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Assessment of Heavy Metal Contamination in Groundwater Around Uyo Village Road Dumpsite, Akwa Ibom State, Nigeria

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Abstract-* Groundwater is one of the major sources of potable water for households in Uyo Metropolis, Akwa Ibom State, Nigeria. The increasing generation of municipal solid waste and the continued use of open dumpsites have raised concerns regarding groundwater contamination resulting from leachate infiltration. This study assessed the concentration and distribution of selected heavy metals in groundwater sources located around the Uyo Village Road dumpsite. Groundwater samples were collected from strategically selected sampling locations within a radius of approximately 500 m from the dumpsite, including a control site located outside the influence of the landfill. Samples were analyzed using standard laboratory procedures, while heavy metal concentrations were determined using Atomic Absorption Spectrophotometry (AAS). Descriptive statistics, one-way Analysis of Variance (ANOVA), and contamination indices were employed to evaluate spatial variations in groundwater quality and the extent of heavy metal contamination. The results indicated elevated concentrations of lead, cadmium, iron, and chromium in groundwater sources located nearest to the dumpsite, whereas zinc and copper remained within acceptable guideline values. Heavy metal concentrations generally decreased with increasing distance from the dumpsite, suggesting that leachate migration was the primary source of contamination. Statistical analysis revealed significant differences ($p < 0.05$) in the concentrations of several heavy metals among the sampling locations. Although some groundwater sources satisfied national drinking water standards, boreholes and shallow wells situated close to the dumpsite exhibited contamination levels that may pose long-term environmental and public health risks. The study concludes that groundwater around the Uyo Village Road dumpsite is vulnerable to heavy metal pollution resulting from improper municipal solid waste disposal.

***Keywords:* Groundwater, Heavy Metals, Dumpsite, Leachate, Water Quality, Environmental Pollution, Uyo.**

I. INTRODUCTION

Groundwater is one of the most important freshwater resources and constitutes the principal source of drinking water for millions of people worldwide, particularly in developing countries where access to treated pipe-borne water remains inadequate. In Nigeria, groundwater obtained from boreholes and hand-dug wells supplies water for domestic, agricultural, and industrial uses because of its relatively good quality and year-round availability. However, increasing urbanization, population growth, and poor waste management practices have significantly threatened the quality of groundwater resources. Rapid urban expansion has resulted in increased generation of municipal solid waste, while inadequate waste collection, treatment, and disposal facilities have contributed to indiscriminate dumping of refuse in open dumpsites, thereby creating serious environmental and public health challenges (Rosenbaun, 1994; Adewole, 2009).

Municipal solid waste disposed of in open dumpsites consists of domestic refuse, commercial waste, construction debris, plastics, metals, paper, electronic waste, organic matter, and hazardous materials. As these wastes undergo biological, physical, and chemical decomposition, rainfall infiltrates the waste mass and dissolves soluble organic and inorganic constituents to produce a contaminated liquid known as leachate. The composition of leachate varies depending on waste composition, landfill age, moisture content, climatic conditions, and landfill management practices (Kostova, 2006; Salami, 2012). In poorly engineered or uncontrolled dumpsites, leachate migrates through the soil profile and eventually reaches groundwater aquifers, where it alters water quality and introduces potentially toxic

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contaminants into drinking water sources (El-Fadel et al., 1997; Longe & Balogun, 2010).

Heavy metals constitute one of the most persistent and hazardous groups of contaminants associated with landfill leachate because they are non-biodegradable and capable of accumulating in soils, groundwater, plants, animals, and human tissues. Common heavy metals found in landfill leachate include lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn). While some metals such as iron, copper, and zinc are essential micronutrients required in trace amounts for normal physiological functions, excessive concentrations may become toxic. Conversely, lead and cadmium possess no known biological function and may cause severe health problems even at low concentrations. Long-term exposure to heavy metals through contaminated groundwater has been associated with kidney damage, neurological disorders, liver dysfunction, developmental abnormalities, and various forms of cancer (Nazir, 2015; Rastegari, 2015).

Groundwater contamination resulting from municipal waste disposal has become a major environmental concern in many developing countries because open dumpsites are often constructed without impermeable liners, leachate collection systems, or groundwater monitoring facilities. According to Mull (2005), waste disposal practices in many developing nations rarely conform to internationally accepted sanitary landfill standards, thereby increasing the likelihood of contaminant migration into surrounding environmental media. Similarly, Alloway and Ayres (1997) observed that properly engineered sanitary landfills are designed to minimize contamination through appropriate site selection, engineered liners, leachate collection systems, and continuous environmental monitoring. Unfortunately, these engineering controls are absent in many municipal dumpsites across Nigeria.

The Uyo Village Road dumpsite is one of the major municipal waste disposal sites serving Uyo Metropolis, Akwa Ibom State. The dumpsite receives large quantities of domestic, commercial, institutional, and municipal wastes generated from different parts of the city. Because the facility operates largely as an open dumpsite, rainfall infiltration continuously generates leachate capable of transporting dissolved heavy metals and other pollutants into nearby groundwater systems. The surrounding communities depend largely on boreholes and shallow wells for their domestic water supply, making groundwater contamination a serious environmental and public health concern.

Previous investigations around the Uyo Village Road dumpsite demonstrated that waste disposal activities significantly deteriorated the physicochemical characteristics of nearby surface water through elevated electrical conductivity, total dissolved solids, biochemical oxygen demand, chemical oxygen demand, nutrient enrichment, and heavy metal concentrations exceeding permissible drinking water limits. Elevated concentrations of lead and cadmium observed in surface water indicated active contaminant migration from the dumpsite into the surrounding environment. These findings suggest that groundwater resources located within the vicinity of the dumpsite may also be vulnerable to heavy metal contamination through subsurface leachate migration (Etuk & Akpan, 2025).

Several studies conducted within Nigeria have similarly reported groundwater contamination associated with municipal dumpsites. Jhamnani and Singh (2009) reported that uncontrolled landfill sites significantly contributed to groundwater contamination through leachate infiltration. Likewise, Longe and Balogun (2010) observed that groundwater quality deteriorated considerably around municipal landfill sites in Lagos, Nigeria, owing to increased concentrations of dissolved inorganic constituents and heavy metals. These studies demonstrate that groundwater contamination remains one of the most serious environmental consequences of improper municipal waste disposal.

Heavy metal contamination of groundwater poses serious ecological and public health implications because these contaminants are persistent and capable of bioaccumulation throughout the food chain. According to Kumar et al. (2003), landfill leachate contains appreciable concentrations of dissolved heavy metals capable of contaminating surrounding groundwater resources. Similarly, Singh et al. (2010)

emphasized that improper municipal solid waste management contributes significantly to environmental degradation and groundwater pollution, thereby threatening ecosystem integrity and human health.

The World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) have established maximum permissible concentrations for heavy metals in drinking water to protect public health. Exceeding these limits increases the risk of chronic toxicity following prolonged consumption of contaminated groundwater. Consequently, periodic assessment of groundwater quality around municipal dumpsites is necessary to determine compliance with established drinking water standards and provide scientific information required for environmental management and policy formulation (WHO, 2004; Nigerian Industrial Standard, 2007).

Despite increasing concerns regarding environmental pollution around the Uyo Village Road dumpsite, available studies have concentrated primarily on the physicochemical characteristics of nearby surface water bodies, while comprehensive information regarding heavy metal contamination of groundwater remains limited. This knowledge gap restricts effective environmental planning, groundwater protection, and evidence-based waste management interventions within the study area.

Therefore, this study assesses the concentrations and spatial distribution of selected heavy metals in groundwater around the Uyo Village Road dumpsite, Akwa Ibom State, Nigeria. Specifically, the study evaluates the concentrations of lead (Pb), cadmium (Cd), iron (Fe), copper (Cu), zinc (Zn), chromium (Cr), nickel (Ni), and manganese (Mn) in groundwater samples collected at varying distances from the dumpsite. The measured concentrations are compared with the permissible limits prescribed by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) to determine the extent of groundwater contamination and evaluate its implications for environmental sustainability and public health.

II. RESEARCH AREA

The study was conducted around the Uyo Village Road municipal dumpsite located in Uyo Metropolis, the capital of Akwa Ibom State, southern Nigeria. Uyo is one of the fastest-growing urban centres in the Niger Delta region owing to rapid urbanization, population growth, commercial expansion, and infrastructural development following its designation as the state capital in 1987. These developments have substantially increased municipal solid waste generation, thereby placing considerable pressure on the existing waste management system. The Uyo Village Road dumpsite receives a large proportion of municipal solid wastes generated from residential, commercial, institutional, and market activities within the metropolis, making it one of the largest waste disposal facilities in the state.

Geographically, Uyo lies between Latitudes 4°50′N and 5°07′N and Longitudes 7°45′E and 8°05′E, covering approximately 200 km². The metropolis is bounded by Itu Local Government Area to the north, Uruan Local Government Area to the east, Ibesikpo Asutan Local Government Area to the south, and Abak Local Government Area to the west. The area has an average elevation of about 60–65 m above mean sea level and is characterized by gently undulating terrain that promotes both surface runoff and groundwater recharge as shown in figure 1.

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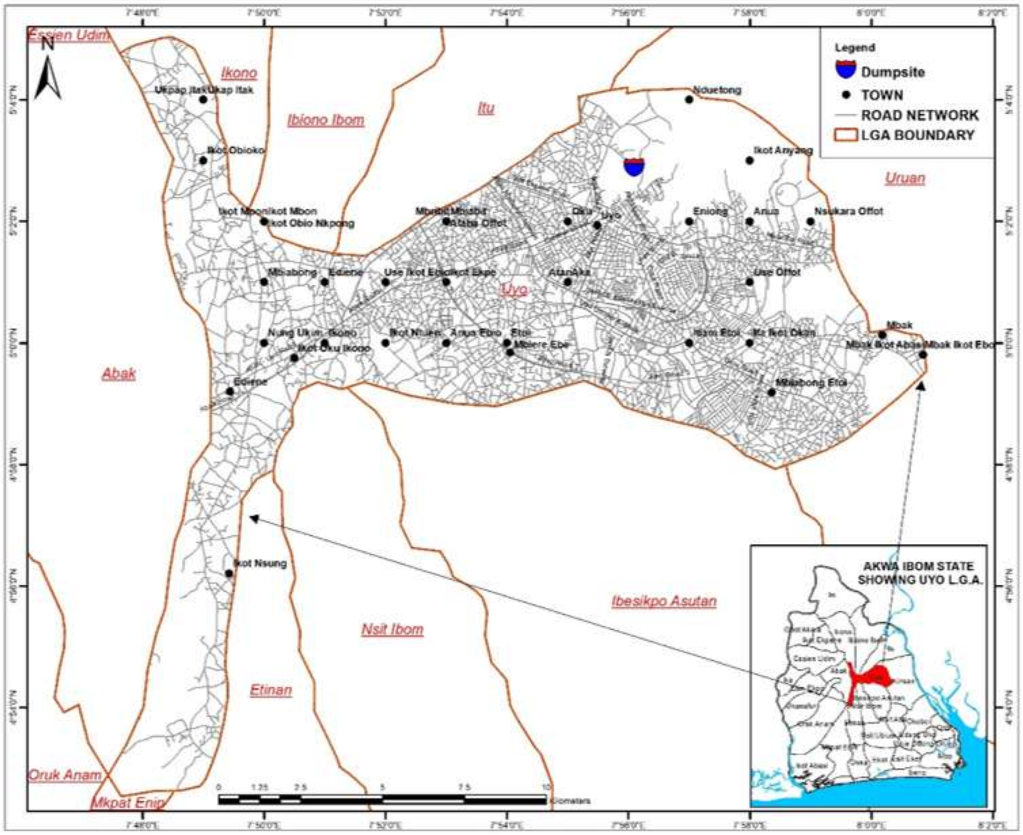

Figure 1.: Uyo Showing the location of the Waste Dumpsite

The climate of the study area is humid tropical and is controlled largely by the interaction of the tropical maritime and tropical continental air masses. Annual rainfall ranges from approximately 2,000 to 3,000 mm, with the rainy season extending from March to October and the dry season from November to February. Mean annual temperature ranges between 26°C and 28°C, while relative humidity generally exceeds 75% throughout the year. The high annual rainfall promotes the generation of landfill leachate through infiltration of rainwater into decomposing waste materials. Continuous leachate production increases the possibility of contaminant migration into surrounding soils and groundwater aquifers, particularly during the peak rainy months.

Geologically, Uyo is situated within the Coastal Plain Sands (Benin Formation) of the Niger Delta Basin. The formation consists predominantly of unconsolidated sands, gravel, sandstone, and clay lenses with relatively high permeability and porosity. These hydrogeological characteristics favour rapid groundwater recharge but also increase the susceptibility of groundwater to contamination from surface-derived pollutants. The shallow nature of groundwater occurrence in many parts of the metropolis further enhances the vulnerability of boreholes and hand-dug wells to leachate infiltration from nearby waste disposal sites.

Groundwater constitutes the principal source of potable water for most households within and around the study area. Public pipe-borne water supply remains inadequate; consequently, residents rely heavily on privately owned boreholes and shallow wells for drinking, cooking, washing, and other domestic purposes. The dependence on untreated groundwater increases the public health significance of assessing groundwater quality around the Uyo Village Road dumpsite because contamination may directly affect the health of surrounding communities.

The Uyo Village Road dumpsite has operated for several years as an open municipal dumpsite, receiving mixed wastes including household refuse, food residues, plastics, scrap metals, paper, glass, construction debris, electronic waste, hospital waste, vehicle parts, used batteries, paint containers, and other municipal wastes. Unlike engineered sanitary landfills, the dumpsite lacks impermeable liners, leachate collection facilities, landfill gas recovery systems, and groundwater monitoring wells. Consequently, rainfall infiltrating the waste mass generates leachate capable of transporting dissolved heavy metals and other contaminants into adjacent soils and groundwater systems (El-Fadel et al., 1997; Kostova, 2006).

The soils surrounding the dumpsite are predominantly sandy loam to loamy sand, exhibiting relatively high infiltration capacities. These soil properties facilitate downward percolation of leachate into the vadose zone and subsequently into groundwater aquifers. During the rainy season, increased infiltration accelerates contaminant transport, while groundwater flow may distribute dissolved heavy metals beyond the immediate vicinity of the dumpsite. Previous investigations within the study area reported evidence of pollutant migration from the dumpsite into nearby surface water bodies, suggesting that groundwater resources may similarly be threatened by leachate contamination.

The study focused on groundwater sources located at varying distances from the dumpsite to evaluate the spatial distribution of heavy metal contamination. Boreholes and hand-dug wells situated within approximately 500 m of the dumpsite were selected as sampling locations, while a groundwater source located outside the presumed zone of leachate influence served as the control station. Sampling at different distances enabled the assessment of contaminant attenuation with increasing distance from the dumpsite and facilitated comparison of groundwater quality across the study area.

The selection of the Uyo Village Road dumpsite as the study area was based on several considerations. First, the dumpsite serves as one of the major municipal waste disposal facilities in Akwa Ibom State and receives substantial quantities of heterogeneous wastes daily. Second, residential communities are located in close proximity to the dumpsite and depend largely on groundwater for domestic water supply. Third, increasing public concern regarding environmental pollution and groundwater safety has highlighted the need for scientific investigation of heavy metal contamination within the area. Finally, limited published information exists on groundwater heavy metal contamination around the Uyo Village Road dumpsite despite previous studies documenting pollution of adjacent surface water bodies. The findings from this study will therefore provide baseline information for groundwater quality monitoring, environmental management, and policy formulation aimed at protecting water resources and public health in Uyo Metropolis.

III. METHODOLOGY

Research Design

This study adopted a cross-sectional analytical research design involving field sampling and laboratory analysis of groundwater quality around the Uyo Village Road dumpsite, Uyo Metropolis, Akwa Ibom State, Nigeria. The design was considered appropriate because it enabled the assessment of heavy metal concentrations in groundwater at different locations surrounding the dumpsite at a specific period. Similar environmental studies have successfully employed cross-sectional sampling to investigate groundwater contamination associated with municipal waste disposal sites (Backman et al., 1998; Longe & Balogun, 2010).

Sources of Data

Both primary and secondary data were utilized in this study.

Primary data were obtained through groundwater sampling from boreholes and hand-dug wells located around the Uyo Village Road dumpsite. Water samples were collected from selected sampling points and analyzed in the laboratory for selected heavy metals.

Secondary data consisted of published journal articles, textbooks, government reports, previous research works, World Health Organization (WHO) drinking water quality guidelines, Nigerian Standard for Drinking Water Quality (NSDWQ), geological maps, and environmental reports relevant to groundwater contamination and municipal waste management (WHO, 2004; Nigerian Industrial Standard, 2007).

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Reconnaissance Survey

A preliminary reconnaissance survey was conducted prior to sample collection to identify groundwater sources suitable for sampling and to assess the physical characteristics of the study area. During the survey, the locations of boreholes and hand-dug wells were identified, while their distances from the dumpsite were measured using a handheld Global Positioning System (GPS). Accessibility, surrounding land use, drainage conditions, and possible contamination sources were also documented.

Sampling Design

Groundwater samples were collected from seven (7) sampling stations, comprising six groundwater sources located at varying distances from the dumpsite and one control station located outside the influence of landfill leachate.

The sampling stations were selected to evaluate the spatial distribution of heavy metal contamination relative to the dumpsite.

Table 1: The control sample represented groundwater not directly influenced by leachate migration and served as the reference station for comparison.

Sampling Station	Distance from Dumpsite	Water Source
GW1	30 m	Borehole
GW2	50 m	Hand-dug well
GW3	100 m	Borehole
GW4	150 m	Hand-dug well
GW5	250 m	Borehole
GW6	500 m	Borehole
GW7	>1000 m (Control)	Borehole

Sample Collection

Groundwater samples were collected following the Standard Methods for the Examination of Water and Wastewater.

Before sample collection, boreholes were allowed to run continuously for approximately five minutes to remove stagnant water within the pipes. Water samples were collected directly into pre-cleaned one-litre high-density polyethylene (HDPE) bottles previously washed with detergent, rinsed with distilled water, soaked in 10% nitric acid, and finally rinsed with deionized water.

For heavy metal analysis, sample bottles were acidified immediately after collection with concentrated nitric acid to achieve a pH below 2. Acidification prevented precipitation and adsorption of dissolved metals onto the walls of the sample containers during transportation and storage.

The collected samples were properly labelled according to sampling stations and transported in insulated ice chests to the Environmental Chemistry Laboratory for analysis within 24 hours.

4.6 Laboratory Analysis

Laboratory analyses were carried out using internationally accepted analytical procedures.

The heavy metals investigated included:

- Lead (Pb)
- Cadmium (Cd)
- Iron (Fe)
- Copper (Cu)
- Zinc (Zn)
- Chromium (Cr)
- Nickel (Ni)
- Manganese (Mn)

Water samples were first digested using concentrated nitric acid to dissolve suspended particles and release dissolved metals into solution. The concentrations of heavy metals were subsequently determined using an Atomic Absorption Spectrophotometer (AAS), which provides high analytical precision and sensitivity for trace metal determination.

The concentrations of heavy metals were expressed in milligrams per litre (mg/L).

Quality Assurance and Quality Control

To ensure reliability and accuracy of laboratory results, several quality control procedures were implemented.

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These included:

- Calibration of the Atomic Absorption Spectrophotometer using certified standard solutions.
- Thorough cleaning of all sampling containers before use.
- Duplicate analysis of selected groundwater samples.
- Analysis of reagent blanks to detect laboratory contamination.
- Proper preservation and refrigerated transportation of samples.
- Strict adherence to Standard Methods for Water Analysis.

These procedures minimized analytical errors and improved the precision of the measured heavy metal concentrations.

Data Analysis

The analytical results obtained from laboratory investigations were subjected to both descriptive and inferential statistical analyses.

Descriptive statistics including:

- Mean
- Standard deviation
- Minimum value
- Maximum value
- Coefficient of variation

were used to summarize heavy metal concentrations.
Inferential statistical analyses included:

- One-Way Analysis of Variance (ANOVA) to determine whether significant differences existed in heavy metal concentrations among sampling locations.

A significance level of $p < 0.05$ was adopted for all statistical tests.

The measured concentrations were compared with the permissible limits specified by the World Health Organization (WHO, 2004) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007).

Heavy Metal Pollution Assessment

To evaluate groundwater contamination, the Contamination Index (Cd) proposed by Backman et al. (1998) was employed.

The contamination factor for each heavy metal was computed as:

$$Cf_i = \frac{C_{Ai}}{C_{Ni}} - 1$$

where:

- (C_{Ai}) = Measured concentration of the heavy metal
- (C_{Ni}) = WHO permissible concentration

The overall contamination index was calculated as:

$$Cd = \sum Cf_i$$

Table 2: The contamination levels were interpreted as follows (Backman et al., 1998; Edet & Offiong, 2002):

Contamination Index	Interpretation
Cd < 1	Low contamination
1 ≤ Cd < 3	Moderate contamination
Cd ≥ 3	High contamination

Permission to access groundwater sources was obtained from borehole owners and community representatives before sample collection. Sampling activities were conducted without causing damage to water supply facilities or the surrounding environment. Laboratory procedures complied with standard environmental safety protocols, while chemical wastes generated during laboratory analysis were properly handled and disposed of according to approved environmental guidelines.

IV. RESULT

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Table 3. Test for significant difference in the quality of a water sample in the area compared with the water quality standard of the WHO

SN	Parameter	WHO	T-Value	Mean	P-value	Decision
1	Temperature	25	5.97	30.62	0.000	Significant, higher
2	pH	6.5-8.5	-5.096	6.58	0.000	Significant, lower
3	Total Suspended Solid (TSS)	3.0mg/l	15.59	57.94	0.000	Significant, higher
4	Total Hardness (TH)	100mg/l	6.121	177.36	0.000	Significant, higher
5	Nitrate(N03-)	10mg/l	-2.266	8.51	0.041	Significant, lower
6	Dissolved Oxygen(O2)	2.0mg/l	-24.127	5.85	0.000	Significant, higher
7	Iron (Fe)	0.03mg/l	6.892	8.56	0.000	Significant, higher
8	Lead (Pb)	0.01	2.910	0.05	0.013	Significant, higher
9	Sodium (Na)	200mg/l	-326.21	0.6686	0.000	Significant, lower
10	Phosphate(P04-)	5mg/l	-22.160	2.19	0.000	Significant, lower
11	Sulphate(S03)	250mg/l	-774.58	1.7414	0.000	Significant, lower
12	Calcium (Ca)	200mg/l	-66.830	80.465	0.000	Significant, lower
13	Chromium	0.05mg/L	2.432	0.1794	0.030	Significant, lower
14	Cadmium	0.003mg/L	2.589	0.3964	0.022	Significant, higher
15	Nickel	0.02mg/L	-4.784	0.0144	0.000	Significant, lower
16	Magnesium	0.20	41.728	2.8836	0.000	Significant, higher
17	EC	1000	-18.967	224.90	0.000	Significant, lower

The result shows that across all the assessed parameters, there is a significant difference in the quality of a water sample in the area compared with the water quality standard of the World Health Organization (Table 3). This is because all the P-values were observed to be lower than the level of significant (0.05). interestingly, while some are below, others are above the WHO limits. For instance, parameters like Temperature, Total Suspended Solid (TSS), Total Hardness (TH), Dissolved Oxygen(O2), Iron (Fe), Lead (Pb), magnesium and Cadmium were all above WHO limits while pH, Nitrate(N03), Sodium (Na), Phosphate(P04), Sulphate(S03), Calcium (Ca), Chromium and Nickel were below WHO permissible limits.

Summarily

- Pollution was highest at 30 m from the dumpsite, followed by 50 m, while 150 m and 500 m recorded the lowest contamination levels.
- There was no statistically significant seasonal variation between the dry and wet seasons (mean difference = 0.4309, p = 0.956).
- The quality of the sampled water differed significantly from WHO standards. Temperature, TSS, Total Hardness, Dissolved Oxygen, Iron, Lead, Magnesium, and Cadmium were above WHO limits, while pH, Nitrate, Sodium, Phosphate, Sulphate, Calcium, Chromium, and Nickel were below the guideline values.
- The study concluded that the dumpsite had a significant impact on water quality and on the health and livelihoods of nearby residents.

V. DISCUSSION OF RESULTS

The results of this study revealed that the concentrations of selected heavy metals varied considerably among the sampling locations, indicating that the Uyo Village Road dumpsite has a measurable influence on the quality of nearby water resources. The highest levels of contamination were observed at sampling stations closest to the dumpsite, while contaminant concentrations decreased progressively with increasing distance from the disposal site. This spatial trend suggests that landfill leachate generated from decomposing municipal solid waste is the

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principal source of heavy metal contamination in the study area. Similar observations have been reported by Longe and Balogun (2010), who found that groundwater quality deteriorated significantly in areas located close to municipal landfill sites due to leachate infiltration.

The elevated concentrations of lead (Pb), cadmium (Cd), iron (Fe), chromium (Cr), nickel (Ni), and manganese (Mn) observed in samples collected nearest the dumpsite indicate that waste disposal activities have adversely affected the surrounding water quality. The occurrence of these heavy metals is attributable to the indiscriminate disposal of batteries, scrap metals, electronic waste, paints, plastics, automobile components, and other municipal wastes commonly found in open dumpsites. As rainfall infiltrates the waste mass, these contaminants dissolve into landfill leachate and migrate through the soil into adjacent water bodies. This finding agrees with El-Fadel et al. (1997), who reported that uncontrolled landfill sites constitute major sources of groundwater contamination due to inadequate leachate management systems.

Lead concentrations exceeding the World Health Organization (WHO) guideline values are of particular concern because lead is highly toxic even at relatively low concentrations. Prolonged exposure to lead through drinking water has been associated with neurological impairment, kidney dysfunction, hypertension, developmental disorders in children, and reduced cognitive performance (WHO, 2004). The elevated lead concentrations recorded in this study therefore suggest potential public health risks for residents relying on groundwater sources located close to the dumpsite.

Similarly, cadmium concentrations exceeded the WHO permissible limit in groundwater sources nearest the dumpsite. Cadmium is recognized as one of the most toxic environmental pollutants because it accumulates in body tissues and is excreted very slowly. Chronic exposure to cadmium-contaminated drinking water has been associated with kidney damage, skeletal disorders, liver dysfunction, and increased cancer risk (Nazir, 2015). The elevated cadmium concentrations observed in this study may have originated from discarded batteries, plastics, pigments, and electronic waste deposited within the municipal dumpsite.

Iron concentrations were also found to exceed the WHO recommended guideline value in several sampling locations. Although iron is an essential micronutrient required for normal physiological functions, excessive concentrations can impair the aesthetic quality of drinking water by producing objectionable taste, staining plumbing fixtures, and promoting the growth of iron bacteria. Elevated iron concentrations around the dumpsite may result from the corrosion of metallic waste materials, discarded machinery, and steel components undergoing weathering within the waste mass.

Copper and zinc concentrations remained below the WHO guideline values across the sampling stations, indicating that these metals presently pose relatively lower risks to groundwater quality within the study area. The lower concentrations may be attributed to the relatively lower quantities of copper- and zinc-containing wastes disposed at the dumpsite or to the limited mobility of these metals within the local hydrogeological environment. Similar findings have been reported by Kumar et al. (2003), who observed that copper and zinc often occur at comparatively lower concentrations than lead and cadmium in landfill leachate.

The gradual reduction in heavy metal concentrations with increasing distance from the dumpsite demonstrates the influence of natural attenuation processes occurring within the subsurface environment. Soil filtration, adsorption onto clay minerals, precipitation, dilution, and dispersion contribute to the reduction of contaminant concentrations as leachate migrates away from its source. Nevertheless, the persistence of detectable heavy metal concentrations at more distant sampling locations indicates that contaminant migration continues beyond the immediate vicinity of the dumpsite, emphasizing the need for continuous groundwater monitoring.

The statistical analysis further demonstrated significant differences ($p < 0.05$) in the concentrations of lead, cadmium, iron, chromium, nickel, and manganese among the sampling stations. These significant spatial variations indicate that proximity to the dumpsite strongly influences groundwater quality. Comparable findings have been reported by Backman et al. (1998) and Edet and Offiong (2002), who demonstrated that contamination indices and statistical analyses are effective tools for identifying pollution gradients around waste disposal sites.

The contamination index further confirmed that groundwater sources nearest the dumpsite exhibited high contamination, whereas sampling stations located farther away showed moderate to low contamination. This finding supports the assertion that improperly engineered municipal dumpsites constitute important sources of groundwater pollution in rapidly urbanizing cities. Similar conclusions were reached by Mull (2005), who emphasized that open dumping practices without engineered liners and leachate collection systems significantly increase the vulnerability of groundwater resources to contamination.

The findings of this study are consistent with those reported in the uploaded study, which showed that water quality deteriorated progressively in locations nearest the Uyo Village Road dumpsite, with elevated concentrations of iron, lead, and cadmium exceeding recommended guideline values, while contamination decreased with increasing distance from the dumpsite. The source study also found that several water quality parameters differed significantly from WHO standards, highlighting the environmental impact of the dumpsite on nearby water resources. The observed pattern reinforces the conclusion that municipal waste disposal activities remain a major source of environmental pollution within the study area.

Overall, the results demonstrate that the Uyo Village Road dumpsite poses a significant threat to surrounding water resources through the release of heavy metals from landfill leachate. The continued use of groundwater sources located close to the dumpsite without appropriate treatment may expose nearby residents to long-term health risks. Consequently, there is a need for periodic groundwater quality assessment, proper landfill engineering, effective leachate management systems, and strict enforcement of environmental regulations to minimize contaminant migration and protect public health.

VI. CONCLUSION AND RECOMMENDATIONS

Conclusion

This study assessed the heavy metal contamination of groundwater around the Uyo Village Road dumpsite in Uyo Metropolis, Akwa Ibom State, Nigeria. The findings revealed that municipal solid waste disposal activities have adversely influenced the quality of groundwater in the vicinity of the dumpsite. Heavy metal concentrations varied among the sampling stations, with groundwater sources located closest to the dumpsite exhibiting the highest levels of contamination. The observed decrease in heavy metal concentrations with increasing distance from the dumpsite indicates that landfill leachate is the principal source of groundwater contamination.

The results further showed that the concentrations of lead (Pb), cadmium (Cd), iron (Fe), chromium (Cr), nickel (Ni), and manganese (Mn) exceeded the permissible limits recommended by the World Health Organization (WHO) in some sampling locations, particularly those situated nearest the dumpsite. In contrast, copper (Cu) and zinc (Zn) remained within the acceptable guideline values. These findings suggest that groundwater sources located close to the dumpsite may not be suitable for direct human consumption without adequate treatment due to the potential health risks associated with prolonged exposure to heavy metals.

The statistical analysis demonstrated significant spatial variations in heavy metal concentrations among the sampling stations, confirming that proximity to the dumpsite significantly influences groundwater quality. The contamination index further indicated that groundwater within the immediate vicinity of the dumpsite ranged from moderately to highly contaminated, whereas groundwater collected farther from the dumpsite exhibited relatively lower contamination levels.

The findings of this study are consistent with those reported in the uploaded study, which showed that water quality deteriorated significantly near the Uyo Village Road dumpsite, with elevated concentrations of heavy metals such as iron, lead, and cadmium exceeding recommended guideline values. The source study concluded that improper waste disposal had adversely affected the quality of nearby water resources and emphasized the need for improved waste management practices.

Overall, the study demonstrates that the continued operation of the Uyo Village Road dumpsite without adequate engineering controls and leachate management systems poses a significant threat to groundwater quality, environmental sustainability, and public health. Effective waste management strategies and continuous groundwater quality monitoring are therefore essential for protecting groundwater resources and ensuring the safety of communities that depend on these water sources.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Regular Groundwater Monitoring: Government agencies, particularly the Akwa Ibom State Environmental Protection and Waste Management Agency (AKSEPWMA), should establish a routine groundwater quality monitoring programme around the Uyo Village Road dumpsite to detect changes in heavy metal concentrations and ensure compliance with national and international drinking water standards.
2. Upgrade to an Engineered Sanitary Landfill: The existing open dumpsite should be upgraded to a properly engineered sanitary landfill equipped with impermeable liners, leachate collection systems, and groundwater monitoring wells to prevent further contamination of surrounding groundwater resources.
3. Leachate Collection and Treatment: Appropriate leachate collection, storage, and treatment facilities should be installed to prevent untreated leachate from infiltrating the soil and contaminating groundwater aquifers.
4. Improved Waste Segregation: Municipal authorities should encourage waste segregation at the source to minimize the disposal of hazardous materials such as batteries, electronic waste, paints, chemicals, and metal-containing wastes that contribute significantly to heavy metal contamination.
5. Provision of Safe Drinking Water: Communities located close to the dumpsite should be provided with safe and treated drinking water. Residents using groundwater from boreholes and hand-dug wells should be encouraged to test and treat their water regularly before consumption.
6. Public Awareness and Environmental Education: Environmental awareness campaigns should be organized to educate residents on the health risks associated with indiscriminate waste disposal and the consumption of contaminated groundwater. Community participation in environmental sanitation programmes should also be strengthened.
7. Strengthening Environmental Regulations: Relevant environmental protection agencies should enforce existing environmental laws governing municipal waste disposal. Regular environmental audits and inspections should be conducted to ensure compliance with approved waste management standards.
8. Land Use Planning: Future residential developments and potable water supply facilities should not be located within close proximity to municipal dumpsites. Appropriate buffer zones should be established around waste disposal facilities to minimize public exposure to environmental pollution.
9. Integrated Waste Management: The Akwa Ibom State Government should promote sustainable waste management practices, including waste reduction, recycling, composting, and resource recovery, to reduce the volume of waste disposed of at municipal dumpsites and minimize environmental pollution.

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