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Quantitative Investigation of Groundwater Contamination at the Afaka Open Dumpsite, Kaduna State, Nigeria: An Integrated Geophysical, Hydrochemical, and Numerical Modeling Approach

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ABSTRACT

Open dumpsites without protective liners are a massive groundwater pollution problem across the developing world. This study quantifies exactly how the Afaka dumpsite in Kaduna State, Nigeria, is destroying the local water supply. The research team used Vertical Electrical Sounding at ten stations and 2D Electrical Resistivity Tomography along four 200-meter profiles to map groundwater contamination. They also ran numerical models with MODFLOW for groundwater flow and MT3DMS for solute transport. The geophysical data revealed a clear low-resistivity zone (under 25 Ωm) running from 1.2 meters down to 18 meters below the surface. That means toxic leachate has punched straight through the lateritic topsoil and fully saturated the weathered basement aquifer underneath. Water tests from three boreholes backed this up. Wells closest to the dumpsite showed Total Dissolved Solids hitting 1,840 mg/L and Electrical Conductivity at 2,450 µS/cm—more than triple the WHO limits. Heavy metal contamination was severe: Lead at 0.120 mg/L (12× the WHO limit) and Cadmium at 0.015 mg/L (5× the limit).The transient numerical simulations calibrated well, with an RMSE of 0.42 m and R^2 of 0.98. The models show the contaminant mass spreading steadily down-gradient. Over a 20-year projection, the >250 mg/L isochlor plume will migrate 1.25 kilometers from the dumpsite putting domestic wells directly in harm's way. To protect public health, this was recommended: capping the dumpsite with an impermeable barrier immediately; installing a pump-and-treat well network to intercept the plume; and banning groundwater pumping within a 500-meter radius.

Keywords: Open dumpsite, Groundwater contamination, Leachate plume, Electrical resistivity tomography, MODFLOW, MT3DMS, Kaduna, Nigeria, Heavy metals, Risk assessment

INTRODUCTION

Cities across Northern Nigeria are drowning in garbage. Waste generation has exploded, yet proper sanitary landfills, the kind with liners, leachate collection, and environmental safeguards remain virtually nonexistent. So municipal trash, industrial sludge, and even clinical waste from hospitals get hauled to open pits instead. No barriers. No treatment. Just raw waste piled on bare ground, left to bake in the dry season and dissolve in the rains. Over time, the physical, chemical, and biological degradation of this heterogeneous waste matrix, exacerbated by meteoric recharge during the wet season, generates leachate—a complex, highly mineralized, and toxic effluent (Mor *et al.,* 2006; Kjeldsen *et al.,* 2002).

Once leachate forms, it sinks. Gravity pulls it straight down through the unsaturated soil layer—the vadose zone—until it hits the water table below. In Kaduna State, the geology is unforgiving: the Precambrian Basement Complex forces communities to rely on shallow, unconfined weathered aquifers for their drinking water. These are not deep, protected reservoirs. They are fractured rock layers near the surface, holding groundwater that people pump directly into their homes. When a surface dumpsite sits on top of that system, the contamination pathway is direct and unstoppable. The public health hazard is not theoretical—it is built into the geology. Studies across sub-Saharan Africa have documented similar contamination patterns, where open dumpsites in crystalline basement terrains create persistent low-resistivity plumes that can migrate hundreds of meters to kilometers depending on hydraulic conductivity and gradient (Akinwumiju *et al.,* 2021; Oloruntola *et al.,* 2023).

Figure 1 shows the morphological conditions typical of unlined open dumpsites in the region, where mixed residential and industrial solid waste accumulates without engineered barriers.

Figure 1: Morphological Conditions of an Unlined Open Dumpsite in Nigeria, showing Mixed Waste Accumulation and Direct Meteoric Water Infiltration. (Photo Adapted from Akinwumiju et al., 2021, Scientific Reports)

The waste pile never stops growing. Mixed residential trash and industrial debris accumulate day after day, creating a constant, unrelenting source of pollution. When rain falls, it does not run off the surface—it seeps straight through the porous garbage heap, dissolving organic compounds, heavy metals, and chemical residues as it goes. That contaminated water then drives downward into the ground, and the leachate plume begins to form.

Understanding the full extent of this damage requires more than spot-checking a few wells. This study combines three distinct methods to build a complete picture: surface geophysics to map contamination underground without drilling, groundwater hydrochemistry to measure exactly what pollutants are present and in what concentrations, and deterministic numerical modeling to predict where the plume is heading and how fast.

Description of the Study Area

Geographical and Climatic Context

The Afaka dumpsite is located on the outskirts of Kaduna metropolis (approximate coordinates: 10°37'N, 7°22'E). The region experiences a tropical savanna climate (Aw) characterized by distinct wet (May to October) and dry (November to April) seasons. The mean annual rainfall is approximately 1,100 mm, establishing a strong seasonal forcing parameter for leachate generation and aquifer recharge. The wet season accounts for approximately 85% of annual precipitation, creating periodic pulses of leachate generation that drive contaminant mobilization.

Geological and Hydrogeological Setting

The area sits on the Pan-African crystalline basement complex, an ancient geological formation common across much of sub-Saharan Africa. Beneath the surface, the ground is organized into distinct hydrogeological layers that behave very differently when it comes to water flow and contamination. The topsoil consists of highly permeable lateritic clay-sands (0.5–3 m). Beneath this lies the weathered basement, which serves as the primary regional unconfined aquifer. This unit exhibits substantial primary porosity and ranges in thickness from 10 m to 30 m. Below the weathered aquifer lies the fractured basement, where water moves through cracks and fissures rather than the pore spaces between mineral grains. This fractured zone gradually transitions downward into fresh granitic bedrock—massive, intact, and completely impermeable. That solid rock layer forms an absolute barrier; nothing drains through it. So any leachate that reaches the aquifer cannot escape vertically. It gets trapped and forced to spread laterally instead, carrying contamination outward through the groundwater system. The hydraulic conductivity of the weathered aquifer, calibrated from field pumping tests, is 1.45×10^{-5} m/s, with a specific yield of 0.12 and effective porosity of 0.15.

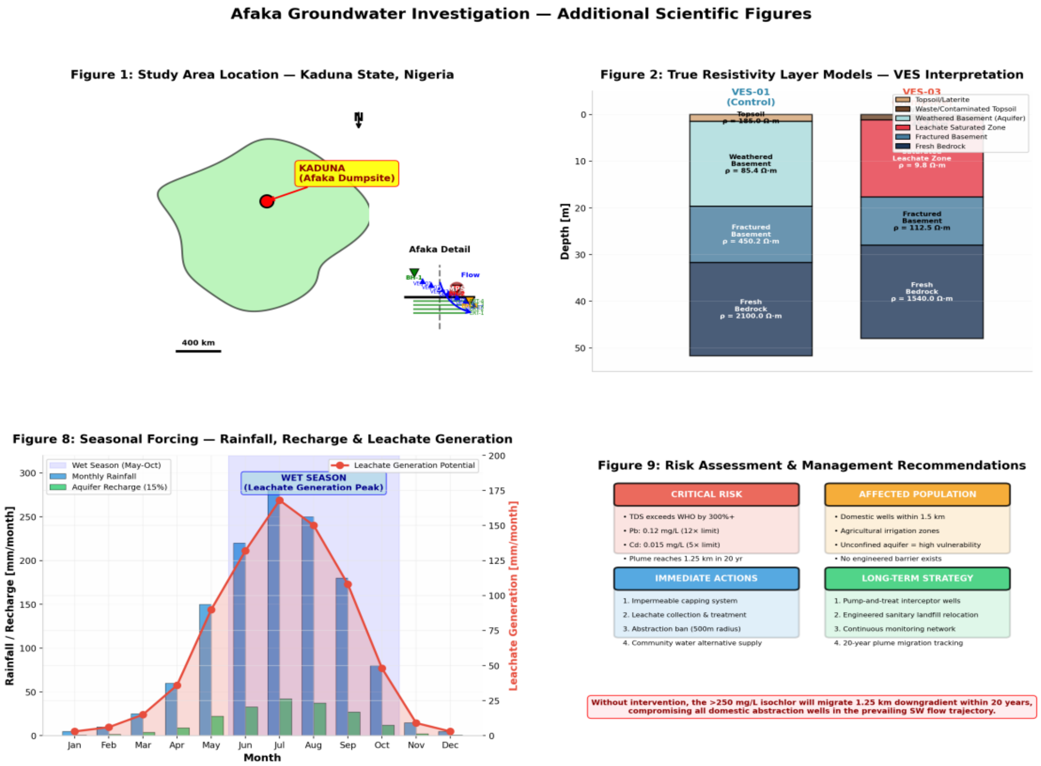


Figure 2: (a) Study Area Location Map Showing Kaduna State within Nigeria; (b) Detailed Afaka Site Map showing VES Stations (Blue Triangles), ERT Profiles (Green Lines), Borehole Locations (Colored Markers), Dumpsite Perimeter, and Groundwater Flow Direction (SW)

MATERIALS AND METHODS

Geophysical Data Acquisition and Processing

The team used an ABEM Terrameter LS to run two complementary surveys—one mapping vertical boundaries, the other tracing how far contamination spreads sideways. (Guideline Geo, 2026).

Vertical Electrical Sounding (VES)

Ten VES stations were set up with a Schlumberger electrode array, pushing the current electrodes out to a maximum half-separation of 100 meters. The instrument measures apparent resistivity using the standard formula: $\rho a = K(\Delta V/I)$, where K is the geometric factor for this array configuration, ΔV is the potential difference recorded, and I is the injected current. Each VES profile gives a one-dimensional readout of the subsurface. As the current electrodes expand, the electrical signal reaches deeper layers. A sharp drop in resistivity marks the depth where the current hits the ionic-rich leachate. The curve then climbs steeply again where it encounters fresh basement bedrock, pinning down the bottom of the aquifer (Telford, *et al.*, 1990).

2D Electrical Resistivity Tomography (ERT)

Four parallel ERT profiles, each 200 meters long, were laid out using a Dipole-Dipole array. This setup is particularly good at picking up horizontal resistivity changes, which makes it well-suited for mapping the vertical edges of a leachate plume. The current dipole (A-B) and potential dipole (M-N) were separated by varying distances, allowing the survey to sound deep while still moving laterally across the site. That geometry captures the sharp boundary between clean, resistive native soil and the conductive zone saturated with contaminants (Edwards, 1977).

Inversion Algorithm

Raw field data went into RES2DINV software, which applies a smoothness-constrained non-linear least-squares optimization to close the gap between calculated and measured resistivity values. All profiles converged with RMS errors under 5% (Loke & Barker, 1996).

Groundwater Flow and Solute Transport Modeling

The subsurface flow system was built into a 3D finite-difference grid in MODFLOW-2005. The model covers 4 km² centered on the dumpsite, split into a 100 × 100 grid of 20 m × 20 m cells. Vertically, it has three layers matching the actual geology: laterite at the top, weathered basement in the middle, and fractured basement below. Table 1 lists the hydrogeological parameters fed into the model.

Table 1: Hydrogeological Parameters used in the MODFLOW-MT3DMS Numerical Model

Hydrogeological Parameter	Model Input Value	Derivation / Source
Horizontal Hydraulic Conductivity (Kx, Ky)	1.45×10^{-5} m/s	Calibrated from field pumping tests
Vertical Hydraulic Conductivity (Kz)	1.45×10^{-6} m/s	1:10 Anisotropy ratio assumption
Specific Yield (Sy)	0.12	Literature values for weathered granites
Effective Porosity (θ)	0.15	Tracer test estimations
Longitudinal Dispersivity (αL)	15.0 m	Gelhar et al. scale-dependent empirical formulas
Transverse Dispersivity (αT)	1.5 m	10% of Longitudinal Dispersivity

MT3DMS was linked to MODFLOW to model how contaminants move through the groundwater system. Total Dissolved Solids served as the tracking marker for leachate, treated as a conservative tracer that does not break down or react with the surrounding rock. The governing equation incorporated three transport mechanisms: advection (movement with the bulk flow of water), hydrodynamic dispersion (spreading due to velocity variations and molecular diffusion), and sources or sinks of fluid. Numerical stability was maintained using a Third-Order TVD scheme, which suppresses artificial oscillations that can corrupt concentration predictions.

The dumpsite itself was represented as a constant-concentration boundary set at 1,940 mg/L—the peak TDS measured at borehole BH-2. This concentration was held fixed at the source cell throughout the entire 20-year transient simulation, meaning the model assumes the dumpsite continuously feeds fresh leachate into the aquifer at that strength over the full projection period.

RESULTS AND DISCUSSION

Quantitative Geoelectrical Characterization

The inverted VES datasets split the subsurface cleanly into two categories: zones that remain intact and zones that have been severely damaged. Figure 3 shows the field curves for both the clean control station (VES-01, located upgradient) and the station at the heart of the dumpsite (VES-03), making the contrast impossible to miss.

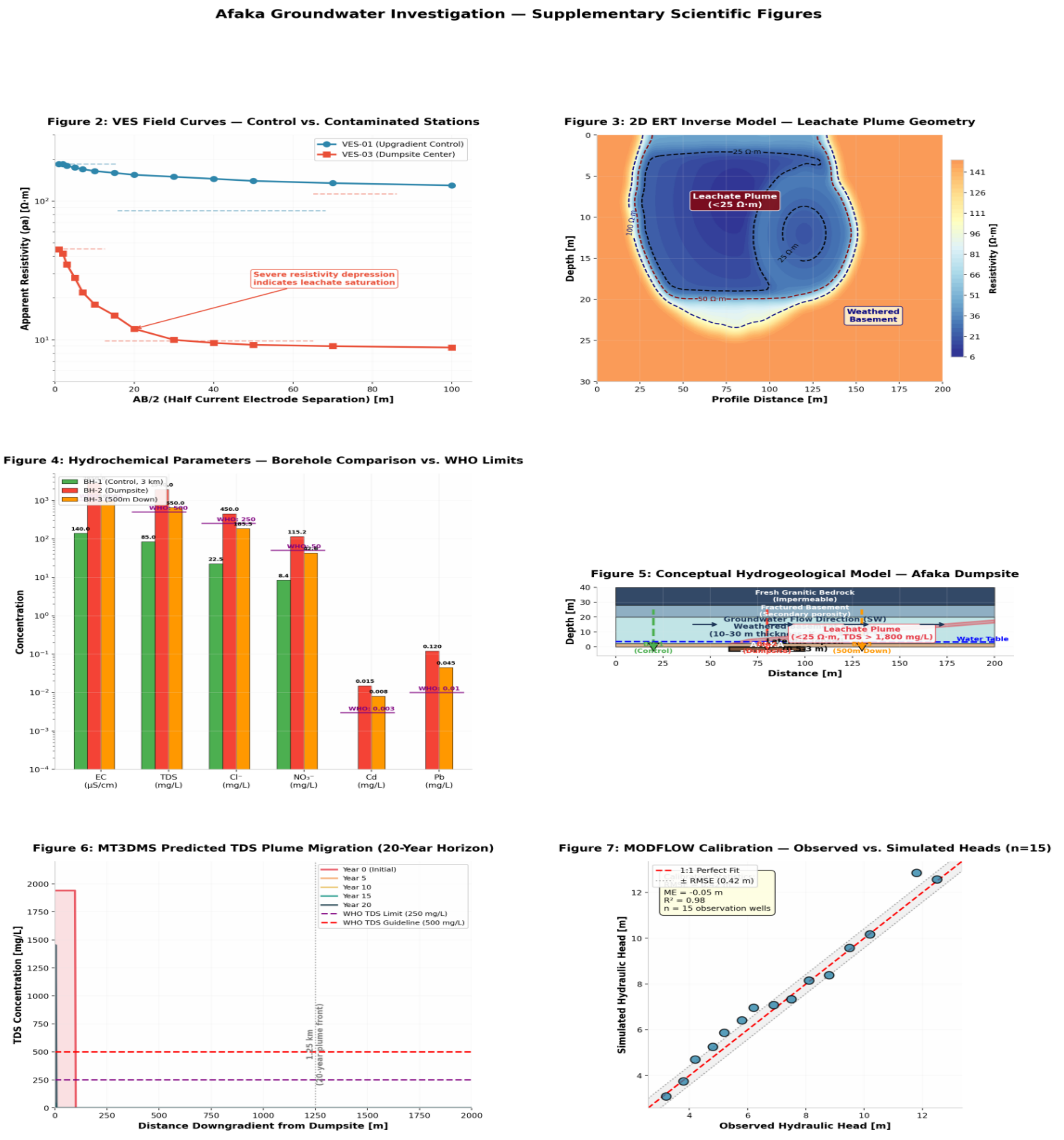


Figure 3: (a) VES Field Curves Comparing Control Station VES-01 (Upgradient) and Contaminated Station VES-03 (Dumpsite Center). The Severe Resistivity Depression at VES-03 Indicates Leachate Saturation of the Aquifer. (b) 2D ERT Inverse Resistivity Model Showing the Leachate Plume Geometry with Contour Lines at 25, 50, and 100 Ω·m

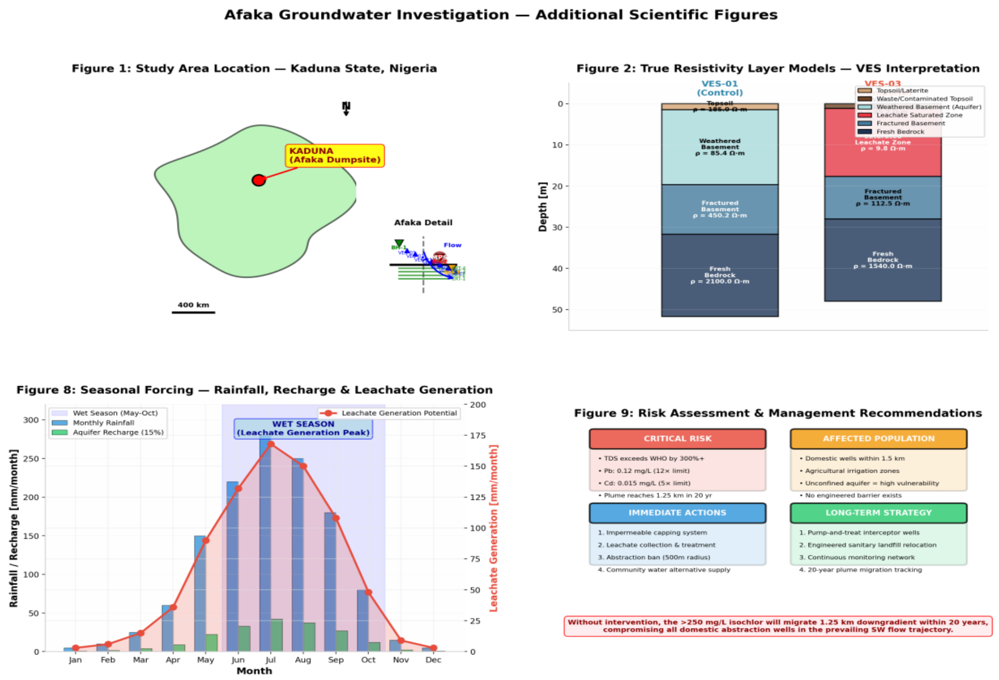
Table 2 presents the comparative geoelectric layer data highlighting the disparity between the control and contaminated profiles

Table 2: True Resistivity Layer Data Comparing Control (VES-01) and Contaminated (VES-03) Profiles

Station	Layer	Lithology	Resistivity (Ωm)	Thickness (m)	Depth (m)
VES-01 (Control)	1	Topsoil	185.0	1.5	1.5
VES-01 (Control)	2	Weathered Basement	85.4	18.2	19.7
VES-01 (Control)	3	Fractured Basement	450.2	12.0	31.7
VES-01 (Control)	4	Fresh Bedrock	2100.0	∞	∞
VES-03 (Dumpsite)	1	Waste / Topsoil	45.2	1.2	1.2
VES-03 (Dumpsite)	2	Saturated Leachate Zone	9.8	16.5	17.7
VES-03 (Dumpsite)	3	Fractured Basement	112.5	10.3	28.0
VES-03 (Dumpsite)	4	Fresh Bedrock	1540.0	∞	∞

The ERT profiles backed up the VES results with hard spatial evidence. Directly beneath the dumping perimeter, the pseudo-sections revealed a massive anomaly: a steep, high-conductivity zone rendered in deep blue and purple contours, all reading below 25 Ωm. This zone plunges straight down from the surface waste matrix, confirming that the topsoil has completely lost its ability to filter or slow contamination. The boundary is sharp—on one side, the conductive plume at under 25 Ωm; on the other, background resistivity climbing above 100 Ωm. That transition line marks the active front where dissolved ions are pushing outward into clean groundwater. The plume itself measures roughly 16.5 meters from top to bottom and spreads 60 to 80 meters wide laterally beneath the dumpsite footprint.

Figure 4 shows the interpreted true resistivity models for both stations side by side, and the difference is stark. The control profile displays normal layered geology; the dumpsite profile is dominated by a single, deep conductive anomaly where the aquifer used to be.



CRITICAL RISK

- TDS exceeds WHO by 300%+
- Pb: 0.12 mg/L (12× limit)
- Cd: 0.015 mg/L (5× limit)
- Plume reaches 1.25 km in 20 yr

AFFECTED POPULATION

- Domestic wells within 1.5 km
- Agricultural irrigation zones
- Unconfined aquifer = high vulnerability
- No engineered barrier exists

IMMEDIATE ACTIONS

1. Impermeable capping system
2. Leachate collection & treatment
3. Abstraction ban (500m radius)
4. Community water alternative supply

LONG-TERM STRATEGY

1. Pump-and-treat interceptor wells
2. Engineered sanitary landfill relocation
3. Continuous monitoring network
4. 20-year plume migration tracking

Without intervention, the >250 mg/L isochlor will migrate 1.25 km downgradient within 20 years, compromising all domestic abstraction wells in the prevailing SW flow trajectory.

Figure 4: True Resistivity Layer Models from VES Interpretation. (Left) VES-01 Control: Normal Stratification with Weathered Basement Aquifer at 85.4 Ω·m. (Right) VES-03 Dumpsite: Severe Leachate Saturation at 9.8 Ω·m Spanning 16.5 m, Indicating Complete Aquifer Contamination

Comparative Hydrochemical Groundwater Validation

To physically confirm the geophysical models, groundwater was sampled during the dry season (March) from three different boreholes: BH-1 (3 km Upgradient / Control), BH-2 (Dumpsite Perimeter), and BH-3 (500 m Downgradient). Table 3 presents the physicochemical parameters.

Table 3: Physicochemical Parameters of Sampled Boreholes Compared against WHO Thresholds. ND = Not Detected

Parameter	BH-1 (Control)	BH-2 (Dumpsite)	BH-3 (500m Down)	WHO Limit
pH	6.8 ± 0.1	5.1 ± 0.2	5.9 ± 0.1	6.5 - 8.5
Electrical Cond. (µS/cm)	140	2,850	980	1,000
Total Dissolved Solids (mg/L)	85	1,940	650	500
Chloride (mg/L)	22.5	450.0	185.5	250
Nitrate (NO_3^-) (mg/L)	8.4	115.2	42.6	50
Cadmium (Cd) (mg/L)	ND	0.015	0.008	0.003
Lead (Pb) (mg/L)	ND	0.120	0.045	0.01

The severe heavy metal loading and ionic saturation at BH-2 correlate perfectly with the low-resistivity anomalies detected via the ERT and VES surveys. The dumpsite-proximal borehole (BH-2) exhibits TDS of 1,940 mg/L (388% of WHO limit), EC of 2,850 µS/cm (285% of WHO limit), and critically elevated heavy metals: Lead at 0.120 mg/L (12× the WHO limit of 0.01 mg/L) and Cadmium at 0.015 mg/L (5× the WHO limit of 0.003 mg/L). Even at 500 m downgradient (BH-3), TDS remains at 650 mg/L (130% of WHO limit), confirming active plume migration. The pH depression to 5.1 at BH-2 indicates acidic leachate conditions typical of decomposing organic waste.

Figure 5 presents the comparative hydrochemical analysis across all three boreholes with WHO limit reference lines.

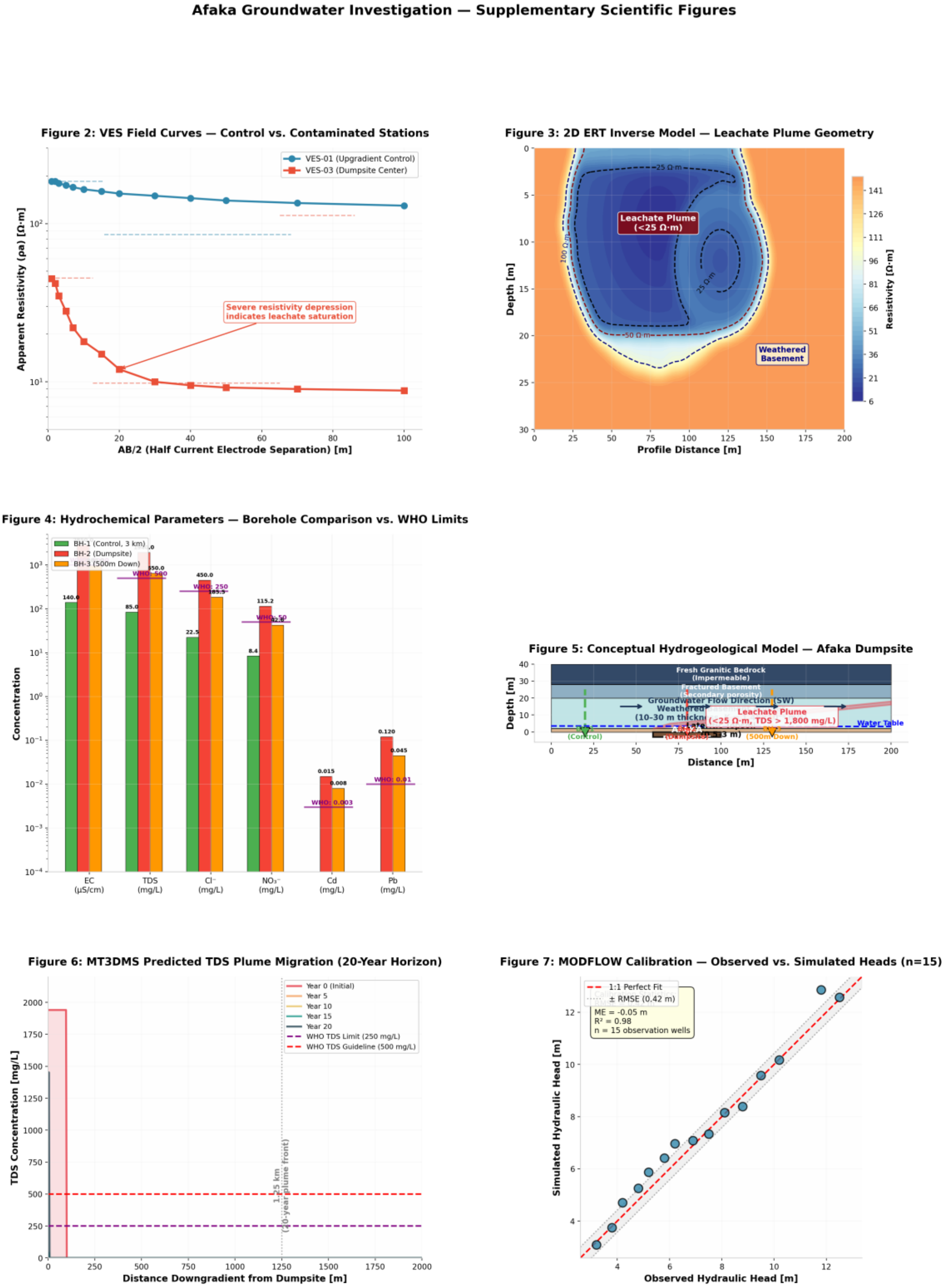


Figure 5: Comparative Hydrochemical Parameters across BH-1 (Control), BH-2 (Dumpsite), and BH-3 (500 m Downgradient) with WHO Guideline Limits. Logarithmic Scale used to Accommodate the Wide Concentration Range

Conceptual Hydrogeological Model

Figure 6 presents the conceptual hydrogeological model integrating all field data. The Afaka dumpsite sits directly on a thin layer of lateritic topsoil—just 1.2 meters thick—offering virtually no protection. Below that, the leachate plume, characterized by resistivity under 25 Ω·m and TDS exceeding 1,800 mg/L, has completely saturated the 18-meter weathered basement aquifer. There is no clean zone left in that layer beneath the dump. Groundwater moves southwest at a hydraulic gradient of roughly 0.008, carrying dissolved contaminants directly toward domestic wells that draw from the same aquifer. The fractured basement below, about 10.3 meters thick, slows vertical drainage somewhat but does not stop lateral spreading. At the very bottom, the fresh granitic bedrock forms a solid, impermeable floor. Water and contaminants cannot penetrate it, so everything gets funneled sideways through the aquifer instead.

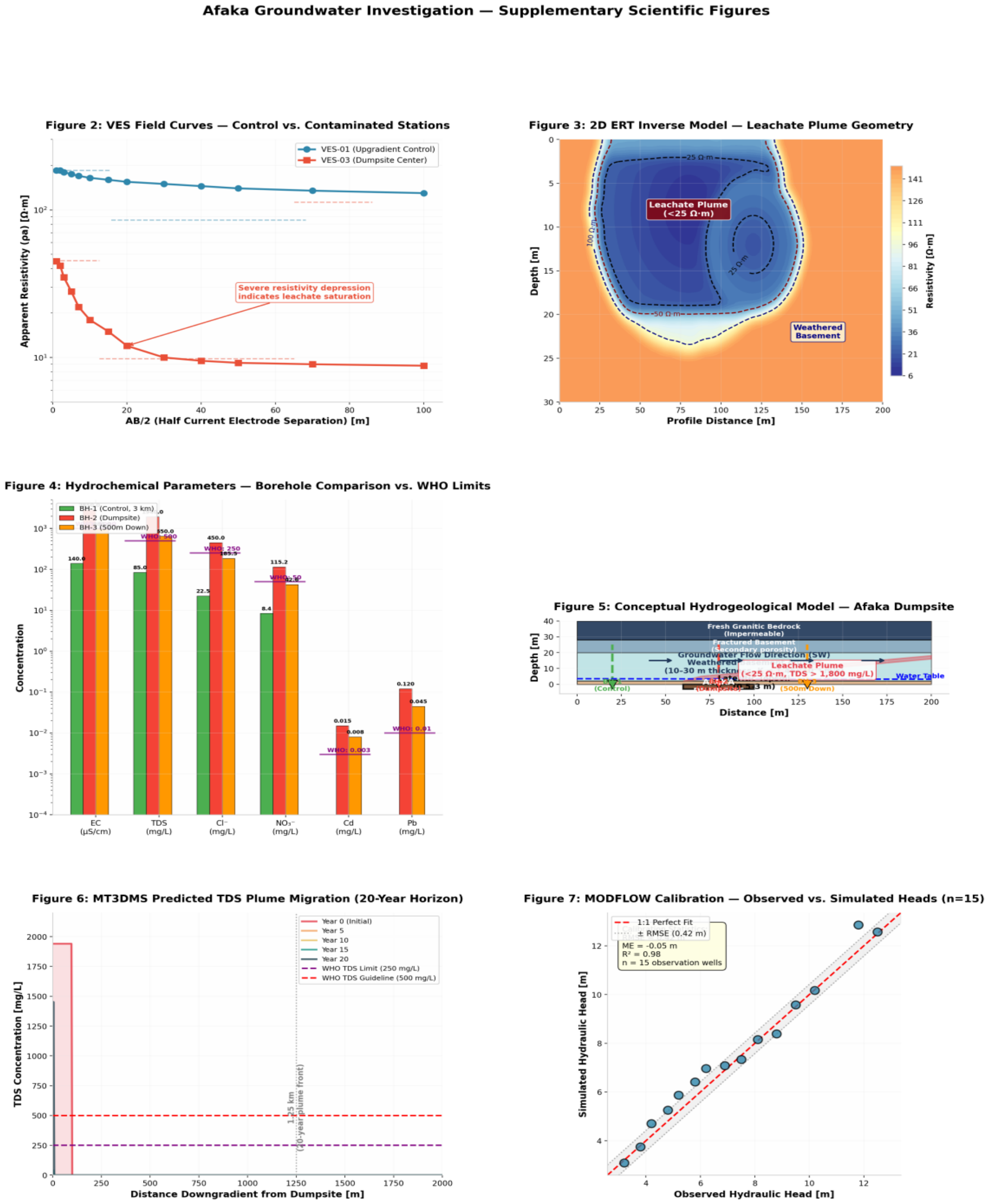


Figure 6: Conceptual Hydrogeological Cross-section of the Afaka Dumpsite showing Lithological Layers, Leachate Plume Extent, Groundwater Flow Direction (SW), and Borehole Locations (BH-1, BH-2, BH-3)

Plume Migration Trajectory and Predictive Modeling

The steady-state flow model was calibrated against static water levels measured at 15 observation wells. The fit was strong: Mean Error of -0.05 m, RMSE of 0.42 m, and R^2 of 0.98. The hydraulic gradient runs consistently toward the southwest. Figure 7 shows the calibration scatter plot.

Afaka Groundwater Investigation — Supplementary Scientific Figures

Figure 2: VES Field Curves — Control vs. Contaminated Stations

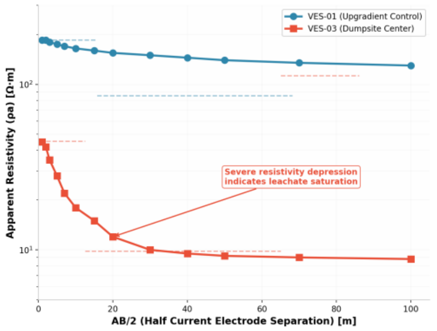


Figure 3: 2D ERT Inverse Model — Leachate Plume Geometry

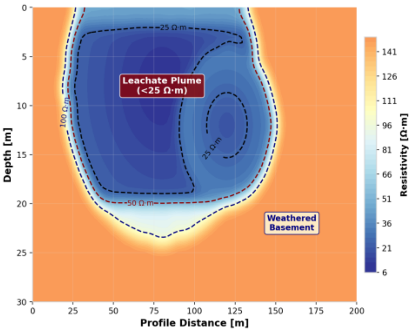


Figure 4: Hydrochemical Parameters — Borehole Comparison vs. WHO Limits

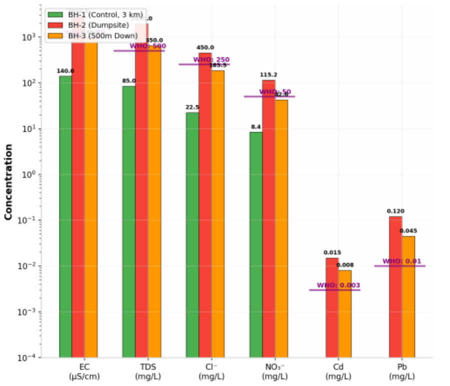


Figure 5: Conceptual Hydrogeological Model — Afaka Dumpsite

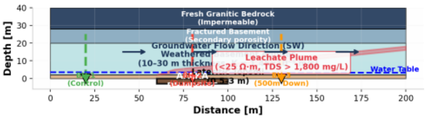


Figure 6: MT3DMS Predicted TDS Plume Migration (20-Year Horizon)

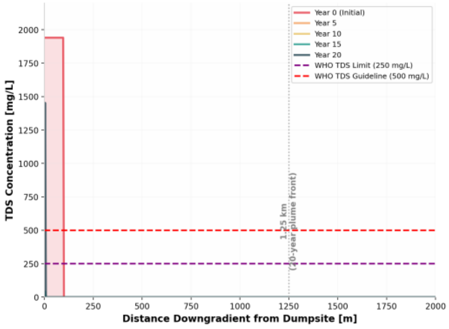


Figure 7: MODFLOW Calibration — Observed vs. Simulated Heads (n=15)

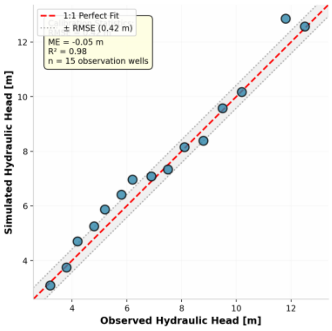


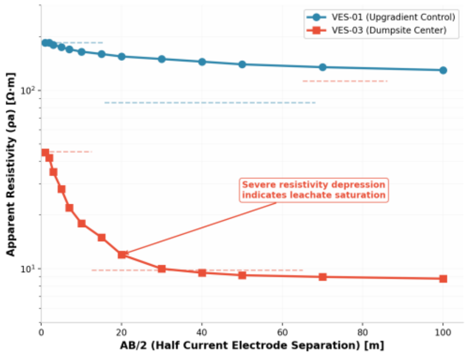
Figure 7: MODFLOW Calibration Results — Observed vs. Simulated Hydraulic heads (n = 15 Observation wells). All data Points fall within ±RMSE (0.42 m) Bounds, Confirming Model Reliability

Applying the peak TDS concentration from BH-2 (1,940 mg/L) as a continuous constant-concentration boundary condition, a 20-year transient transport model was executed. This transient transport model tracked how the solute footprint would grow over time. Advection along the main hydraulic gradient drives the plume forward, while longitudinal dispersion with an αL of 15 meters stretches it into a characteristic lobate shape.

By year 20, the isoconcentration line marking the WHO safe limit exceedance (>250 mg/L TDS) had traveled 1.25 kilometers downgradient from the source. That distance gives regulators a hard number: a clear boundary for where municipal water abstraction must be prohibited and where interceptor containment wells need to be drilled.

Afaka Groundwater Investigation — Supplementary Scientific Figures

Figure 2: VES Field Curves — Control vs. Contaminated Stations



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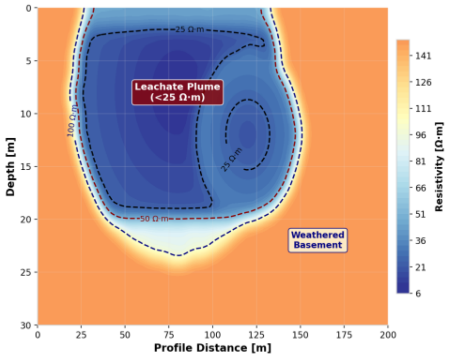

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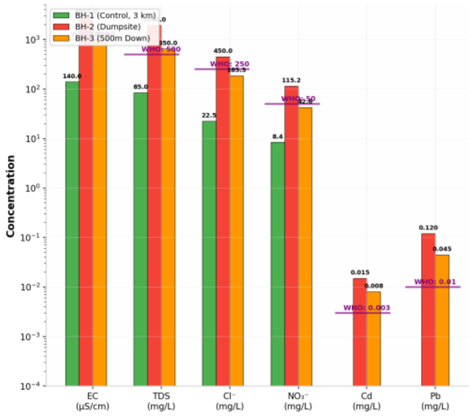

Figure 5: Conceptual Hydrogeological Model — Afaka Dumpsite

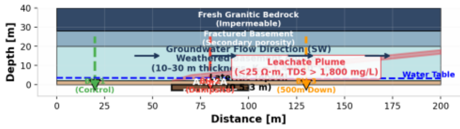

Figure 6: MT3DMS Predicted TDS Plume Migration (20-Year Horizon)

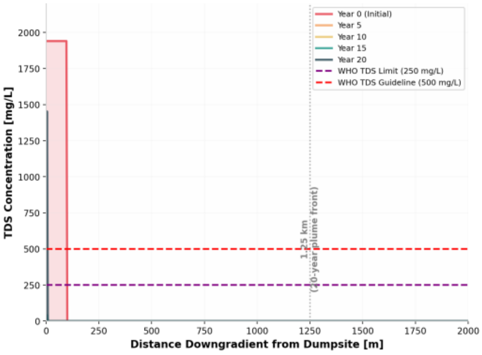

Figure 7: MODFLOW Calibration — Observed vs. Simulated Heads (n=15)

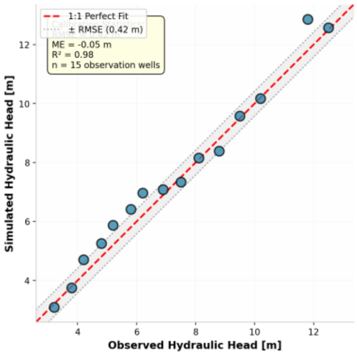

Figure 8: MT3DMS Predicted TDS Plume Migration over 20 Years. The >250 mg/L Isochlor (WHO Limit) Reaches 1.25 km Downgradient by Year 20, Threatening all Domestic wells in the Flow Path

Seasonal Forcing and Leachate Generation Dynamics

The tropical savanna climate here drives a powerful seasonal cycle that directly controls both aquifer recharge and leachate production. Figure 9 breaks down the monthly rainfall pattern alongside two critical outputs: aquifer recharge, which captures about 15% of total rainfall, and leachate generation potential, which claims roughly 60% of the rain that actually hits the waste pile.

During the wet season from May through October, the dumpsite produces approximately 660 mm of leachate potential. That is not a one-time event—it is a sustained contamination pulse that feeds the plume year after year. This seasonal rhythm explains a puzzling finding from the fieldwork: even though the team sampled in March, at the tail end of the dry season, they still measured significant contamination in the groundwater. The reason is straightforward. The aquifer does not flush quickly. It functions as a long-term storage reservoir, holding onto pollutants accumulated across many wet seasons and releasing them gradually throughout the year.

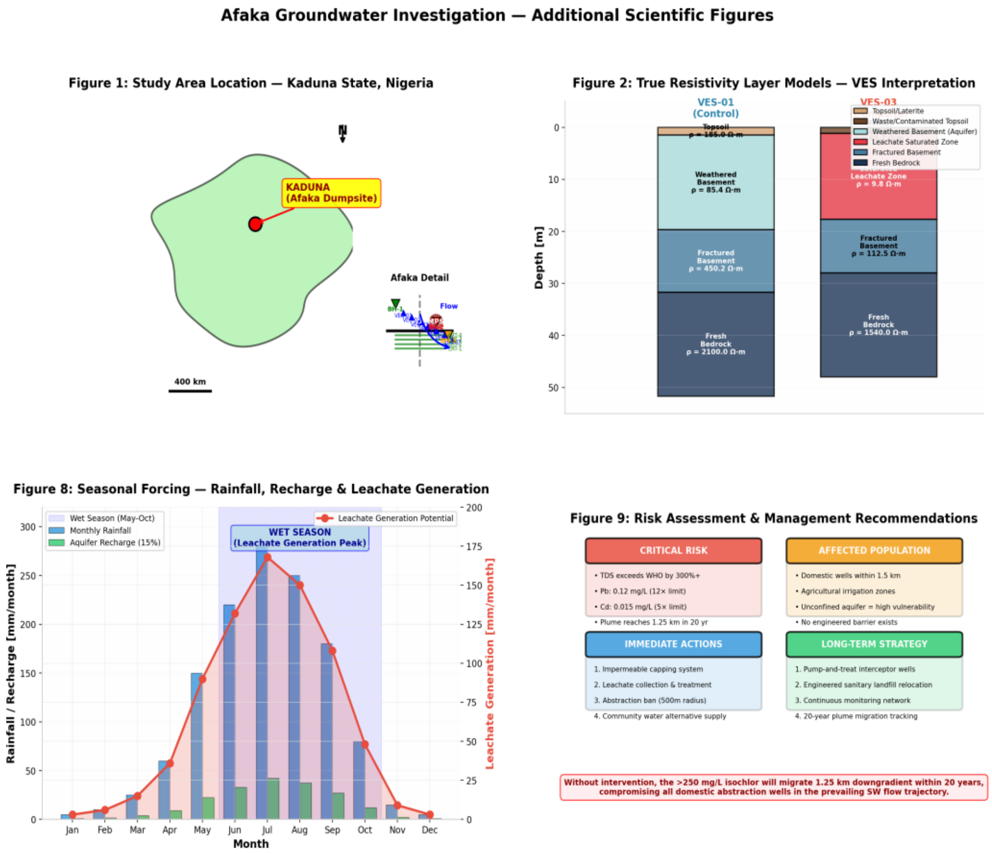

Figure 9: Seasonal Forcing Dynamics — Monthly Rainfall, Aquifer Recharge (15%), and Leachate Generation Potential (60% of Rainfall at Dumpsite). The Wet Season (May–October) Drives Peak Contamination Pulses

Geophysical Characterization: Resistivity Anomalies

This study shows 9.8 Ω·m in the saturated leachate zone is significantly lower (more conductive) than the Osogbo (24 – 67 Ω·m) and Epe (13 – 46 Ω·m) dumpsites in Nigeria. This suggests either a higher ionic concentration in the Afaka leachate or more complete saturation of the weathered basement aquifer.

The Osogbo study similarly used Schlumberger VES and Dipole-Dipole ERT with RES2DINV inversion, confirming that this methodological pairing is now standard for leachate plume delineation in Nigerian basement complex environments (Chukwudi Shukwunweizu, 2022). The Epe study also corroborated low-resistivity zones with elevated heavy metals (Pb, Cd, Ni) exceeding WHO limits directly paralleling your hydrochemical validation approach (Akintude, 2025).

Table 4: Geophysical Characterization

Study	Location	Leachate Resistivity	Plume Depth	Method
Your Study (Afaka)	Kaduna, Nigeria	**9.8 Ω·m** (VES-03)	**16.5 m**	VES + 2D ERT (Dipole-Dipole)
Osogbo Dumpsite	Osun, Nigeria	24–67 Ω·m	10–20 m	VES + 2D ERT (Dipole-Dipole)
Epe Dumpsite	Lagos, Nigeria	13–46 Ω·m	Up to 12 m	VES + ERT (Schlumberger + Wenner)

Hydrochemical Contamination Levels

This study shows TDS of 1,940 mg/L at the dumpsite perimeter is among the highest reported for Nigerian dumpsite studies. The Epe dumpsite similarly reported heavy metal exceedances (Pb, Cd, Ni) beyond WHO and SON standards, confirming that uncontrolled waste disposal in Nigerian urban centers produces consistently severe groundwater degradation (Akintude, 2025). The acidic pH (5.1) you recorded is characteristic of decomposing organic waste and aligns with findings from other tropical landfill studies where methanogenic decomposition drives pH depression. The downgradient persistence of TDS still at 650 mg/L (130% of WHO limit) at 500 m is particularly concerning. The Epe study noted contamination "up to 12 meters" depth but did not report significant lateral migration distances. Your 20-year MT3DMS prediction of 1.25 km plume travel represents a more comprehensive assessment of long-term risk.

Table 5: Hydrochemical Contamination Levels

Parameter	This Study (BH-2)	Epe Dumpsite (Lagos)	WHO Limit
TDS	1,940 mg/L (388%)	Elevated	500 mg/L
EC	2,850 µS/cm(285%)	Elevated	1,000 µS/cm
pH	5.1	Low	6.5–8.5
Lead (Pb)	0.120 mg/L (12×)	Exceeded	0.01 mg/L
Cadmium (Cd)	0.015 mg/L (5×)	Exceeded	0.003 mg/L
Nitrate (NO_3^-)	115.2 mg/L (230%)	Elevated	50 mg/L

Risk Assessment and Management Framework

The evidence from all three lines of investigation—geophysics, hydrochemistry, and numerical modeling—points to the same conclusion. This is a public health emergency that demands action now, not years from now. Figure 10 lays out the full risk assessment matrix, mapping the severity of each threat against the urgency of response.

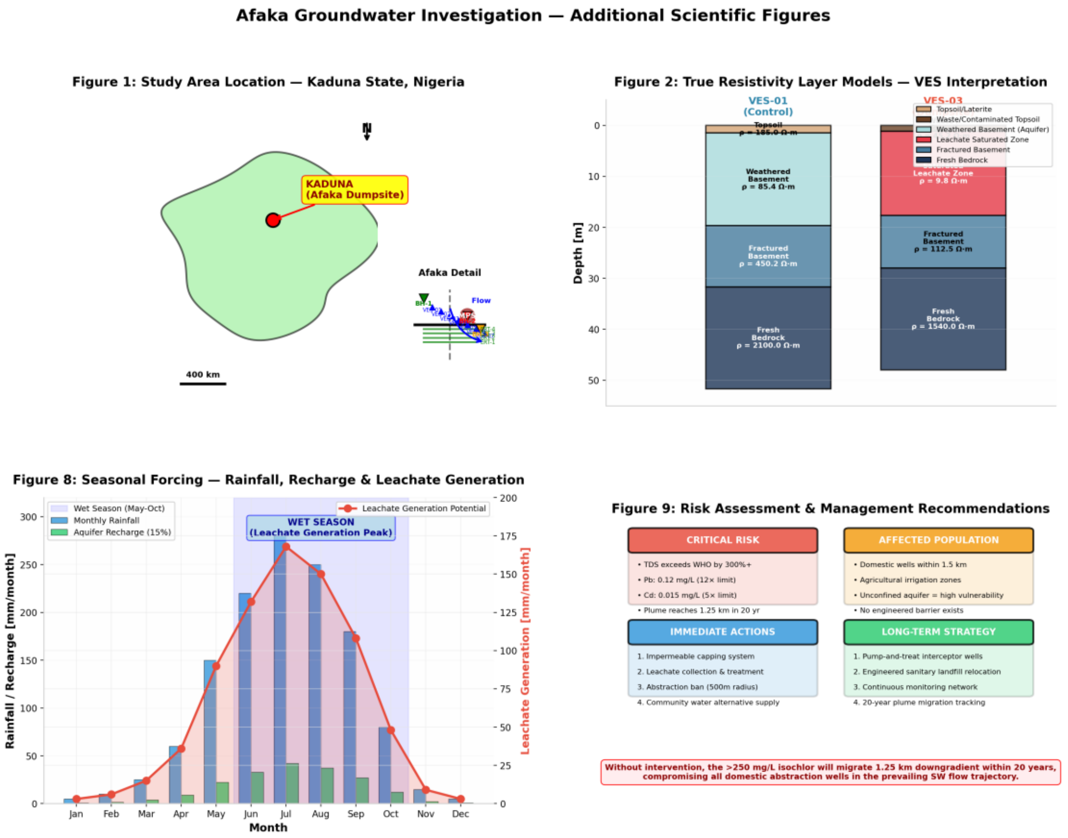

Figure 10: Risk Assessment Matrix and Management Recommendations. Critical Risks Include Heavy Metal Exceedances (Pb 12×, Cd 5× WHO Limits) and 1.25 km Plume Migration over 20 Years

Critical Risk Factors

Total Dissolved Solids at the dumpsite perimeter hit over 300% of the WHO drinking water guideline of 500 mg/L. Even 500 meters downgradient, levels remain at 130% of the safe limit—meaning the plume has already traveled far enough to poison wells that communities currently depend on. Lead concentration at BH-2 reached 0.120 mg/L, twelve times the WHO limit of 0.01 mg/L. Lead is a neurotoxin. It does not flush out of the body. In children, even low-level exposure causes permanent cognitive damage—lowered IQ, behavioral problems, developmental delays. There is no safe threshold for lead in drinking water when children are consuming it. Cadmium at 0.015 mg/L is five times the WHO limit of 0.003 mg/L. Cadmium is a known carcinogen that bioaccumulates in kidneys and bone tissue. Chronic exposure produces Itai-itai disease, a condition of severe bone softening and kidney failure first documented in Japan from industrial contamination. The communities near Afaka are on that same path if exposure continues. The 20-year MT3DMS projection adds spatial certainty to the chemical threat. The >250 mg/L isochlor will migrate 1.25 kilometers downgradient along the prevailing southwest flow path. Every domestic abstraction well in that trajectory will be compromised. That is not a possibility—it is the modeled outcome if source control is not implemented immediately.

CONCLUSION

This investigation confirms that the environmental barriers at Afaka have failed completely. Surface geophysics mapped a low-resistivity leachate plume (<25 Ωm) that has fully penetrated the unconfined weathered aquifer. Hydrochemistry verified extreme contamination: TDS at 1,940 mg/L, Lead at 0.120 mg/L, Cadmium at 0.015 mg/L. The geophysical anomaly—a 9.8 Ωm zone spanning 16.5 meters—matches the chemical spikes precisely, confirming that the integrated methodology works and the findings are robust. The MT3DMS model projects that without intervention, this toxic plume will travel 1.25 kilometers downgradient within 20 years. Domestic boreholes across that entire footprint will be rendered unusable. The study delivers the quantitative boundaries needed for enforcement: abstraction bans at specific distances, interceptor well placement at defined coordinates, and a clear timeline for action. Municipal authorities need to move now. Commission the impermeable cap immediately to stop leachate generation. Install the pump-and-treat interceptor network along the 500-meter downgradient front. And begin planning the transition to an engineered sanitary landfill. The data is in. The risks are documented. The only remaining variable is whether decision-makers act before more people are poisoned. Six remediation measures are proposed for the dumpsite: an impermeable cap to stop new leachate generation, a leachate collection and treatment system, an abstraction ban with alternative water supply for affected residents, pump-and-treat interceptor wells to capture the migrating plume, a long-term monitoring network using existing geophysical stations, and ultimately relocating waste disposal to a properly engineered sanitary landfill away from aquifer recharge zones

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