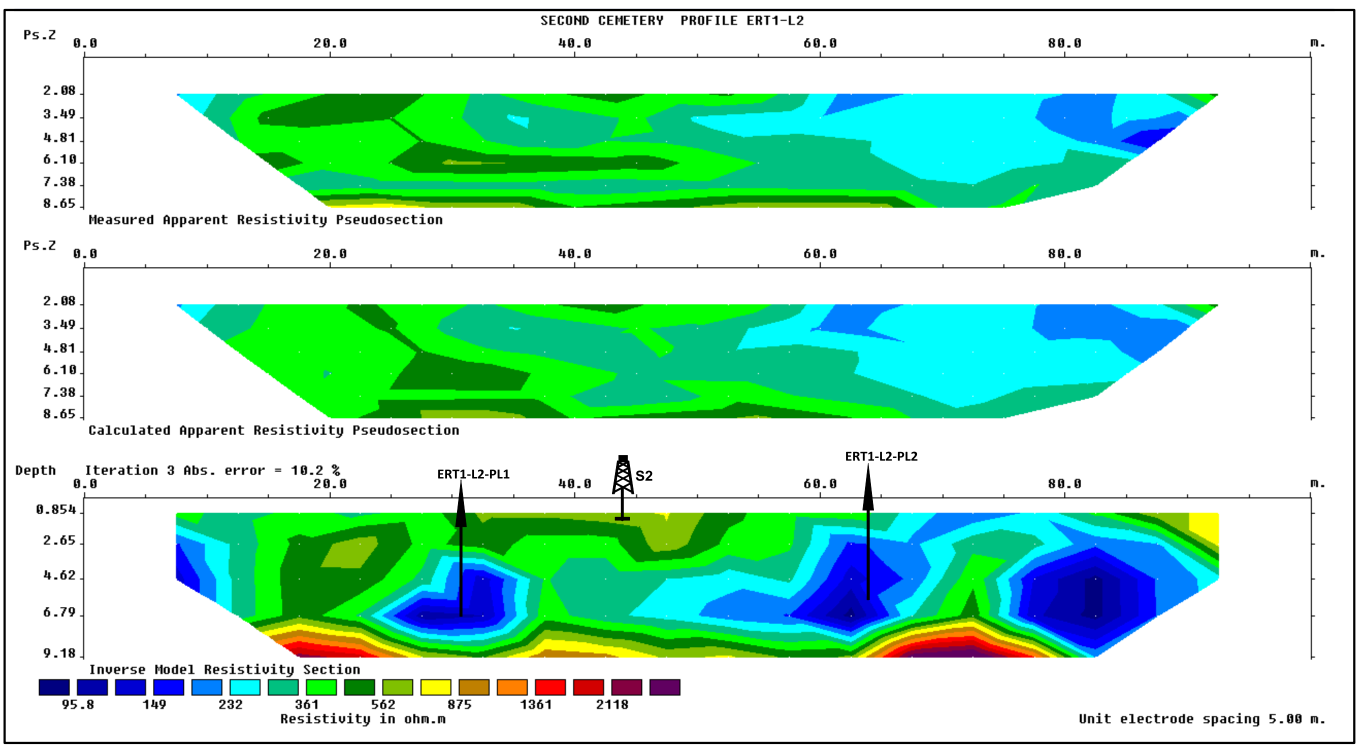

Figure 9: 2D Geo-electrical Image of Second Cemetery, Profile ERT1-L2

The conductors are seen to be displayed between 26.5 m and 33.8 m marks, and between 57.5 m and 67.6 m marks respectively on the ERT1-L2 model section. The electrical resistivity of the conductors are 96 Ωm, which is within limit of the control value 1-120 Ωm, and are labeled as ERT1-L2-PL1 and ERT1-L2-PL2. These are very likely to be leachate plumes. The ERT1-L2-PL1 occurs 4.13 m below the ground surface, and extends vertically to a depth of 7.99 m. The vertical and horizontal extents are 3.86 m and 7.3 m respectively. The ERT1-L2-PL2 occurs 2.65 m below the ground surface, and extends vertically to a depth of 7.99 m. The vertical and horizontal extents are 5.34 m and 10.1 m respectively.

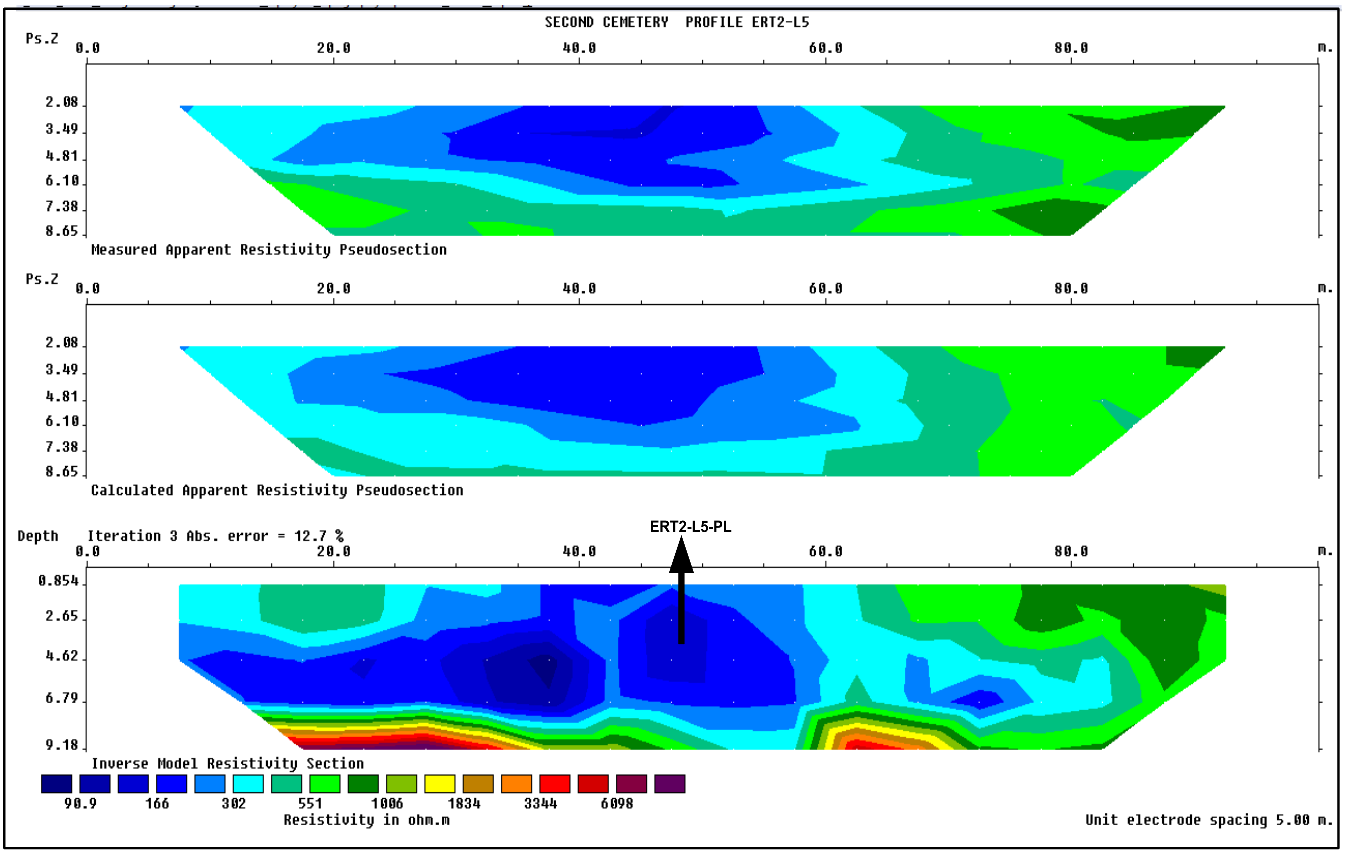

Figure 10: 2D Geo-electrical Image of Second Cemetery, Profile ERT2-L5

The conductors are seen to be displayed between 46.3 m and 50.0 m marks on the ERT2-L5 model section. The electrical resistivity of the conductor is 91 Ωm, which is within the limit of the control value 1-120 Ωm, and is labeled as ERT2-L2-PL.This is very likely to be leachate plumes. The ERT2-L2-PL occurs 2.20 m below the ground surface, and extends vertically to a depth of 5.71 m. The vertical and horizontal extents are 3.51 m and 3.70 m respectively.

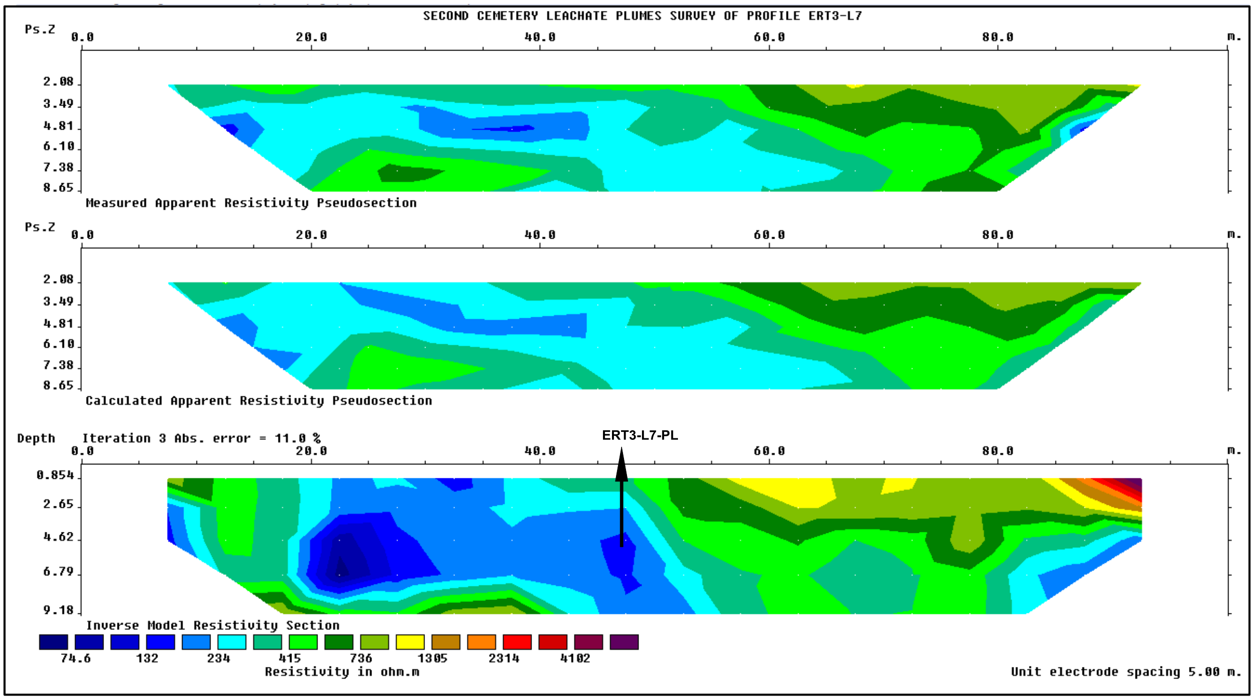

Figure 11: 2D Geo-electrical Image of Second Cemetery, Profile ERT3-L7

The conductors are seen to be displayed between 45 m and 50 m marks on the ERT3-L7 model section. The electrical resistivity of the conductor is 103 Ωm, which is within the limit of the control value 1-120 Ωm, and is labeled as ERT3-L7-PL.This is very likely to be leachate plumes. It occurs 4.62 m below the ground surface, and extends vertically to a depth of 7.99 m. The vertical and horizontal extents are 3.37 m and 5.0 m respectively.

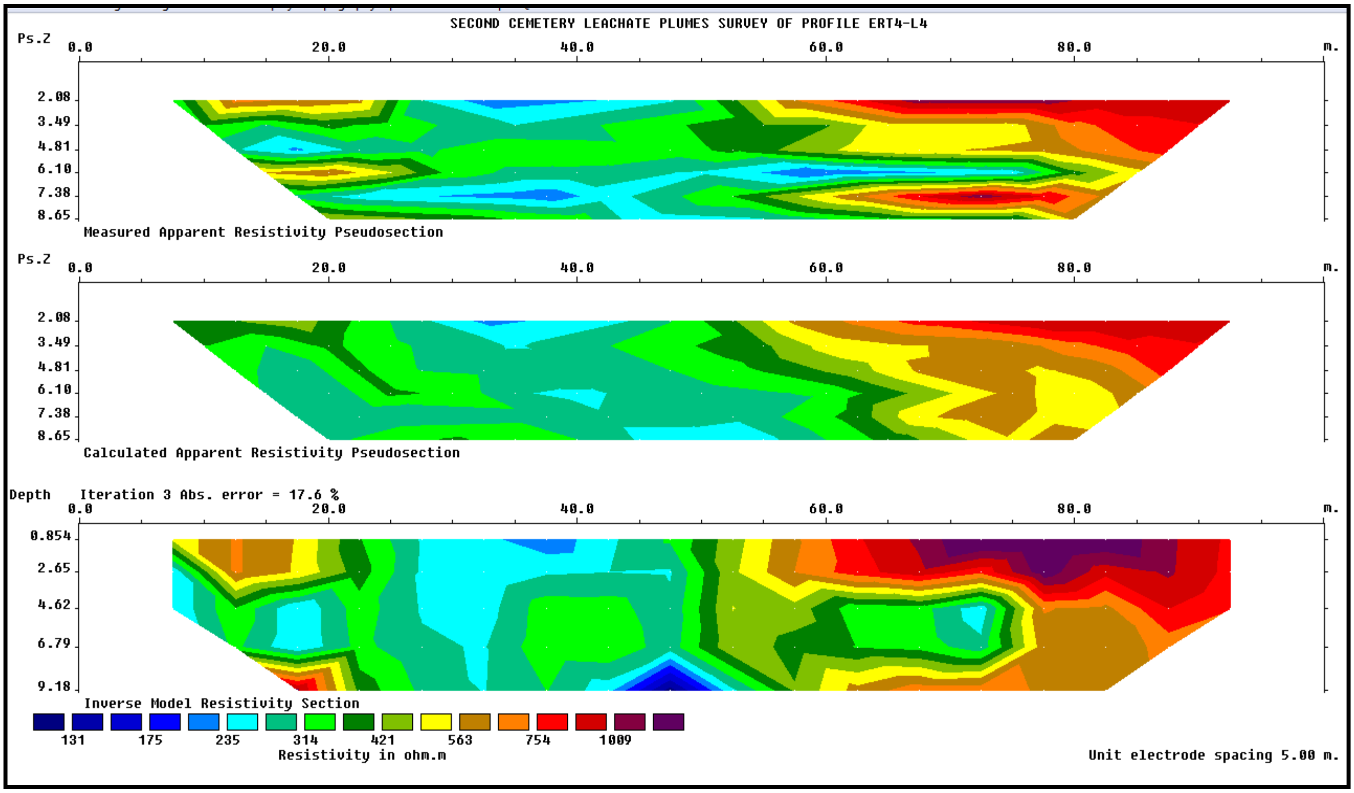

Figure 12: 2D Geo-electrical Image of Second Cemetery, Profile ERT4-L14

The conductors are seen to be displayed between 42.5 m and 52.5 m marks on the ERT4-L14 model section but not wholly captured with the top at 7.99 m, the electrical resistivity of the conductor is greater than 131 Ωm, which is above the upper limit of the control value 1-120 Ωm. This is very likely a non leachate plume.

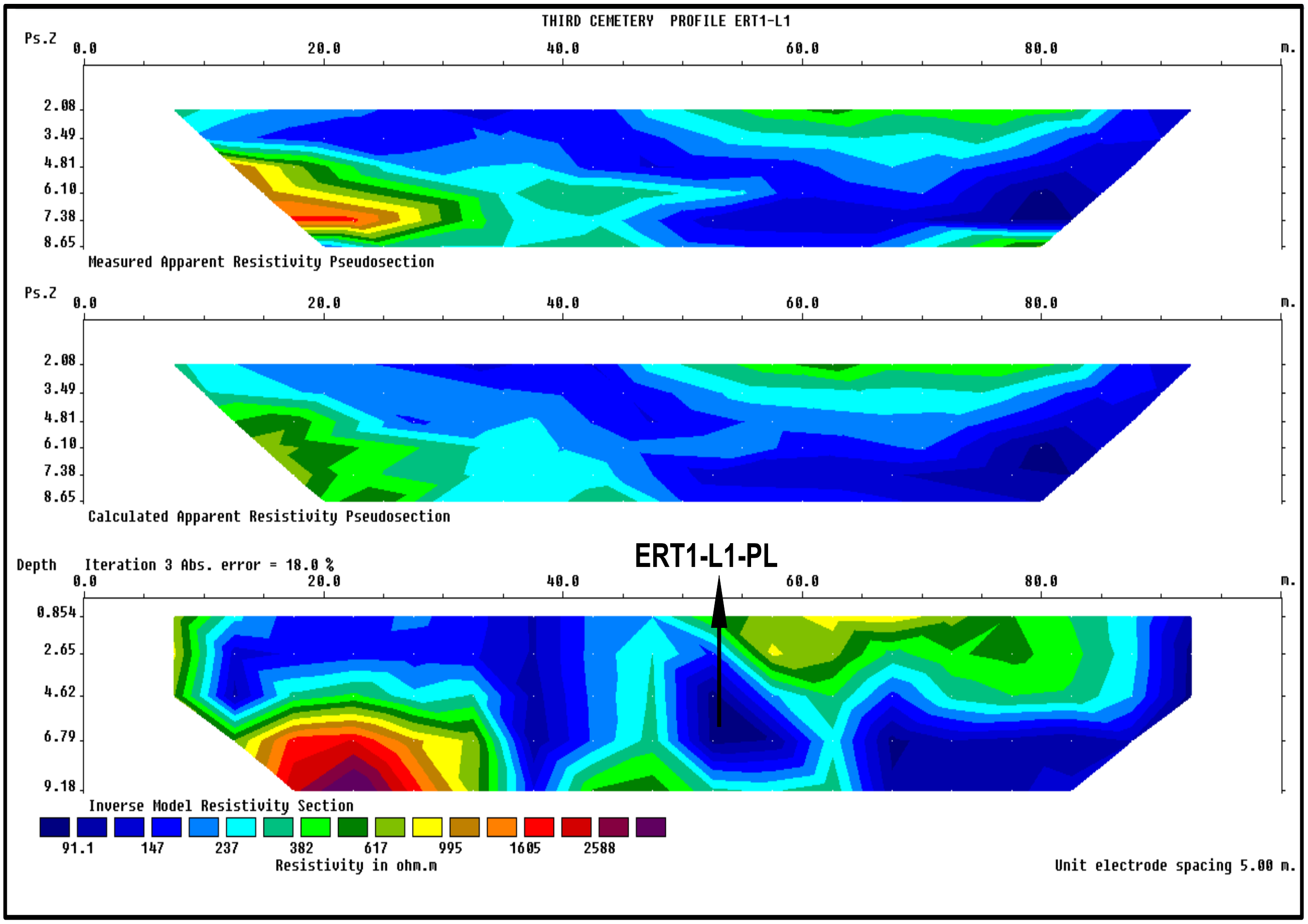

Figure 13: 2D Geo-electrical Image of Third Cemetery, Profile ERT1-L1

There is resistivity anomaly between 48.8 m and 60.0 m marks with electrical resistivity of 91 Ωm, which is within the limit of the control value 1-120 Ωm. This is very likely to be leachate plume, and labeled ERT1-L1-PL. It occurs 2.65 m below the ground surface, and extends vertically to a depth of 7.99 m. The vertical and horizontal extents are 5.34 m and 11.2 m respectively.

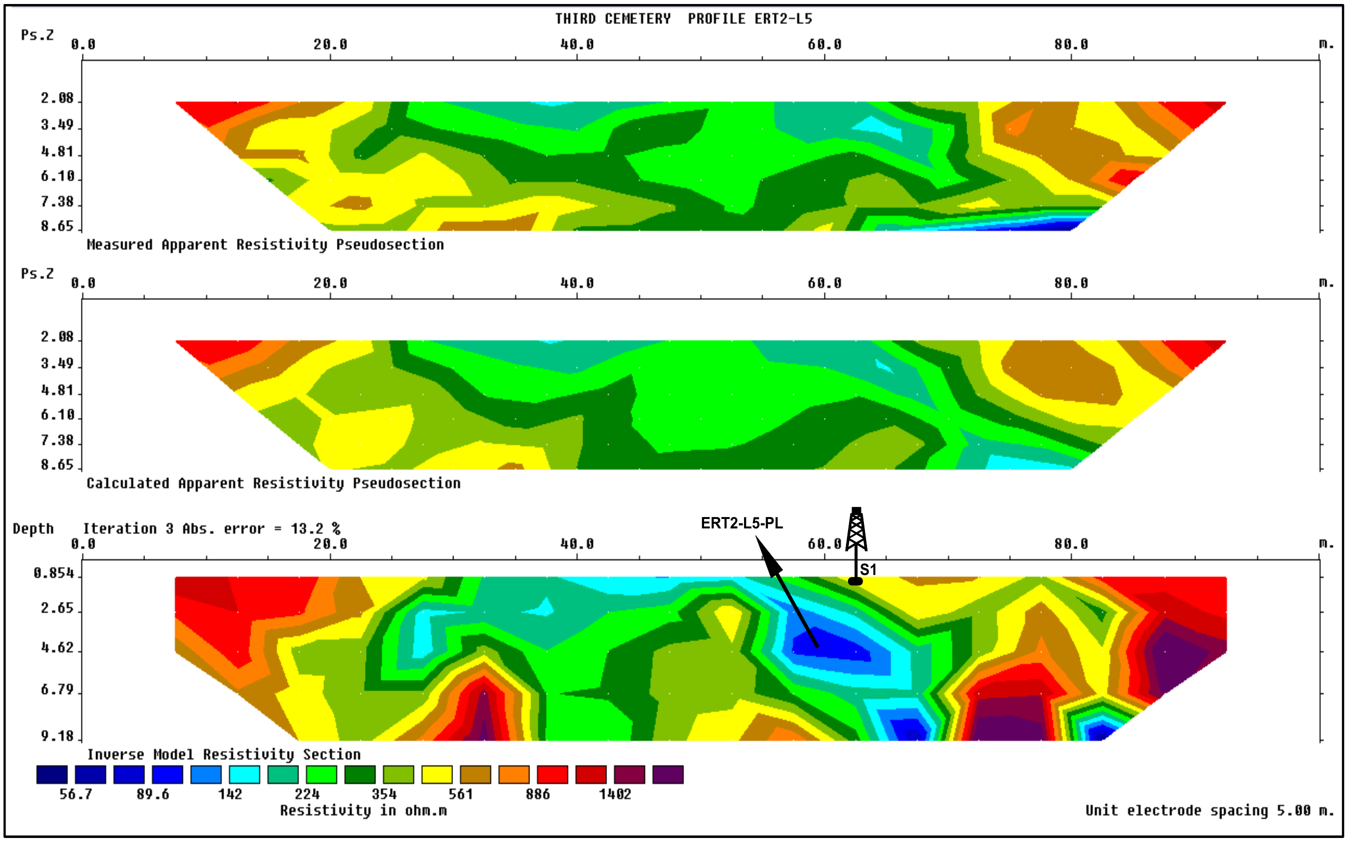

Figure 14: 2D Geo-electrical Image of Third Cemetery, Profile ERT2-L5

There is resistivity anomaly between 57.5 m and 63.8 m marks with electrical resistivity of 73.2 Ωm, which is within the limit of the control value 1-120 Ωm. This is very likely to be leachate plume, and labeled ERT2-L5-PL. It occurs 3.64 m below the ground surface, and extends vertically to a depth of 4.62 m. The vertical and horizontal extents are 0.98 m and 6.30 m respectively.

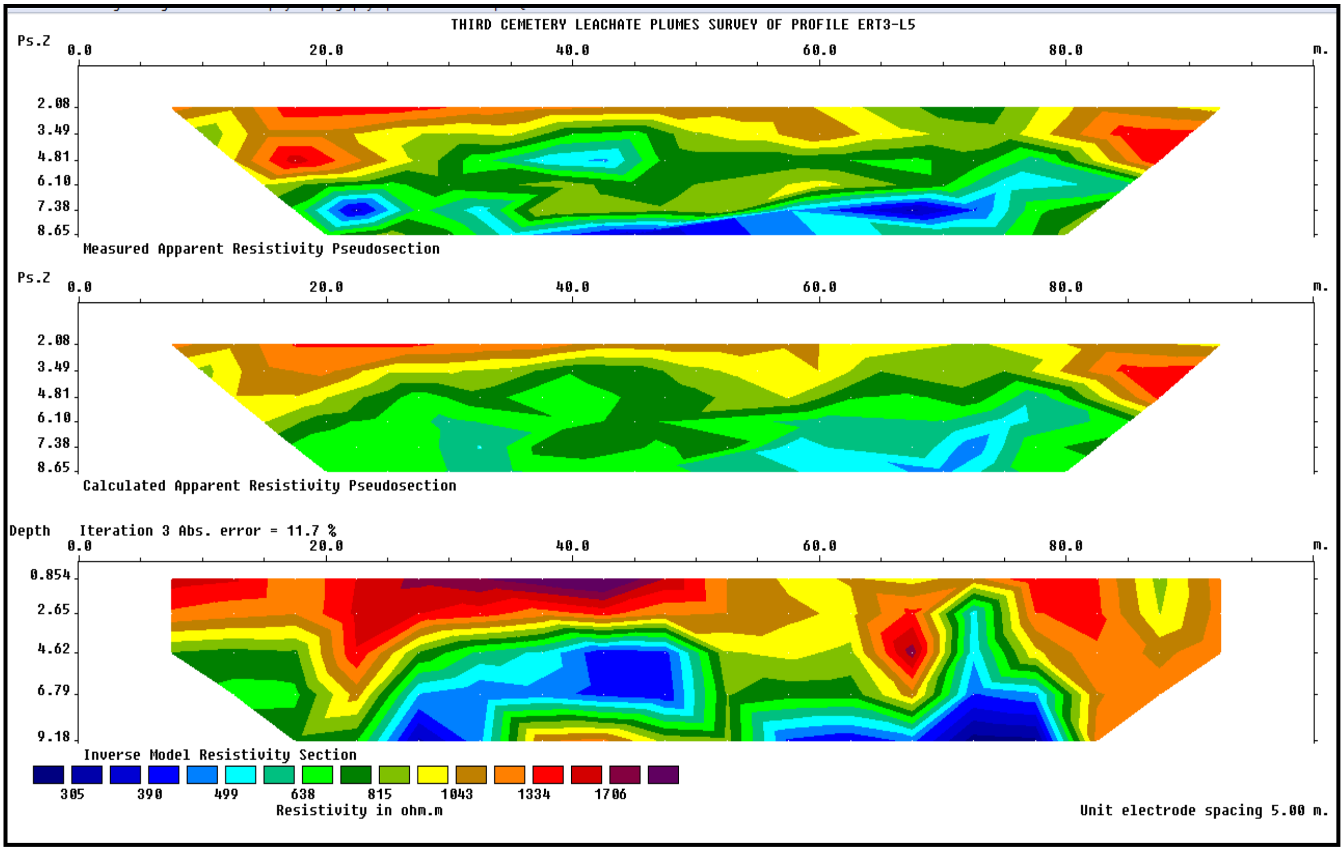

Figure 15: 2D Geo-electrical Image of Third Cemetery, Profile ERT3-L15

The dark blue colour on the model section has resistivity of 305 Ωm, which is above the upper limit of the control value 1-120 Ωm. This is very likely non leachate plume.

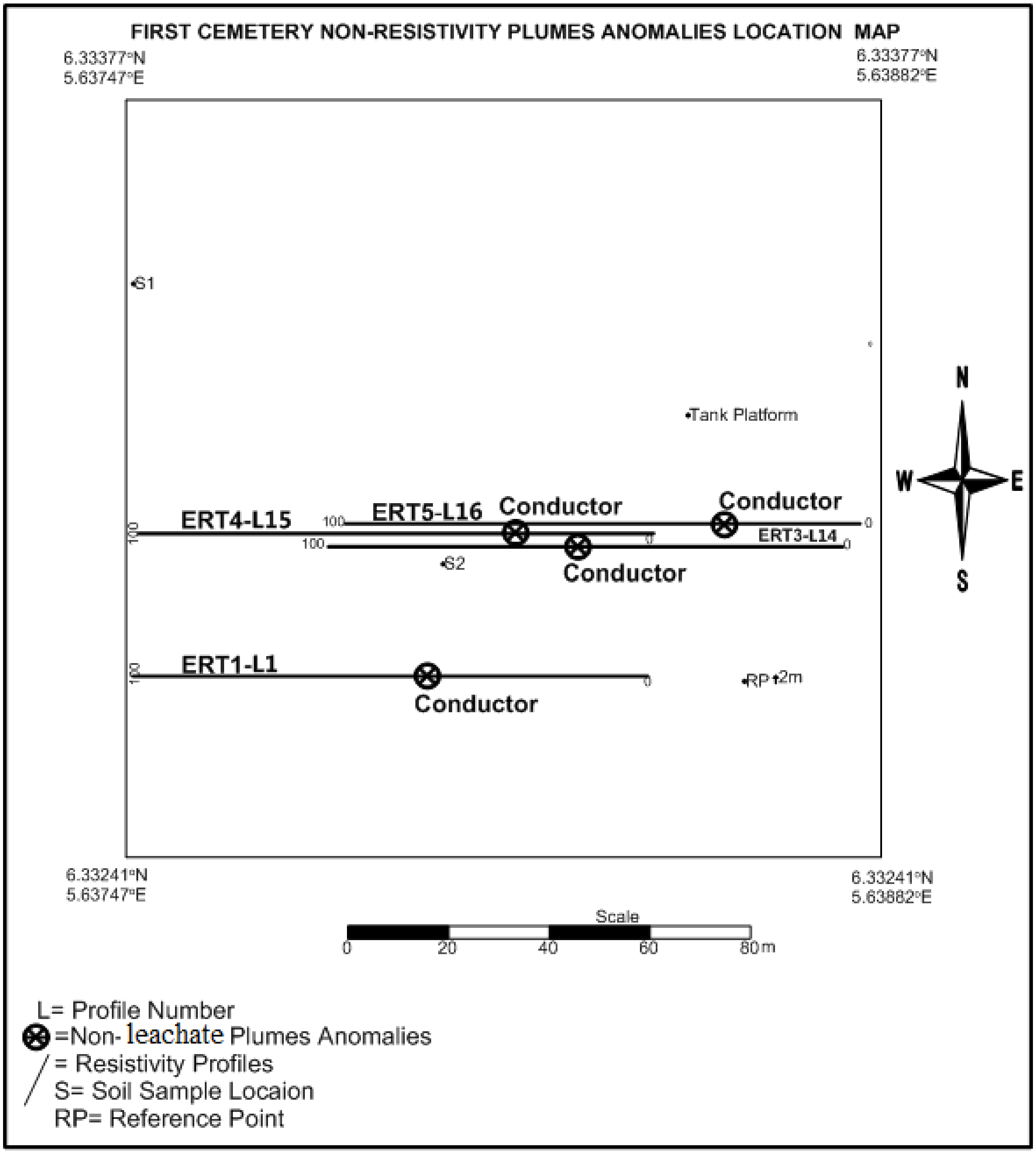

Figure 16: First Cemetery Non- Leachate Plumes Anomalies Location Map

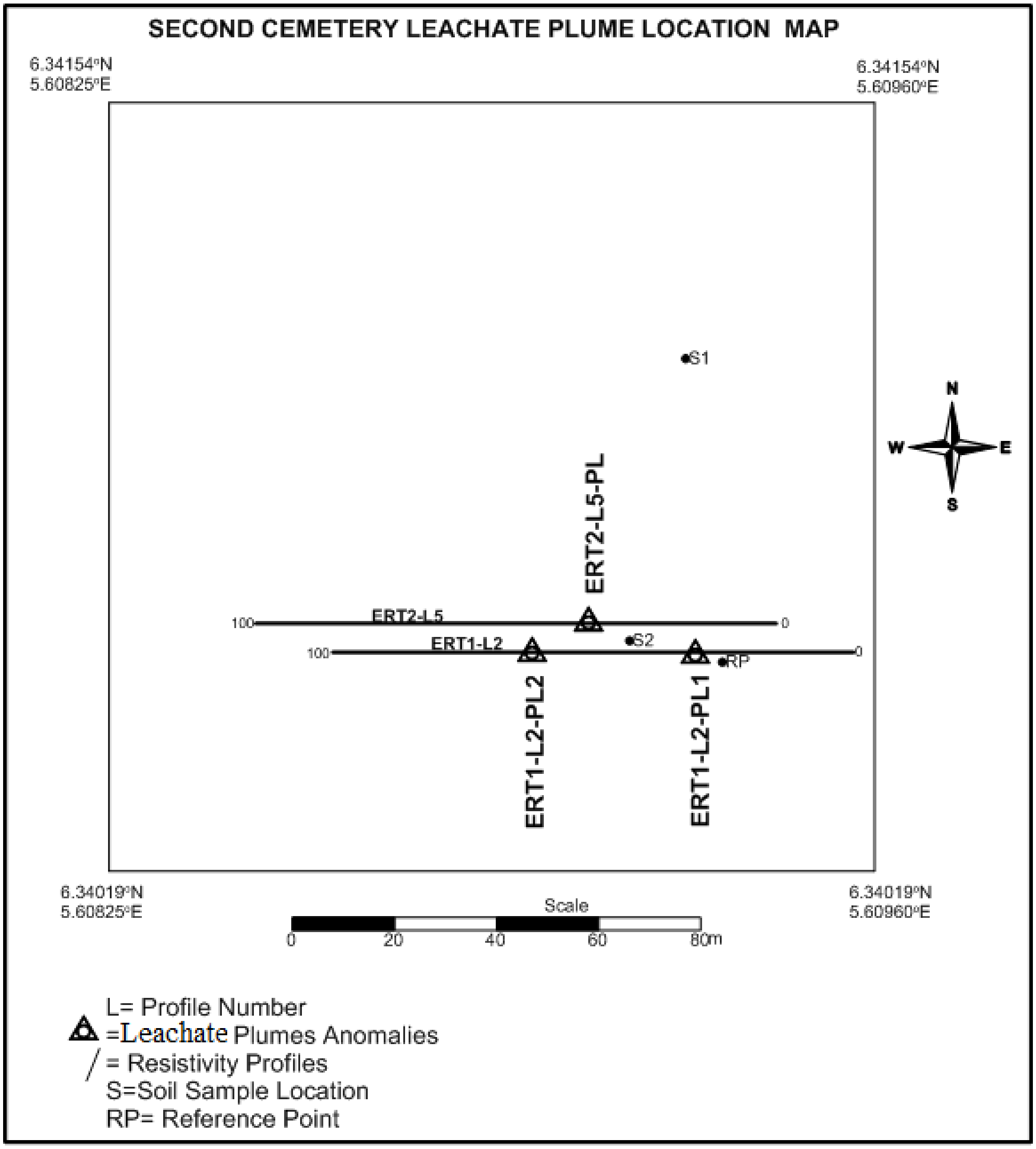

Figure 17: Second Cemetery Leachate Plumes Anomalies Location Map

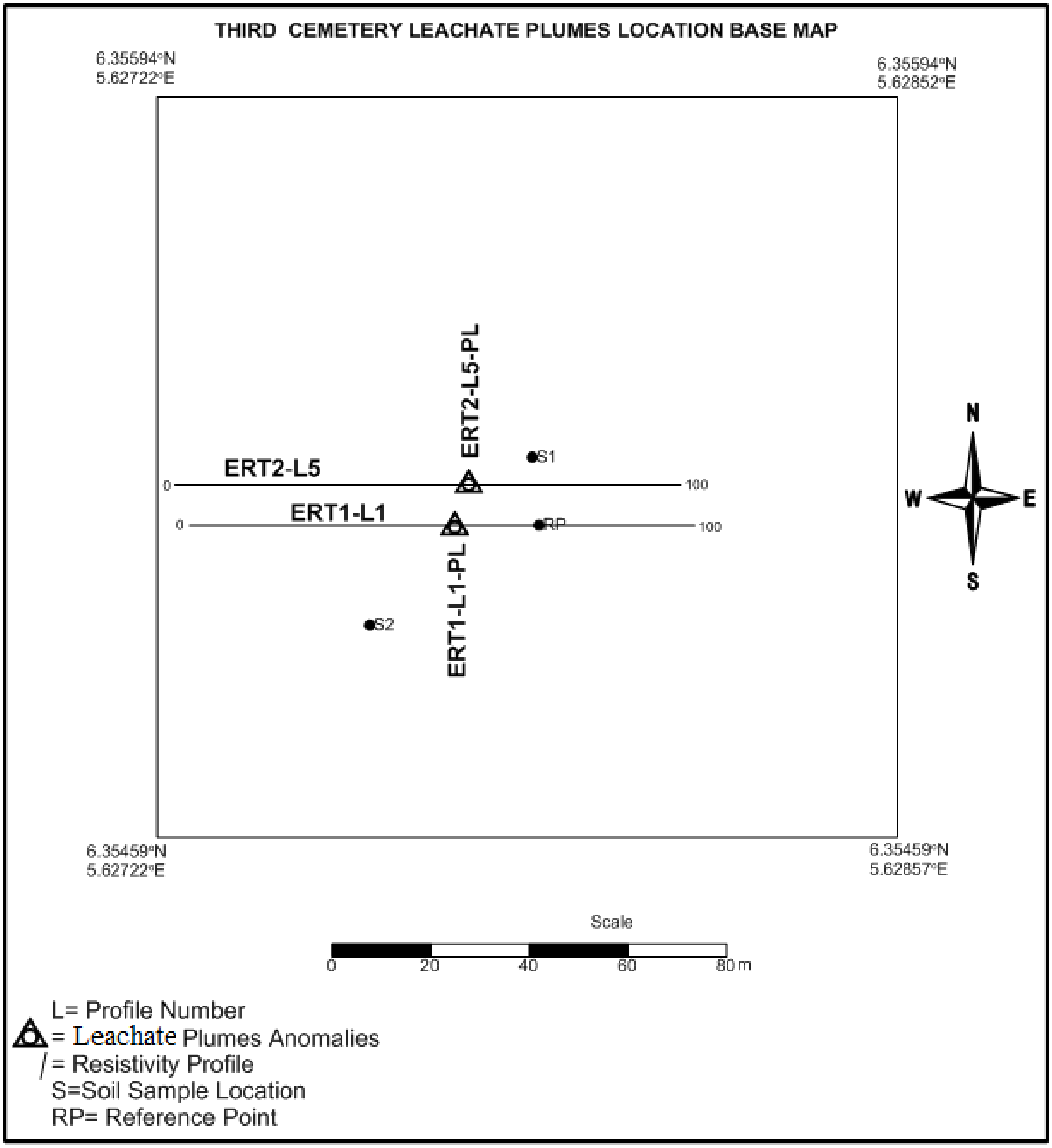

Figure 18: Third Cemetery Leachate Plumes Anomalies Location Map

5. DICUSSION

Plume Zones Resistivities in the Survey Period

The plumes were identified, for resistivity values between 1 Ωm and 120 Ωm in the absence of clay in the laterite. Thus, representative resistivity values of each of the plume zones at the different survey periods were read easily on the colour bars. These are shown in Table 1 and Table 2.

Table 1: Electrical Resistivities of Plume Zones in the Second Cemetery at the different Periods

PLUME NO.	SURVEYED DATE	RESISTIVITY(Ωm)	REMARKS
ERT1-L2-PL1	6/08/2014	96	The plume observed in 2014 was present in 2015 display. It may have been concentrated with excess leachate which is responsible for the decrease in resistivity.
ERT1-L2-PL1	11/08/2015	91	
ERT1-L2-PL2	6/08/2014	96	The plume observed in 2014 was present in 2015 display. It may have been diluted with water for the concentration to be reduced which is responsible for the increase in resistivity
ERT1-L2-PL2	11/08/2015	194	
ERT2-L5-PL	6/08/2014	91	The plume observed in 2014 was present in 2015 display. It may have been diluted with water for the concentration to be reduced which is responsible for the increase in resistivity.
ERT2-L5-PL	11/08/2015	103	

Table: 2: Electrical Resistivities of Plumes Zones in the Third Cemetery at the different Periods

PLUME NO.	SURVEYED DATE	RESISTIVITY(Ωm)	REMARKS
ERT1-L1-PL	05/08/2014	91	The plume observed in 2014 was present in 2015 display. It may have been diluted with water for the concentration to be reduced which is responsible for the increase in resistivity.
ERT1-L1-PL	10/08/2015	111	
ERT2-L5-PL	05/08/2014	73	The plume observed in 2014 was present in 2015 display. It may have been diluted with water for the concentration to be reduced which is responsible for the increase in resistivity..
ERT2-L5-PL	10/08/2015	117	

The first ERT survey was conducted in August 2014, peak of raining season, so plumes were delineated. At the beginning of the dry season (October), pore spaces of the surface soil, laterite must have undergone shrinkage, which then promotes rapid migration of the plumes till March. The second ERT survey was executed exactly 12 months later, in August 2015, when the plumes must have been diluted with excess infiltrating water or more leachate added and so move faster in the horizontal and vertical directions.

6. CONCLUSION

With recent concerns about the environmental impact of decomposing corpses and burial items, ERT survey was successfully carried out in the three cemeteries in Benin City. This research work show the arrival time of the plumes to the next layer (just below the laterite layer) in the second and third cemeteries in the study area is estimated to be 4 years which gives a migration rate of 2.3 m/yrs in lateritic environment in the study area. It can been seen from the research that the 2D ERT survey shows the presence of plume emanating from cemeteries as a result of dead body migration to the subsurface. The result of this study also point out the need for environmental education and proper management/location of cemeteries by various Governments in the country.

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