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(Research Article)

Effect of dumpsite on groundwater quality: A case study of bonny island rivers state

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Abstract

This study investigates the effect of dumpsite activities on groundwater quality in Bonny Island, Rivers State, Nigeria. Bonny Island, an ancient coastal city with significant economic importance due to its oil and gas industries, faces potential environmental threats from dumpsite activities. The research utilized vertical electrical sounding (VES) and 2D resistivity profiling (ERT) to assess subsurface contamination. Measurements were taken to determine the lateral and vertical spread of contaminants at the dumpsite. Complemented by laboratory analysis of groundwater samples from the two dumpsites, groundwater samples were analyzed for a range of physical, chemical, and biological parameters, such as pH, TDS, TSS, DO, Nitrates, Sulphates, Chlorides, heavy metals, and other pollutants. Results obtained indicate that the groundwater near the dumpsites exhibits varying levels of contamination. The VES and ERT profiles revealed low resistivity zones at shallow depths, indicating possible clay-rich soil or topsoil contamination from leachate. High resistivity areas in the middle depths suggest cleaner zones, but low resistivity at both ends of the profiles indicates further spread of the leachate. Laboratory analyses of groundwater sample showed that most parameters were within acceptable limits set by WHO and NSDWQ, except iron, which exceeded the permissible limit, suggesting contamination of iron at the site. These findings highlight the need for continuous monitoring and remediation efforts to prevent further deterioration of groundwater quality. This study underscores the critical importance of protecting groundwater in economically vital and ecologically sensitive regions like Bonny Island.

Keywords: Dumpsites; Bonny Island; Electrical Resistivity Tomography (ERT); Vertical electrical sounding (VES); Biological parameters; Heavy metals

1. Introduction

Bonny Island, located in the southern part of Nigeria, is a strategically significant island in the Niger Delta region characterized by a network of rivers, creeks, and mangrove swamps. It lies along the Bonny River and the Bight of Bonny, with the Atlantic Ocean to its south. The island is part of Rivers State and hosts key infrastructure related to the oil and liquefied natural gas (LNG) sectors, contributing significantly to the nation's economy. The island is not without its challenges, as Rapid urbanization, often associated with environmental impacts, has raised concerns about the conservation of Bonny's natural resources. Issues such as waste management, pollution, and the impact of industrial activities on the local ecosystem require careful consideration. Though Bonny Island is surrounded by surface water, Groundwater holds profound significance for Bonny Island and its residents. While urbanization is bringing economic opportunities, it also comes with environmental costs. The reliance on groundwater for drinking and industrial processes underscores its pivotal role in sustaining life on the island. The management of waste generated by industrial and residential activities becomes a critical factor. It is within this context that the presence of a dumpsite on Bonny Island forms the Centre of our inquiry. The impact of dumpsites on groundwater quality is a critical environmental concern that has garnered attention from researchers around the world. [1] Conducted comprehensive research to assess the impact of waste dumpsites on the shallow groundwater and surface water quality close to an active dumpsite in the Oshogbo metropolis. In their studies, all major ions revealed concentration within the acceptable limit of both

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standards except chloride and sodium in some of the wells. [2] Researched on the Environmental impact of landfills on groundwater quality and agricultural soils in Nigeria. His studies reveal that the concentration of waste materials in the landfill site had systematically polluted the soil and groundwater over time. The effect of such pollution as determined from the study declined away from the polluting source. This implied that the contamination of the groundwater was more dependent on the proximity to the dump sites. Groundwater, being a primary source of freshwater in Bonny Island, is crucial to the well-being of both the environment and the community. Understanding the dynamics of this relationship is very important for devising sustainable environmental management strategies.

2. Material and Methods

2.1. Study Area

The research was conducted in Bonny Island, an ancient coastal city and a Local Government Area in Rivers State in southern Nigeria. The island is located approximately 40 km south of Port Harcourt [3]. The Island lies on the Lat. 4° 27N and Long 7° 10E with an estimated population of 270,000, and is known for its strategic economic importance, rich natural resources, and unique environmental setting. The Island has a relatively flat topography on an elevation of 3.05 atmospheric mean sea level with a total land area of 214.52 m^2 [4]. Generally, the water table in the area is dynamic and ranges between 0.1–3 m depending on the season.

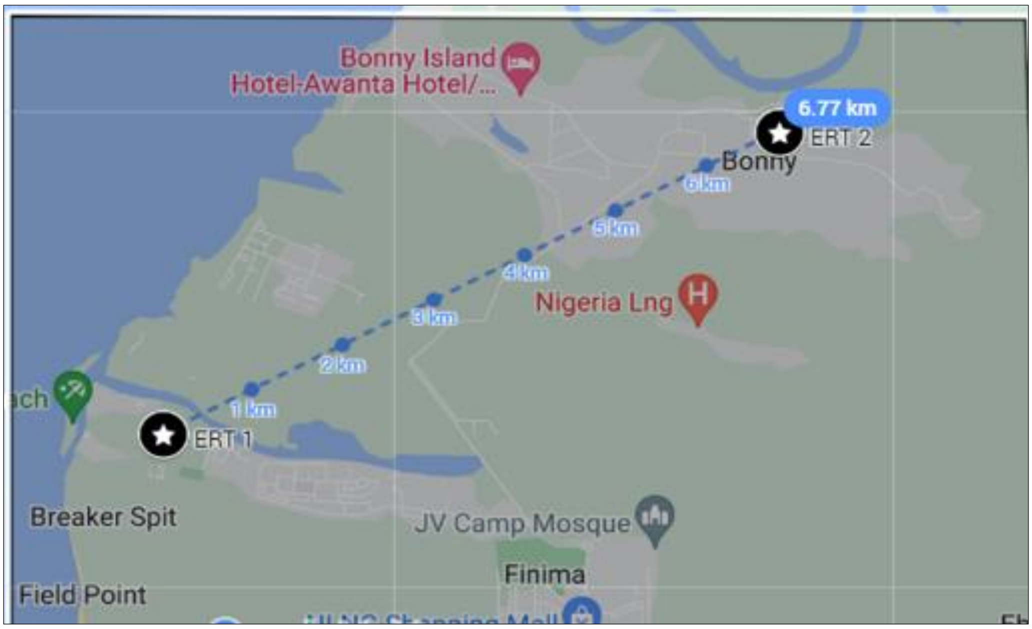


Figure 1 Map of Bonny L.G.A Showing the study locations ERT1 & ERT2 (Google Map)

The island is a critical hub for Nigeria's oil and gas sector, hosting several multinational corporations, including the Nigeria Liquefied Natural Gas (NLNG) plant. The presence of these industries drives the local economy, providing employment and boosting economic activities. Bonny Island is home to a mix of indigenous communities and a significant number of migrants working in the oil and gas industry. The population is diverse, with a blend of different ethnic groups and cultures.

2.2. Theory of Electrical Resistivity

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. The fundamental physical law used in resistivity surveys is Ohm's Law which governs the flow of current in the ground.

$$R = \frac{V}{I}$$

With V being the potential (V) and I being the current (A)

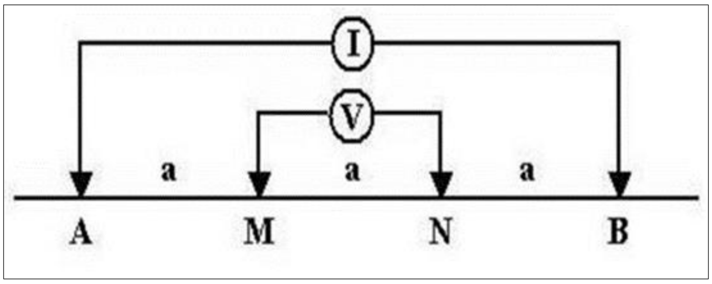


Figure 2 A conventional four electrode array to measure the subsurface resistivity

In this configuration (Fig 2), four electrodes are equally spaced along a straight line so that AM=MN=NB=a. For this configuration, the apparent resistivity reduces to:

$$\rho_a = \frac{\Delta V}{I}\left\{\frac{2\pi}{\frac{1}{a}-\frac{1}{2a}-\frac{1}{2a}+\frac{1}{a}}\right\}$$

$$\rho_a = \frac{\Delta V}{I}\left\{\frac{2\pi}{\frac{2}{a}-\frac{1}{a}}\right\}$$

$$\rho_a = 2\pi.\frac{\Delta V}{I}(a)$$

$$\rho_a = 2\pi a.\frac{\Delta V}{I}$$

Where 2πa is the geometric factor.

2.3. Data Acquisition and Processing

2.3.1. Vertical Electrical Sounding (VES) and 2D Resistivity Data

The field procedure adopted in this study are Vertical Electrical Sounding (VES) using Schlumberger configuration and 2D Electrical resistivity profiling (ERT). Two VES survey were conducted using the Schlumberger electrode configuration with maximum current electrode spread of AB/2 = 300 m. Additionally, two profiles using the Wenner electrode configuration with a spread of 100 meters were conducted on Bonny Island at the Bonny dumpsite and Finima dumpsite to determine the lateral spread of contaminated zones. Resistivity meter (Herojat Geoscience Rhomega Smart) Terrameter and its other accessories such as electrodes, connecting wires, etc, were used in the data acquisition. The Terrameter was positioned between the potential electrodes (M and N) away from the current electrodes (A and B). The Schlumberger VES was performed first, followed by recording coordinates with a GPS. The Wenner configuration was then used for the 2D resistivity profiling, with measurements taken every 5 meters from the starting point (0 m) to the endpoint (100 m). Electrodes were mounted side by side with the wire reels and connected. After each reading, the wire reels and electrodes were moved 5 meters forward and then returned after skipping 10 meters. The collected data were interpreted quantitatively for VES and qualitatively for 2D profiling to determine the thickness, nature, vertical and lateral variations of the geological formations, creating a comprehensive geological picture of the area. VES data were entered into the computer, and curves were plotted using IPI2WIN interpretation software. The true resistivity and layer thicknesses were translated into geological information using the region's geological history. 2D resistivity survey data were processed using RES2DINV.

2.3.2. Laboratory Analysis of Groundwater Samples

The laboratory analysis of groundwater and soil samples involves a series of steps to assess various physical and chemical parameters. Water samples were collected with clean bottles from the two dumpsites using a hand auger. These samples collected at 2 m depth were analyzed for different parameters such as pH, TDS, TSS, DO, Nitrate (NO^3), Sulphate (SO_4^{2-}), Chloride (Cl^-), Phosphate (PO_4^{3-}), Hardness, Alkalinity, BOD, COD, Magnesium (Mg), Potassium (K), Sodium (Na), Copper (Cu), Chromium (Cr), Cadmium (Cd), Nickel (Ni), Arsenic (As), Iron (Fe), Mercury (Hg), Lead (Pb), Zinc (Zn), Calcium (Ca), and Manganese (Mn). The samples were subjected to Physical tests, Anions & Nutrients, and

Metals tests. The metals were analyzed using the ALPHA method, Anions and Nutrients using the ALPHA and EPA method, while the Physical test was also analyzed using the ALPHA and PHOTOMETRIC method. Throughout the analysis process, strict quality assurance and quality control measures were implemented to ensure the accuracy, precision, and reliability of the results.

3. Result and Discussion

3.1. Laboratory Analysis of Groundwater

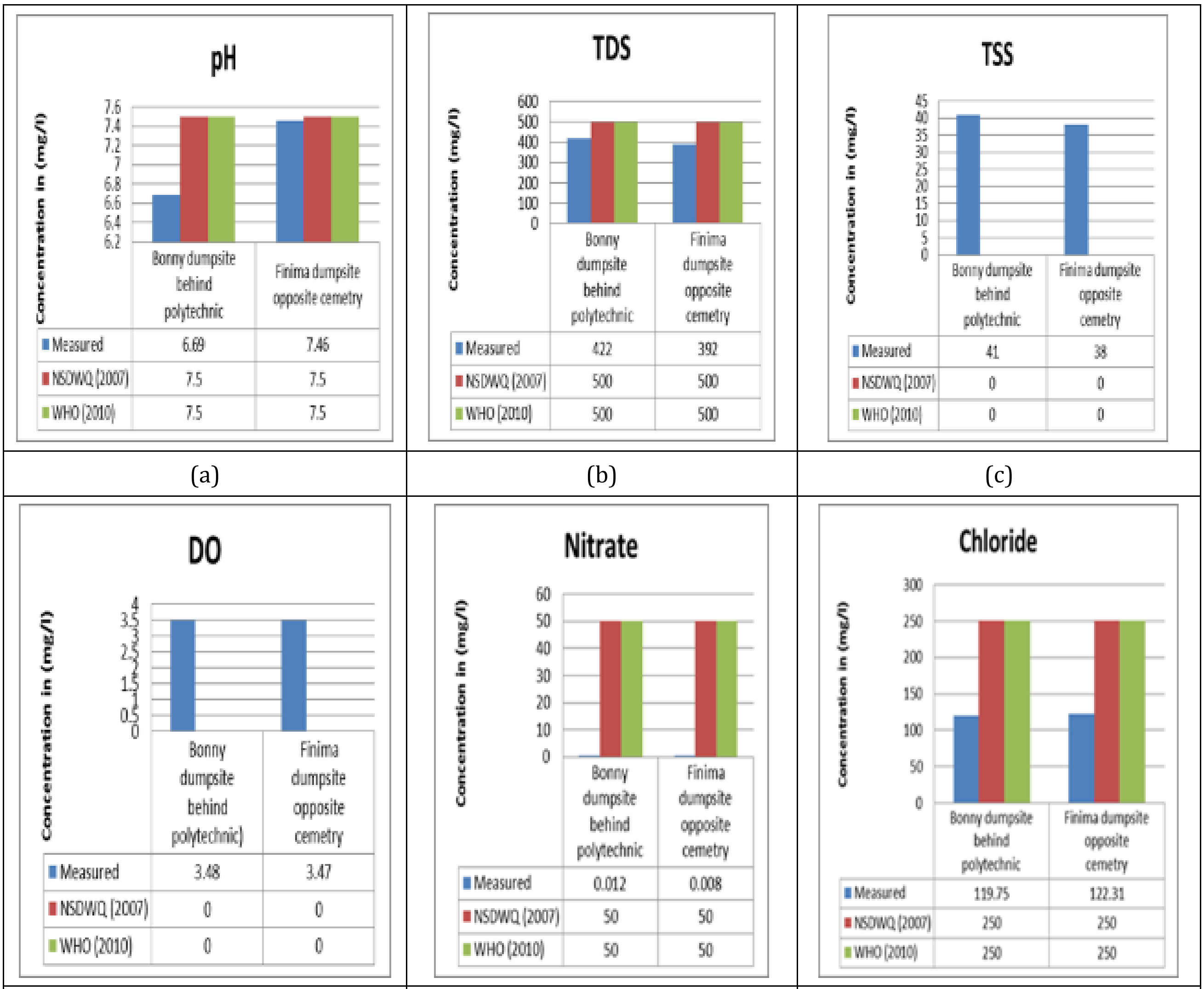
Physical tests, Anions & Nutrients, and heavy metal analyses of the groundwater samples were carried out in the laboratory and the result is presented below (Table 1). This table shows the statistical summary of those analyzed water samples compared with [5] and WHO [6, 7, 8, 9, 10, 11] acceptable standards. Table 2 shows the layered parameters from the interpretation of the two (2) geoelectric sounding data acquired in two selected dumpsites in Bonny Island.

Table 1 Summary of Groundwater Parameters in the study area compared with NSDWQ and WHO

Parameter (mg/l)	**Method**	**Measured Value (mg/l)**		**NSDWQ (2007) [5] (mg/l)**	**WHO (1997,1999,2003,2010,2011,2024) [6, 7, 8, 9, 10, 11] (mg/l)**
		Bonny Dumpsite	**Finima Dumpsite**		
Physical Test					
pH	APHA 4500-H+ B	6.96	7.46	6.8 -8.5	6.8 – 8.5
TDS	APHA 2510 B	422.00	392.00	500.0	500.0
TSS	8006 PHOTOMETRIC	41.00	38.00	NG	NG
DO	APHA 4500 C	3.48	3.47	NG	NG
Anions and Nutrients					
Nitrate(NO_3)	APHA 4500-NO_3-E	0.012	0.008	50.0	50.0
Chloride (Cl^-)	APHA 4500-Cl-B	119.75	122.31	250.0	250.0
Sulphate (SO_4^{2-})	EPA375.4 (600/4-79-020)	24.16	26.31	100.0	100.0
Phosphate (PO_4^{3-})	APHA 4500-PE	ND	ND	NG	1.0
Hardness ($CaCO_3$)	APHA 2340 A	31.00	35.00	150	200
Alkalinity	APHA 2320	102.00	97.00	NG	NG
Biological oxygen demand (BOD)	APHA 5210A	1.92	1.87	NG	NG
Chemical oxygen demand (COD)	APHA 5220C	6.34	6.55	NG	NG
Metals					
Magnesium(mg)	APHA 3111B	1.30	1.28	20	50
Potassium (K)	APHA 3111B	9.04	9.24	NG	55
Sodium (Na)	APHA 3111B	80.21	76.45	200.0	200.0
Copper (Cu)	APHA 3111B	ND	ND	1.0	2.0
Chromium (Cr)	APHA 3111B	ND	ND	0.05	0.05

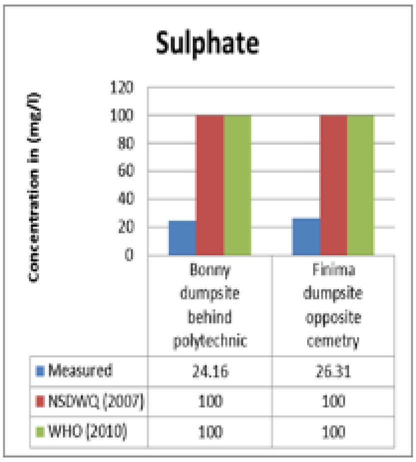
Cadmium (Cd)	APHA 3111B	ND	ND	0.003	NG
Nickel (Ni)	APHA 3111B	ND	ND	0.02	NG
Arsenic (As)	APHA 3111B	ND	ND	0.01	0.01
Iron (Fe)	APHA 3111B	0.61	0.49	0.3	0.3
Mercury (Hg)	APHA 3111B	ND	ND	0.001	NG
Lead (Pb)	APHA 3111B	ND	ND	0.01	0.01
Zinc (Zn)	APHA 3111B	0.04	0.02	3.0	5.0
Calcium (Ca)	APHA 3111B	10.45	11.26	NG	75.0
Manganese (Mn)	APHA 3111B	ND	ND	0.2	NG

ND = Not detected, NG = Not Given



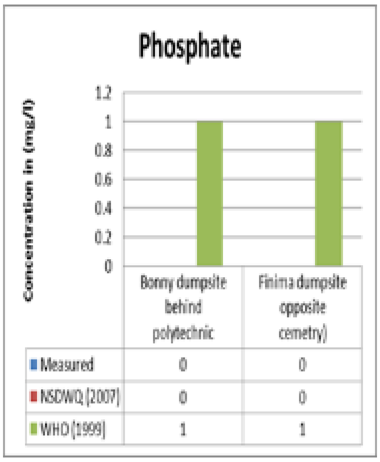
(a) (b) (c)

(d) (e) (f)



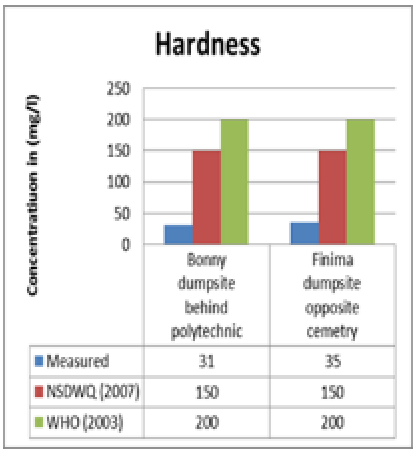
	Bonny dumpsite behind polytechnic	Finima dumpsite opposite cemetry
🟦 Measured	24.16	26.31
🟥 NSDWQ (2007)	100	100
🟩 WHO (2010)	100	100

(g)



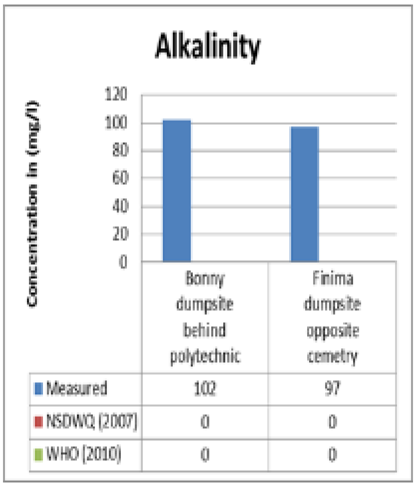
	Bonny dumpsite behind polytechnic	Finima dumpsite opposite cemetry)
🟦 Measured	0	0
🟥 NSDWQ (2007)	0	0
🟩 WHO (1999)	1	1

(h)



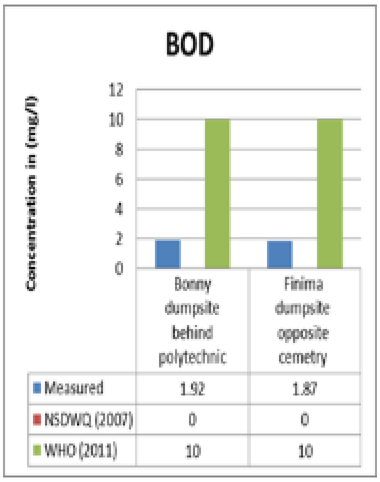
	Bonny dumpsite behind polytechnic	Finima dumpsite opposite cemetry
🟦 Measured	31	35
🟥 NSDWQ (2007)	150	150
🟩 WHO (2003)	200	200

(i)



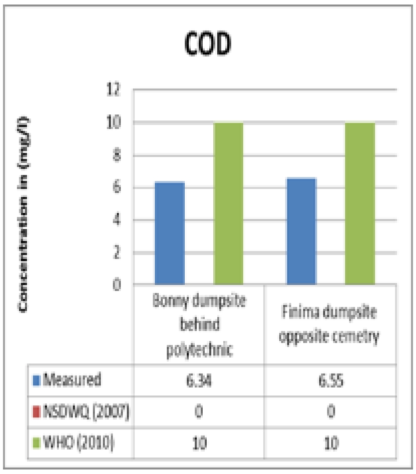
	Bonny dumpsite behind polytechnic	Finima dumpsite opposite cemetry
🟦 Measured	102	97
🟥 NSDWQ (2007)	0	0
🟩 WHO (2010)	0	0

(j)



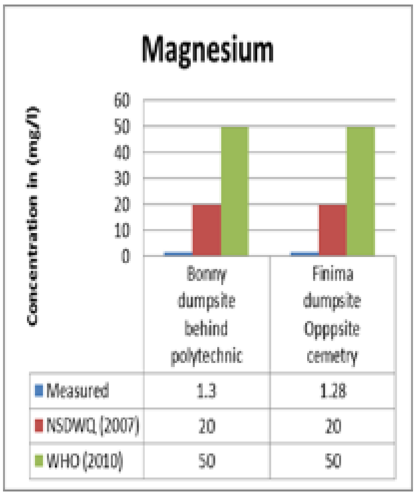
	Bonny dumpsite behind polytechnic	Finima dumpsite opposite cemetry
🟦 Measured	1.92	1.87
🟥 NSDWQ (2007)	0	0
🟩 WHO (2011)	10	10

(k)



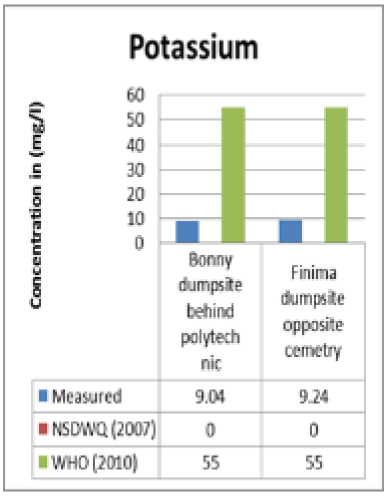
	Bonny dumpsite behind polytechnic	Finima dumpsite opposite cemetry
🟦 Measured	6.34	6.55
🟥 NSDWQ (2007)	0	0
🟩 WHO (2010)	10	10

(l)



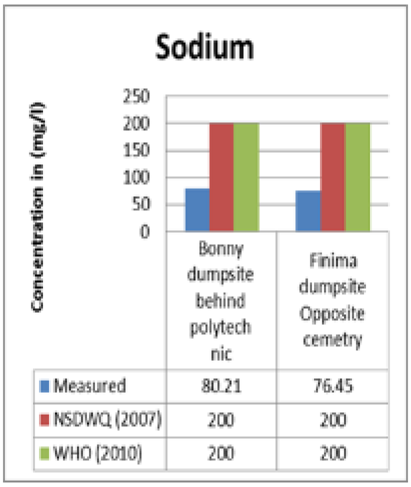
	Bonny dumpsite behind polytechnic	Finima dumpsite Oppsite cemetry
🟦 Measured	1.3	1.28
🟥 NSDWQ (2007)	20	20
🟩 WHO (2010)	50	50

(m)



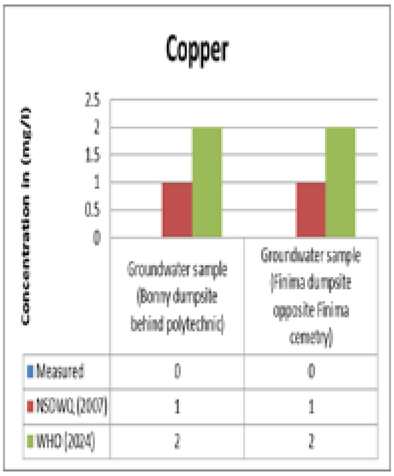
	Bonny dumpsite behind polytech nic	Finima dumpsite opposite cemetry
🟦 Measured	9.04	9.24
🟥 NSDWQ (2007)	0	0
🟩 WHO (2010)	55	55

(n)

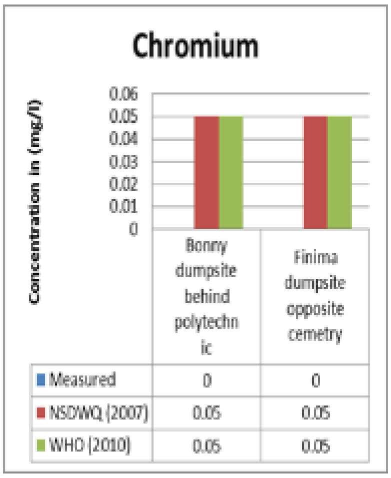


	Bonny dumpsite behind polytech nic	Finima dumpsite Opposite cemetry
🟦 Measured	80.21	76.45
🟥 NSDWQ (2007)	200	200
🟩 WHO (2010)	200	200

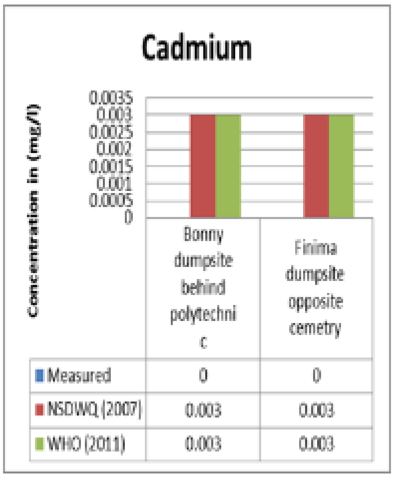
(0)


Copper
Concentration in (mg/l)
2.5
2
1.5
1
0.5
0
Groundwater sample (Bonny dumpsite behind polytechnic)
Groundwater sample (Finima dumpsite opposite Finima cemetry)
Measured 0 0
NSDWQ (2007) 1 1
WHO (2024) 2 2

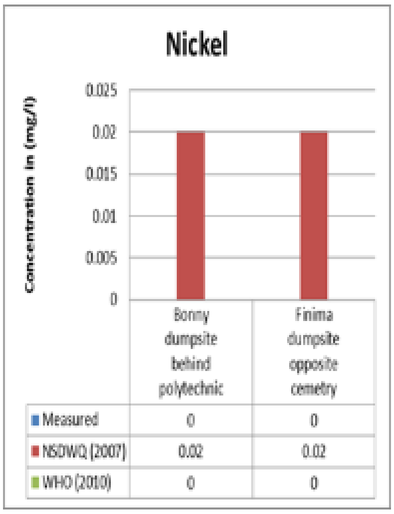
(p)


Chromium
Concentration in (mg/l)
0.06
0.05
0.04
0.03
0.02
0.01
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite cemetry
Measured 0 0
NSDWQ (2007) 0.05 0.05
WHO (2010) 0.05 0.05

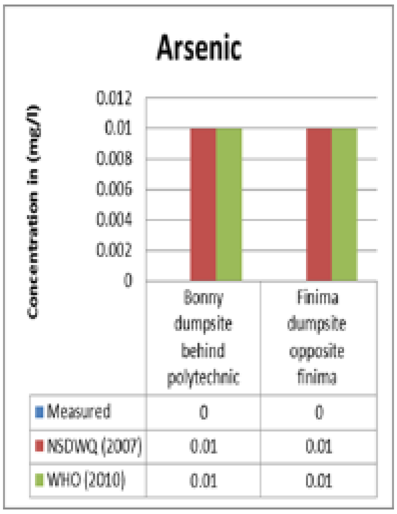
(q)


Cadmium
Concentration in (mg/l)
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite cemetry
Measured 0 0
NSDWQ (2007) 0.003 0.003
WHO (2011) 0.003 0.003

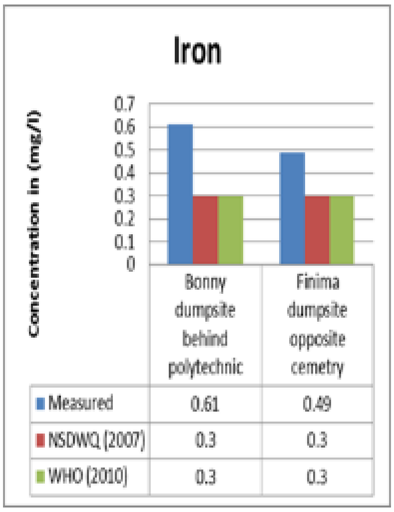
(r)


Nickel
Concentration in (mg/l)
0.025
0.02
0.015
0.01
0.005
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite cemetry
Measured 0 0
NSDWQ (2007) 0.02 0.02
WHO (2010) 0 0

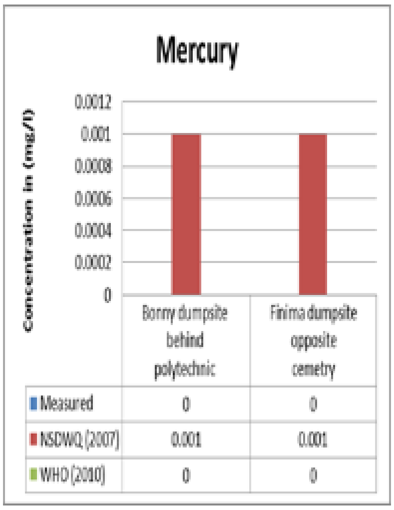
(s)


Arsenic
Concentration in (mg/l)
0.012
0.01
0.008
0.006
0.004
0.002
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite finima
Measured 0 0
NSDWQ (2007) 0.01 0.01
WHO (2010) 0.01 0.01

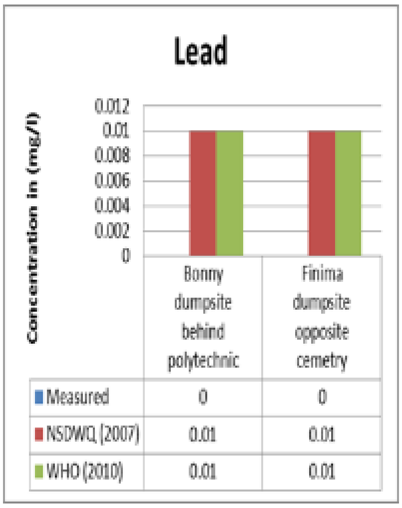
(t)


Iron
Concentration in (mg/l)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite cemetry
Measured 0.61 0.49
NSDWQ (2007) 0.3 0.3
WHO (2010) 0.3 0.3

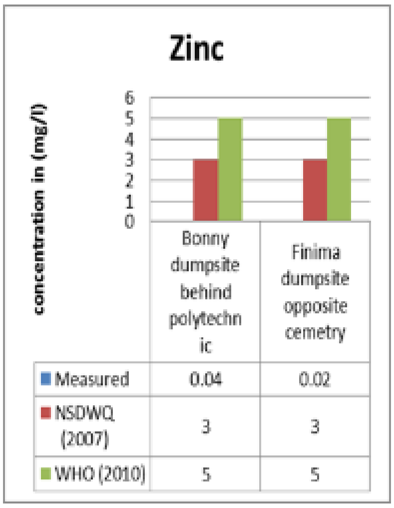
(u)


Mercury
Concentration in (mg/l)
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite cemetry
Measured 0 0
NSDWQ (2007) 0.001 0.001
WHO (2010) 0 0

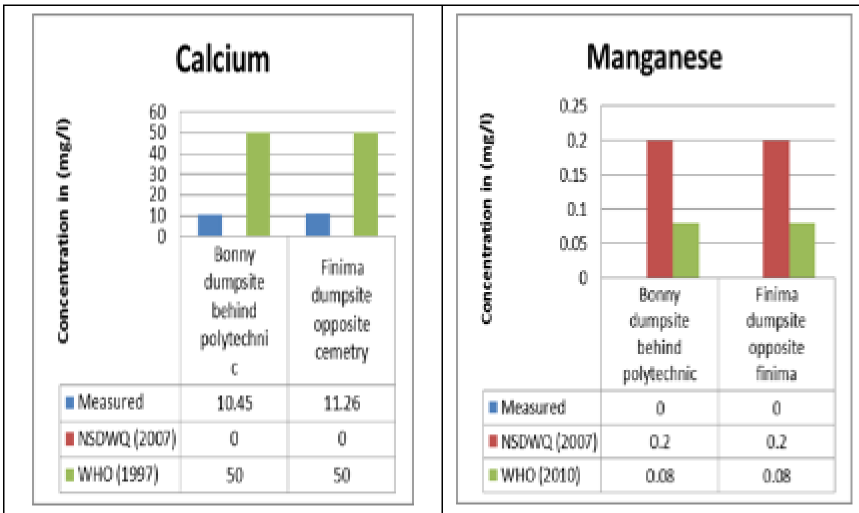
(v)


Lead
Concentration in (mg/l)
0.012
0.01
0.008
0.006
0.004
0.002
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite cemetry
Measured 0 0
NSDWQ (2007) 0.01 0.01
WHO (2010) 0.01 0.01

(w)


Zinc
concentration in (mg/l)
6
5
4
3
2
1
0
Bonny dumpsite behind polytechnic
Finima dumpsite opposite cemetry
Measured 0.04 0.02
NSDWQ (2007) 3 3
WHO (2010) 5 5

(x)



(y) (z)

Figure 3 (a-z) Concentration of parameters compared with NSDWQ and WHO standard

3.1.1. Hydrogen ion Concentration (pH)

pH is a critical factor in determining the health of aquatic ecosystems, as it affects the survival of macroinvertebrates and fish [12]. Neutral pH has a value of 7, and above this is alkaline or basic and below is acidic. Low pH (< 6.5) water can be acidic, soft, and corrosive, potentially leaching toxic metals like iron. While High pH (> 8.5) water is alkaline, and can be hard, causing aesthetic problems like scale formation on pipes, skin irritation etc. The values of the pH of the water sample from the two dumpsites are 6.96 and 7.46. This is within the permissible limit of 6.5 m to 8.5 recommended by [9] and [5] (Table 1).

3.1.2. TDS

Total dissolved oxygen refers to the total weight of solids that are dissolved in the water. It provides insights into the mineral content, taste, and overall quality of water. Drinking water generally has a TDS below 500 mg/l. High TDS levels, usually above 500 mg/l, can give water a bitter, salty, or unpleasant taste. The values of TDS from the analyzed water samples are 392 mg/l and 422 mg/l, which is below the maximum permissible limit recommended by [9] and [5] (Table 1).

3.1.3. TSS

Total Suspended Solid (TSS) in groundwater analysis refers to the dry weight of suspended particles that are not dissolved in a water sample. TSS reduces the clarity and transparency of groundwater, making it appear cloudy or murky. High TSS levels above 1,000 mg/l can make water appear cloudy or murky, affecting its aesthetic quality, [13]. While there is no recommended permissible value for TSS by [9] and [5], the results from the analyzed samples are 38 mg/l and 41 mg/l, which depict an area devoid of TSS contamination.

3.1.4. DO

Dissolved oxygen directly impacts the survival of aquatic organisms. The ideal value for dissolved oxygen in water is 14.6 mg/l, and the standard permissible value for drinking water is 5 mg/l [14]. Extremely low DO concentrations, sometimes below 1 mg/l, can suggest the presence of organic contaminants that consume oxygen through microbial degradation [15]. The [5] and [9] did not give any guideline on the permissible value for dissolved oxygen, while the values for the analyzed sample from the two dumpsites are 3.47 mg/l and 3.48 mg/l, which depict an area devoid of contamination from dissolved oxygen.

3.1.5. NITRATE (NO_3)

Nitrate primarily originates from agricultural activities such as use of mineral fertilizers and manure. Additionally, long-term leaks in sewer lines and septic systems can also lead to nitrate contamination. Long-term exposure to high nitrate levels in drinking water has been linked to various health risks such as brain tumour, and oxygen depletion in aquatic ecosystems [16]. The values of Nitrate from the analyzed water sample from the two dumpsites are 0.012 mg/l and 0.008 mg/l, which are far below the maximum permissible limit recommended by [5] and [9] (Table 1).

3.1.6. CHLORIDE (Cl^-)

Chlorine is important for assessing water quality and identifying potential sources of contamination. According to the Missouri Department of Natural Resources, Chloride concentrations above 250 mg/l can affect the taste and odour of drinking water, corrode pipes and infrastructure, leading to maintenance and repair issues, and also harm aquatic life. Chlorine from the analyzed samples from the two dumpsites are 119.75 mg/l and 122.31 mg/l, which is below the maximum permissible limit recommended by [9] and [5] (Table 1).

3.1.7. SULPHATE (SO_4^{2-})

Sulphate is a common inorganic anion in groundwater. High Sulphate concentrations in drinking water can pose health risks such as Catharsis, Dehydration, and Diarrhea [17]. Permissible standards for sulphate in drinking water vary across countries and regions. The results of the analyzed water sample from the two sites are 24.16 mg/l and 26. 26.31 mg/l. This is below the permissible limit of 100 mg/l set by [5] and [9].

3.1.8. PHOSPHATE (PO_4^{3-})

Phosphate is crucial for assessing water quality and identifying potential sources of contamination. A rise in its concentration can lead to proliferation of algae in water bodies. The permissible value for phosphate in groundwater varies depending on the regulatory bodies. According to the World Health Organization standard [7], the permissible limit of phosphate in drinking water is 1 mg/L, while the U.S Environmental protection Agency (USEPA) has a stringent desire limit of 0.305 mg/l. Result of the analyzed water samples from the two sites shows no detection (ND) of phosphate contamination in the area.

3.1.9. HARDNESS ($CACO_3$)

Hardness refers to the presence of metal ions, primarily calcium (Ca_2^+) and magnesium (Mg_2^+), which are responsible for the water's ability to precipitate soap and other detergents, making it difficult to lather. Although not strictly enforced, the [5] and [9] guidelines for drinking water quality recommend that the total hardness of water should not exceed 150 mg/l and 200 mg/l. Results from the analyzed water sample from the two sites are 31 mg/l and 35 mg/l, which depict an area with no sign of contamination or hardness in the water.

3.1.10. Alkalinity

Alkalinity is an aggregate property that indicates the amount of bases, such as bicarbonates (HCO_3^-), carbonates (CO_3^{2-}), and hydroxides (OH^-), present in water. High levels of alkalinity can result in a bitter or soapy taste in groundwater. This is due to the reaction between alkalinity and cations in the water, leading to the formation of precipitates and coatings that can affect the taste and odour of the water [18]. While there is no specific guideline from WHO and NSDWQ on Alkalinity, The ideal range for alkalinity in drinking water is typically within 20-200 mg/l [18]. The result of the water sample from the two sites is 97 mg/l and 102 mg/l, which indicates no sign of alkaline contamination.

3.1.11. Biological Oxygen Demand (BOD)

BOD reflects the amount of oxygen consumed by microorganisms to break down organic matter. Higher BOD values indicate a greater amount of organic matter present in the water, which can have negative impacts on aquatic life and water quality [19]. In summary, the permissible guideline for BOD in groundwater set by WHO is 10 mg/L [10], while the BOD levels in the groundwater samples collected at the two sites are 1.87 mg/l and 1.92 mg/l. This indicates no contamination from organic matter.

3.1.12. Chemical Oxygen Demand (COD)

COD is used as an indicator of the level of organic pollution. High COD levels in groundwater can indicate the presence of organic pollutants from sources such as wastewater, industrial effluents, agricultural runoff, Leachate from landfills and dumpsites, Septic systems and sewage [20]. World Health Organization (WHO) recommends a maximum permissible limit of 10 mg/l for COD in drinking water. The result obtained from the two dumpsites is below the WHO limit, indicating an area with no trace of chemical oxygen demand contamination.

3.1.13. Magnesium (Mg)

Magnesium is a key contributor to the taste of groundwater, with high levels often resulting in a bitter or unpleasant taste. The permissible guideline for magnesium in groundwater varies depending on the source. Nigerian standards for drinking water quality [5] and the World Health Organization [9] recommend a maximum permissible limit of 20 mg/l and 50 mg/l for magnesium in drinking water (Table 1). The result of the water sample from the two sites is 1.3 m/l and 1.28 mg/l, which indicates no sign of magnesium contamination.

3.1.14. Potassium (K)

Potassium is naturally present in groundwater due to the weathering of potassium-bearing minerals like clay minerals, and can also enter groundwater through agricultural activities, such as the application of fertilizers and manure [21]. The result from the two dumpsites shows a concentration of 9.04 mg/l and 9.24 mg/l, which is below the WHO standard. While the exact permissible limit may differ slightly between guidelines, most sources recommend keeping potassium levels in groundwater below 12 mg/l for drinking purposes [22], as Concentrations above this level may indicate potential contamination from sources like fertilizers or waste products.

3.1.15. Sodium (Na)

Sodium is a highly soluble chemical element that is often naturally found in groundwater. Sodium levels in groundwater can be elevated due to natural sources such as weathering of minerals in the soil, and salt-bearing geological formations. Human activities like salt use and sewage effluent can also contribute to high sodium levels [23]. While sodium is essential for human health, excessive intake can be problematic for individuals with hypertension, heart disease, or kidney problems. Sodium from the analyzed samples is 76.45 mg/l and 80.21 mg/l, which is below the maximum permissible limit recommended by[5] and [9] (Table 1). This result depicts a site free from Sodium contamination.

3.1.16. Copper (Cu)

Copper is a crucial element in groundwater analysis, as it can impact the quality and safety of drinking water. Long-term exposure to copper contamination in drinking water poses significant health risks such as Liver and Kidney Problems and anaemia [24]. The exact permissible limit of copper differs slightly between guidelines as seen in WHO (2 mg/l) and NSDWQ (1 mg/l), as most sources recommend keeping copper levels in groundwater below 2 mg/l for drinking purposes. The result of the analyzed sample from the two dumpsites shows no detection (ND) of copper in these study locations.

3.1.17. Chromium (Cr)

Chromium analysis in groundwater is crucial for identifying contamination and assessing health risks. Hexavalent Chromium (Cr^6) is the most toxic and mobile form of chromium, which is often associated with industrial activities and can contaminate groundwater. Health risks associated with Cr^6 in drinking water include Digestive problems, respiratory issues, and cancer [25]. Results from the analyzed sample from the two dumpsites show no detection (ND) of Chromium.

3.1.18. Cadmium (Cd)

Cd is a toxic heavy metal that can contaminate groundwater from various sources such as mining, agriculture (use of phosphate fertilizers), and industrial activities. Long exposure to Cd in drinking water, even at relatively low levels, can lead to kidney damage, skeletal effects, and potential neurological impacts, especially in children. While the maximum permissible guideline for cadmium in groundwater for both [10] and [5] is 0.003 mg/l. The result from the two dumpsites shows no detection (ND) of cadmium.

3.1.19. Nickel (Ni)

Nickel (Ni) is a heavy metal that can contaminate groundwater through processes such as industrial activities, sewage, chemical fertilizers, pesticides and leaching from stainless steel well materials & plumbing. Exposure to high levels of nickel in drinking water can pose several health risks such as skin rash or irritation, asthma attacks or eczematous flare-up reactions in the skin, lung fibrosis, kidney and liver damage (WHO). The maximum permissible limit of Nickel by [5] is 0.02 mg/l, while Information from the analyzed sample in the two dumpsites shows no trace of nickel presence.

3.1.20. Arsenic (As)

Arsenic (As) contamination of groundwater is a major environmental and public health concern. Sources of Arsenic include Arsenic-bearing minerals and sediments that release Arsenic through geochemical processes like reductive dissolution of iron oxides. Prolonged exposure to arsenic through contaminated groundwater can lead to various health problems including skin lesions, cancer, and neurological effects [26], while a short-term health effect includes Stomach pain, vomiting, and diarrhoea. The result from the two dumpsites showed no trace of Arsenic contamination.

3.1.21. Iron (Fe)

Iron (Fe) is a significant chemical issue in groundwater analysis due to its widespread occurrence and potential impact on water quality and human health. Iron contamination in drinking water can lead to unpleasant taste and odour issues, including metallic tastes and smells, the altered appearance of food, and strong unpleasant odours (WHO). From the result, the concentrations of Iron are 0.49 mg/l and 0.61 mg/l. (Table 1). These values exceed the maximum permissible limit of 0.03 mg/l recommended by [5] and [9].

3.1.22. Mercury (Hg)

Mercury (Hg) is a toxic element and can be found in soils and groundwater at many industrial production sites. Mercury contamination poses serious health risks, with methylmercury being the most concerning due to its ability to bioaccumulate in the food chain and impair neurological development, especially in fetuses and young children. Elemental mercury vapour and inorganic mercury salts can also cause neurological, behavioural, and kidney effects with high exposures [11]. Mercury was not detected (ND) in the analyzed sample, while the permissible limit according to [5] is 0.001 mg/l.

3.1.23. Lead (Pb)

Lead (Pb) is a significant contaminant in groundwater analysis due to its widespread occurrence. Lead naturally occurs in rocks and mineral deposits with varying degrees of solubility, which can cause elevated lead concentrations in groundwater through leaching [27]. Exposure to lead can cause neurological damage, developmental delays, and other health problems. Though lead was not detected (ND) in the analyzed sample, the [9] and [5] recommend a maximum permissible limit of 0.01 mg/l for lead in drinking water.

3.1.24. Zinc (Zn)

Zinc (Zn) is a significant parameter and is naturally present in groundwater. Industrial sources such as coal combustion, traffic activities, and waste incineration are major contributors to zinc contamination in groundwater. High levels of zinc in drinking water can cause gastrointestinal problems, such as nausea, vomiting, and diarrhoea [28]. The concentration of zinc from the analyzed sample is 0.02 mg/l and 0.04 mg/l, which is below the recommended value by [9] and [5] (Table 1).

3.1.25. Calcium (Ca)

Calcium (Ca) is a significant parameter and can occur naturally. Sources of calcium in groundwater include the decomposition of carbonate rocks, such as limestones and dolomites, which are dissolved by carbonic acid in groundwater, and Agricultural fertilizers containing lime. Medically, High levels of calcium in drinking water can cause gastrointestinal problems, such as nausea, vomiting, and diarrhoea [22]. Concentrations of Calcium from the analyzed samples are 10.45 mg/l and 11.26 mg/l, which are below 50 mg/l recommended by [6].

3.1.26. Manganese (Mg)

Manganese is a naturally abundant transition metal. It can be found in both groundwater and surface water from natural sources or as a result of human activities such as mining and industrial discharges. High concentrations of manganese in drinking water (0.2 mg/l or greater) can cause neurotoxicity in humans and animals, leading to symptoms such as Parkinson's disease, emotional instability, and hallucinations [29]. Water analysis from the site shows zero presence of manganese contamination. (Table 1)

Table 2 Summary of VES survey

S/N	VES Location	Coordinate (Long/Lat)	Apparent resistivity(Ωm)	Thickness (m)	Depth (m)
1	Bonny Dumpsite (Behind Polytechnic)	7^{0} 11′ 38.9364″ 4^{0} 26′ 2.562″	976, 53.5, 603, 11.3, 19923	1.38, 1.32, 3.00, 7.07, -	1.38, 2.7, 5.7,12.8, -
2	Finima dumpsite (opposite cemetery)	7^{0} 8′ 39.9948″ 4^{0} 24′ 4.23″	441, 1.36, 172, 55220, 38.5	0.282, 0.863, 1.76, 43.1, -	0.282, 1.14, 2.91, 46, -

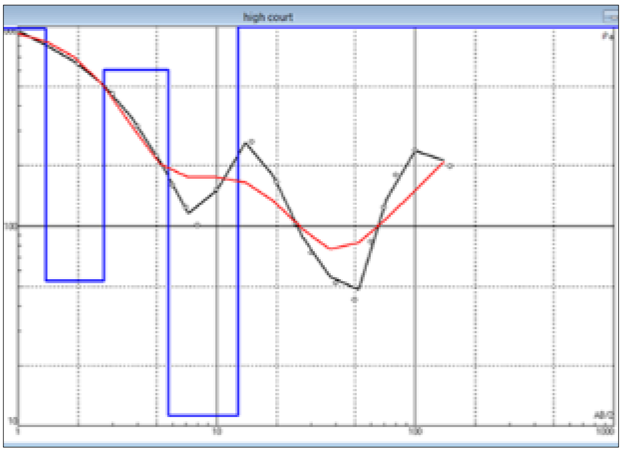
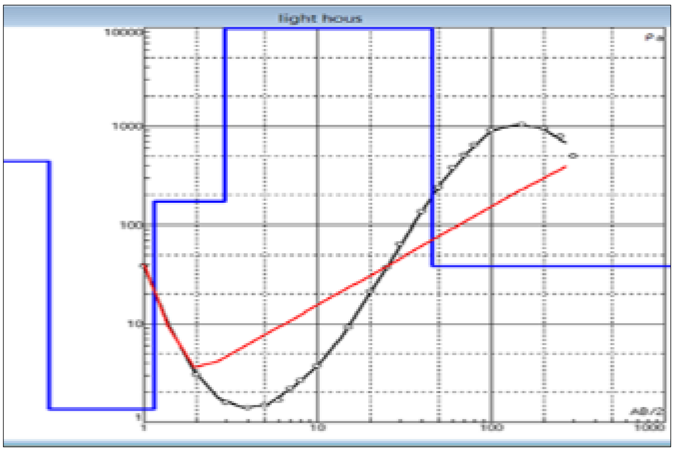
	
VES Curve 1 (Bonny Dumpsite)	VES Curve 2 (Finima Dumpsite)

Figure 4 VES Curve at both dumpsite

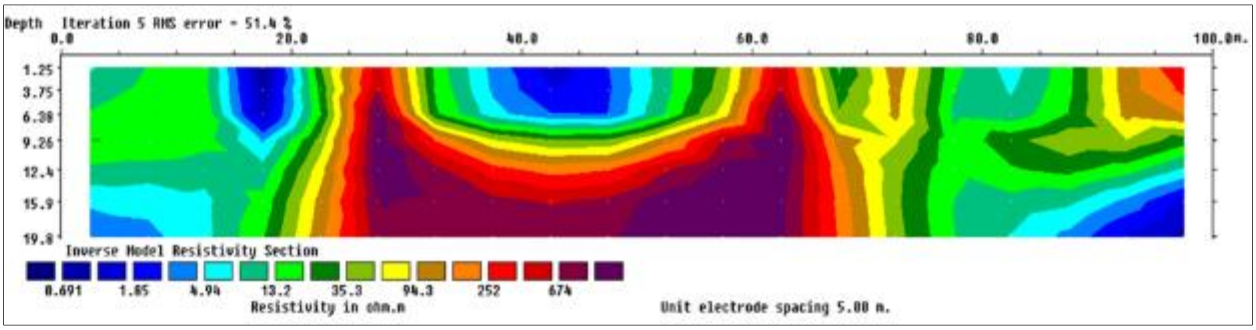


Figure 5 Resistivity model for profile 1 (Bonny dumpsite behind polytechnic)

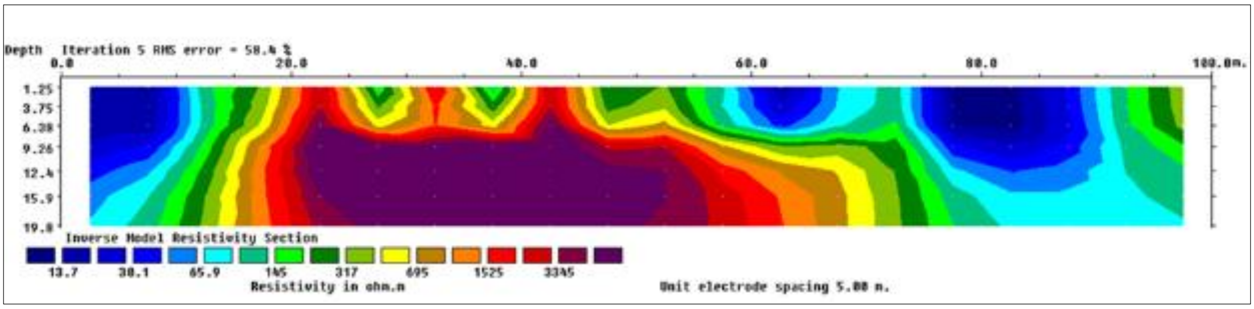


Figure 6 Resistivity model for profile 2 (Finima dumpsite opposite cemetery)

3.2. Survey Interpretation

3.2.1. VES 1 (Bonny Dumpsite Behind Polytechnic)

Five subsurface layers were identified using computer iteration software (IPI2win) (Fig 4). The topsoil which is the first layer has an apparent resistivity of 976 Ωm and a thickness of 1.38 m. This high resistivity layer at a shallow depth of 1.38 m likely represents a low conductive material. The second layer with a lower resistivity, thickness and depth of 53.5 Ωm, 1.32 m and 2.7 m respectively indicates a change in lithology, possibly to a more saline layer or possible contaminated zones. The apparent resistivity increases again to 603 Ωm in the third layer, suggesting medium-coarse sand formations with a thickness of 3.0 m. The fourth layer with apparent resistivity, thickness and depth of 11.3 Ωm, 7.07 m and 12.8 m respectively, likely represents a migration to the more saline zone. The fifth layer with an extremely high apparent resistivity of 19923 Ωm in the bottommost layer at an infinite thickness suggests a very dry, unsaturated formation such as bedrock. In summary, this VES profile shows a complex layered sequence with alternating high and low resistivity layers. The low resistivity at the second and fourth layers can be attributed to the presence of leachate.

3.2.2. VES 2 (Finima Dumpsite Opposite Cemetry)

Five subsurface layers were identified using computer iteration software (IPI2win) (Fig 4). The first layer is the topsoil with an apparent resistivity, thickness and depth of 441 Ωm, 0.282 m, and a depth of 0.282 m respectively, indicating fine or medium sand formations. The second layer is highly conductive with an apparent resistivity of 1.36 Ωm at a shallow depth. This indicates a possible contaminated formation. The third layer has a resistivity of 172 Ωm at thickness and depth of 1.76 m and 2.91 m respectively. This layer is moderately conductive and possibly a dry sandy formation. The fourth layer has an apparent resistivity of 55220 Ωm, thickness of 46 m and depth of 12.8 m respectively. This is a low conductive layer, possibly a layer of bedrock. The fifth layer has an apparent resistivity of 38.5 Ωm at infinite thickness and depth. The low resistivity at the second layer can be attributed to the presence of leachate.

3.2.3. Electrical Resistivity Imaging

Resistivity models were generated 10 meters away from the dumpsite area using RES2DINV software, as shown in Figures 5 and 6. At Bonny dumpsite, the model indicates predominantly low resistivity at a shallow depth, suggesting the presence of water-saturated sediments such as clay-rich soil or contamination of the topsoil due to leachate plume accumulation. The middle depth reveals high resistivity in the central area and low resistivity at both ends of the profile, indicating further leachate spread down the layer. The deeper layer follows the same pattern as the middle layer, with contamination spreading more towards both sides of the profile.

At Finima dumpsite, the resistivity model shows a similar trend to that of the Bonny site. The top layer exhibits predominantly low resistivity, indicating either clay-rich soil or topsoil contamination from the leachate plume. The middle depth transitions to a high resistivity layer in the central column, while both ends of the profile maintain low resistivity values, suggesting further contamination spread. The deeper layer also mirrors the middle layer's trend, with contamination spreading more towards both sides of the profile.

4. Conclusion

The comprehensive physicochemical analysis of groundwater quality in the vicinity of the Bonny Island dumpsite was carried out to analyze the presence of contaminants in groundwater. Parameters such as pH, TDS, TSS, DO, Nitrate (NO_3^-), Sulphate (SO_4^{2-}), Chloride (Cl^-), Phosphate (PO_4^{3-}), Hardness, Alkalinity, BOD, COD, Magnesium (Mg), Potassium (K), Sodium (Na), Copper (Cu), Chromium (Cr), Cadmium (Cd), Nickel (Ni), Arsenic (As), Iron (Fe), Mercury (Hg), Lead (Pb), Zinc (Zn), Calcium (Ca), and Manganese (Mn), was analyzed and the following findings was made. Firstly, parameters such as Phosphate, Copper, Chromium, Cadmium, Nickel, Arsenic, Mercury, Lead and Manganese revealed not detected (ND) of any contaminant. Secondly, the values of all other parameters fell within the permissible limits set by relevant environmental standards, except for iron which revealed 0.49 mg/l and 0.61 mg/l as against 0.3 mg/l by the relevant bodies like the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). This indicates that the dumpsite's influence on groundwater is relatively contained, with iron being the sole parameter exceeding safe levels. Iron concentrations surpassing permissible limits suggest localized contamination, likely due to the leachate from the dumpsite interacting with groundwater. Elevated iron levels can pose risks to human health and ecosystem integrity, highlighting the need for targeted remediation efforts. While the groundwater quality around Bonny dumpsites is largely within acceptable limits, the elevated iron levels warrant specific attention and action to safeguard public health and environmental quality. In conclusion, the combination of geophysical and physiochemical techniques has proven effective in assessing the impact of dumpsites on the groundwater quality in some parts of Bonny Island. The findings underscore the need for proper waste management practices and groundwater monitoring to ensure the availability of safe and potable water for the residents of Bonny Island.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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