



Impact of Open Dumpsites on Groundwater Quality: Geophysical and Hydrochemical Evidence from Ijan-Ekiti, Nigeria

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Abstract

Rapid urbanization and poor waste management practices in many developing regions have increased the risk of groundwater contamination from open dumpsites. This study investigates the impact of leachate migration from the Ikota Street dumpsite in Ijan-Ekiti, southwestern Nigeria, using an integrated geophysical and hydrochemical approach. Audio-magnetotelluric (ADMT) surveys were conducted along two traverses to delineate subsurface resistivity structures, while water samples from a hand-dug well and a nearby stream were analyzed for physicochemical parameters and heavy metal concentrations. Geophysical results reveal a heterogeneous subsurface characterized by high-resistivity zones in the near surface, underlain by low-resistivity anomalies interpreted as leachate plumes. These plumes occur at depths between approximately -70 m and -190 m and exhibit both vertical and lateral migration through preferential pathways such as fractures and permeable layers. A deep, highly conductive zone identified between -250 m and -310 m suggests the presence of a groundwater reservoir potentially impacted by leachate infiltration. Physicochemical analysis indicates that general water quality parameters, including pH and total dissolved solids, fall within limits recommended by the World Health Organization. However, elevated concentrations of toxic trace metals, particularly arsenic (0.015 mg/L) and cadmium (0.004 mg/L) in stream water, exceed permissible limits, indicating contamination. The presence of lead, cadmium, and arsenic in both water sources confirms leachate influence and highlights potential risks of bioaccumulation and long-term health effects. Generally, the study demonstrates that the dumpsite is actively contributing to groundwater and surface water contamination. The findings underscore the vulnerability of fractured basement aquifers to pollution and emphasize the need for improved waste management and groundwater protection strategies.

Keywords: Open dumpsite; groundwater; audio-magnetotelluric; water quality; basement complex; Ijan-Ekiti.

1.0 Introduction

Rapid urbanization and population growth in many developing countries have led to a corresponding rise in municipal solid waste generation, often without adequate planning for safe disposal and management [22]; [35]; [37]. In most Nigerian towns and semi-urban communities, open and unplanned dumpsites remain the dominant waste disposal system, despite their known environmental and public health implications [7]; [18]. Such dumpsites serve as long-term sinks for heterogeneous municipal solid waste, including biodegradable organic matter, plastics, metals, and construction debris, which decompose and generate leachate rich in organic and inorganic contaminants [1]; [7]. Leachate produced in dumpsites is one of the most critical environmental threats due to its high mobility and capacity to transport dissolved heavy metals, nutrients, pathogens, and persistent organic pollutants into surrounding soil and groundwater systems [6]; [13]; [19]; [32]. Once generated, leachate percolates through the vadose zone, particularly in environments underlain by highly weathered, permeable, or fractured basement rock aquifers, where secondary porosity enhances vertical fluid movement, eventually reaching shallow groundwater systems that commonly serve as the primary source of domestic water supply in many rural and peri-urban communities [5]; [8]; [16]; [34]. This process significantly increases aquifer vulnerability, particularly where natural protective layers such as clay or lateritic horizons are thin or discontinuous. Numerous studies across southwestern Nigeria have shown that groundwater systems around active dumpsites often exhibit elevated electrical conductivity, high total dissolved solids, and anomalous heavy-metal concentrations, indicating leachate intrusion [3]; [25]; [36]. These impacts are often spatially variable, depending on subsurface lithology, groundwater flow direction, and the age and composition of waste deposits [27]; [33]. Consequently, understanding subsurface contamination pathways requires an integrated investigative approach that combines both geophysical and hydrochemical techniques [17]; [38]. Integrated geophysical methods, particularly electrical resistivity techniques such as Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), have proven highly effective in delineating subsurface lithological layers and mapping contaminant plumes due to their sensitivity to variations in pore fluid conductivity [21]; [23]; [24]. These methods are often complemented by hydrochemical analyses of groundwater samples, which provide quantitative evidence of contamination levels through parameters such as pH, electrical conductivity, total dissolved solids, and major ion chemistry, while also serving to validate and constrain geophysical interpretations of subsurface conditions [8]; [12]; [14]. The integration of geophysical and hydrochemical approaches has been widely recognized as providing a more robust and reliable

characterization of both the spatial extent and severity of subsurface pollution, particularly in dumpsite environments where heterogeneity of waste and subsurface materials can complicate single-method interpretations [4]; [9]; [20]; [28]. In recent years, several investigations in southwestern Nigeria have demonstrated the effectiveness of integrated geophysical and hydrochemical assessments in evaluating the impacts of dumpsites on groundwater quality [2]; [8]; [26]. Studies conducted in locations such as Akure, Ile-Ife, and Ado-Ekiti have consistently reported that leachate migration from unregulated dumpsites leads to significant degradation of shallow aquifers, resulting in elevated electrical conductivity, increased total dissolved solids, and elevated concentrations of potentially toxic elements, thereby posing serious health risks to nearby populations [5]; [15]; [29]. These findings underscore the widespread nature of dumpsite-related contamination in crystalline basement terrains, where secondary porosity, weathered overburden, and fracture networks provide preferential pathways for contaminant transport [16]; [34]. Despite significant advances in environmental geophysics and hydrochemical assessment, site-specific investigations remain essential due to pronounced spatial variability in geology, hydrogeology, waste composition, and land-use practices that strongly influence contaminant transport and aquifer vulnerability [8]; [10]; [11]. In many communities within Ekiti State, including Ijan-Ekiti, rapid peri-urban expansion and unplanned residential development have increasingly encroached upon informal waste disposal sites, thereby heightening the potential risk of groundwater contamination [5]; [30]. However, despite these growing environmental pressures, detailed subsurface geophysical and hydrochemical investigations remain limited in these areas, particularly in terms of delineating leachate migration pathways and quantitatively assessing aquifer vulnerability within the crystalline basement complex terrain of southwestern Nigeria [2]; [31]. Therefore, this study focuses on the Ikota Street dumpsite in Ijan-Ekiti, southwestern Nigeria, employing an integrated geophysical and hydrochemical approach to evaluate subsurface resistivity structures, delineate leachate migration zones, and assess groundwater quality. The study aims to provide a comprehensive understanding of the interaction between waste disposal practices and subsurface hydrogeological conditions, thereby contributing to improved environmental management strategies and sustainable groundwater protection in the region.

1.1 Description of the Study Area: Ikota Street Dumpsite, Ijan-Ekiti

Ijan-Ekiti, located in the tropical rainforest belt of Southwestern Nigeria, is a developing community situated within a gently undulating terrain with elevations ranging from approximately 250–400 m above sea level, and the Ikota Street dumpsite (7°37'23.62"N, 5°22'50.13"E) lies within this setting (Figure 1). The area experiences a humid tropical climate with distinct wet (April–October) and dry (November–March) seasons, with annual rainfall exceeding 1500 mm and humidity reaching 80–100% during the rainy season, which promotes intense leachate generation and migration, while the dry season is characterized by Harmattan winds and lowered groundwater levels. The natural vegetation is typically rainforest in origin, but has been largely modified into secondary regrowth and agricultural clearings due to urban expansion and farming activities. Geologically, the site is underlain by the Precambrian Basement Complex of southwestern Nigeria, comprising quartzite–quartzofeldspathic gneiss, charnockite, and older granites formed during the Pan-African orogeny (2700–2000 Ma), which are generally impermeable in their fresh state but are extensively fractured and jointed, thereby providing secondary porosity that enhances subsurface fluid movement. Hydrogeologically, the subsurface consists of a thin lateritic topsoil (approximately 0.5–1.2 m) overlying a thicker saprolitic weathered zone that may extend to about 15 m and often forms a shallow perched aquifer, underlain by a fractured basement aquifer system where groundwater occurrence is controlled by fracture connectivity and weathering intensity; importantly, the dumpsite is also adjacent to a seasonal stream that facilitates pollutant transport via surface runoff during rainfall events. Demographically, Ijan-Ekiti is a medium-sized, rapidly growing settlement with a population engaged in agriculture, commerce, and education, generating increasing volumes of heterogeneous municipal solid waste at the open, unlined Ikota Street dumpsite, consisting of biodegradable organics, plastics, metals, and electronic waste, while nearby domestic hand-dug wells create a direct source–pathway–receptor linkage that heightens the risk of leachate infiltration into groundwater resources used for domestic supply.

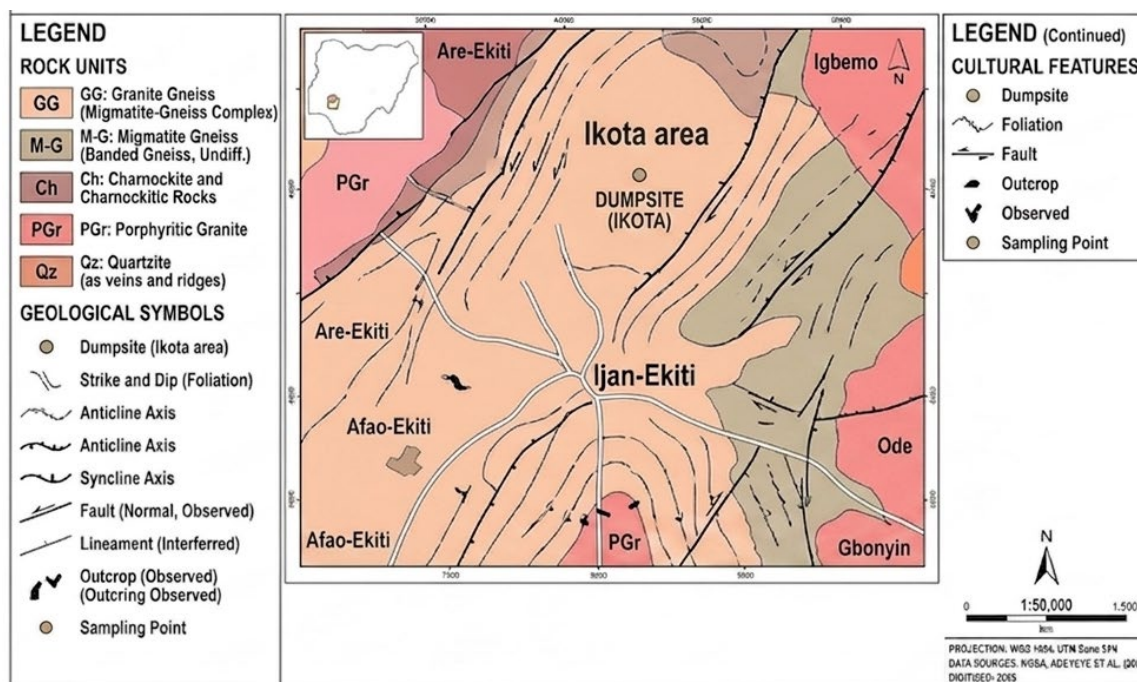


Figure 1: Geological map of Ijan-Ekiti and environment [39]

2.0 Materials and Methods/Methodology

2.1 Geophysical Survey

A geophysical investigation was conducted using the audio-magnetotelluric (ADMT) method to characterize subsurface conditions beneath the dumpsite. A total of eleven vertical soundings were acquired along two east–west oriented traverses (T1 and T2), each measuring 50 m in length. The survey stations were established at 5 m intervals, providing adequate spatial coverage for subsurface imaging. The ADMT system employed in this study measures subsurface resistivity by utilizing both natural and controlled electromagnetic fields, enabling the delineation of variations in lithology and fluid content. Data acquisition followed standard field procedures, with electrode spacing extended up to a maximum of 100 m to ensure sufficient depth of investigation. The acquired data were processed using specialized proprietary software to generate two-dimensional (2D) resistivity sections (isographs). These sections were interpreted based on established resistivity contrasts, where low resistivity values are indicative of conductive materials such as clay-rich or leachate-saturated zones, while high resistivity values correspond to more resistive formations, including fresh or competent bedrock.

2.2 Water Sampling and Analysis

Water samples were collected from a nearby stream and a hand-dug well about 20 m away from the dumpsite to evaluate their physicochemical and hydrochemical characteristics. In-situ measurements of key physicochemical parameters—including pH, electrical conductivity (S/m), total dissolved solids (TDS) mg/L, and salinity (%) were carried out using calibrated portable meters to ensure accuracy and minimize alterations during transport. Following field measurements, water samples were collected in pre-cleaned, acid-washed polyethylene bottles and transported under appropriate conditions to the laboratory for detailed analysis. The concentrations of major and trace elements, including Fe, Cu, Zn, Pb, Cd, and As, were determined using Atomic Absorption Spectrometry (AAS) in accordance with established analytical protocols and standard calibration procedures. Quality assurance and quality control (QA/QC) measures were strictly adhered to throughout the analysis, including the use of reagent blanks, duplicate samples, and standard reference materials to ensure data reliability and precision. The analytical results were subsequently compared with guideline values recommended by the World Health Organization to assess the suitability of the water for domestic use.

3.0 Results and Discussion

3.1 Geophysical Results

The upper section of the profile, extending from the surface to approximately –65 m depth, comprises the topsoil, weathered layer, and fractured basement. This section is dominated by low-conductivity zones ranging from 0.27 to 0.31 S/m, represented by red to orange colours in Figure 2. These conductivity values suggest the presence of relatively dry or unsaturated materials, such as fine-grained sand or compacted clayey sand, which may correspond to the waste mass core or dry overburden. The thickness of the overburden is considered sufficient to reduce the infiltration of leachate into the groundwater system. Beneath this layer, between approximately –65

m and -150 m depth, the profile reveals distinct lens-shaped zones of very low conductivity values ranging from 0.07 to 0.13 S/m, represented by blue to green colours. These zones are interpreted as saturated formations likely containing groundwater. In addition, the occurrence of intense purple and blue zones between approximately -160 m and -190 m depth provides strong evidence of fractured zones that may serve as aquifers. At depths of about -190 m to -230 m, a moderately conductive zone extends laterally across most of the surveyed profile and is interpreted as the top of the fresh basement. Below this, from approximately -230 m to -310 m depth, another low-conductivity zone is observed, which is suspected to represent the fresh basement with the possible presence of a deep-seated aquifer, as illustrated in Figure 2.

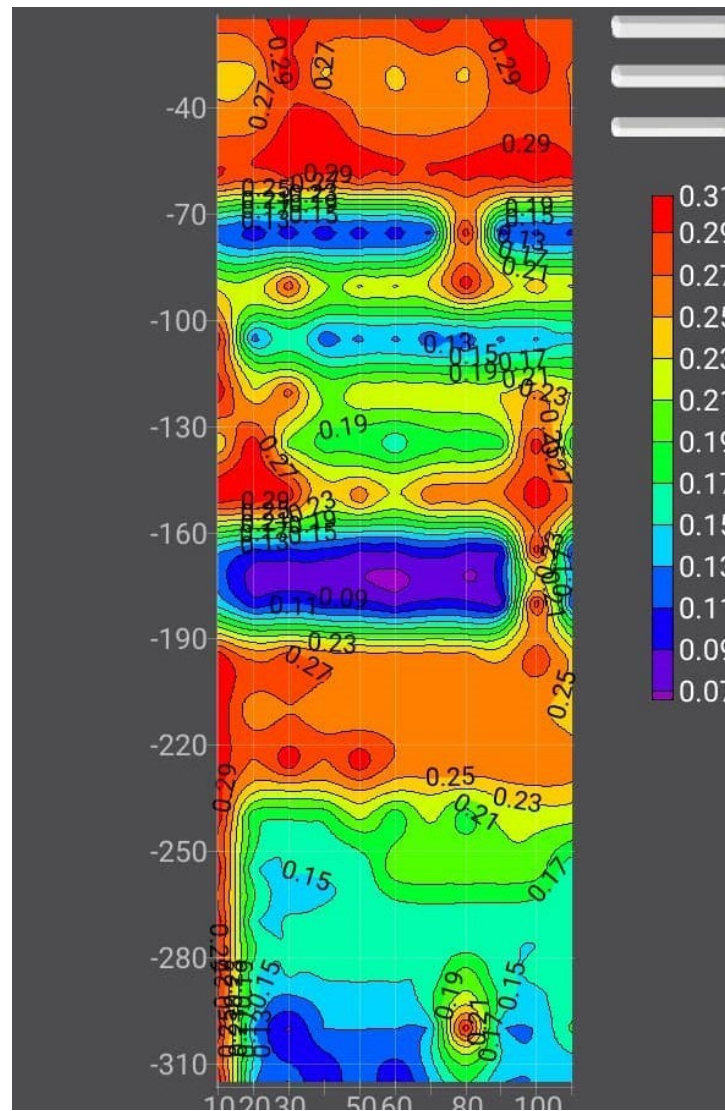


Figure 2: 2D electrical resistivity model (Traverse 1) of the Ikota Street dumpsite area

Figure 3 presents the 2D conductivity model for Traverse 2, which is situated directly on the dumpsite. The profile reveals less uniform subsurface layering and thickness, indicating a more heterogeneous geological and waste-disposal environment. The near-surface layer, extending from 0 m to approximately -50 m depth, is moderately conductive (>0.10 S/m), suggesting the presence of upper waste materials or topsoil that has already been partially saturated by contaminants. Beneath this, between about -50 m and -85 m depth, a relatively horizontal conductive layer with conductivity values ranging from 0.080 to 0.095 S/m is observed. This layer likely represents a semi-permeable zone composed of compact lithology or comparatively drier materials. Between approximately -85 m and -190 m depth, the model shows irregular and alternating bands of low-to-moderate conductivity, which indicate the presence of a heterogeneous rock unit. This suggests that fluid migration within the subsurface is not uniform but rather controlled by fractures and more resistive bedrock units. Below this interval, between about -190 m and -250 m depth, another rock layer with conductivity values of 0.080–0.095 S/m is interpreted as fractured basement rock. This fractured zone possesses the potential for fluid migration and may also serve as an aquifer. At greater depth, from approximately -250 m to -310 m, the conductivity model shows a distinct transition into an extremely low-conductivity zone (dark blue to purple colours, <0.060 S/m), forming

the basal layer. This zone appears as a large and continuous purple-blue block beginning around -250 m depth, suggesting the presence of a naturally impermeable formation. In this region, fluid movement is expected to occur only through secondary porosity features such as faults, joints, fractures, or shear zones.

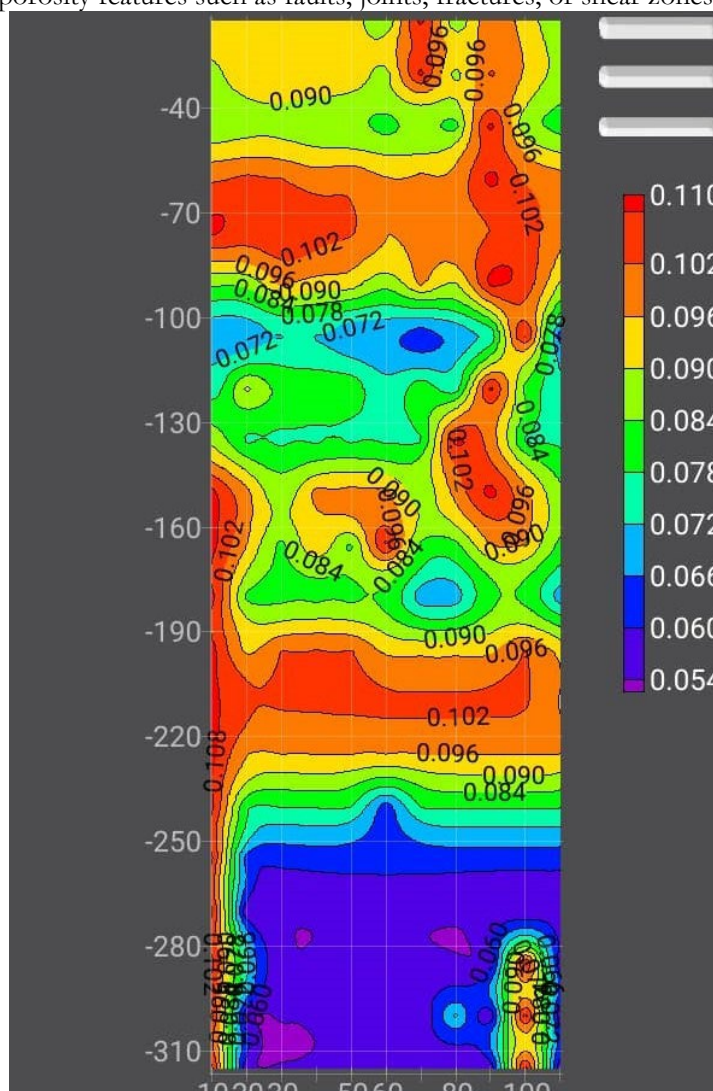


Figure 3: 2D electrical resistivity model (Traverse 2) of the Ikota Street dumpsite area

3.2 Physicochemical Analysis

The general physicochemical characteristics of both well and stream water indicate that most parameters fall within acceptable limits recommended by the World Health Organization (Table 1). The pH value of 7.5 shows that the water is neutral and comfortably within the WHO permissible range of 6.5–8.5, suggesting that the water has not undergone significant acidification, typically associated with leachate contamination. Similarly, the Total Dissolved Solids (TDS) values for both sources are below the 500 mg/L guideline limit. However, the well water exhibits relatively higher electrical conductivity (173.2 $\mu\text{S}/\text{cm}$) and salinity (84.1 mg/L) compared to the stream, indicating a greater concentration of dissolved inorganic salts in the groundwater, likely due to leachate percolation into the subsurface. In contrast, the assessment of heavy metals reveals more critical concerns. While concentrations of Iron (Fe), Copper (Cu), and Zinc (Zn) remain within WHO permissible limits, trace metals present a different scenario. Notably, Arsenic (As) in the stream water has a concentration of 0.015 mg/L, exceeding the WHO limit of 0.01 mg/L, while Cadmium (Cd) is recorded at 0.004 mg/L, surpassing the permissible value of 0.003 mg/L (Figure 4). Trend analysis further shows that although metals such as Zinc and Copper appear negligible due to their relatively higher allowable limits (3.0 mg/L and 2.0 mg/L, respectively), elements like Lead (Pb), Cadmium (Cd), and Arsenic (As) have extremely low safety thresholds, reflecting their high toxicity even at trace concentrations. The occurrence of toxic metals such as Lead, Cadmium, and Arsenic in both well and stream samples strongly indicates leachate migration from the Ikota Dumpsite. As waste materials decompose, infiltrating rainwater mobilizes heavy metals from sources such as batteries, electronic waste, and other refuse, forming leachate that percolates into groundwater and flows into nearby surface water bodies. Over time, these metals accumulate in stream sediments and aquatic organisms, leading to bioaccumulation and potential entry into the human food chain.

Consequently, residents of Ijan-Ekiti who depend on these water sources are exposed to significant long-term health risks associated with heavy metal toxicity. Overall, the findings suggest that the dumpsite is actively contributing to groundwater and surface water contamination. Although the well water currently appears relatively safer with respect to Arsenic and Cadmium levels, the stream water is already compromised. Without adequate containment measures, such as proper lining of the dumpsite or implementation of effective water treatment systems, the contamination plume is likely to expand, further deteriorating groundwater quality in the area.

Table 1: Physicochemical parameters of water samples from Ikota dumpsite area (well and stream)

Parameter	Well Water	Stream Water	WHO Guideline
pH	7.5	7.5	6.5–8.5
Conductivity ($\mu\text{S}/\text{cm}$)	173.2	28.3	—
TDS (mg/L)	12.1	27.9	<500
Salinity (mg/L)	84.1	27.8	—
Heavy Metals (mg/L)			
Fe	0.15	0.07	0.3
Cu	0.02	0.03	2.0
Zn	0.05	0.04	3.0
Pb	0.005	0.006	0.01
Cd	0.002	0.004	0.003 \triangle
As	0.008	0.015 \triangle	0.01
Cr	0.01	0.012	0.05

\triangle Values exceeding World Health Organization (WHO, 2017) permissible limits.

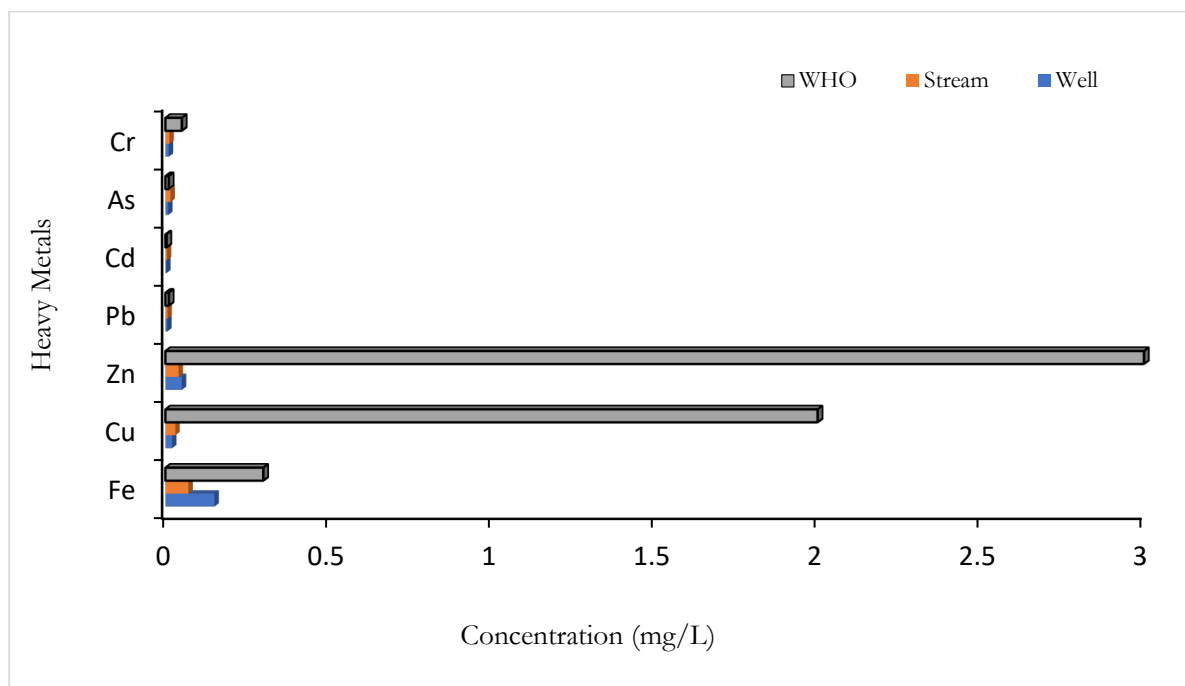


Figure 4: Comparison of the mean values of some heavy metals and their corresponding WHO permissible limits

4.0 Conclusion

The integrated geophysical and physicochemical investigations clearly demonstrate that the Ikota dumpsite is exerting a significant impact on the subsurface environment and surrounding water resources. The geophysical results reveal distinct highly-conductive zones interpreted as leachate plumes migrating laterally through preferential pathways such as fractures and permeable layers. These plumes occur at varying depths and show strong connectivity, indicating active subsurface contaminant transport. The presence of conductive zones extending toward deeper sections suggests that leachate has the potential to reach and interact with the main groundwater system, thereby posing a serious risk of aquifer contamination. The absence or thinning of protective resistive layers in some sections further enhances the vulnerability of the groundwater to pollution. The physicochemical analysis supports these findings, showing that although general water quality parameters such as pH and TDS remain within permissible limits set by the World Health Organization, the presence of elevated

concentrations of toxic trace metals—particularly Arsenic and Cadmium in stream water—indicates contamination beyond safe thresholds. The detection of Lead, Cadmium, and Arsenic in both well and stream samples confirms the influence of leachate derived from waste decomposition. Generally, the results indicate that while groundwater is not yet severely degraded in those locations, the contamination plume is actively developing and poses a long-term threat to water quality, ecosystem health, and public safety in Ijan-Ekiti.

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