Journal of Scientific Research & Reports

27(3): 50-74, 2021; Article no.JSRR.68353
ISSN: 2320-0227

Determination of Leachate Plume Migrations from Selected Cemeteries in Benin-City Metropolis using Integrated Physicochemical and Geophysical Methods

O. J. Airen[1*]

[1] *Department of Physics, Faculty of Physical Sciences, University of Benin, Benin City, Nigeria.*

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JSRR/2021/v27i330369
Editor(s):
(1) Dr. Shahid Naseem, University of Karachi, Pakistan.
Reviewers:
(1) Ojo, Akintayo O, Federal College of Dental Technology and Therapy, Nigeria.
(2) Yusuf Tanko Usman, Ibrahim Badamasi Babangida University, Nigeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/68353

Original Research Article

Received 10 March 2021
Accepted 15 May 2021
Published 19 May 2021

ABSTRACT

Environmental geo-forensics which involves an integrated suite of geochemical and geophysical techniques was used to detect and evaluate contaminant plume migrations from three cemeteries (names of the cemeteries are; First, second and third cemeteries, all in Benin City) within Benin-City metropolis, South-South Nigeria. The study aimed at determining the risks to groundwater and soil by assessing the rate of leachate plume migrations on the study area. The Very Low Frequency-Electromagnetic (VLF-EM) surveys revealed locations of conductive bodies. The Electrical Resistivity Imaging (ERI) surveys showed patterns and resistivity values indicating the presence of leachate plumes around second and third cemeteries, and no presence of leachate around first cemetery. Soil samples from shallow depths within the vicinities of the cemeteries revealed pollution which had probably migrated from the study area. The surface and subsurface soil investigations showed pure laterites which is impervious to fluid flow. Generally, many depressions were identified within the study area, although migration rate is low because it is controlled mainly by the 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 (second and third)

**Corresponding author: E-mail: osariere.airen@uniben.edu;*

cemeteries. Also, the arrival time of migrating plumes in laterite layer under was estimated to be 4 years. This investigation demonstrates the suitability of environmental and criminal geo-forensics for identification and evaluation of electrically conductive contaminant plumes, and also to monitor the plume as it travels within the subsurface.

Keywords: Geophysical methods; migration; physicochemical.

1. INTRODUCTION

Minerals that are used in coffin-making may corrode or decay releasing harmful toxic substances [1]. 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 such areas [2,3,4] (Kim et al., 2008; Williams et al., 2009) [5] Most existing cemeteries were sited without thinking about potential risks to the local environment or community (WHO, 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 [6].

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 [7].

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. (Young et al., 1999). Plume slowly spreads under the graves in the direction of the hydraulic gradient as a result of leachate plumes viscosity and density in relation to water, and the dispersion depends on several factors including the infiltrating rainfall, the hydraulic conductivity, the water table and the characteristics of the contaminant source [8]. 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 [9].

1.1 Hydrochemistry of Cemeteries

When rain falls on land, some water may infiltrate to become soil moisture and groundwater if permeable rocks or soils (aquifers) are present, other rainfall components may evaporate or run off into streams. Cemeteries like any other land use are situated in part of a hydrological cycle that will be particular for the topography and geology of the area. Fig. 1 illustrates in a generalised way how solutes from cemeteries may interact with the water processes and potentially reach groundwater and streams.

Cemeteries can be conceptualised as a special kind of landfill, and from this model, an understanding of the hydrogeological processes at work can be developed. Landfill in the classic sense is where new land is created and the surface topography so altered that it bears little resemblance to the starting topography because of the addition of large volumes of new material. Cemeteries cannot comply with this definition, however, but they are a fill in the sense that some new materials - a coffin and human remains are incorporated in a prepared space.

1.2 Grave Function: Bucket Effect

The cemetery site ultimately consists of a highly disturbed surface layer typical with a framework of *in-situ* soil walls and corridors, all sitting on a continuous, yet most likely variable, sub-soil or weathered rock, irregular surface. The variability is due to natural processes, and the irregularity is due to differences in grave invert levels and altered topographic grades at the outset [11].

Depending on local management and cultural practices grave sites may be more or less covered by monumental masonry, gardens, lawn, bushland or some combination of these. Consequently, the cemetery site experiences irregular infiltration and percolation effects, potentially very uneven distribution of infiltration processes or events, and ultimately of recharge to any local or regional groundwater system. A principal confounding concern is the retention of water in the grave- *the bucket effect* (Fig. 2). In addition, this retention also occurs because the disturbed backfill over the interred remains has a higher porosity and permeability than the native soil. This is likely to be true in most cases except perhaps clayey sands if they are watered-in at the time of backfilling thus allowing for repacking of grains and flushing of clays into pore spaces [13].

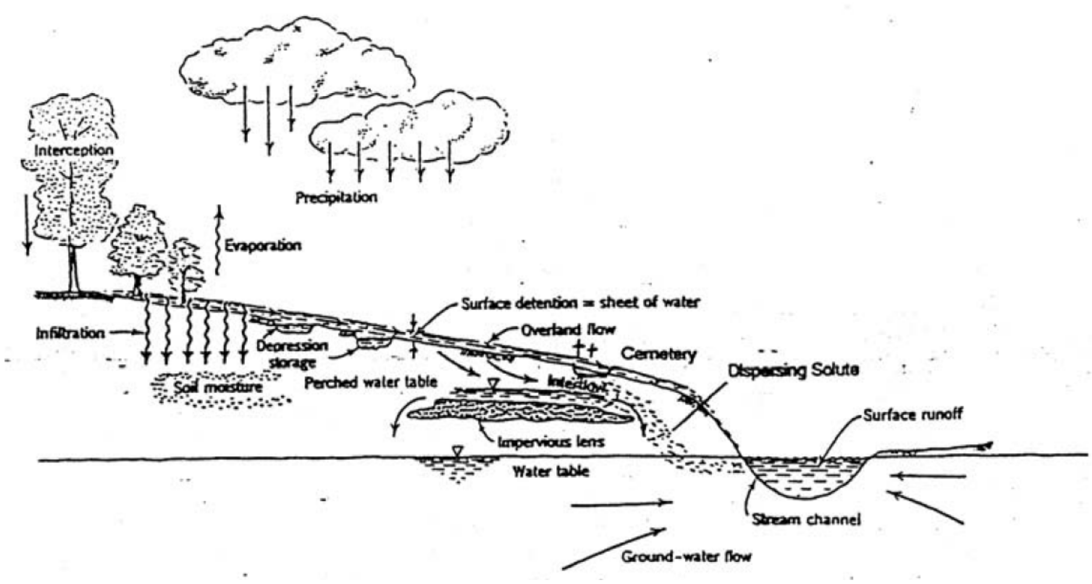

Fig. 1. Generalised hydrological cycle in relation to cemetery land use [10]

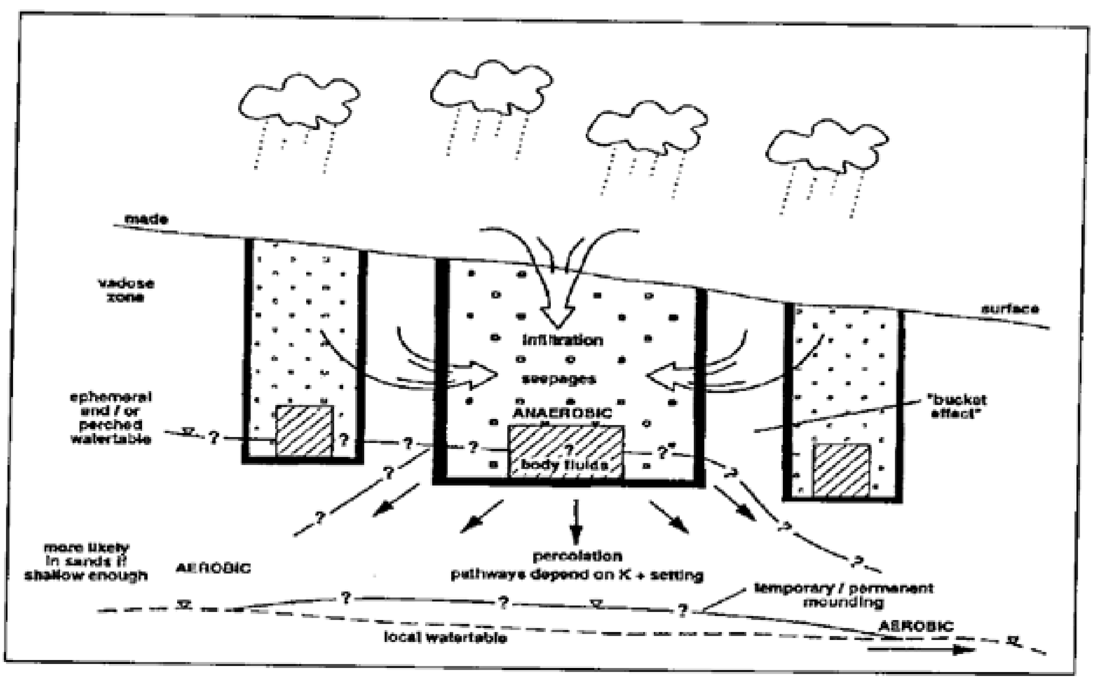

Fig. 2. Representation of hydrological processes operable for a grave and possible relationship in percolation patterns that might develop [12]

Other backfill types ultimately settle and/or differential settlement occurs as the interred remains decompose and coffins collapse; some clayey backfill bridge-essentially leaving cavities at depth. With settlement, a surface depression develops; this forms an unsatisfactory collection point for water and gives rise to a greater potential infiltration at this grave [14].

In terms of recharge, the grave bucket leads to a potential mounding effect for below-invert percolation to the groundwater system. This system may consist of one or more interflow pathways or a perched (regional) water table, depending on the hydrogeological setting. Seepage effects may continue beyond a cemetery's boundaries and for a distance reflective of local conditions; but solely dependent on the local hydrogeology. In such cases, decomposition products may readily be introduced to surrounding ecosystems or natural waterways or groundwater systems. The presence of well-planned buffer zone, particularly in topographic lows and where shallow flow lines may surface is a very important management aspect [12].

2. METHODOLOGY

This research work commenced after permission from the Government of Edo State, Nigeria through the Ministry of Environment, Benin City was sought, so as to have free access to the Cemeteries. A reconnaissance survey was carried out in the three Cemeteries. Geochemical survey was conducted to monitor differences of subsurface activities within and outside the cemeteries. Soil and water samples were taken and analyzed at Quality Analytical Laboratory Services Ltd., located in Benin City. The pH and EC were obtained using pH and EC meters respectively. Calcium, magnesium, chloride and alkalinity were analyzed using the titration method. Nitrate, sulphate and phosphate were analyzed with a UV spectrophotometer and heavy metals with an Atomic Absorption Spectrophotometer (AAS).

Around each cemetery, three holes were drilled, two within and one outside (as control) with hand auger to a depth of 5 ft (1.524 m). Water samples were collected at boreholes close to and far away from each cemetery in a triangular pattern.

Environmental and criminal geoforensic (VLF-EM and ERT) was conducted to locate and delineate migration pathways of electrically conductive contaminant plumes detected through chemical analysis of the soil samples, and to predict when the flow through the surface soil (laterite) might reach the sandy layer just below it.

The VLF-EM method is an excellent, cheap and rapid tool for reconnaissance mapping of conductive bodies and water-bearing fractures [15]. Almost all EM field sets include a portable power source. However, limited use has been made of radio transmission stations in the frequency range 100 kHz to 10 MHz and particularly in the very low frequency range (VLF), 15 to 25 kHz. [16].

The VLF-EM survey (preliminary investigation) was conducted to locate near vertical and inclined conductors which were investigated further for conductive leachate plumes generated from decomposed and decomposing corpse.

The VLF-EM data were collected using Abem Wadi in arrays of 16 parallel lines each of length 100 m in First and Second Cemeteries and 60 m in Third Cemetery, oriented in East-West direction and spaced equally at 2 m. The electromagnetic response gave real and imaginary values and were read and recorded at 5 m interval along each line.

The data were analyzed by preparing curves of filtered real and filtered imaginary values with station distances in Matlab Graphical User Interface (MGUI), and contour maps of the filtered real values drawn in surfer 11.0. The VLF-EM Pseudosections were constructed using KHFFILT software. The combined curves and 2D pseudosections were interpreted to locate near surface conductive anomalies suspected to be the leachate plumes detected by the geochemical analysis. The VLF-EM anomalous points were picked where the filtered real curves showed positive bulge and at shallow depths in the corresponding VLF-EM Pseudosections.

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 [17].

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.

The 2D geoelectrical images were used to interpret the VLF-EM anomalies. The positions of the EM anomalies were plotted into the prepared ERT survey location base map, and the corresponding positions on the ERT survey lines were noted, and used to pick out the resistivity anomalies on the geoelectrical images.

The second ERT survey was used to check for displacement of the plumes in vertical and horizontal directions, identified in the first ERT survey. This was conducted on the same profile of the first ERT survey using the same equipment for data collection and processing software. The vertical and horizontal migrations, migration rates and arrival times (predicted) of plumes at the sandy layer just below the surface layer were then computed.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Analysis

In Table 1, values of water analyzed with a control are displayed showing twenty-six analytes. By way of comparison which influenced the justification of this research work, it was observed that the pH of Borehole (BH) water from the three cemeteries was slightly lower (showing acidity) than the control. The temperature and colour can be said to be the same.

The Electrical Conductivity (EC), Total Dissolved Solid (TDS), Dissolved Oxygen (DO), Calcium, Magnesium, Total Hardness, Ammonium-Nitrogen, Nitrate, Alkalinity, Chloride, Sodium, Potassium, Iron, Manganese and Nickel can be seen in Table 1 to be far higher than control parameters, while Zinc and Copper are very low compared to control.

Soil samples were also analyzed and the results presented in Table 2. A total of twenty-two analytes were investigated with the pH in the three cemeteries showing mainly acidity while control was slightly alkaline. It is noted that the following parameters-EC, TDS (for Second and Third cemeteries) Calcium, Magnesium, Ammonium-Nitrogen, Chloride, Iron, Chromium, Manganese, Lead, Cadmium, Nickel, Phosphate, Nitrate and Sulphate had high values showing that the observed analytes in the water sample as seen earlier, could be as a result of migration of these metals. Other parameters showed varying amount (Figs. 3-20).

3.2 Geo-Forensic Analysis

Geo-forensic evaluation for this research work was done using VLF-EM to locate buried conductive materials. Most of the graves are unmarked and so for a proper investigation, these points must be located, including the marked graves (some contain conductive leachate while others do not) so that planning for Electrical Resistivity Tomography, which formed the detailed investigation for this research, was well structured.

3.2.1 Data analysis and geological interpretation

The VLF-EM sections were plotted as Karous-Hjelt filtered real component [18] for the selected profiles on which conductors suspected to be leachate plumes were identified, using KHFFILT program. This process yields pseudosection of relative current density variation with depth. Apparent current density cross-section also gives a rough idea about the dip direction. However, exact dip angle cannot be estimated due to the vertical axis variable being a pseudo depth only [19]. It is possible to differentiate between conductive and resistive structures using apparent current density cross-section, where a high positive value corresponds to conductive subsurface structure and low negative values are related to resistive structure [20,19]. Qualitatively, it is difficult sometimes to discriminate between deep and shallow sources [19].

In the first cemetery, apparent current density cross-section of five profiles was plotted. Profile 1 showed the presence of anomalies (both conductive and resistive) that begins from a depth of 5 to 7 m and is extended laterally from 62 to 71 m. Profile 2 showed the presence of anomalies that begin from a depth of 5 to 15 m, and is extended laterally from 62 to 79 m. Profile 14 showed the presence of anomalies that begin from a depth of 5.0 to 7.3 m, and is extended

Table 1. Analysis of borehole water within the vicinity of the three cemeteries in Benin City and comparison with a control

Analyte	Standard Method	Control	1st Cemetery			2nd Cemetery			3rd Cemetery		
pH	**ASTM D1293B-95**	**4.5**	**BH1**	**BH2**	**BH3**	**BH1**	**BH2**	**BH3**	**BH1**	**BH2**	**BH3**
			4.4	**4.0**	**4.5**	**4.0**	**3.8**	**3.8**	**3.8**	**4.0**	**4.0**
Temp (^{0}C)	EPA 79	32.1	29.8	31.1	31.1	31.1	31.1	30.9	30.4	30.6	30.6
COLOUR		Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
EC (µS/cm)	ASTM D1125-95	15	182	395	190	168	126	118	44	14	17
TDS (mg/l)	ASTM D1868	7.5	91	198	95	84	64	59	23	7	9
DO (mg/l)	ASTM D8812	2.4	5.6	6.0	7.6	6.8	8.0	7.2	6.8	9.6	6.4
BOD (mg/l)	ASTM D6731	1.6	0.8	2.8	5.2	3.2	4.4	1.2	1.2	4.0	1.2
Ca (mg/l)	ASTM D1126-96B	3.85	14.75	33.35	14.11	7.70	0.64	8.34	3.21	1.28	0.64
Mg (mg/l)	ASTM D1126-96B	1.17	6.61	9.73	5.84	5.45	7.39	2.72	15.56	23.34	7.78
Total Hardness (mg/l)	ASTM D1126-96	9.6	36.8	83.2	35.2	19.2	1.6	20.8	8.0	3.2	1.6
NH_4-N (mg/l)	ASTM D1426-93	0.03	<0.001	0.36	0.10	0.13	0.10	0.16	0.04	0.17	0.15
SO_4 (mg/l)	ASTM D1688-95	<0.001	0.243	0.008	0.507	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
PO_4 (mg/l)	ASTM D515-88	0.32	0.02	0.82	0.14	0.40	0.07	0.10	0.06	0.76	0.05
NO_3 (mg/l)	ASTM D3889-90	0.06	2.43	3.89	2.19	2.30	1.76	1.90	0.70	0.05	0.33
Alkalinity (mg/l)	ASTM D1067-92	9.15	9.15	18.30	15.25	9.15	6.10	9.15	9.15	15.25	12.20
Chloride (mg/l)	ASTM D1067-92	4.80	35.45	106.35	44.31	44.31	17.73	26.59	17.73	8.86	8.86
Sodium (mg/l)	ASTM D2791-92A	3.0	36.4	79.0	38.0	33.6	25.2	23.6	8.8	2.8	3.4
Potassium (mg/l)	ASTM D2791-93	3.9	47.3	60.7	49.4	43.6	32.8	30.7	11.4	3.6	4.4
Iron (mg/l)	ASTM D1068-96	1.58	0.36	1.02	0.84	1.66	0.16	0.24	0.33	0.16	1.22
Zinc (mg/l)	ASTM D1691-95	0.63	0.20	0.16	0.39	0.07	0.04	0.15	0.20	0.08	1.04
Copper (mg/l)	ASTM D1688-95	0.04	0.17	0.19	0.06	0.03	<0.05	<0.05	<0.05	<0.05	<0.05
Manganese (mg/l)	ASTM D858-95	<0.05	0.30	0.84	0.37	0.44	0.30	0.64	0.64	0.08	0.34
Chromium (mg/l)	ASTM D1687-92	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cadmium (mg/l)	ASTM D3557-95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nickel (mg/l)	ASTM D95	0.07	0.77	0.49	0.54	1.76	0.49	0.16	0.17	0.72	1.01
Lead (mg/l)	ASTM D3559-96	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

BH1 = BOREHOLE 1; BH2 = BOREHOLE 2; BH3 = BOREHOLE 3; ND = NOT DETECTED

Table 2. Analysis of soil sample inside the three cemeteries in Benin City and comparison with a control outside the Cemeteries

Analyte	Standard Method	1st Cemetery			2nd Cemetery			3rd Cemetery		
pH	**ASTM D 1293B-95**	**Control**	**S1**	**S2**	**Control**	**S1**	**S2**	**Control**	**S1**	**S2**
		6.3	**4.3**	**4.6**	**6.4**	**3.7**	**3.5**	**6.0**	**3.5**	**3.6**
Temp (^{0}C)	EPA 79	28.2	27.5	27.4	28.3	27.5	27.4	28.2	27.3	27.5
EC (µS/cm)	ASTM D1125-95	12	36	11	25	10	165	40	48	55
TDS (mg/l)	ASTM D1868	32.5	18.0	5.5	11.5	5.0	82.5	10	24.0	27.5
Ca (mg/l)	ASTM D1126-96B	304.6	192.4	176.4	641.2	208.4	1494	577.2	853	339.5
Mg (mg/l)	ASTM D1126-96B	155.6	953	930	175	1035	1023	223.6	669	537
Na (mg/l)	ASTM D2791-92A	130	72	22	450	20	330	336	96	110
k (mg/l)	ASTM D2791-93	169	93.6	28.6	585	26.0	429	436.8	124.8	143
NH_4-N (mg/l)	ASTM D1426-93	8.28	20.79	336.5	3.17	34.03	27.41	1.6	29.3	16.87
Alkalinity (mg/l)	ASTM D1067-92	183	91.5	122	336	91.5	91.5	214	122	122
Chloride (mg/l)	ASTM D1067-92	212.7	266.3	147.9	183.6	207.1	118.3	154.5	207.1	384.6
Iron (mg/l)	ASTM D1068-96	17.6	29.4	20.2	13.4	31.8	20.2	18.9	66.2	30.4
Zinc (mg/l)	ASTM D1691-95	10.3	12.8	6.5	6.2	10.2	8.7	8.6	32.9	18.3
Copper (mg/l)	ASTM D1688-95	2.2	4.7	14.0	1.5	9.5	10.7	6.6	8.1	14.1
Chromium (mg/l)	ASTM D1687-92	0.3	0.17	0.87	0.41	0.74	0.28	0.3	0.12	0.43
Manganese (mg/l)	ASTM D858-95	1.54	3.66	11.18	1.9	3.52	12.66	2.73	3.61	17.42
Lead (mg/l)	ASTM D3559-96	1.04	1.3	3.23	1.37	3.99	2.95	2.43	4.54	4.98
Cadmium (mg/l)	ASTM D3557-95	0.56	0.8	1.82	0.23	0.23	0.68	0.27	0.25	0.71
Nickel (mg/l)	ASTM D95	1	1.3	22.3	<0.05	<0.05	<0.05	<0.05	<0.05	24.9
Phosphate (mg/l)	ASTM D515-88	18	18.6	31.5	17.8	32.8	24.2	28.8	32.6	30.3
Nitrate (mg/l)	ASTM D3889-90	1.1	5.9	2.5	<0.001	0.5	7.68	<0.001	<0.001	0.5
Sulphate (mg/l)	ASTM D1688-95	1.23	33.75	2.83	0.72	15.71	2.6	0.81	35.3	40.3

S1 = SAMPLE 1; S2 = SAMPLE 2

laterally from 28 to 33 m. Profile 15 showed the presence of anomalies that begin from a depth of 5 to 6.3 m, and is extended laterally from 68 to 72 m. Profile 16 showed the presence of anomalies that begin from a depth of 5 to 15 m, and is extended laterally from 20 to 35 m.

In the second cemetery, apparent current density cross-section of four profiles was plotted. Profile 2 showed the presence of anomalies that begin from a depth of 5 to 15 m and is extended laterally from 20 to 33 m. Profile 5 showed the presence of anomaly that begins from a depth of 5 to 15 m and is extended laterally from 35 to 53 m. Profile 7 showed the presence of anomaly that begins from a depth of 5 to 15 m and is extended laterally from 38 to 53 m. Profile 14 showed the presence of anomalies that begin from a depth of 5 to 7 m and is extended laterally from 45 to 46 m.

In the third cemetery, apparent current density cross-section of three profiles was plotted. Profile 1 showed the presence of anomalies that begin from a depth of 5 m to 8 m and is extended laterally from 37 m to about 42 m. Profile 5 showed the presence of anomaly that begins from a depth of 5 m to 7 m and is extended laterally from 35 m to about 39 m. Profile 15 showed the presence of anomalies that begin from a depth of 5 m to 7 m and is extended laterally from 34 m to about 37 m.

3.3 VLF Curves from the Cemeteries

3.3.1 Conclusion of report for very low frequency–EM survey

Very Low Frequency–Electromagnetic Survey adequately revealed subsurface distribution of near vertical and vertical electrical conductors, artificial and geologic within the cemeteries. However, the result of interpretation cannot actually confirm the nature and type of conductors responsible for the VLF anomalies. The predicted locations of leachate emanating from water flowing through decomposing corpses and associated burial items was then investigated using Electrical Resistivity Tomography (ERT) with the ultimate aim to determine the nature, depths, sizes, lateral locations of the conductors.

3.4 ERT

3.4.1 First 2D electrical resistivity tomography (ERT) survey

The first ERT survey was designed using the result of VLF-EM interpretation. The Very Low Frequency Electromagnetic survey curves and Pseudo Images interpretation were used to plan the survey. The electrical profile length, locations and inter-electrodes spacing in the lines were decided using the result of interpretation of the VLF data. In each cemetery, Electrical Resistivity Survey Location Base Maps were constructed using the VLF-EM anomalous points. Each survey profile was positioned such that the VLF-EM anomaly is at the centre of the line (totally crossed location of the suspected leachate plume), for complete capture of the feature in the 2D resistivity image. The inter-electrode spacing was chosen to be 5m which is less than the expected width (apparent) of the plumes as visualized in the VLF Pseudosections. This was to ensure complete 2D geo-electrical visualization of the targets to confirm the nature (artificial or geologic), depths, and lateral extensions of the VLF anomalies.

The Electrical Resistivity Profiles were systematically indexed on the base maps to facilitate interpretation with the VLF survey and laboratory analysis of the soil samples. This program map shows the survey line locations, orientation, begin and end of electrode locations, 0 and 100 marks for the three cemeteries.

The conductor located in VLF-EM Curves, L1 at 56 m mark is 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.

The conductors located in VLF-EM Curves, L2 at 7 m and 41 m marks are 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 is 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.

This electrical imaging survey profile was laid close to the soil sample location (2 m away), and

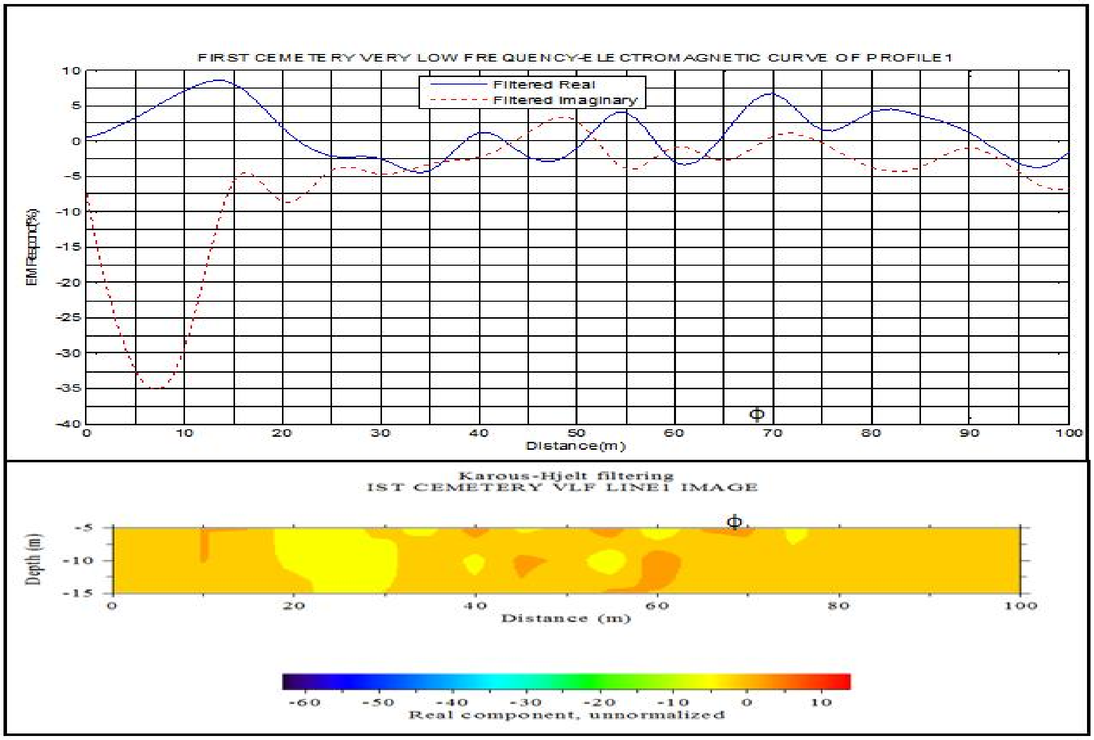

Fig. 3. VLF curve interpretations for first cemetery, profile 1

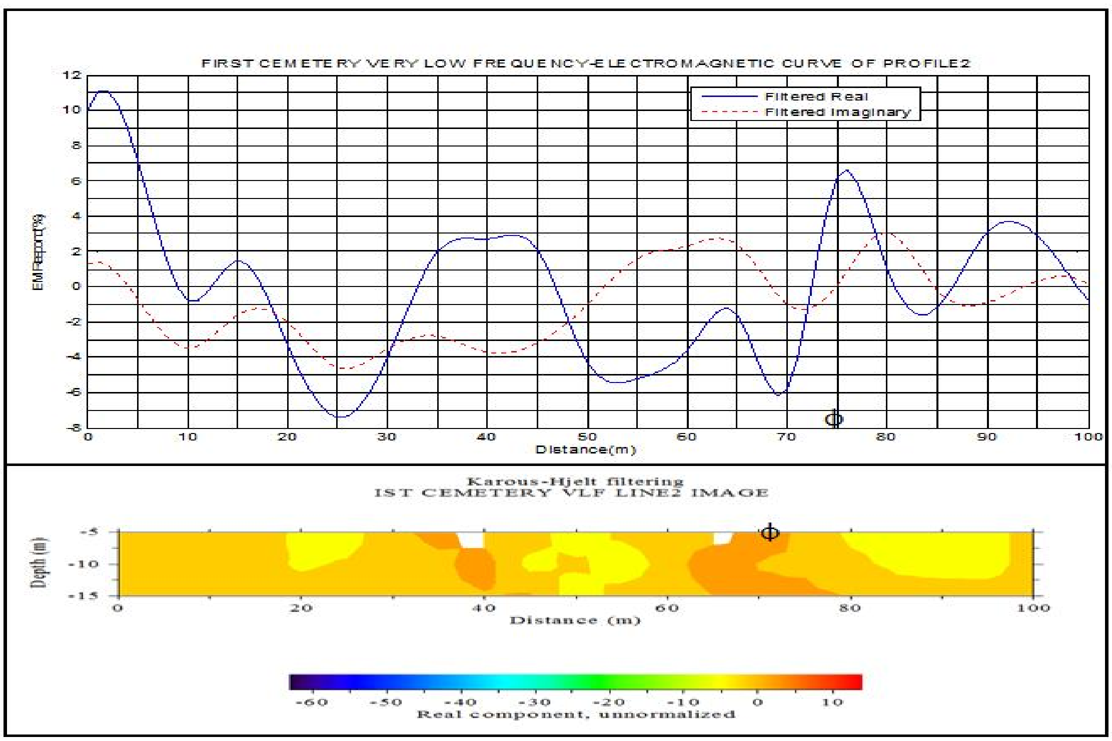

Fig. 4. VLF curve interpretations for first cemetery, profile2

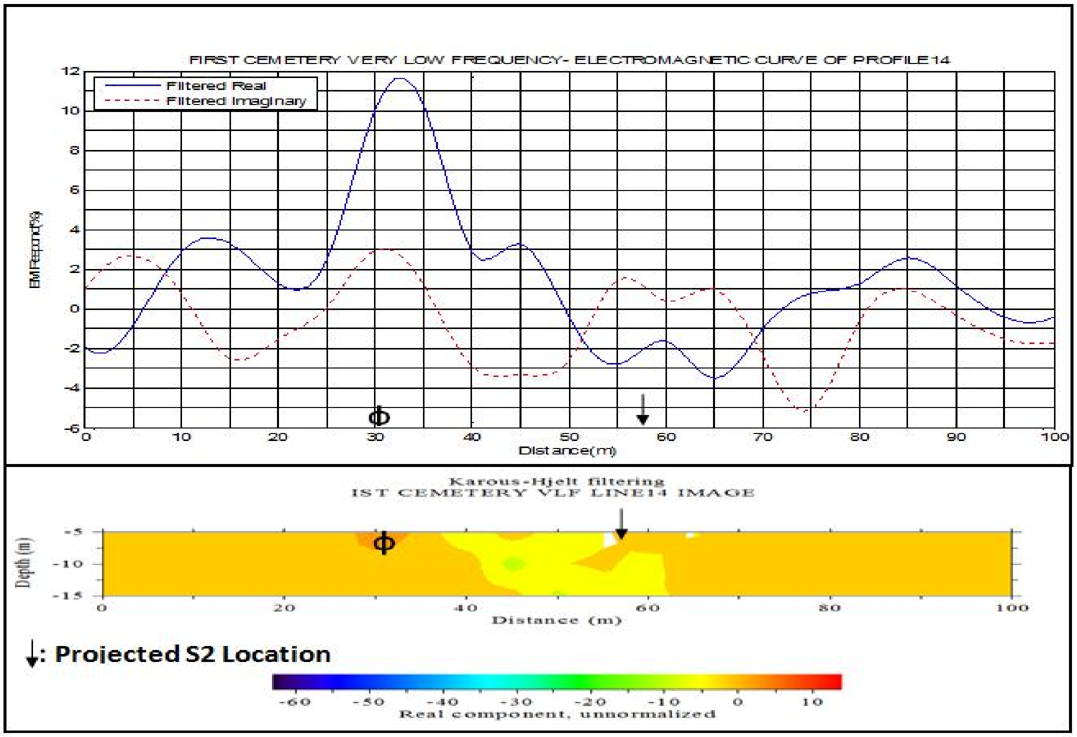

Fig. 5. VLF curve interpretations for first cemetery, profile 14

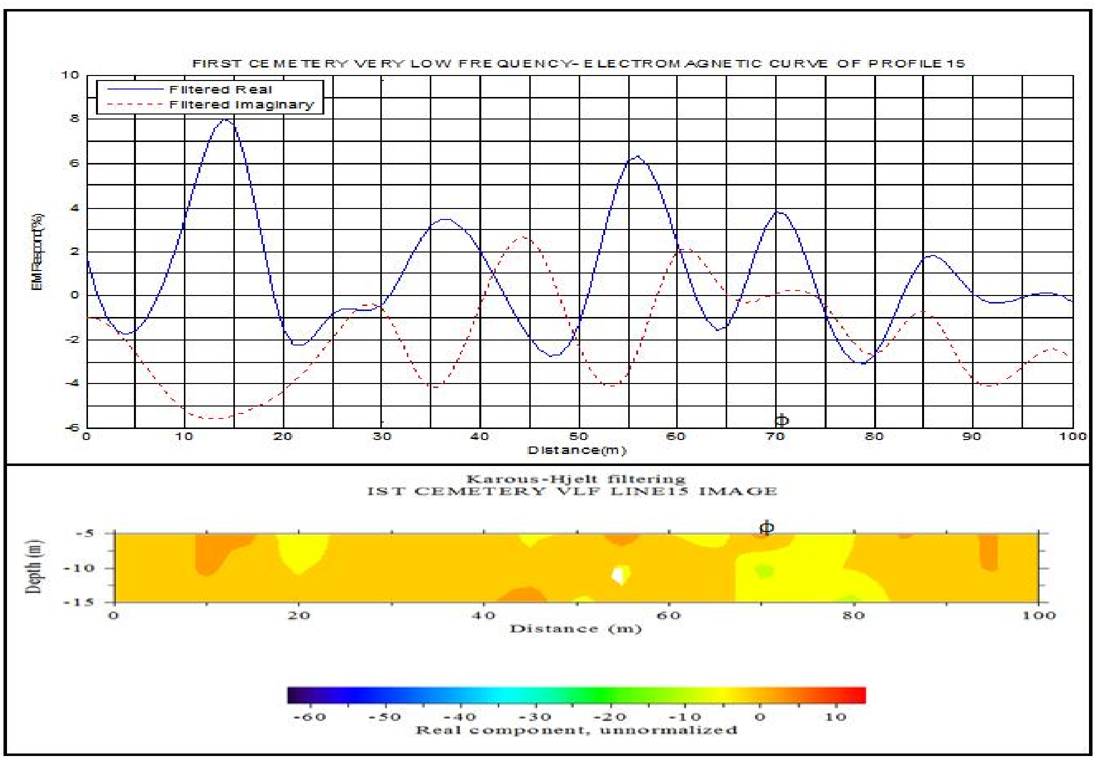

Fig. 6. VLF curve interpretations for first cemetery, profile15

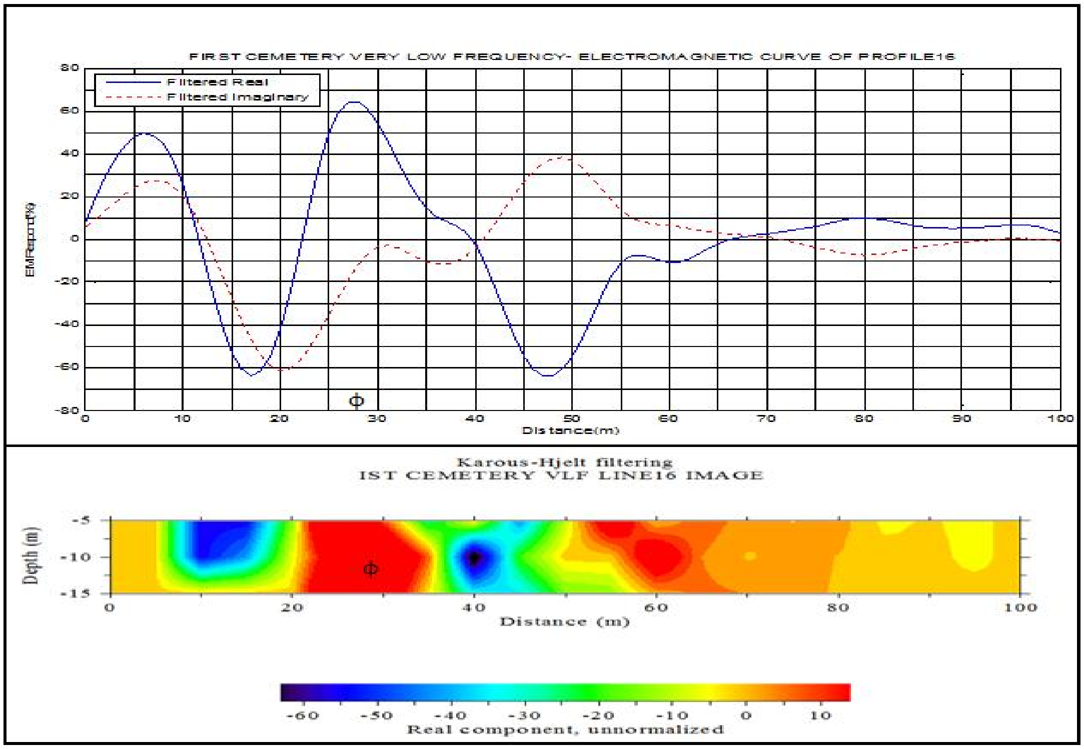

Fig. 7. VLF curve interpretations for first cemetery, profile16

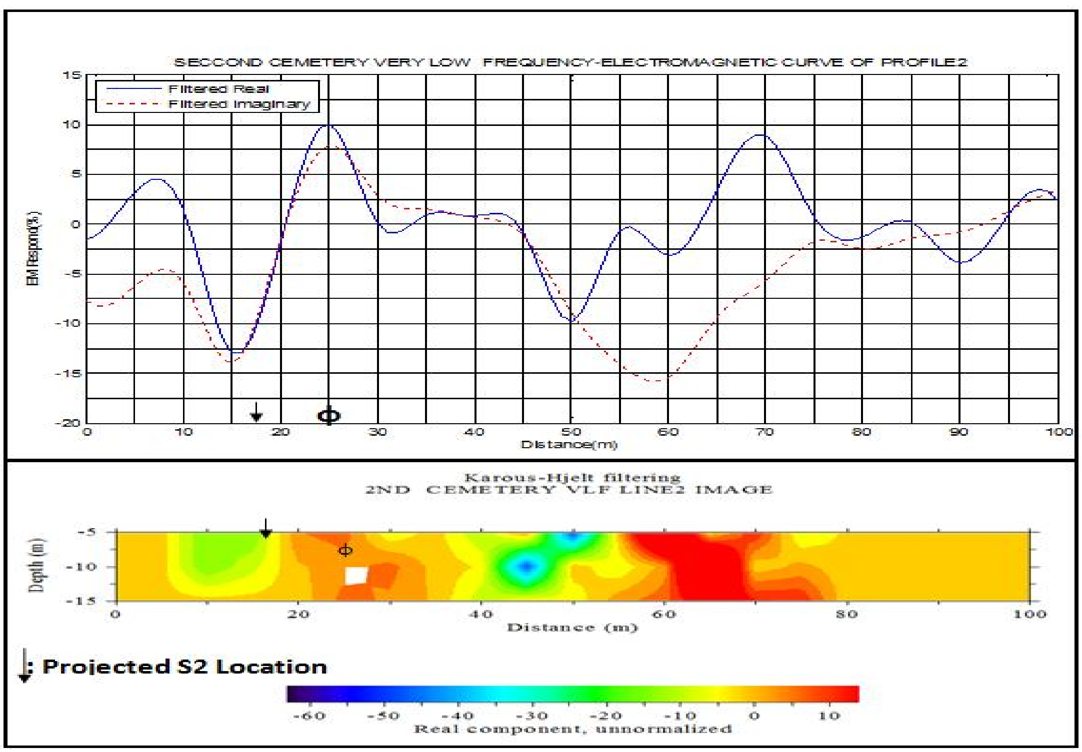

Fig. 8. VLF curve interpretations for second cemetery, profile2

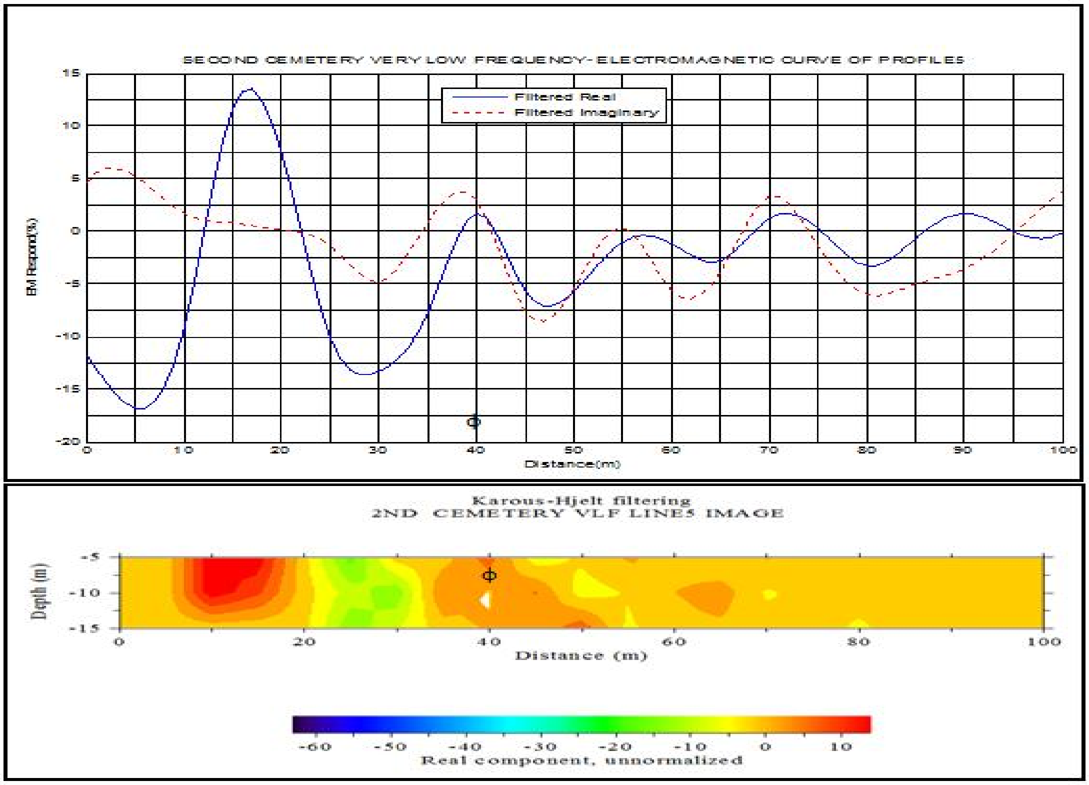

Fig. 9. VLF curve interpretations for second cemetery, profile5

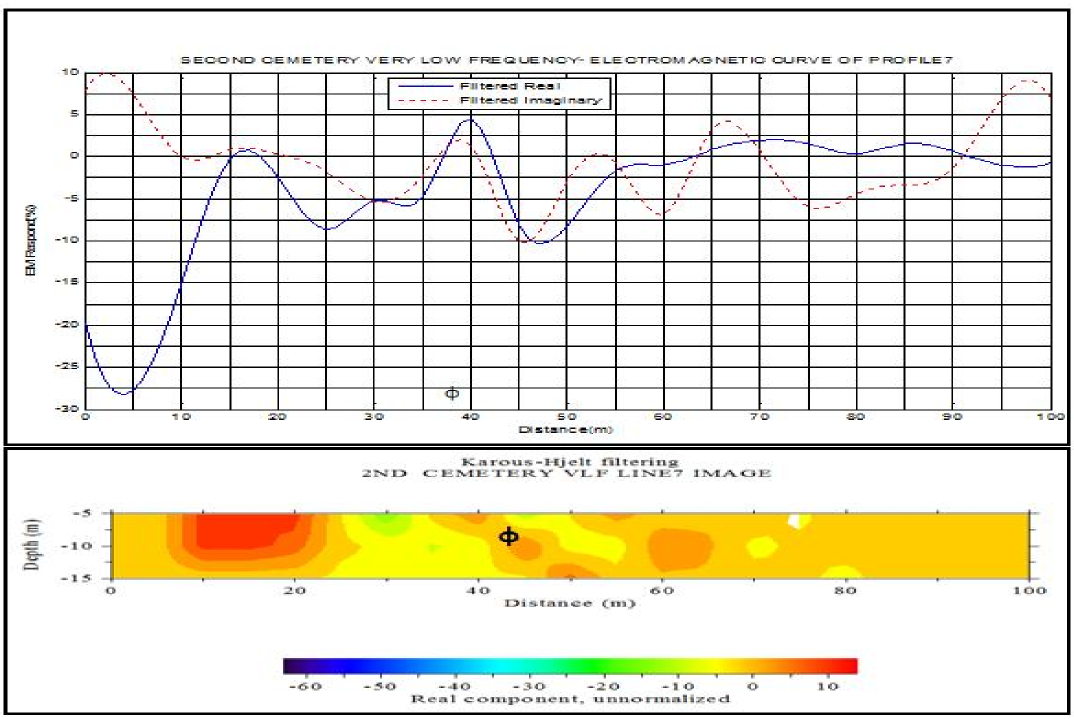

Fig. 10. VLF curve interpretations for second cemetery, profile7

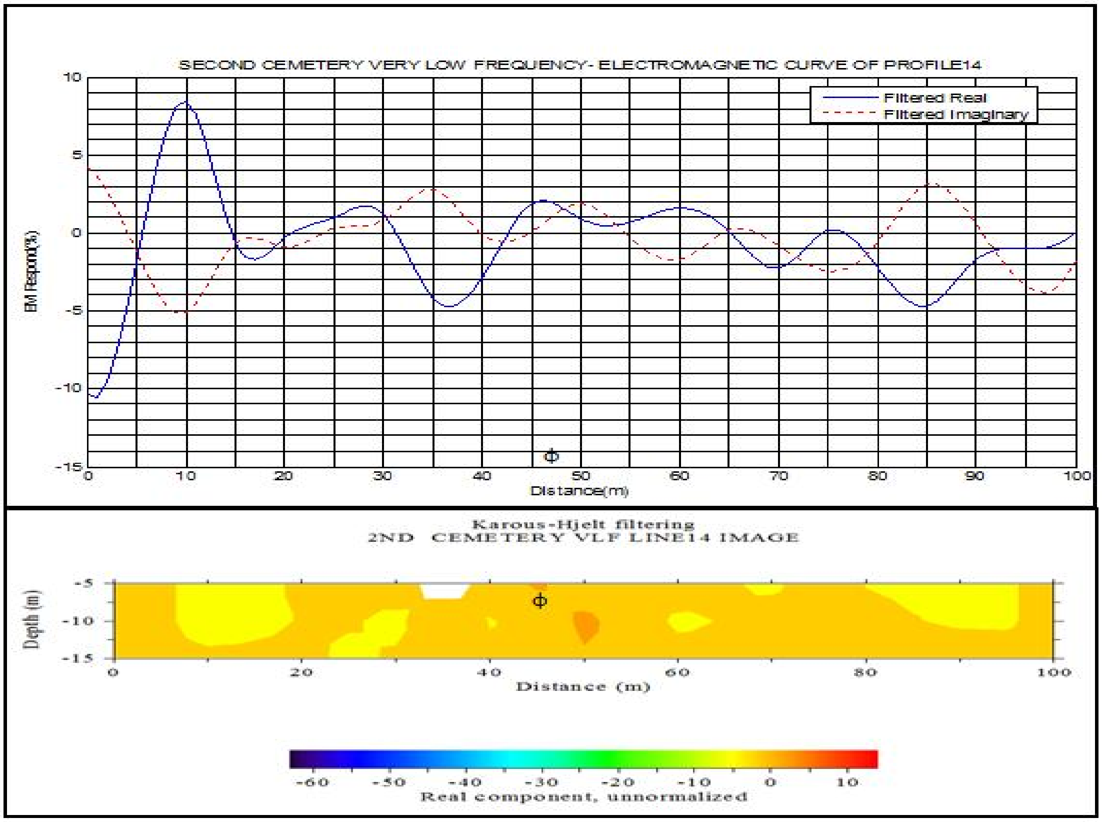

Fig. 11. VLF curve interpretations for second cemetery, profile14

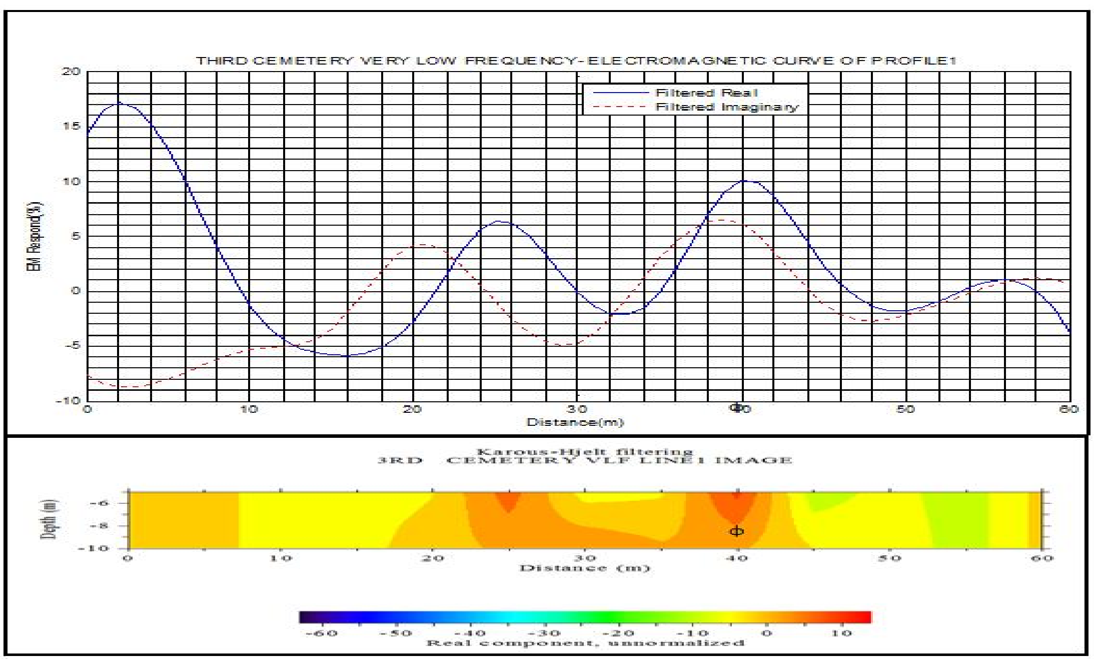

Fig. 12. VLF curve interpretations for third cemetery, profile 1

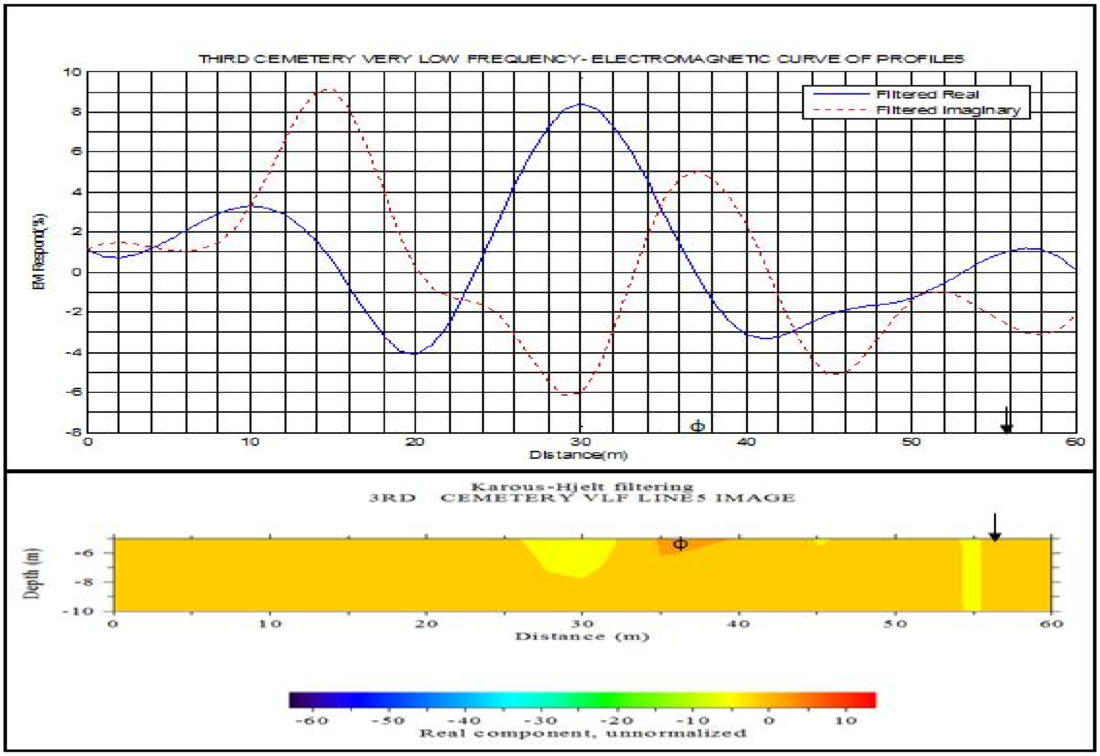

Fig. 13. VLF curve interpretations for third cemetery, profile5

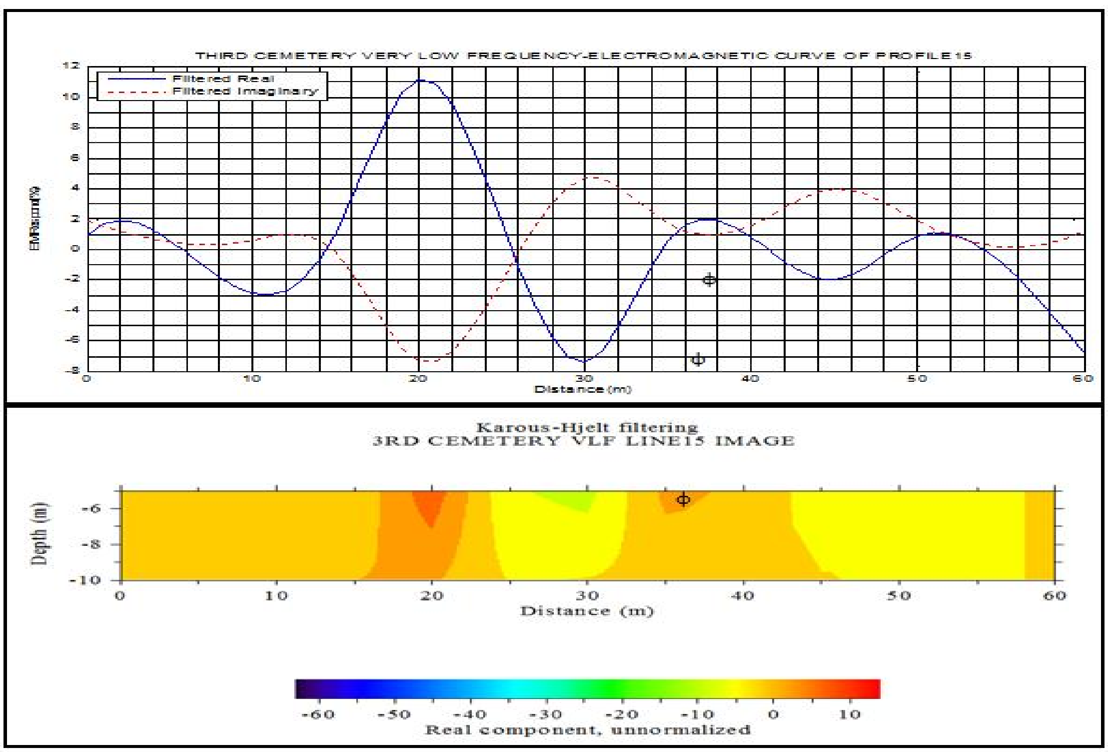

Fig. 14. VLF curve interpretations for third cemetery, profile15

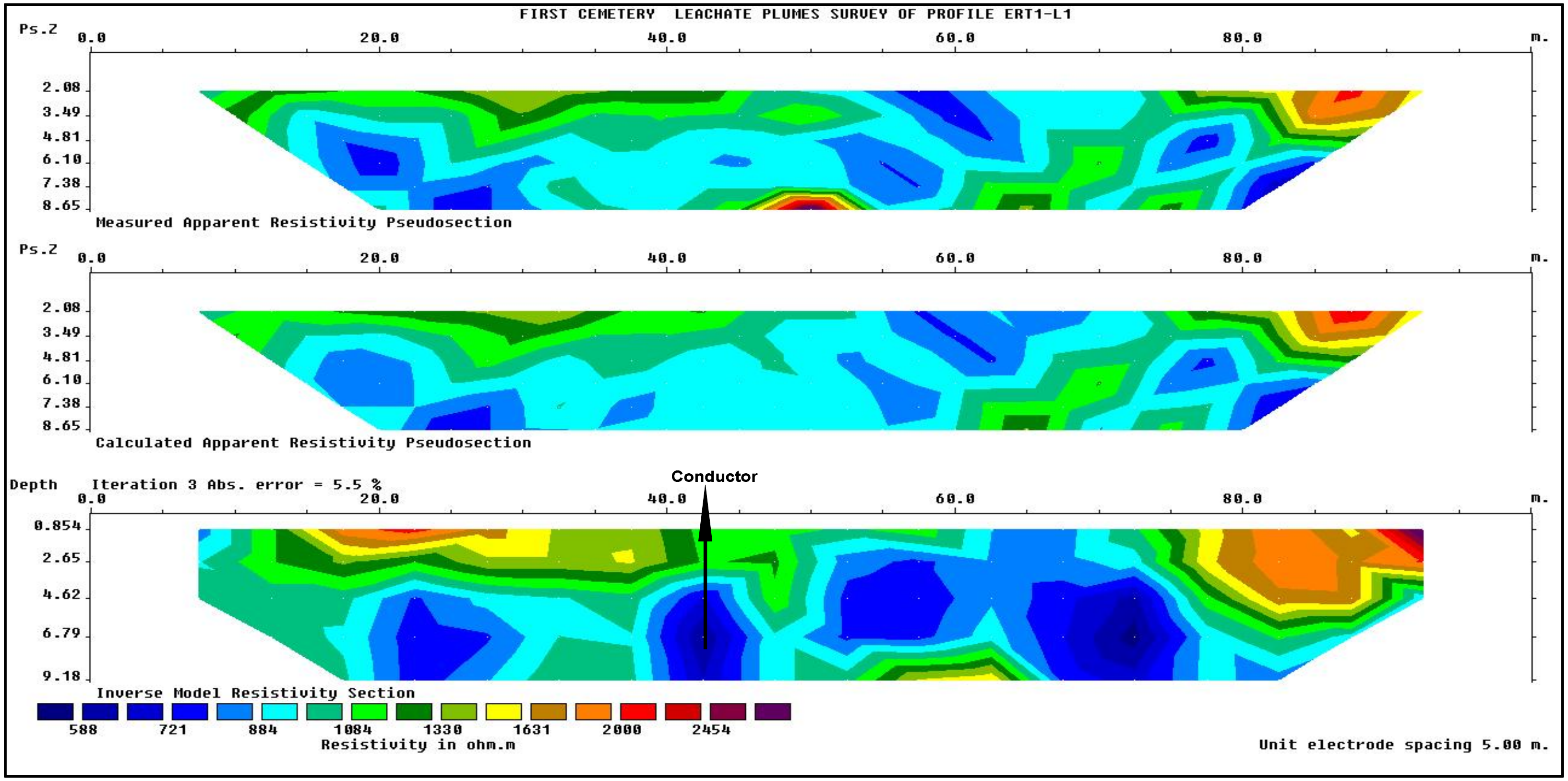

Fig. 15. 2D Geo-electrical Image of first cemetery, profile ERT1-L1

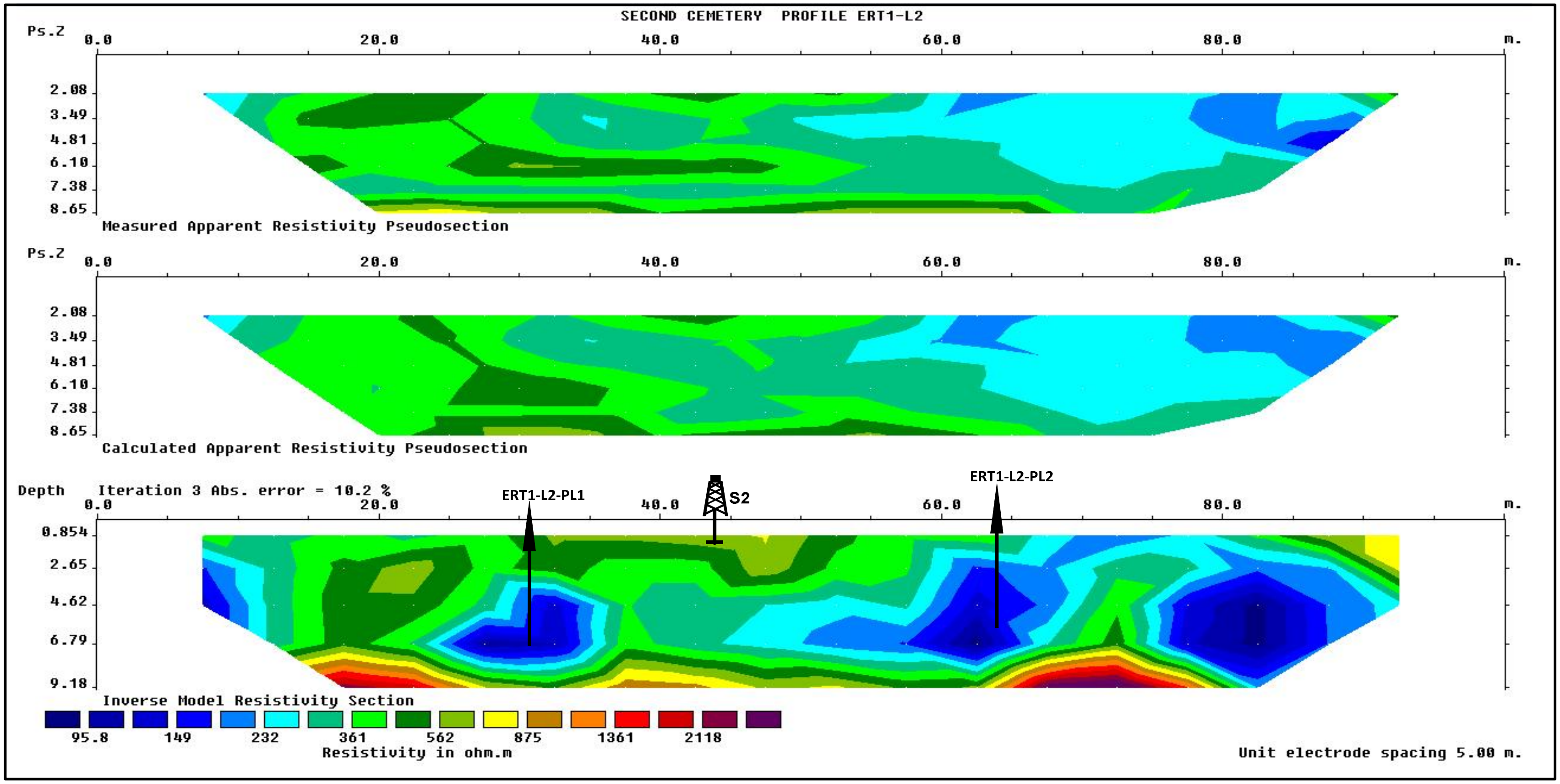

Fig. 16. 2D geo-electrical image of second cemetery, profile ERT1-L2

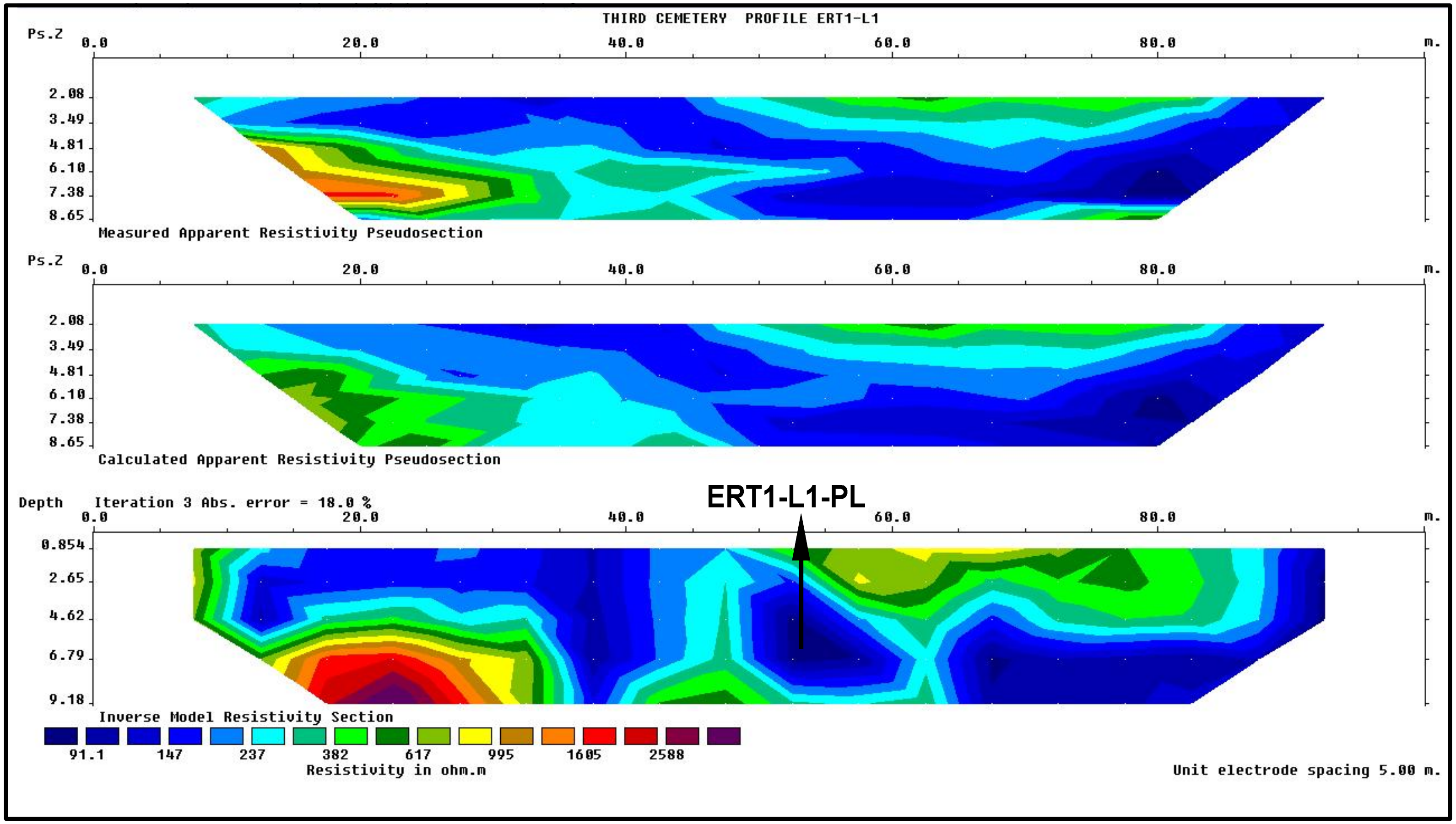

Fig. 17. 2D Geo-electrical image of third cemetery, profile ERT1-L1

projected position on the profile labeled S2 (44 m distance on the section). There is no resistivity anomaly directly below it interpreted as leachate plume. The laboratory analysis of the soil sample revealed high electrical conductivity (EC)-165 µS/cm (control 25 µS/cm), Total Dissolved Solids (TDS)-82.5 mg/l (control 11.5 mg/l) and Cl^- 118.3 mg/l (control 183.6 mg/l), from inorganic chemicals associated with leachate. Traces of this leachate must have been present at the depth where the soil sample was taken, which is evident from the resistivity interpretation.

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.

3.4.2 ERT carried out after a time lapse of 12 months

The field data were processed with the same software and same processing parameters used in the ERT survey. The processed data were interpreted on the same geological consideration as in first ERT survey. The images (only three images presented, one for each cemetery) were observed for changes in vertical and horizontal positions of the plumes as well as changes in concentration observed in the first ERT survey.

The conductor (488 Ωm) laterally located between 40.0m and 50.0 m marks at depth 4.62 m in the first ERT resistivity model section (Fig. 5) did not appear in this second ERT model section, it may have been diluted and the zone becomes compacted as indicated by higher resistivity of 1326 Ωm.

The plume (96 Ωm) located and labeled in the first survey (Fig. 11) as ERT1-L2-PL1 appears in this second ERT model sections at the lateral locations at 22.5 m and 31.4 m, and the electrical resistivity is 91 Ωm, which is within the limit of the control value 1-120 Ωm. It occurs 2.20 m below the ground surface, and extends vertically to a depth of 6.79 m. The vertical and horizontal extents are 4.59 m and 8.9 m respectively. This plume becomes more concentrated over time; more leachate must have been added.

The plume (91 Ωm) located and labeled in the first survey (Fig. 13) as ERT1-L1-PL appears in this second ERT model sections at the lateral locations at 51.3 m and 53.8 m, and the electrical resistivity is 111 Ωm, which is within the limit of the control value 1-120 Ωm. It occurs 2.65 m below the ground surface, and extends vertically to a depth of 5.71 m. The vertical and horizontal extents are 3.06 m and 2.50 m respectively. This leachate plume is diluted with excess water (becomes more resistive) over time.

3.5 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 surveyed period were read easily on the colour bars. These are shown in Table 3 and Table 4.

3.6 Time Lapse Study

The resistivity survey executed in 2014 over the Very Low Frequency–Electromagnetic anomalies in the First Cemetery indicated high resistivity (376 Ωm to 666 Ωm), and these are far above resistivity anomalies to be interpreted as leachate plumes in the absence of clay in the laterite zone.

Although leachate plumes were not located in the First Cemetery, a time lapse study was still carried out to actually confirm the 2014 ERT survey. The resistivities recorded for the 2015 survey on some survey lines varied from 376 Ωm to 488 Ωm. This was found to be in agreement with the 2014 interpretation. A time lapse study of the Second and Third Cemeteries to monitor the migration of contaminants plumes shows that the maximum rate of contaminant migration within the subsurface in the vertical direction in the Second and Third Cemeteries is 19.2 cm/month, while the horizontal migration rates are 41.6 cm/month and 51.7 cm/month respectively. These results show the status of the cemeteries: the First Cemetery is an old cemetery and no longer in operation as at the time of this survey, while Second and Third Cemeteries are still very much in use and active as at the time of this survey. Table 5 and Table 6 give the detail of the computation of migration rates.

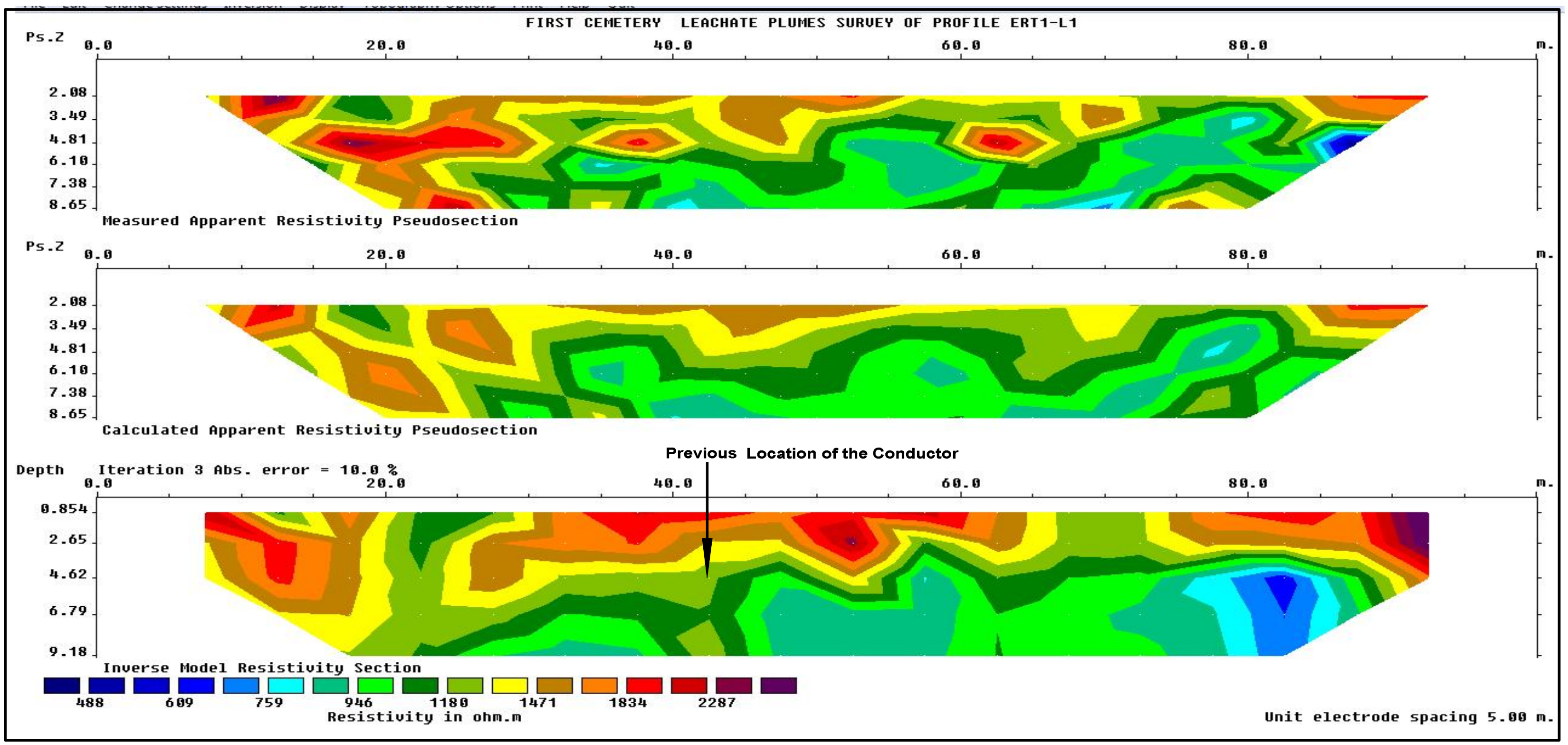

Fig. 18. Second 2D Geo-electrical image of first cemetery, profile ERT1-L1

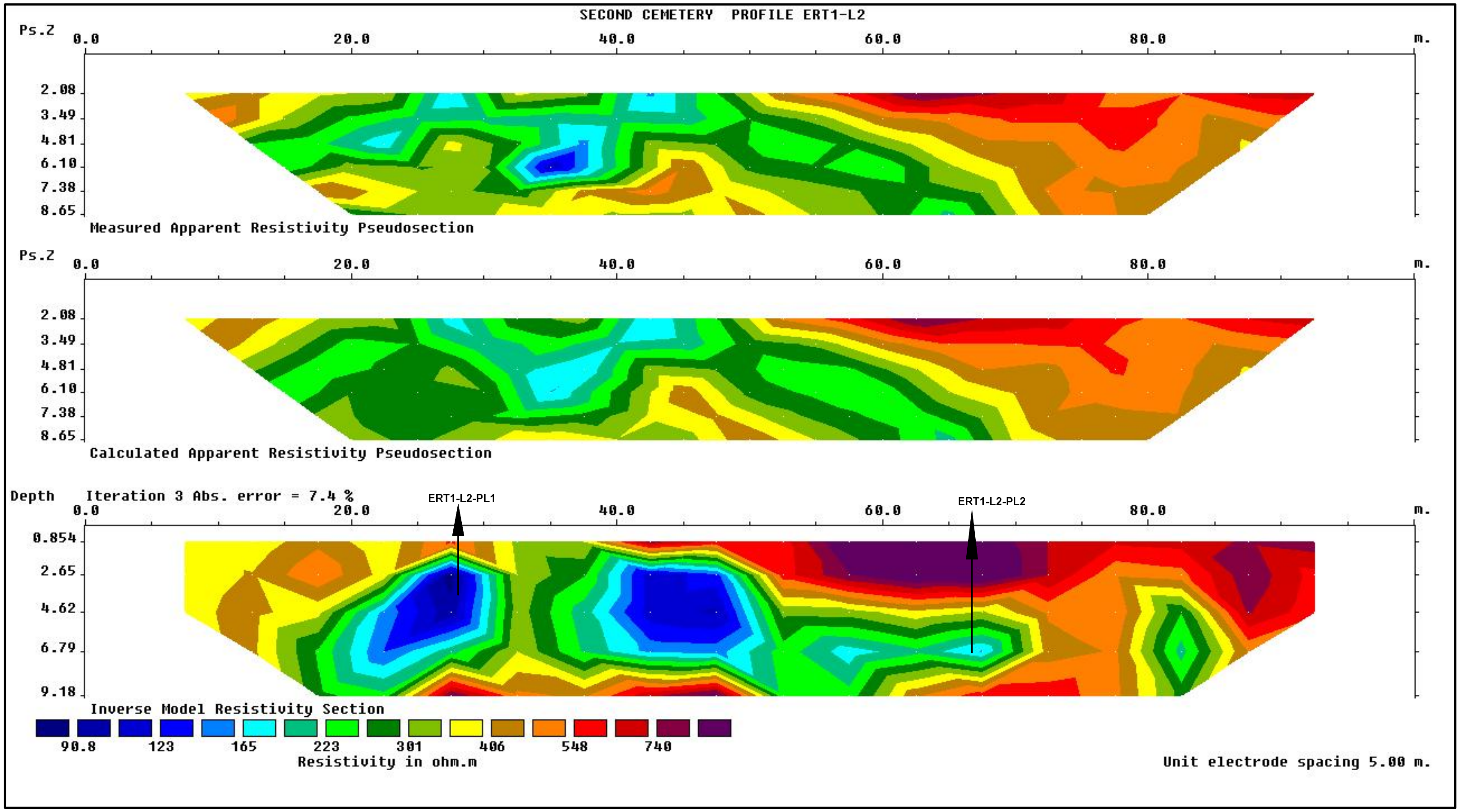

Fig. 19. Second 2D geo-electrical image of second cemetery, profile ERT1-L2

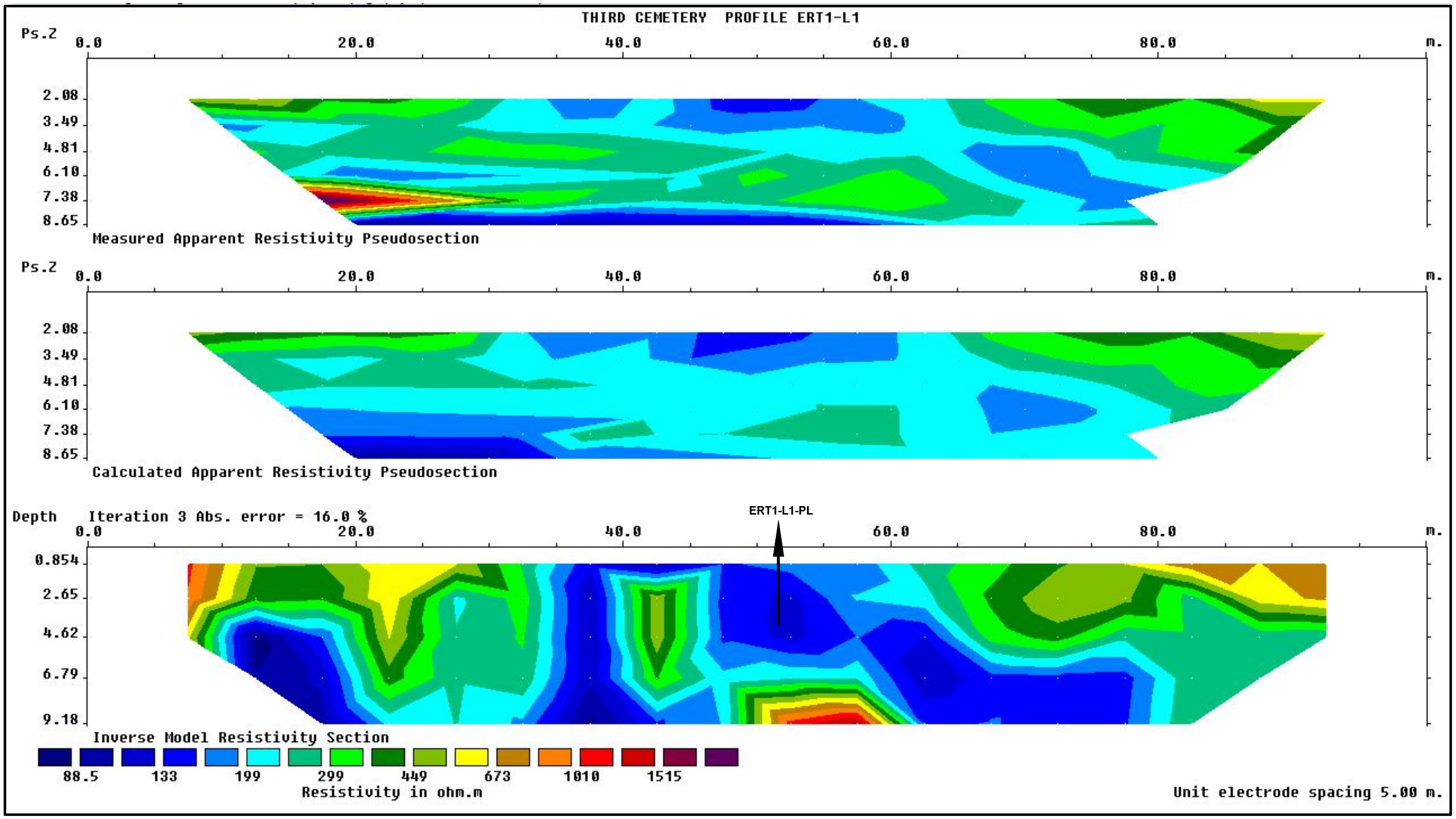

Fig. 20. Second 2D geo-electrical image of third cemetery, profile ERT1-L1

Table 3. Electrical resistivities of plume zones in the second cemetery at the different periods

Plume NO.	Surveyed date	Resistivity(Ωm)	Remarks
ERT1-L2-PL1 ERT1-L2-PL1	6/08/2014 11/08/2015	96 91	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-PL2 ERT1-L2-PL2	6/08/2014 11/08/2015	96 194	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 ERT2-L5-PL	6/08/2014 11/08/2015	91 103	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.

Table 4. Electrical Resistivities of plumes zones in the third cemetery at the different periods

Plume no.	Surveyed date	Resistivity(Ωm)	Remarks
ERT1-L1-PL ERT1-L1-PL	05/08/2014 10/08/2015	91 110	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.
ERT2-L5-PL ERT2-L5-PL	05/08/2014 10/08/2015	73 117	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.

Table 5. Result of time lapse study of the second cemetery

Plume No.	Date	Vertical Position (m)	Horizontal Position (m)	Vertical Migration (m)	Horizontal Migration (m)	Vertical Migration Rate (cm/month)	Horizontal Migration Rate (cm/month)
ERT1-L2-PL1	6/08/14	8.0	33.8	1.2	2.4	10.0	20.0
	11/08/15	6.8	31.4				
ERT1-L2-PL2	6/08/14	8.0	67.6	0.1	1.3	0.83	10.8
	11/08/15	8.1	68.8				
ERT2-L5-PL	6/08/14	5.7	50.0	2.3	5.0	19.2	41.6
	11/08/15	8.0	45.0				

Table 6. Result of time lapse study of the third cemetery

Plume No.	Date	Vertical Position (m)	Horizontal Position (m)	Vertical Migration(m)	Horizontal Migration(m)	Vertical Migration Rate(cm/month)	Horizontal Migration Rate(cm/month)
ERT1-L1-PL	5/08/2014	7.99	60.0	2.3	6.2	19.2	51.7
	10/08/2015	5.71	53.8				
ERT2-L5-PL	5/08/2014	4.62	53.8	0.54	6.2	4.5	51.7
	10/08/2015	5.16	60.0				

Table 7. Contaminant plume migration rates in the different locations

Location	Maximum vertical migration rate(cm/month)	Maximum horizontal migration rate(cm/month)
Second Cemetery	19.2	41.6
Third Cemetery	19.2	51.7

Table 8. Migrating plume arrival time in subsoil in the different locations

Location	Maximum vertical migration rate(m/month)	Surface layer average thickness(m)	Predicted arrival time in the underlain sandy soil (years)
Second Cemetery	0.192	9.1	4
Third Cemetery	0.192	9.1	4

The first ERT survey was conducted in August, 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 and move faster in the horizontal and vertical directions.

The rate of migration depends on the permeability of the soil, incline topography and depressions. The migration rates are pronounced in the Second and Third Cemeteries. Again, it is seen that if the vertical migration rate is constant in the laterite layer (average thickness of about 9.1m from borehole drilling information), then it will take about 4 years for the plume in the Second and Third Cemeteries respectively to arrive at the sandy layer just below it. Table 7 shows the different values of contaminant plume migration rates between the locations while Table 8 shows the detail of the computation of arrival time to the sandy layer.

It is also seen that the rate of migration in the horizontal direction is higher than that in the vertical direction by margins of 21.8 cm/month and 32.5 cm/month and in the Second and Third Cemeteries respectively. Horizontal permeability usually higher than the vertical permeability except in solution fracture (Djebbar et al, 2004). Also, presence of depressions created by decomposed corpses and collapse burial materials aid infiltration into the subsurface.

4. CONCLUSION

Physicochemical analysis done in the cemetery environment revealed the presence of high values of parameters like EC, TDS and other heavy metals when compared with the control taken at some other locations. Geoforensic (VLF-EM) analysis identified subsurface distribution of both near vertical and vertical electrical conductors which can either be artificial or geologic. ERT survey performed on the VLF-EM anomalous points identified some of the conductor anomalies to be leachate since metallic ores are not expected within the cemetery.

There is variation in the resistivity of leachate plume in the cemeteries under investigation between 2014 and 2015, which is as a result of dilution/migration of the plume with passage of time.

Quantitative evaluation of the cemetery activities shows that there is migration of leachate at different rates in the three cemeteries.

For constant vertical migration rate in a laterite zone, it would take an average of 4 years for leachate plume emanating from a cemetery environment to arrive the next subsurface region.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Spongberg AL, Becks P. Inorganic soil contamination from cemetery leachate. Water, Air, and Soil Pollution. 2000;117:313–327.
2. Jonker C, Olivier O. Mineral contamination from cemetery soils: case study of Zandfontein cemetery, South Africa. International Journal of Environmental Research and Public Health. 2012;9(2):511-520
3. Engelbrecht P. Ground water pollution from cemeteries—a case study. In proceedings of environmental: situation and perspectives for the European union, Porto, Portugal. 2010;6–10.
4. Dent BB, Knight MJ. Cemeteries: A special kind of landfill. Groundwater: Sustainable Solutions, Conference of the International Association of Hydrogeologists, Melbourne. 1998;451–456.
5. Canninga L, Szmigina I. Death and disposal: The universal, environmental dilemma. J. Market. Manag. 2010;26:1129-1142.

6. Zychowski J. Impact of Cemeteries on groundwater chemistry. Catena Sciverse Science Direct. 2012;(93):29-37.
7. Ucisik AS, Rushbrook P. The impact of cemeteries on the environment and public health – an introduction briefing. WHO, Regional Office for Europe, World Health Organization. Rept. EUR/ICP/EHNA 01 04 01 (A). 1998;1–11.
8. Hudak PF. Principles of Hydrogeology. Lewis Publishers, Boca Raton, FL, USA; 1999.
9. Rodrigues L. Thesis presented for the degree of Master in Hydrobiology by the University of Porto, Oporto, Portugal; 2002.
10. Davis SN, Dewiest RJM. Hydrogeology, John Wiley NY;1966.
11. Zychowski J. Geological aspects of decomposition of corpses in mass graves from WW1 and 2, located in SE Poland. Environmental Earth Sciences. 2011;64(2):437–448.
12. Dent BB. Vulnerability and the Unsaturated Zone – The Case for Cemeteries Proceedings “Where Waters Meet”. Joint Conference – New Zealand Hydrological Society, International Association of Hydrogeologists (Australian Chapter and New Zealand), Soil Science Society, Auckland. 2005;A13.
13. El Mouine Y, El Hamdi A, Morarech M, Kacimi I, Touzani M, Mohsine I, Tiouiouine A, Ouardi J, Zouahri A, Yachou H, Dakak H. Landfill pollution plume survey in the Moroccan Tadla using spontaneous potential. Water. 2021;13(7):910.
14. Ajani OO, Adagunodo TA, Adeniji AA, Fashae B, Omeje M, Adewoyin OO. Investigation of groundwater contamination from leachate migration: a case study of Bowen University dumpsite, Nigeria. InIOP Conference Series: Earth and Environmental Science. 2021;655;(1):012069. IOP Publishing.
15. Reynolds JM. An introduction to applied and environmental geophysics. John Wiley and Sons ltd., London UK. Second Edition. 1998;423.
16. Telford MW, Geldert LP, Sheriff RE. Applied geophysics second edition, cambridge university press. 2001;343
17. Loke MH. Tutorial: 2D and 3D electrical imaging surveys; 2014. Available at www.geotomosoft.com
18. Karous M, Hjelt SE. Linear filtering of VLF dip-angle measurements, Geoph. Prospecting. 1983;31:782-794.
19. Sharma SP, Baranwal VC. Delineation of ground water-bearing fracture zones in a hard rock area integrating very low frequency electromagnetic and resistivity data. Journal of Applied Geophysics. 2005;57:155-166.
20. Benson A, Payne K, Stubben M. Mapping groundwater contamination using dc resistivity and VLF geophysical methods -A case study. Geophysics. 1997;62(1):80-86.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/68353