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Near-Surface Geophysical Methods for Assessing Waste Disposal Impacts in Niger Delta Communities: A Narrative Review

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ABSTRACT

Improper waste disposal can affect soil, shallow groundwater and the physical integrity of near-surface materials in the Niger Delta. Near-surface geophysical methods offer non-invasive means of investigating subsurface contrasts that may be associated with buried waste, leachate migration and changes in sediment properties. This paper presents a narrative review of the use and limitations of electrical resistivity methods, ground-penetrating radar (GPR), magnetometry, electromagnetic (EM) profiling and seismic methods for environmental waste assessment, with emphasis on their relevance to Niger Delta conditions. The review draws on published Nigerian case studies, methodological literature on landfill investigations and authoritative technical guidance. Studies were identified through targeted searches of scholarly and technical sources using combinations of terms relating to geophysics, landfill, dumpsite, leachate, groundwater contamination and Nigeria/Niger Delta. Eligible sources were compared according to method, target, geological setting, reported interpretation and validation evidence. The reviewed literature indicates that low-resistivity or high-conductivity zones can help delineate conductive subsurface features, but these responses are not unique to leachate and may also arise from clay-rich sediments or saline groundwater. GPR can resolve shallow interfaces and buried objects where electrical conductivity is sufficiently low, while its penetration is commonly restricted in conductive clayey and saline materials. Magnetometry is useful for locating ferrous objects but does not measure leachate or contaminant concentration. The evidence therefore supports the use of geophysics as a screening and site-characterisation tool rather than a stand-alone test of contamination. Integrated interpretation with borehole information and hydrochemical analyses is necessary before contamination is confirmed or remediation decisions are made. The review is limited by its narrative, non-systematic selection of sources and the scarcity of directly comparable Niger Delta waste-site geophysical studies.

INTRODUCTION

The Niger Delta is a low-lying sedimentary and deltaic environment characterised by a complex arrangement of alluvial deposits, coastal plain sands, silts, clays, wetlands, freshwater swamps and mangrove environments. Its communities depend substantially on groundwater, including shallow aquifers, while many settlements are exposed to flooding, saline-water intrusion, petroleum-related pressures, urban expansion and inadequate solid-waste infrastructure. These interacting pressures make the protection of soil and groundwater a significant environmental concern. Regional hydrogeological reviews identify waste leachate among several potential threats to shallow groundwater, alongside saline intrusion, sewage

disposal, petroleum activities and urbanisation (Abam & Nwankwoala, 2020).

Waste disposed of on or below the ground may generate leachate as water percolates through decomposing refuse. The resulting fluid can contain dissolved ions and organic constituents and may alter the electrical and dielectric properties of surrounding materials. The migration of leachate is influenced by waste composition, rainfall, groundwater level, sediment permeability, hydraulic gradients and the presence of preferential pathways. However, a geophysical anomaly is an indirect response to changes in physical properties; it does not, by itself, identify a chemical contaminant or establish that a water source is unsafe.

Near-surface geophysical methods can complement conventional environmental investigations by providing spatial information between widely spaced boreholes. Electrical resistivity methods respond to contrasts in bulk electrical properties; GPR responds to contrasts in electromagnetic properties; magnetometry responds to variations in the Earth's magnetic field; and seismic methods respond to elastic-property contrasts. Their usefulness depends on the target, survey design, depth of investigation, resolution and geological setting. In the Niger Delta, clay content, pore-water salinity, moisture variation, peat and seasonal flooding can produce responses similar to those attributed to waste-related contamination.

Published Nigerian studies demonstrate the application of geoelectrical and integrated methods to waste-site investigations, although several prominent examples are from southwestern Nigeria rather than the Niger Delta. For example, Oladunjoye et al. (2011) investigated an abandoned waste-dump site in Ibadan using geoelectrical imaging, while Okpoli (2013) used two-dimensional electrical resistivity tomography to delineate conductive zones around a landfill in Iku, Ikare-Akoko. Adepelumi et al. (2005) combined electrical resistivity and electromagnetic surveys around oxidation sewage ponds in southwestern Nigeria. These studies provide methodological evidence relevant to Nigerian conditions, but their geological settings should not be treated as direct equivalents of Niger Delta coastal and deltaic sediments.

A key gap is therefore not simply whether geophysical methods can detect anomalies, but how confidently those anomalies can be attributed to waste disposal under the heterogeneous and often conductive subsurface conditions of Niger Delta communities. This review addresses that gap by critically comparing method capabilities, geological confounders, depth and resolution constraints, and the need for independent validation.

The aim of this paper is to critically review published evidence on the capabilities and limitations of near-surface geophysical methods for assessing waste-disposal impacts on subsurface materials and groundwater vulnerability in Niger Delta communities.

REVIEW METHODOLOGY

Review Design and Information Sources

The paper adopts a narrative desk-review design. It synthesises published case studies and methodological literature relevant to geophysical investigation of waste-disposal sites, leachate migration and shallow groundwater. The source material available for this revision did not contain a documented database export, search log or screening record. Accordingly, the review is not presented as a systematic review, and no claim is made that all potentially relevant publications were identified.

For the revised synthesis, targeted searches were undertaken using combinations of the following terms: "waste disposal" OR "landfill" OR "dumpsite"; "leachate" OR "groundwater contamination"; "electrical resistivity" OR "electrical resistivity tomography" OR "ground penetrating radar" OR "magnetometry" OR "electromagnetic survey"; and "Nigeria" OR "Niger Delta". Scholarly search results and publisher or institutional records were consulted to check bibliographic details where available. Searches were focused on Nigerian field investigations and established methodological sources that explain the physical response and limitations of the methods.

Eligibility and Selection

Sources were considered relevant when they addressed at least one of the following: (a) geophysical investigation of a landfill, dumpsite, sewage pond or waste-affected site; (b) geophysical delineation of conductive or potentially contaminated subsurface zones; (c) the physical principles and limitations of a method used in environmental geophysics; or (d) hydrogeological conditions relevant to interpreting waste-related anomalies in the Niger Delta. Sources that did not provide an identifiable publication record or whose bibliographic details could not be independently established were not used as evidential support in the revised synthesis.

Data Extraction and Synthesis

For each retained source, the review considered the study location and geological context, geophysical method, target or inferred feature, principal interpretation, and whether the interpretation was supported by borehole, geological or hydrochemical information. The evidence was synthesised thematically rather than statistically because the studies differed in location, survey design, instrumentation, depth, geological setting and reporting. No pooled resistivity threshold or regional performance estimate was calculated. Tables 1 and 2 are literature-derived analytical summaries; they are not original field results.

Review Limitations

The review is narrative and non-systematic. It does not provide a complete reproducible screening count, formal risk-of-bias score or quantitative meta-analysis. The available literature also contains relatively few directly comparable geophysical investigations of waste sites in Niger Delta communities. Consequently, findings from other Nigerian geological settings and international landfill studies are used only to explain method behaviour, not as proof of region-wide performance.

NEAR-SURFACE GEOPHYSICAL METHODS AND THEIR ENVIRONMENTAL APPLICATIONS

Electrical Resistivity Methods

Electrical resistivity methods measure the resistance of subsurface materials to the flow of electrical current. In environmental investigations, vertical electrical sounding and two-dimensional electrical resistivity tomography (ERT) are used to identify lateral and vertical contrasts that may be associated with waste bodies, leachate-affected zones, lithological boundaries or groundwater conditions. Leachate containing dissolved ions can increase pore-water conductivity and reduce bulk resistivity. This makes conductive anomalies useful targets for further investigation.

Nigerian case studies illustrate the application of resistivity imaging around waste sites. Oladunjoye et al. (2011) reported geoelectrical imaging at an abandoned waste-dump site in Ibadan. Okpoli (2013) applied two-dimensional resistivity tomography at a landfill in Iku, Ikare-Akoko, and interpreted conductive zones around the waste repository. These studies demonstrate how resistivity sections can help identify spatially variable subsurface electrical properties. They do not establish a universal resistivity value for leachate in the Niger Delta.

The frequently quoted range of 1–20 Ωm should therefore not be treated as a diagnostic leachate threshold unless its origin, site conditions, inversion model and independent validation are explicitly documented. Low resistivity may reflect leachate, but it can also be caused by clay minerals, saline or brackish groundwater, high moisture content, conductive natural pore fluids or combinations of these factors. Conversely, a relatively resistive response does not necessarily exclude contamination where the waste or leachate is heterogeneous, the plume is narrow, or survey resolution is inadequate. Interpretation should be made against local background conditions and supported by borehole lithology and water chemistry.

Ground-Penetrating Radar

Ground-penetrating radar transmits high-frequency electromagnetic pulses into the ground and records reflections generated by contrasts in dielectric

permittivity and electrical conductivity. It can produce high-resolution images of shallow interfaces, buried objects, disturbed ground and some waste-body boundaries. Hyperbolic reflections may be generated by discrete objects, while disrupted or discontinuous reflectors may indicate heterogeneous or disturbed subsurface materials. These patterns are not unique to waste and require geological interpretation.

The principal limitation in the Niger Delta is attenuation in electrically conductive materials. Clay-rich sediments, saline pore water and saturated fine-grained deposits can absorb radar energy and reduce penetration depth. The US Environmental Protection Agency's technical guidance explains that conductive media attenuate radar signals and that GPR reflections do not have an automatic one-to-one correspondence with geological or hydrological properties (U.S. Environmental Protection Agency, n.d.). Thus, GPR may be useful in relatively dry, sandy or low-conductivity settings but may be ineffective or restricted to very shallow depths in saline or clay-rich locations.

Magnetometry

Magnetometry measures spatial variations in the Earth's magnetic field. Ferrous materials such as iron and steel can generate local magnetic anomalies, making the method useful for locating buried metallic debris or mapping parts of a waste body containing magnetic objects. It can provide rapid coverage over accessible terrain and may be used as a reconnaissance method before more detailed surveys.

Magnetic anomalies are not direct measurements of total waste volume, leachate movement, heavy-metal concentration or groundwater contamination. Non-ferrous metals, plastics and organic waste may produce little or no diagnostic magnetic response. Natural magnetic minerals, lateritic materials, buried infrastructure, fences, vehicles and other cultural features can also generate anomalies. Interpretation therefore requires careful site reconnaissance and, where possible, complementary methods.

Electromagnetic Profiling

Frequency-domain or time-domain electromagnetic methods estimate subsurface electrical conductivity without requiring direct electrode contact. They can support rapid lateral screening and help identify conductive zones that may warrant detailed ERT or sampling. Their response is influenced by instrument configuration, operating frequency, coil spacing, survey height, depth sensitivity and near-surface conditions. EM profiling should not be labelled categorically as less accurate than ERT or GPR: the methods measure different physical properties and serve different survey purposes. Accuracy depends on the target, calibration, data processing, inversion and validation.

Seismic Methods

Seismic refraction and related seismic methods provide information on subsurface elastic properties, commonly expressed through seismic-wave velocities. They may help characterise layering, compaction contrasts, weathered zones or mechanical conditions beneath and around waste deposits. However, high- or low-velocity zones cannot automatically be equated with fractures or leachate pathways. Velocity is affected by lithology, porosity, saturation, effective stress, degree of compaction and survey geometry. Claims about fractures require site-specific corroboration, such as borehole logs, outcrop evidence or other geotechnical information.

LITERATURE-DERIVED EVIDENCE AND COMPARATIVE SYNTHESIS

The studies summarised in Table 1 differ in location and purpose. The Nigerian examples provide evidence that geoelectrical and integrated geophysical methods have been used to investigate waste-related subsurface conditions. They do not form a homogeneous dataset from which a single Niger Delta resistivity range, detection depth or method ranking can be inferred.

Table 1: Table 1: Summary of Selected Geophysical and Hydrogeological Studies on Waste-Disposal Impacts and their Relevance to the Niger Delta

Study	Location / setting	Method or focus	Evidence relevant to this review	Transferability to Niger Delta
Adepelumi et al. (2005)	Oxidation sewage ponds, southwestern Nigeria; hard-rock setting	Electrical resistivity and electromagnetic surveys	Integrated surveys were used to investigate effluent-related soil conductivity contrasts and possible plume pathways.	Useful Nigerian methodological example; hard-rock geology differs from deltaic sediments.
Oladunjoye et al.	Abandoned waste	Geoelectrical	Shows application of	Supports method

(2011)	dump, Ibadan, southwestern Nigeria	imaging	electrical imaging to subsurface characterisation at a waste-dump site.	relevance, not direct regional calibration for Niger Delta soils.
Okpoli (2013)	Landfill at Iku, Ikare-Akoko, southwestern Nigeria	2-D electrical resistivity tomography	Interpreted conductive zones around the landfill, including reported conductive features extending into the shallow subsurface.	The reported depths and resistivity response are site-specific; basement setting differs from deltaic aquifers.
Soupios et al. (2007)	Landfill investigations; international methodological study	Integrated geophysical methods	Discusses the value of combining geophysical methods for waste-disposal area mapping.	Useful for method design; not Niger Delta field evidence.
Abam and Nwankwoala (2020)	Eastern Niger Delta hydrogeological review	Hydrogeological synthesis	Identifies waste leachate among multiple potential threats to shallow groundwater and describes regional hydrogeological complexity.	Direct regional context, but not a waste-site geophysical survey.
Odipe et al. (2018)	Ijemikin waste dump, Akure, southwestern Nigeria	2-D resistivity imaging, VES and hydrochemical analysis	Integrated geophysical and hydrochemical investigation provides an example of independent water-quality validation.	Demonstrates validation approach; geological setting is not the Niger Delta.

Interpreting Conductive Anomalies in Deltaic Environments

The principal interpretive challenge for resistivity and EM surveys in the Niger Delta is non-uniqueness. Clay-rich layers may have low resistivity because of surface conduction and bound water. Saline or brackish groundwater can also produce high conductivity independently of waste disposal. Seasonal saturation and changes in pore-water chemistry may alter measured responses. In coastal and estuarine settings, natural salinity gradients may overlap spatially with waste-affected zones. Consequently, a conductive anomaly near a dumpsite is a hypothesis about subsurface conditions, not proof of leachate contamination.

The 1–20 Ωm interval sometimes presented in secondary discussions should not be reproduced as a region-wide diagnostic range. The reviewed sources do not establish that interval as a validated Niger Delta threshold. A defensible interpretation would require the original study's site geology, electrode configuration, inversion parameters, depth of investigation, background resistivity and independent chemical results. Without those details, the interval should be omitted from any categorical classification.

Depth, Resolution and Inversion Uncertainty

Depth of investigation is controlled by survey geometry and instrument configuration, as well as subsurface conductivity and noise. For resistivity surveys, electrode spacing and array type influence depth sensitivity and lateral resolution. Increasing investigation depth commonly involves a trade-off with resolution. ERT inversion produces a model that explains measured data subject to regularisation and assumptions; it is not a direct photograph of the subsurface. Different models may fit the same data within acceptable error, especially where geology is complex or data coverage is sparse.

GPR generally offers finer resolution in suitable ground but is constrained by attenuation and scattering. Magnetometry can detect small ferrous objects under favourable conditions, but source depth and geometry affect anomaly amplitude and shape. EM methods provide rapid conductivity screening but have depth-weighted responses and may be affected by cultural metal. Seismic methods are sensitive to elastic contrasts

but may not uniquely distinguish fractures, changes in saturation and lithological boundaries. These limitations argue against ranking methods by a single label such as "most accurate."

What the Available Evidence can and cannot Establish

The literature supports the proposition that geophysical methods can identify physical-property anomalies associated with waste disposal and can guide the placement of confirmatory sampling points. It does not support the stronger proposition that geophysical measurements alone identify a contaminant, quantify its concentration or establish its toxicity. Hydrochemical measurements are needed to test water quality, while soil or sediment sampling may be required to assess contamination in the solid phase. Useful validation parameters may include pH, electrical conductivity, total dissolved solids, major ions, nitrate, ammonium, selected metals and microbiological indicators, chosen according to the suspected waste stream and relevant standards.

The available Nigerian case studies also reveal a geographical evidence gap. Studies from southwestern Nigeria demonstrate methods and interpretation strategies, but differences in geology, groundwater salinity, sediment texture, hydrology and landform prevent direct transfer of their numerical results to Bayelsa, Rivers or Akwa Ibom. The Niger Delta therefore requires locally calibrated investigations rather than the adoption of thresholds developed elsewhere.

Comparative Suitability and Limitations of Methods

Table 2 summarises the principal environmental targets, strengths and limitations of the methods. The table is a literature-derived synthesis, not a measured performance ranking. Suitability depends on site-specific conditions, survey objectives and the availability of independent validation.

Table 2: Summary of the Potential Contributions, Limitations and Recommended Applications of Near-Surface Geophysical Methods in Waste-Disposal Assessment

Method	Potential contribution to waste assessment	Key limitations and confounding factors	Recommended role
Electrical resistivity / ERT	Maps contrasts in bulk resistivity; may delineate conductive zones, waste boundaries and possible leachate-affected pathways.	Low resistivity is non-unique; clay, saline groundwater and moisture can produce similar responses. Inversion is non-unique; depth and resolution depend on array and spacing.	Detailed subsurface screening, interpreted with local geology and water chemistry.
Ground-penetrating radar (GPR)	High-resolution imaging of shallow interfaces, buried objects and disturbed zones in suitable ground.	Signal attenuation in conductive clay and saline/saturated sediments; depth of penetration is site-dependent; reflections are not uniquely diagnostic.	Targeted shallow mapping in relatively resistive, low-conductivity materials.
Magnetometry	Locates ferrous debris and magnetic contrasts within or near waste deposits.	Does not detect leachate or contaminant concentration directly; non-ferrous and organic waste may be undetected; cultural and geological sources create anomalies.	Rapid reconnaissance for metallic waste and buried ferrous objects.
Electromagnetic profiling	Rapid, non-contact screening of lateral conductivity variations.	Depth-weighted response; sensitivity to instrument configuration, cultural metal and conductive geology; requires calibration and follow-up.	Reconnaissance and prioritisation of locations for ERT or sampling.
Seismic methods	Characterises elastic contrasts, layering and some mechanical	Velocity anomalies are not unique indicators of fractures or contamination;	Supplementary geotechnical characterisation where

	conditions of subsurface materials.	affected by lithology, saturation, compaction and stress.	mechanical structure is a study objective.

Discussion

The reviewed evidence suggests that no single near-surface geophysical technique can adequately characterise all components of a waste-disposal site. Resistivity and EM methods are potentially useful for identifying conductive features, while GPR can resolve shallow buried structures in favourable ground and magnetometry can locate ferrous debris. Seismic methods may contribute information on mechanical layering and subsurface competence. The methods should therefore be selected according to the question being investigated rather than combined automatically.

For Niger Delta communities, electrical resistivity and EM surveys may be useful first-line tools where the objective is to screen for conductivity contrasts around a dumpsite. However, the region's clay interbeds, saturated sediments and saline groundwater complicate interpretation. A conductive zone extending from a dumpsite towards a shallow well may warrant targeted sampling, but it cannot be described as a confirmed leachate plume until supported by hydrochemical evidence and a plausible groundwater-flow interpretation. Similarly, a resistivity boundary that coincides with a geological clay layer should not be attributed to waste without further evidence.

GPR may provide valuable detail at selected sites, particularly where the near-surface material is sandy and relatively dry. Its performance should be tested with a short pilot line before a full survey is designed. In conductive swamp, estuarine or clay-rich settings, GPR penetration may be too limited to address the target depth. Magnetometry may efficiently locate buried metallic objects but should not be interpreted as a map of overall waste contamination. EM profiling should be treated as a rapid screening approach, not as inherently less accurate than other methods.

An integrated investigation should begin with site history, topographic and drainage assessment, waste characterisation, geological mapping and a preliminary hydrogeological conceptual model. Geophysical profiles should then be designed to test specific hypotheses about waste-body geometry or possible migration pathways. Boreholes, test pits or monitoring wells should be positioned to sample both anomalous and background areas. Water samples should be analysed for parameters relevant to the waste source, and the results should be compared with applicable drinking-water or environmental criteria. This process reduces the risk of assigning a contaminant source to a geophysical response that is actually caused by natural lithology or salinity.

The review also identifies an evidence gap in the direct application of near-surface geophysics to waste sites across the Niger Delta. More field studies are needed in contrasting geomorphological settings, including upland communities, freshwater swamp, mangrove and coastal/estuarine environments. Such studies should report coordinates, seasonal conditions, instrument settings, array geometry, data quality, inversion parameters, depth-of-investigation estimates, borehole logs and hydrochemical results. Reporting these details would make findings more comparable and support the development of locally appropriate interpretation procedures.

CONCLUSION

This narrative review finds that near-surface geophysical methods can contribute to the assessment of waste-disposal impacts by identifying subsurface physical-property contrasts that may be associated with buried waste, conductive zones, metallic debris and disturbed ground. Electrical resistivity and EM methods can help screen conductive features; GPR can image shallow interfaces and buried objects where ground conductivity permits; magnetometry can locate ferrous materials; and seismic methods can provide supplementary information on elastic structure. These capabilities are conditional on geological setting, survey design, depth and resolution.

The review does not establish a universal resistivity threshold for leachate in the Niger Delta, nor does it demonstrate region-wide detection performance, continuous monitoring capability or a functioning early-warning system. Clay-rich sediments, saline groundwater and variable moisture can produce anomalies that resemble waste-related effects. The principal limitations of this review are its narrative, non-systematic source selection, the scarcity of directly comparable Niger Delta waste-site surveys and the absence of original field measurements. Geophysical anomalies should therefore be treated as indicators for further investigation, not as standalone confirmation of contamination.

The central recommendation is that waste-site investigations in the Niger Delta should combine appropriately selected geophysical surveys with borehole or sediment logging and hydrochemical analysis before contamination is confirmed or remediation decisions are taken.

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