Journal of NAMP 71, (2025) 173-186

The Nigerian Association of Mathematical Physics

Journal homepage: https://nampjournals.org.ng

INTEGRATED GEOPHYSICAL INVESTIGATION OF POLLUTION EXTENT IN A CEMETERY ENVIRONMENT: A CASE STUDY OF THE SECOND CEMETERY, BENIN CITY, SOUTH-SOUTH NIGERIA.

[1]IYERE P. S*. AND [1]TUABOBOH, P. O.

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

ARTICLE INFO

Article history:
Received xxxxx
Revised xxxxx
Accepted xxxxx
Available online xxxxx

Keywords:
Leachate, Unconsolidated soils, Anomaly detection, VLF-EM profiling, Electrical Resistivity Tomography (ERT), Groundwater contamination

ABSTRACT

This study applied Very Low Frequency Electromagnetic (VLF-EM) profiling and Electrical Resistivity Tomography (ERT) to investigate potential subsurface contamination within a cemetery environment in Benin City, Nigeria. Conductive anomalies detected from the VLF-EM survey were further examined using two-dimensional resistivity imaging. The ERT results revealed zones of markedly low resistivity (1–120 Ωm), characteristic of leachate-saturated, unconsolidated sandy soils. Several contaminant plumes were delineated, extending to depths of approximately 3–12 m, with some migrating downward toward the shallow aquifers that supply water to surrounding residential communities. These findings raise concerns regarding the potential degradation of groundwater quality in the area. The integrated VLF-EM/ERT approach proved effective in identifying conductive anomalies, enhancing interpretational confidence, and improving subsurface delineation within this complex burial setting.

1 INTRODUCTION

Cemeteries are increasingly recognized as potential sources of soil and groundwater contamination due to the release and migration of decomposition products, particularly in shallow groundwater environments [1]. Although flowing surface water is generally less susceptible to contamination, subsurface systems may retain or transmit leachates depending on local hydrogeological conditions. As urban areas expand and burial grounds become embedded within residential settings, the need to understand subsurface impacts has become more critical. Near-surface geophysical methods have proven effective for groundwater investigations, offering non-invasive approaches to mapping aquifer geometry, confining layers, and zones of altered subsurface conductivity associated with contamination [2], [3].

*Corresponding author: IYERE P. S

E-mail address: persyl.007@gmail.com

https://doi.org/10.60787/jnamp.vol71no.605

In contrast to direct hydrochemical sampling which is costly, intrusive, and often restricted in burial environments electrical and electromagnetic surveys provide continuous spatial coverage and improved interpretability, making them suitable for cemetery studies.

Previous research across Europe, Africa, and other regions reports elevated concentrations of ions, organic compounds, and microbial contaminants in groundwater near cemeteries, though contamination levels vary with soil permeability, burial density, and depth to the water table [4], [10], [24], [28], [31]. High-permeability sandy formations and shallow unsaturated zones have been particularly associated with enhanced leachate migration [30], [31]. In Nigeria, studies from Benin City and other urban centers indicate that wells situated near cemeteries often exceed WHO limits for heavy metals and bacteriological parameters, highlighting persistent risks to groundwater quality [40], [41], [44]. Geophysical investigations, especially electrical resistivity tomography (ERT), have further identified low-resistivity anomalies that correlate with leachate-impacted zones [42], [43].

Despite these advances, significant gaps remain. Many studies rely solely on point-based water quality assessments or shallow resistivity imaging without integrating multiple geophysical techniques or considering deeper lithological controls on contaminant transport. As a result, spatial patterns of leachate migration and their interaction with groundwater flow systems remain poorly constrained, particularly in Nigerian urban cemeteries.

This study addresses these gaps by employing an integrated geophysical approach combining VLF-EM profiling and 2D electrical resistivity imaging to map subsurface structures and delineate potential contaminant pathways within a major cemetery in Benin City. Through this multi-method investigation, the research aims to enhance understanding of cemetery-related impacts on the subsurface environment and provide evidence to support improved groundwater protection and environmental management.

2. MATERIALS AND METHODS

2.1 STUDY AREA

The study was conducted in Benin City, the capital of Edo State, located in the Mid-Western region of Nigeria (Figure 1). The city lies between latitudes 6°20´–6°58´N and longitudes 5°35´–5°41´E. Edo State is bordered by Kogi State to the north, Ondo State to the west, and Delta State to the east and south. Benin City falls within the Sub-Humid Tropical Zone, with an average temperature of approximately 27°C and annual rainfall exceeding 2000 mm [32].

Benin City experiences two main seasons: a wet season from March to October and a dry season from November to February. Seasonal rainfall variations are influenced by the Inter-Tropical Discontinuity (ITD), with peaks in July and September, separated by a brief “August Break.” The dry season corresponds to minimal precipitation, primarily in December and January. Prevailing winds are dominated by the tropical maritime air mass, supplemented by the tropical continental air mass. Monthly rainfall is typically highest between May and October [33].

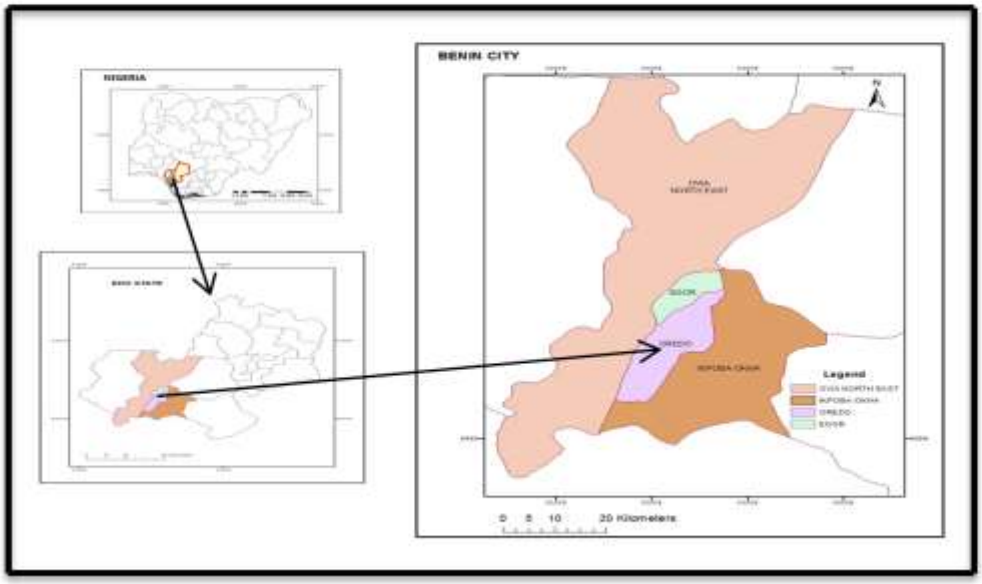

Figure 1: Study Area Map Showing Benin City with Four Local Government Areas.

2.2 Geophysical Surveys

An integrated geophysical approach combining Very Low Frequency Electromagnetic (VLF-EM) profiling and Electrical Resistivity Tomography (ERT) was employed to delineate subsurface structures and potential contaminant pathways within the cemetery.

An integrated geophysical approach combining Very Low Frequency Electromagnetic (VLF-EM) profiling and Electrical Resistivity Tomography (ERT) was employed to delineate subsurface structures and identify potential contaminant migration pathways within the study area. This approach is consistent with geoforensic and environmental applications in which electromagnetic, electrical, and radar methods have been used to detect buried materials and map conductive anomalies associated with anthropogenic processes (e.g., [34]). In this study, VLF-EM and ERT were applied to characterize conductive plumes and evaluate the movement of contaminants from the lateritic surface layer into the underlying sandy formation.

2.2.1 VLF-EM Survey

The VLF-EM method was adopted as a preliminary reconnaissance tool due to its rapid acquisition capability and sensitivity to conductive structures such as fractures, faults, and leachate-impacted zones (e.g., [35]). Unlike active EM systems that require an artificial transmitter, the VLF approach utilizes signals from existing radio transmitters operating between 15 and 25 kHz (e.g., [36]). These signals induce secondary electromagnetic fields within the subsurface, enabling the detection of conductive anomalies.

A) Data Acquisition

A preliminary survey was conducted using an ABEM WADI VLF receiver along sixteen (16) parallel traverses, each measuring 100 m in length. The traverses were oriented in the east–west direction, with 2 m spacing between profiles and 5 m station intervals. The instrument recorded both the real and imaginary components of the VLF response, providing the basis for identifying near-vertical and inclined conductive bodies for subsequent detailed investigation.

B) Data Processing and Interpretation

Processing involved filtering the real and imaginary components using the MATLAB-based MGUI software. Filtered real-component contour maps were generated in Surfer 11.0, and 2D VLF pseudosections were produced using KHFFILT. Interpretation relied on the combined assessment of the filtered real values where positive peaks indicated conductive features and the pseudosections, which highlighted shallow conductive anomalies. These anomalies were interpreted as potential leachate plumes, consistent with both field observations and geochemical evidence.

2.2.2 Electrical Resistivity Tomography (ERT)

Following the reconnaissance survey, detailed subsurface imaging was performed using Electrical Resistivity Tomography. The dipole–dipole array configuration was selected for its high sensitivity to lateral resistivity contrasts, making it particularly effective for detecting horizontal discontinuities and mapping laterally extensive conductive zones associated with contaminant transport (e.g., [37]). Although less sensitive to vertical variations, the array offers superior lateral resolution, which is essential in identifying plume geometry and boundaries.

2.2.3 Inversion and Modeling

ERT data were inverted using the standard resistivity inversion software **RES2DINV** to produce two-dimensional (2D) subsurface models. Measured resistivity values were converted into apparent resistivity distributions, allowing the identification of conductive zones associated with leachate infiltration. These models facilitated the interpretation of plume geometry, spatial extent, and potential migration pathways.

3. RESULTS AND DISCUSSION

3.1 VLF-EM Survey Results

The VLF-EM survey provided an initial reconnaissance of subsurface conductive features within the cemetery. Given the presence of unmarked graves, this step was crucial to delineate both marked and unmarked burial sites, allowing targeted Electrical Resistivity Tomography (ERT) profiling in areas with higher probabilities of conductive anomalies.

Filtered real components of the VLF-EM data were processed and visualized in Surfer 11.0, generating color-shaded contour maps for each traverse. Conductive zones appeared as blue (negative values), while resistive zones appeared as red (positive values). Simultaneous plotting of filtered real and imaginary components in MATLAB (MGUI) improved the interpretative accuracy by highlighting sharp, localized positive peaks typical of near-surface conductive bodies, including leachate plumes and buried metallic objects (Figures 2–6).

Karous–Hjelt (KHFFILT) filtered pseudosections emphasized shallow conductors and guided the selection of representative anomalies for subsequent ERT surveys (Figure 7). Conductive zones were inferred to represent either geologic conductors (clayey or saturated layers) or anthropogenic features (leachate plumes or metallic inclusions).

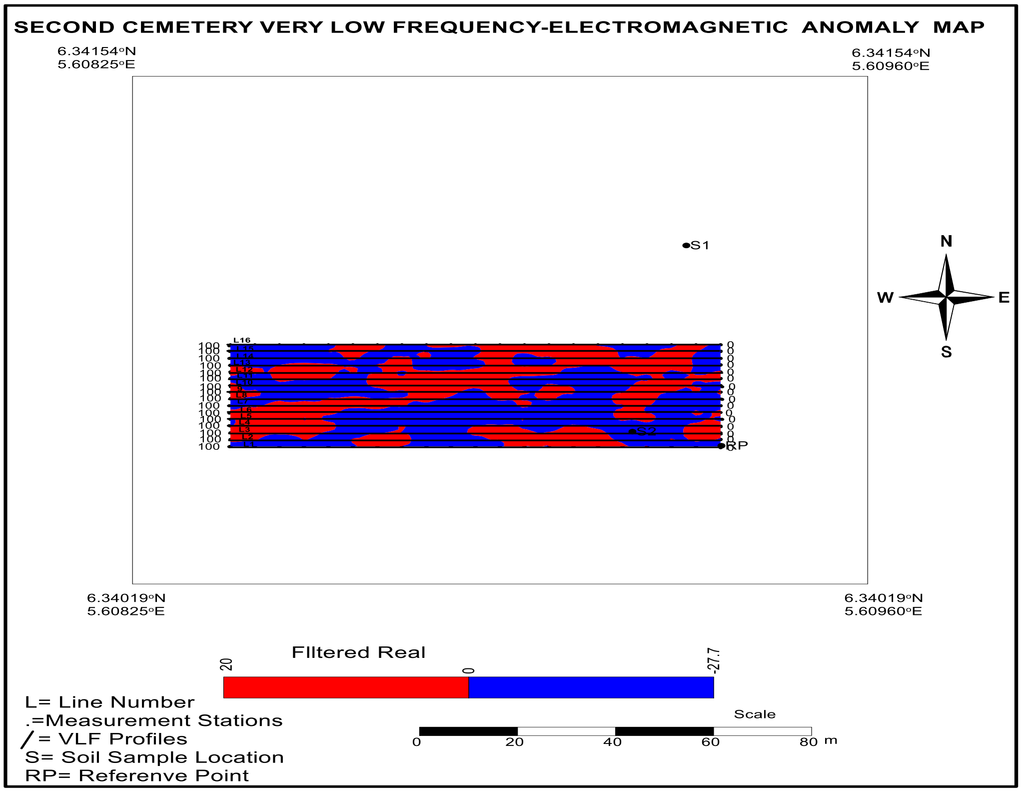

Figure 2: VLF Map for Second Cemetery

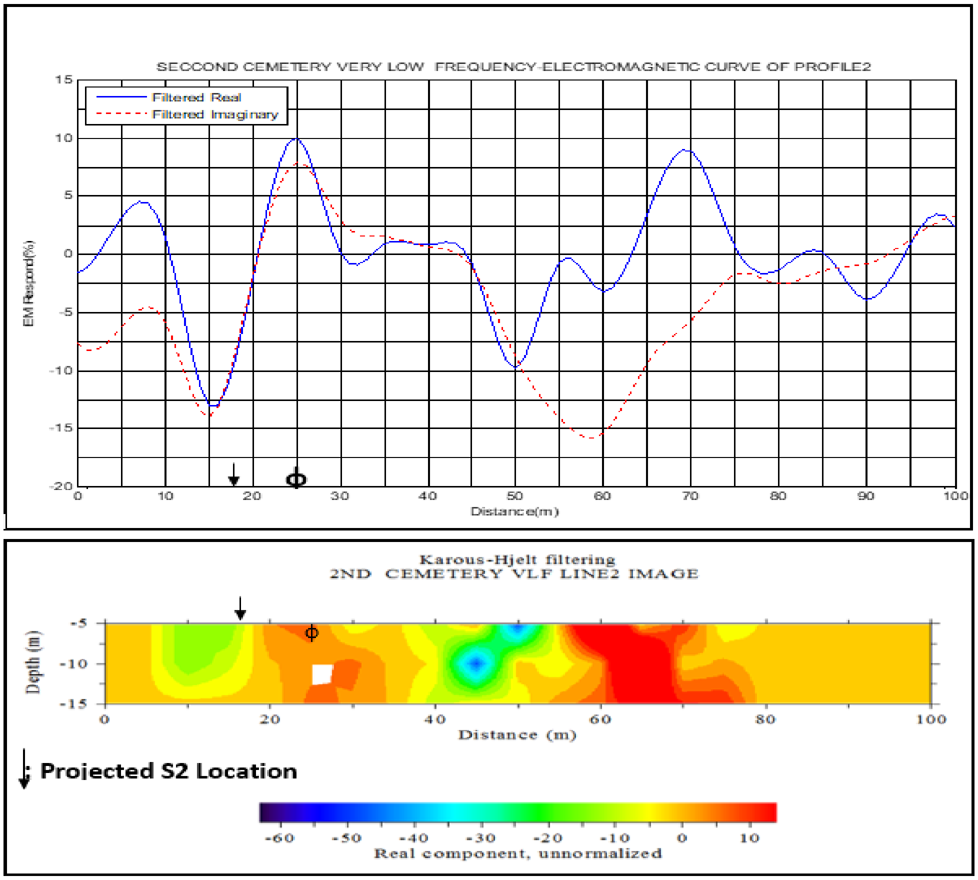

Figure 3: VLF Curve Interpretations for Second Cemetery, Profile 2

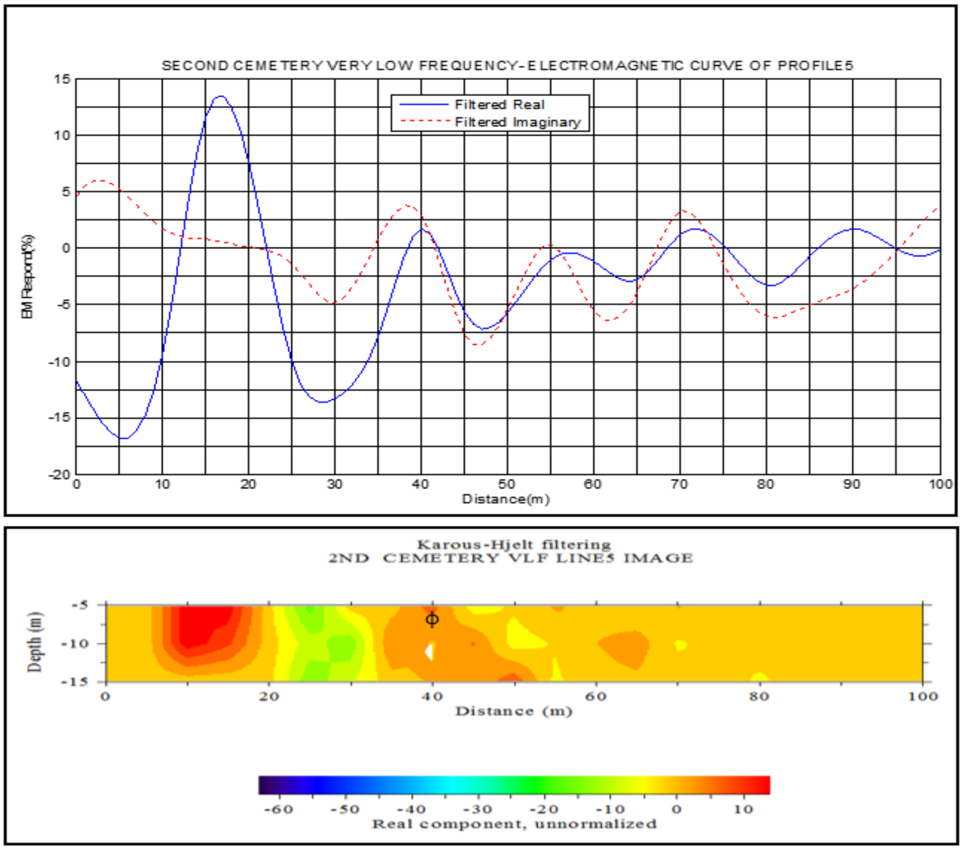

Figure 4: VLF Curve Interpretations for Second Cemetery, Profile 5

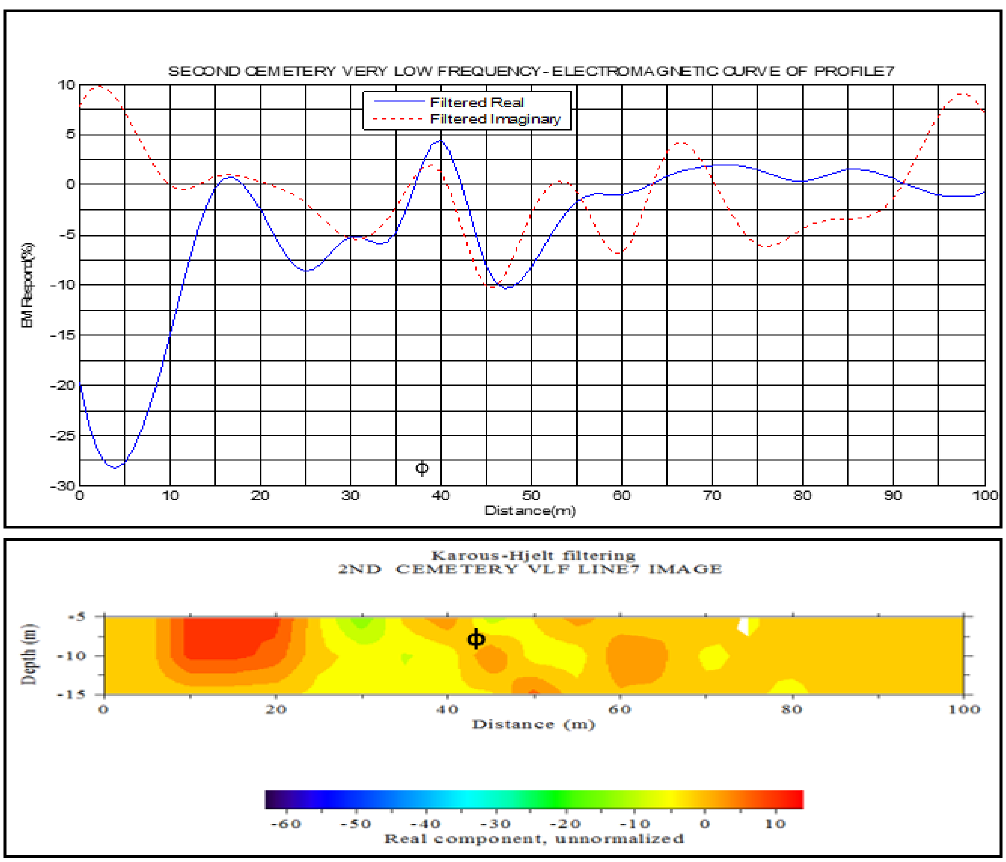

Figure 5: VLF Curve Interpretations for Second Cemetery, Profile 7

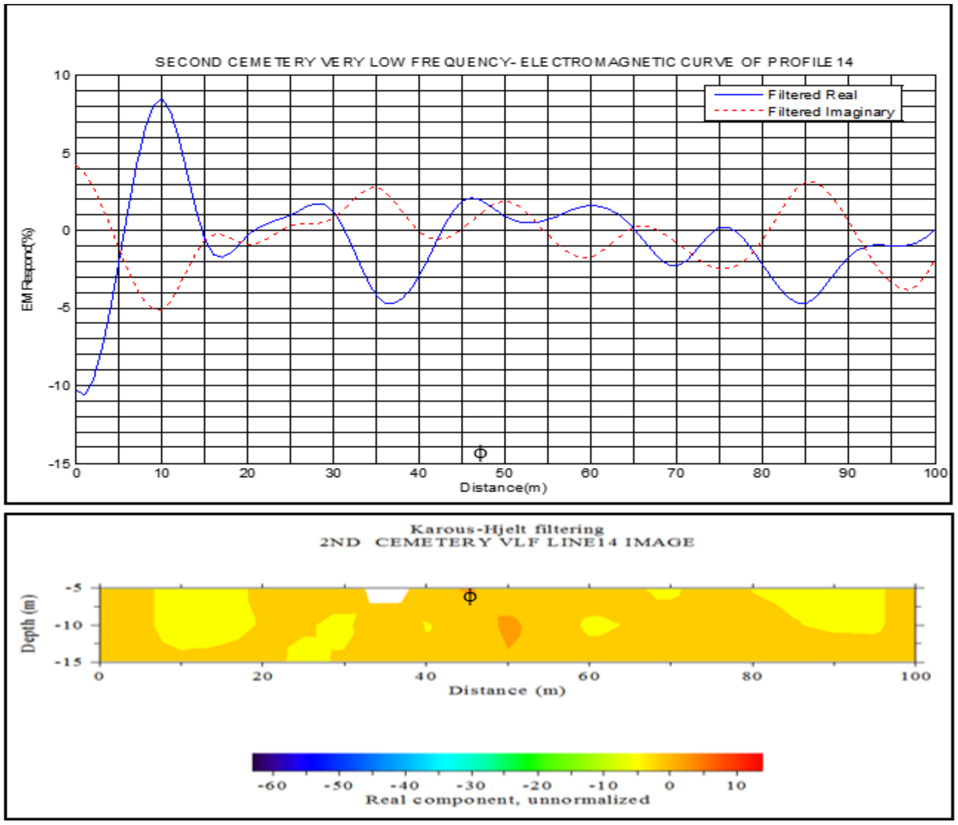

Figure 6: VLF Curve Interpretations for Second Cemetery, Profile 14

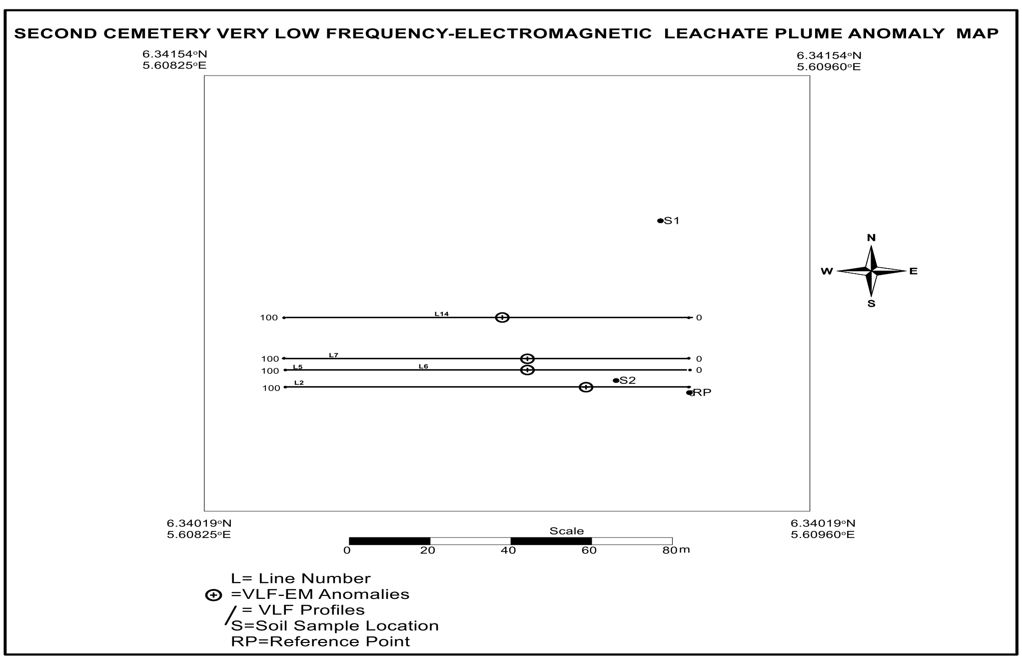

Figure 7: Predicted conductive zones Location Map for the Cemetery

3.2 ERT Survey Results

ERT profiles were positioned to intersect VLF-EM-identified anomalies, ensuring full coverage of suspected leachate plumes. A uniform 5 m inter-electrode spacing provided adequate resolution for capturing the depth, lateral extent, and geometry of conductive zones. The ERT data were systematically indexed, georeferenced, and correlated with VLF-EM anomalies for integrated interpretation (Figure 8).

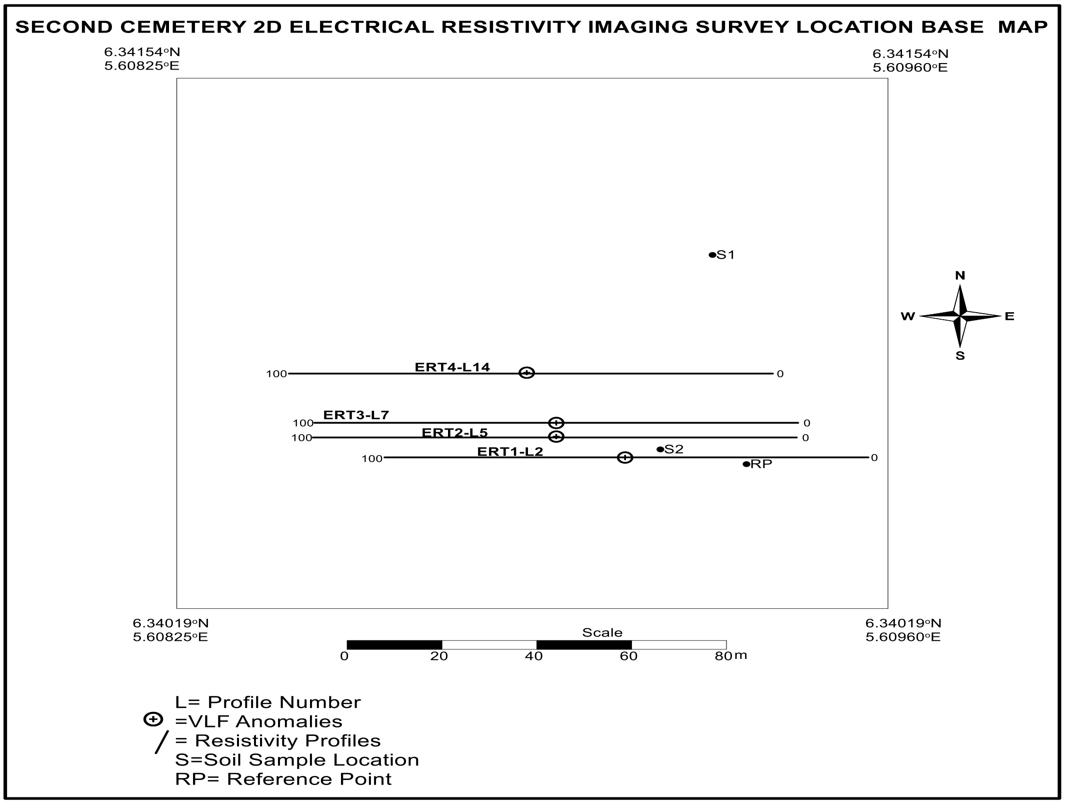

Figure 8: Electrical Imaging Survey Base Map of the cemetery

3.2.1 Resistivity Characteristics

Surface materials consisted predominantly of lateritic soil and laterite, with resistivity ranges of 120–750 Ωm and 800–1500 Ωm, respectively [35]. These low-permeability soils slow leachate migration, whereas leachate-saturated zones exhibit reduced resistivity, typically between 1–120 Ωm.

ERT models revealed conductive zones corresponding to VLF-EM anomalies:

- ERT1-L2: Two plumes (ERT1-L2-PL1 and PL2) with resistivities of 96 Ωm. PL1 extends 4.13–7.99 m depth (vertical 3.86 m, horizontal 7.3 m). PL2 extends 2.65–7.99 m (vertical 5.34 m, horizontal 10.1 m) (Figure 9).
- ERT2-L5: One plume (ERT2-L2-PL) with resistivity 91 Ωm, located 2.20–5.71 m depth, vertical and horizontal extents 3.51 m and 3.70 m, respectively (Figure 10).
- ERT3-L7: Conductive zone (ERT3-L7-PL) with resistivity 103 Ωm, 4.62–7.99 m depth, vertical 3.37 m, horizontal 5.0 m (Figure 11).
- ERT4-L14: Partial plume observed between 42.5–52.5 m, top at 7.99 m depth, consistent with VLF-EM pseudosection (Figure 12).

The spatial correlation between VLF-EM and ERT results confirms that the low-resistivity zones are consistent with leachate-saturated pathways, supporting the integrated geophysical approach for identifying potential contaminant migration.

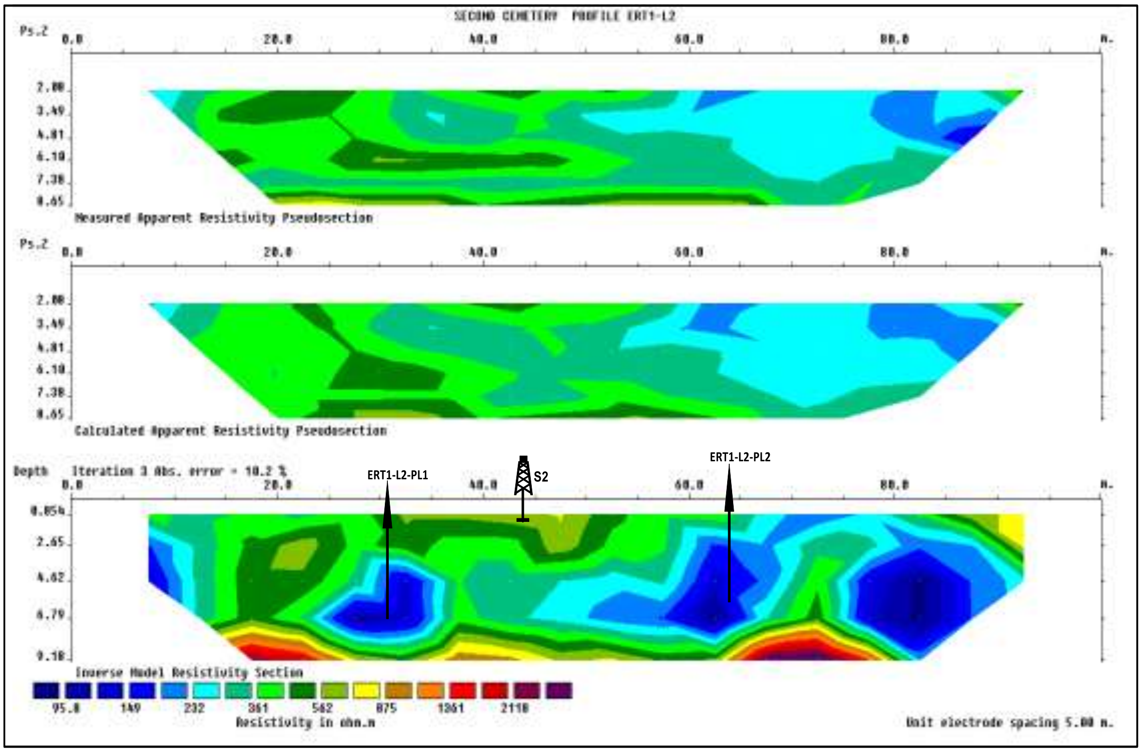

Figure 9: 2D Geo-electrical Image of the Cemetery, Profile ERT1-L2

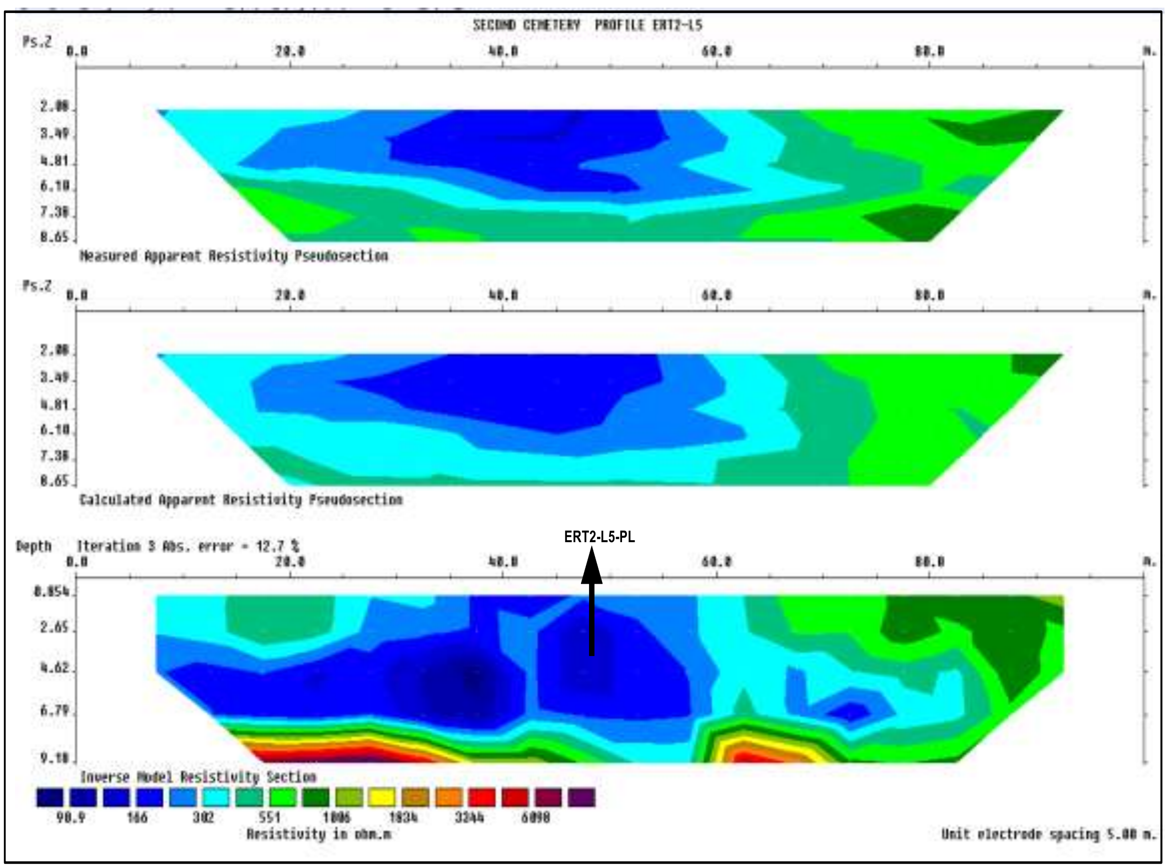

Figure 10: 2D Geo-electrical Image of the Cemetery, Profile ERT2-L5

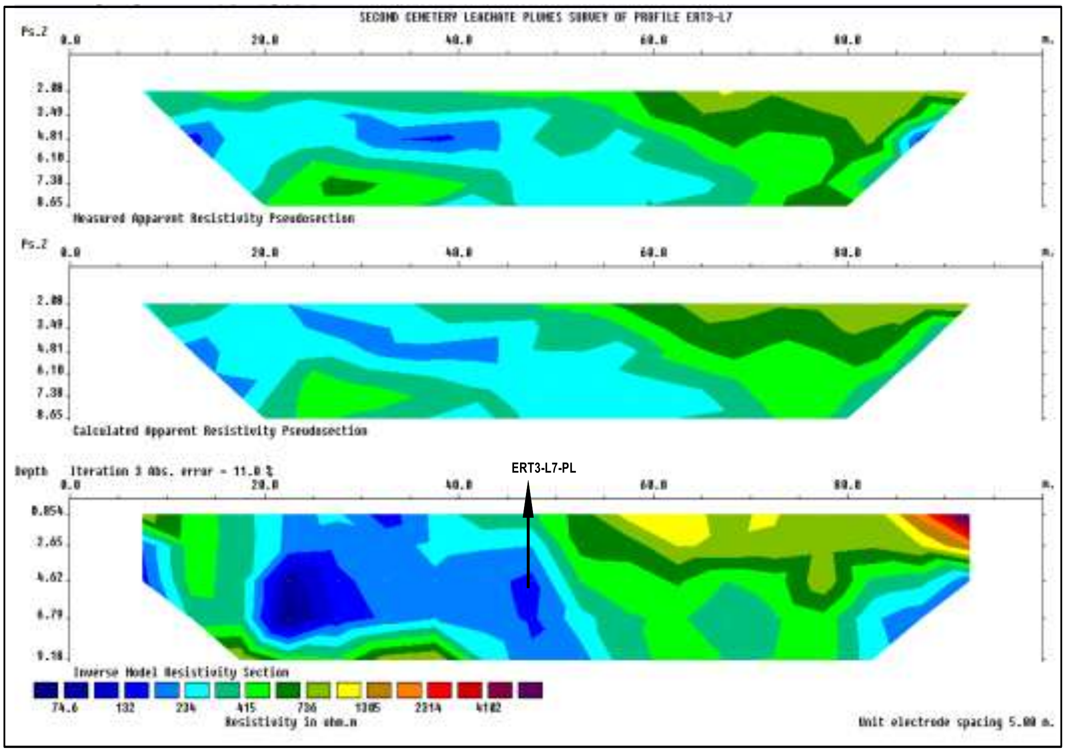

Figure 11: 2D Geo-electrical Image of the Cemetery, Profile ERT3-L7

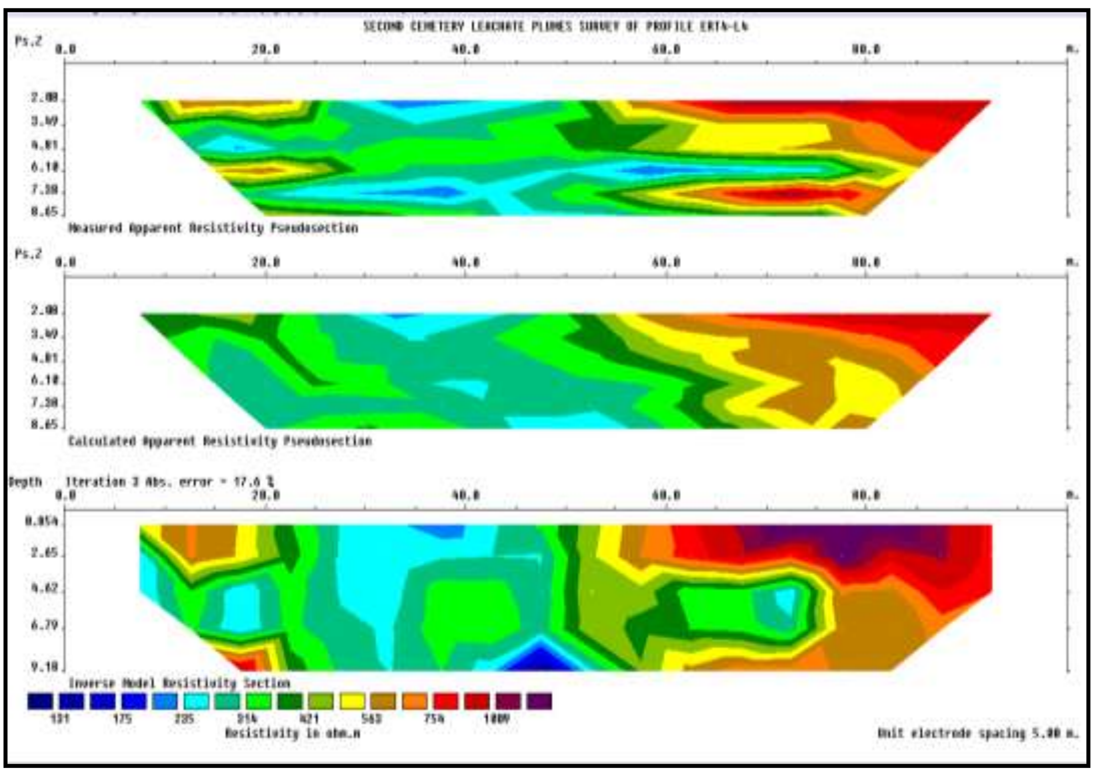

Figure 12: 2D Geo-electrical Image of the Cemetery, Profile ERT4-L14

DISCUSSION

The combined VLF-EM and ERT surveys effectively delineated conductive anomalies, interpreted as leachate plumes originating from burial sites. VLF-EM provided rapid detection of near-surface conductive features, while ERT accurately quantified their depth, geometry, and lateral extent.

Resistivity values within the range of 1–120 Ωm align with literature reports for leachate-impacted soils [39], supporting the interpretation of these zones as contamination pathways rather than natural lithological variability. The integration of these methods reduced interpretative uncertainty and allowed more precise subsurface delineation.
Limitations include the inability to chemically verify plume composition without soil or water sampling. Nonetheless, the methodology provides a cost-effective, non-invasive means to map potential contaminant migration, particularly in sensitive environments like cemeteries. The study highlights the value of integrated geophysical techniques for environmental monitoring, with implications for groundwater protection in urban areas.

CONCLUSION

This study demonstrates the effectiveness of integrating Very Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity Tomography (ERT) methods for assessing subsurface contamination in cemetery environments. The combined geophysical approach enabled the identification, mapping, and delineation of conductive leachate plumes at the Second Cemetery, Benin City, providing detailed insights into their spatial distribution, depth, vertical extent, and resistivity characteristics.
Resistivity values ranging from 1 Ωm to 120 Ωm, in areas with minimal clay content, were interpreted as indicative of leachate-contaminated zones. These anomalies are attributed to the decomposition of buried human remains and associated funerary materials. The observed heterogeneity in conductivity suggests variable contaminant concentrations, with some plumes extending toward the underlying sandy strata, posing potential risks to groundwater quality.
The findings underscore the importance of situating boreholes at depths exceeding 40 m in the study area to minimize contamination risks from near-surface plume migration. Overall, the results confirm that the integrated VLF-EM and ERT approach provides a cost-effective, non-invasive, and reliable method for monitoring cemetery-induced pollution. The study also generates critical baseline data to support environmental protection, groundwater management, and urban planning. This research highlights the growing relevance of environmental geoforensics in Nigeria, demonstrating its successful application in evaluating contamination processes associated with burial and decomposition activities in urban cemetery settings.

REFERENCES

[1] Rodrigues, L., 2002. Thesis presented for the degree of Master in Hydrobiology by the University of Porto, Oporto, Portugal.

[2] Benson, A., Payne, K. and Stubben, M., 1997. Mapping groundwater contamination using dc resistivity and VLF geophysical methods -a case study, *Geophysics*, 62(1), 80-86.

[3] Kalik, C. and Kaya, M.A. 2001. Investigation of Groundwater contamination using Electric and Electromagnetic methods at an open waste disposal site. A case study from Sparta, Turkey. Environmental Geology 40(6) springer-verlag.

[4] Schraps, W.G., 1972. The relevance of soil filtration properties for the installation of cemeteries, 16, 225-229

[5] Zychowski, J., Lach, J. and Kolber, M., 2000a. State and anthropogenic changes of water quality in Poland. Wydawnictwo Uniwersytetu Lodzkiego, Lodz. 1, 249-261.

[6] Dumble, P. and Ruxton, C., 2000. Guidance on monitoring of landfill leachate, groundwater and surface water. Environment Agency, R&D Report. www.environment-

agency.gov.ukhttp://publications.environment-agency.gov.uk/pdf/SCHO0404BGLA-e-e.pdf. Accessed 12 June 2013.

[7] Creely, K.S., 2004. Infection risks and embalming. Research Report TM/04/01. www. iom-world.org/pubs/IOM_TM0401.pdf. Accessed 15 June 2013.

[8] Environment Agency – UK, 2002. Assessing the groundwater pollution potential of cemetery developments. National Groundwater and Contaminated Land Centre. Bristol BS32 4UD, United Kingdom, pp. 1–20 http://www.cas.org/.

[9] Dent, B.B., 2005. 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, Nov 30 – Dec 2, 2005, paper A13 (pdf).

[10] Knight, M.J. and Dent, B.B., 1998. Sustainability of waste and groundwater management systems. Proceedings of International Association of Hydrogeologists Sustainable Solutions Conference, Melbourne, February, pp. 359–374.

[11] Bastianon, D., Matos, B.A., Aquino, W.F., Pacheco, A. and Mendes, J.M.B., 2000. Geophysical surveying to investigate groundwater contamination by a cemetery. The Annual Meeting of the Environmental and Engineering Geophysical Society. Arlington, pp. 709–718.

[12] Braz, V.N., Silva, L.C.E. and Menezes, L.B.C., 2000. 1st joint World Congress on Groundwater, 2000, Fortaleza. Anais, Fortaleza, ABAS.

[13] Chan, G.S., Scafe, M. and Emami, S., 1992. Cemeteries and groundwater: An examination of the potential contamination of groundwater by preservatives containing formaldehyde. Ontario Ministry of the Environment, Water Resources Branch Publication PIBS, 1813, pp. 1–11.

[14] Zychowski, J., Lach, J. and Kolber, M., 2006a. The effect of bedding of mass graves from WW2 on chemical composition of groundwaters. In Ziutkiewicz, M. (ed.), State and anthropogenic changes of water quality in Poland. 5, 349-357.

[15] Zychowski, J., Pawlikowski, M. and Lach, J., 2006b. Products from decomposition of organie compounds, example of a mass grave in Niepołomice near Cracow, Kwartalnik AGH, Kraków, Geologia, 32 (2): 203-224.

[16] Zychowski, J., Lach, J. and Kolber, M., 2003. The occurrence of amino acids of glycine, leucine and isoleucine contents in the groundwater in cemeteries located on different bedrock. Geographia Polonica. 51 (11): 962-963.

[17] Dent, B.B., 2000b. Decay products in cemetery ground waters. Geology and Sustainable Development: Challenges for the Third Millennium. 31st International Geological Congress, Rio de Janeiro. pp. 6–17.

[18] Dent, B.B., 2002. The hydrogeological context of Cemetery operations and planning in Australia. Unpublished thesis submitted to the University of Technology, Sydney. 13-45

[19] Trick, J.K., Williams, G.M., Noy, D.J., Moore, Y. and Reeder, S., 1999. Pollution potential of cemeteries: Impact of the 19th century Carter Gate Cemetery, Nottingham. British

Geological Survey, Keyworth, Nottingham, United Kingdom (Technical Report WE/ 99/4, Environment Agency Technical Report NC/99/24), pp. 1–34.

[20] Rodrigues, L. and Pacheco, A., 2003. Groundwater contamination from cemeteries cases of study. International Symposium Environment 2010 Situation and Perspectives for the European Union, Porto 6–10 May, Portugal.

[21] Fisher, G.J. and Croukamp, L., 1993. Ground Water Contamination and its Consequences, Resulting from the Indiscriminate Placing of Cemeteries in the Third World Context. Conference Africa Needs Groundwater. University of the Witwatersrand, Johannesburg, South Africa.

[22] Alfoldi, L. and Croukamp, L., 1988. Problems and biological treatment, state of the art report. Watscitech 20 (3), 1–131.

[23] Bitton, G., Farrah, S.R., Ruskin, R.H., Butner, J. and Chou, Y.J., 1983. Survival of pathogenic and indicator organisms in groundwater. Ground Water 21 (4), 405–410.

[24] Zychowski, J., 2012. Impact of Cemeteries on groundwater Chemistry. Catena Sciverse Science Direct. (93), 29-37.

[25] Morgan, O., 2004. Infectious disease risks from dead bodies following natural disasters. Revista Panamericana de Salud Pública 15 (5), 307–312.

[26] Ucisik, A.S. and Rushbrook, P., 1998. 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), pp. 1–11.

[27] Rotherham, J., 2011. The Bereavement Services Management Centre in the United Kingdom, The Crematorium Lodge, Brimington, online. http:// bsmconline.org.uk/research.htm.

[28] Van Haaren, F.W.J., 1951. Cemeteries as sources of groundwater contamination. Moorman's Periodieke Pers, Den Haag, 35 (16), 167–172.

[29] Bouwer, H., 1978. Groundwater Hydrology. McGraw-Hill, Inc., New York, NY, pp. 1–480.

[30] Hanzlick, R., 1994. Embalming, body preparation, burial and disinterment. An overview for forensic pathologists. The American Journal of Forensic Medicine and Pathology 15, 122–131.

[31] Gray, D.A., Mather, J.D. and Harrison, J.B., 1974. Review of groundwater pollution from waste disposal sites in England and Wales with provisional guidelines for future site selection. The Quarterly Journal of Engineering Geology 7, 181–196.

[32] Eseigbe J.O., Ufuah M.E., Ifatimehin O.O., 2007. Sources of groundwater resource contamination in Benin metropolis, Edo State. Confluence Journal of Environmental Studies 2:41-47.

[33] Eseigbe, J.O. and Oisasoje, M.O., 2012. Aspects of Gully Erosion in Benin City, Edo State Nigeria. Research on Humanities and Social Sciences. 2(7), 21-26.

[34] Hansen J. D. and Pringle J.K., 2013. Comparison of Magnetic, Electrical and Ground Penetrating Radar Surveys to Detect Buried Forensic Objects in Semi-urban and Domestic Patio Environments, Geological Society, London, Special Publications. 13.

[35] Reynolds, J.M., 1998: An Introduction to Applied and Environmental Geophysics. John Wiley and Sons ltd., London UK. Second Edition. 423

[36] Telford, M.W., Geldert, L.P. and Sheriff, R.E., 2001. Applied Geophysics Second Edition, Cambridge University Press, 343

[37] Loke, M.H., 2014. Tutorial: 2D and 3D electrical imaging surveys. Available at www.geotomosoft.com.

[38] Karous, M. and Hjelt, S.E., 1983. Linear filtering of VLF dip-angle measurements, Geoph. Prospecting, 31, 782-794.

[39] Thomas, T., 2002. 2D Resistivity and Time-Domain EM- aquifer mapping; a Case Study, Norh of lake Naivasha, Kenya.

[40] Ezenwa, I. M., Omoigberale, M., Abulu, R. R., Biose, E., Okpara, B. B., & Uyi, O. (2023). Burial leakage: A human-accustomed groundwater contaminant sources and health hazards study near cemeteries in Benin City, Nigeria. *PLOS ONE, 18*(12).

[41] Ilaboya, I. R., Omosefe, E. B., & Ambrose-Agabi, E. E. (2024). Exploring the impact of cemetery leachates on groundwater quality in Benin City metropolis, South-South Nigeria. *Journal of Energy Technology and Environment*, *6*(2), 1-19.

[42] Ambrose-Agabi, E. E., Izinyon, C. O., & Agbonaye, A. I. (2024). Evaluating groundwater contamination in the vicinity of a cemetery for environmental concerns. *NIPES Journal of Science and Technology Research*, *6*(2), 270-280.

[43] Idehen, O. (2020). A comparative investigation of groundwater contamination in typical dumpsites and cemetery using ERT and physicochemical analysis of water in Benin Metropolis, Nigeria. *Journal of Geoscience and Environment Protection*, *8*, 72-85.

[44] Afangideh, C. B., & Udokpoh, U. U. (2022). Environmental impact assessment of groundwater pollution within cemetery surroundings. *Indian Journal of Engineering*, *19*(51), 100-115.