Landfll Site's Impact on Surface and Ground Water Qualities and Health Risk Assessment at Aba Eku Area, Ona Ara Local Government, Ibadan, Oyo State, Nigeria

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ABSTRACT

Landfilling remains the most common solid waste management method in developing countries due to its economic feasibility. However, poorly engineered landfills pose serious risks to surface and groundwater quality. This study assessed the physicochemical characteristics and heavy metal contamination of water resources around the Aba Eku landfill site in Ona Ara Local Government, Ibadan, Nigeria, and evaluated the potential health risks to nearby residents. Water samples were collected for six consecutive months from three hand-dug wells and surface water sources proximal to the landfill. Standard methods were employed for physicochemical analysis, and metal concentrations were determined using Atomic Absorption Spectrophotometry (AAS). Human health risk assessments for both carcinogenic and non-carcinogenic effects were conducted using United States Environmental Protection Agency (USEPA) models. Results revealed that several parameters including pH, biological oxygen demand (BOD), total hardness, dissolved oxygen (DO), alkalinity, and turbidity exceeded World Health Organization (WHO) permissible limits in both surface and groundwater samples. Heavy metal analysis indicated elevated levels of Fe, Cd, Cr, and Pb in most locations, suggesting leachate migration and pollutant infiltration from the landfill. The calculated Hazard Quotient (HQ) and Hazard Index (HI) values for Cd and Cr exceeded unity (>1), indicating potential non-carcinogenic health risks, while the cancer risk indices (CRI) for Cd and Cr in both adults and children surpassed the acceptable USEPA range (10^{-6}–10^{-4}). Children were found to be at greater risk than adults.This study highlights the urgent need for improved landfill management, groundwater monitoring, and community awareness to mitigate contamination and protect public health.

Key Words: Water, Heavy Metals, Physicochemical analysis, Atomic Absorption Spectrophotometer (AAS), Health Risk Assessment.

INTRODUCTION

Municipal solid waste (MSW) landfilling remains the predominant method of waste disposal in many developing countries, largely due to its relative cost effectiveness and simplicity compared to incineration or advanced recycling systems (Garcia *et al*., 2023). However, when landfill sites are poorly designed and managed such as lacking engineered liners or leachate collection systems, they pose substantial risks to the surrounding environment, especially surface and groundwater resources (Gonzalez *et al*., 2016,Okoye *et al*., 2024). For instance, leachate a highly contaminated liquid formed from percolation of rainfall through waste bodies can

migrate and degrade water quality, with consequent implications for human health and ecosystem integrity (Renou *et al*., 2008, Wang and Qiao, 2024, Zhao *et al*., 2023).

In Nigeria, and more specifically in the southwestern region around Ibadan, the proliferation of unlined or semi-engineered landfill sites has amplified concern. For example, a study of an unlined landfill in Ibadan documented elevated concentrations of NO_3^-, SO_4^{2-}, PO_4^{3-}, NH_4^+, Cl^-, Na, Fe, Mn, Cr and Mo in leachate, and detected impacts on groundwater and surface water chemistry including elevated Pb, Cd and Cu in some wells (Jolaosho et al., 2024, Longe and Balogun, 2010, Ojo et al., 2023).

A well-established pathway for environmental pollution is the migration of leachate from landfill sites into surface and subterranean waters (Yanidar et al., 2018). Leachate formation and plume evolution are influenced by the hydrogeologic context, waste-composition heterogeneity, and seasonal precipitation (Zhao et al., 2024)

Modern studies also show that groundwater contamination near landfill sites is often characterised by elevated electrical conductivity, increased concentrations of heavy metals (e.g., Cr, Pb, Cd), ammonium, and organic loadings (TOC, COD) (Okoye *et al*., 2024, Gunarathne *et al*., 2024, Osae and Manandhar, 2023)

Beyond the mere detection of contaminants, the assessment of potential human health risks associated with landfill-induced water contamination is gaining increased attention. In Nigerian context, though fewer detailed risk-assessment studies exist, elevated levels of heavy metals and other pollutants in groundwater and surface water near landfill sites imply possible exposure routes through drinking water or irrigation, warranting formal risk assessment protocols (Saha *et al*., 2023,Yuan *et al*.,2025, Adewoye *et al*., 2023).

The study area surrounding the Aba Eku landfill site in Ona Ara Local Government Area, Ibadan, Oyo State, Nigeria, is representative of the problems encountered in many developing-nation contexts: growing waste loads, fast urbanization, and landfill management systems that might not adhere to best-practice engineering standards. Notwithstanding the potential hazards, site-specific, current data on surface and groundwater quality as well as the assessment of related health risks are still lacking for this region. Given Nigeria's difficulties of rapid urbanization and increasing garbage generation, it is critical to assess landfill-related contamination in particular areas and identify potential health risks to nearby residents.

MATERIALS AND METHODS

Study Area

As shown in Figure 1, the map and the landfill site which was situated at 13km along Akanran- Ijebu Igbo road in Ona Ara Local Government, Ibadan between the longitude 0030 59' 00 and 0030 59' 30E and latitude 070 19' 15 and 070 19' 40N between the month of September 2024

Figure 1. (A) The Map of the sampling site and (B) the landfill site.

and Febuary, 2025. Three hand dug wells and a flowing water along the landfill were collected at three different sites for physicochemical and heavy metal determination.

The landfill serves as a major municipal solid waste (MSW) disposal site for the Ibadan metropolis and receives both domestic and limited industrial waste. Surrounding communities rely heavily on hand-dug wells and shallow boreholes for domestic water supply, thus creating potential exposure pathways to leachate contamination.

Sampling Techniques and Analysis of Samples

Three sites along the riverbank close to the dumpsites and three wellwaters in the vicinity were sampled for the purpose of analyzing the physical and chemical properties listed in Bhartia *et al*. (2018) and Fekede *et al*. (2020), which include conductivity, temperature, pH, total hardness, dissolved oxygen, and biochemical oxygen demand.

These samples were sent directly to the lab for six consecutive months. After utilizing a Whatman filter to filter each wastewater sample and acidifying it with potent HNO_3 to reduce its pH, fifty milliliters (50 ml) were extracted. Following this, the sample was mixed with five milliliters of concentrated HNO3 in 40 milliliters and left to digest in a contained area for 30 minutes.

After diluting the digested samples with 100 milliliters of distilled water, the metal contents were determined using an Atomic Absorbance Spectrophotometer (Perkin Elmer 3110) (Islam *et al*., 2016). Analyzing the presence of heavy metals in water is essential because they can enter the bodies of humans and animals through the food chain and are dangerous. These metals include Cu, Fe, Pb, Mn, Zn, and Cd. The levels of three different surface water and ground water sites are shown in Table 1 and 2, while the levels of heavy metals in the surface water and the wellwater samples that were taken from the vicinity are shown in Table 2 and 3.

Health Risk Assessment

Heavy metals in the water samples were evaluated for their potential to cause cancer and non-cancer health effects using models developed by the US Environmental Protection Agency. The risk was estimated by computing the heavy metal values gotten during the study period.

The AAS-analyzed heavy metals' cancer and non-cancer risks are evaluated by the chronic daily intake (CDI), according to the formula described by Adewoye *et al.,* 2020. To find the CDI of the HMs when taken orally, we used Equation 1, and to find the CDI when applied topically, we used Equation 2. Table 1 contains a summary of the assessment's parameters.

$$CDIing = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad (1)$$

$$CDIderm = \frac{C \times SA \times AF \times ABF \times EF \times ED}{BW \times AT} \qquad (2)$$

In this instance, "C" denotes the contaminant concentration in the water sample, "IR" stands for the ingestion rate, "ED" for the exposure duration, "EF" for the exposure frequency, "BW" for body weight, and "AT" for the average exposure time (Emmanuel et al., 2022). SA is the skin surface area, ABF is the dermal absorption factor and AF stands for water adherence factor (Adewoye et al., 2020).

Non-Cancer-Inducing Health Risk

Equations 4 and 5 are used to calculate the heavy metals' non-cancer-causing health risk.

$$HQ = \frac{CDI}{RfD} \qquad 4$$

$$HI = \sum HQ \qquad 5$$

The hazard index of each metal in the sample is denoted by HI, while HQ stands for the Hazard Quotient. Table 2 lists each metal's Reference Dose (RfD) for oral and dermal routes of contact as well as the Slope Factor (SF) for assessing human risk (Mileti´c et al., 2023).

According to Jonah and Mendie (2024), a value of HQ or HI less than 1 indicates that there are no major non-cancer-inducing hazards; a value of > 1 indicates that there may be non-cancer-inducing risks; the likelihood increases as the value of HQ or HI increases.

Table 1: Parameters used in the Assessment of Heavy Metal Health Risk

Parameters (Unit)	Values
Concentration (mg/L/)	Heavy Metals
Ingestion Rate (L/day) Adult	2.2
Ingestion Rate (L/day) Children	1
Exposure Frequency (Days/year)	365
Exposure Duration (Years) Adult	30
Exposure Duration (Years)Children	6
Body Weight (kg) Adult	70
Body Weight (kg) Children	15
Average Time (days)Adult	10950
Average Time (days) Children	2190
Surface Area (cm^2) Adult	17500
Surface Area (cm^2) Children	2800
Adherence Factor (mg/cm^2) Adult	0.07
Adherence Factor (mg/cm^2) Children	0.2
Absorbance Factor	0.001

Cancer Risk

The average lifelong exposure to a pollutant is 1 mg/kg body weight/day, which increases the risk of cancer. Equation 6 shows the cancer risk, which was calculated by multiplying the cancer slope factor (CSF), which was recorded in mg/kg/day, by the CDI, which was measured in mg/kg/day.

$$CRI = CDI \times SF \hspace{4cm} 6$$

The USEPA has determined that the lowest or acceptable cancer risk is between 1×10^{-6} and 1×10^{-4} (Osae *et al.,*2023). Only CRI for Pb, Cd, Cr, and As was computed.

Table 2: The Reference Dose and Slope Factor of Heavy Metals

Heavy Metals	RfD_{ing}	RfD_{derm}	SF_{ing}	SF_{derm}
Pb	3.5×10^{-3}	5.25×10^{-4}	0.0085	1.5
Cd	1×10^{-3}	1×10^{-5}	6.1	6.1
Cr	3×10^{-3}	6×10^{-5}	0.5	20
As	3×10^{-4}	1.23×10^{-4}	1.5	3.66
Cu	4×10^{-2}	1.2×10^{-2}	-	-
Zn	3×10^{-1}	6×10^{-2}	-	-
Fe	7×10^{-1}	-	-	-
Ni	2×10^{-2}	5.4×10^{-3}	-	-
Mn	1.4×10^{-1}	1.84×10^{-3}	-	-
Co	2×10^{-2}	2.1×10^{-5}	-	-

Statistical Analysis

Descriptive statistics and analysis of variance (ANOVA) were conducted using SPSS version 26.0 to determine spatial variations among sampling sites. Mean differences were considered statistically significant at $p < 0.05$. Pearson correlation analysis was used to explore relationships between physicochemical parameters and heavy-metal concentrations, aiding in source identification (Adewoye et al., 2023; Li et al., 2024).

RESULTS AND DISCUSSION

The results of mean values of physicochemical parameters of Surfacewater and groundwater are presented in Table 1 and Table 2 respectively.

Table 1. Mean value of physicochemical parameters of Surface water sample at Aba Eku landfill site.

	S1	S2	S3	WHO,NSDWQ, 2011
Temp (^{o}c)	29.61±0.01a	32.71±0.00a	36.03±0.01a	NS
Ph	5.10±0.01b	7.64±0.01a	8.62±0.01b	8.5
EC (µS/cm)	1.26±0.01a	2.12±0.01a	7.10±0.01a	400
BOD (ppm)	17.21±0.01a	15.65±0.01a	31.01±0.01a	<5
Hardness (mg/l)	574.12±0.00b	620.15±0.00b	685.00±0.01a	500
DO(mg/l)	16.23±0.00a	20.51±0.01a	59.02±0.01a	6
Alkalinity (mg/l)	252.30±0.01a	399.90±0.00b	700.12±0.01a	200
Turbidity(NTU)	1.00±0.01b	5.07±0.01b	8.73±0.01b	<5
TDS(mg/l)	6.09±0.01a	9.50±0.01b	9.79±0.01a	500

Table 2. Mean value of physicochemical parameters of Groundwater sample at Aba Eku landfill site

	W1	W2	W3		WHO,NSDWQ, 2011
Temp (^{o}c)	28.00±0.01b	28.50±0.01a	29.15±0.01b	NS	NS
pH	7.30±0.01b 6.65±0.01b		8.30±0.00b	6.5	6.5
EC (µS/cm)	1.12±0.01a 1.45±0.00a		2.70±0.00b	600	600
BOD (ppm)	15.15±0.00a 15.61±0.00a		17.11±0.000a	<5	NS
Hardness (mg/l)	296.00±0.00a 564.01±0.00a		724.01±0.00a	100	100
DO(mg/l)	17.08±0.01b 11.67±0.00a		20.42±0.00a	5	5
Alkalinity (mg/l)	64.00±0.00a 36.00±0.00a		40.04±0.00a	100	100
Turbidity(NTU)	0.07±0.01a 0.54±0.01a		0.1±0.00a	<5	<5
TDS(mg/l)	14.63±0.01a 14.20±0.00a		17.33±0.001a	500	500

Table 3. Heavy metal determination of Surface water sample at Aba Eku landfill site

	S1	S2	S3	WHO, 2011
Fe (mg/kg)	1.20±0.01b	3.53±0.01 b	4.72±0.01b	2.00
Cu (mg/kg)	0.03±0.00a	0.05±0.00a	0.06±0.00a	1.00
Zn (mg/kg)	0.19±0.00a	0.33±0.00a	0.44±0.00a	5.00
Cd (mg/kg)	0.41±0.00a	0.41±0.01a	0.72±0.00a	0.50
Cr (mg/kg)	0.17±0.01a	0.20±0.01a	0.22±0.00a	0.10
Pb (mg/kg)	0.00±0.00a	0.00±0.00a	0.00±0.00a	2.80

Table 4. Heavy metal determination of Ground water sample at Aba Eku landfill site

	W1	W2	W3	WHO, 2011
Fe (mg/kg)	1.05±0.01a	1.08±0.01 a	1.13±0.01a	2.00
Cu (mg/kg)	0.03±0.00a	0.02±0.00a	0.03±0.00a	1.00
Zn (mg/kg)	0.35±0.00a	0.26±0.00a	0.34±0.00a	5.00

Cd (mg/kg)	0.32±0.00a	0.51±0.01a	0.60±0.00a	0.50
Cr (mg/kg)	0.15±0.01a	0.12±0.01a	0.14±0.00a	0.10
Pb (mg/kg)	0.00±0.00a	0.00±0.00a	0.00±0.00a	2.80

Table 5: Surface water Sample from ABA EKU Landfill Site

Non-Cancer Risk

Receptors	Metals	S1				S2				S3			
		CDI_{ing}	CDI_{derm}	HQ_{ing}	HQ_{derm}	CDI_{ing}	CDI_{derm}	HQ_{ing}	HQ_{derm}	CDI_{ing}	CDI_{derm}	HQ_{ing}	HQ_{derm}
Adult	Pb	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Cr	0.0053	0.0030	1.7810	49.5833	0.0063	0.0035	2.0952	58.3333	0.0069	0.0039	2.3048	64.1667
	Cd	0.0129	0.0072	12.8857	717.5000	0.0129	0.0072	12.8857	717.5000	0.0226	0.0126	22.6286	1260.0000
	Cu	0.0009	0.0005	0.0236	0.0438	0.0016	0.0009	0.0393	0.0729	0.0019	0.0011	0.0471	0.0875
	Zn	0.0060	0.0033	0.0199	0.0554	0.0104	0.0058	0.0346	0.0963	0.0138	0.0077	0.0461	0.1283
	Fe	0.0377	0.0210	0.0539	0.0000	0.1109	0.0618	0.1585	0.0000	0.1483	0.0826	0.2119	0.0000
HI				**14.7640**	**767.1825**			**15.2133**	**776.0025**			**25.2385**	**1324.3825**
Children	Pb	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Cr	0.0113	0.0063	3.7778	105.7778	0.0133	0.0075	4.4444	124.4444	0.0147	0.0082	4.8889	136.8889
	Cd	0.0273	0.0153	27.3333	1530.6667	0.0273	0.0153	27.3333	1530.6667	0.0480	0.0269	48.0000	2688.0000
	Cu	0.0020	0.0011	0.0500	0.0933	0.0033	0.0019	0.0833	0.1556	0.0040	0.0022	0.1000	0.1867
	Zn	0.0127	0.0071	0.0422	0.1182	0.0220	0.0123	0.0733	0.2053	0.0293	0.0164	0.0978	0.2738
	Fe	0.0800	0.0448	0.1143	0.0000	0.2353	0.1318	0.3362	0.0000	0.3147	0.1762	0.4495	0.0000
HI				**31.3176**	**1636.6560**			**32.2706**	**1655.4720**			**53.5362**	**2825.3493**

Cancer Risk Index

Receptors	Metals	S1		S2		S3	
		CRI_{ing}	CRI_{derm}	CRI_{ing}	CRI_{derm}	CRI_{ing}	CRI_{derm}

Adult	Pb	0	0	0	0	0	0
	Cr	0.002671	0.0595	0.003143	0.07	0.003457	0.077
	Cd	0.078603	0.043768	0.078603	0.043768	0.138034	0.07686
Children	Pb	0	0	0	0	0	0
	Cr	0.005667	0.126933	0.006667	0.149333	0.007333	0.164267
	Cd	0.166733	0.093371	0.166733	0.093371	0.2928	0.163968

Table 6: Groundwater Sample from ABA EKU Landfill site

Non-Cancer Risk

Receptors	Metals	W1				W2				W3			
		CDI_{ing}	CDI_{derm}	HQ_{ing}	HQ_{derm}	CDI_{ing}	CDI_{derm}	HQ_{ing}	HQ_{derm}	CDI_{ing}	CDI_{derm}	HQ_{ing}	HQ_{derm}
Adult	Pb	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Cr	0.0047	0.0026	1.5714	43.7500	0.0038	0.0021	1.2571	35.0000	0.0044	0.0025	1.4667	40.8333
	Cd	0.0101	0.0056	10.0571	560.0000	0.0160	0.0089	16.0286	892.5000	0.0189	0.0105	18.8571	1050.0000
	Cu	0.0009	0.0005	0.0236	0.0438	0.0006	0.0004	0.0157	0.0292	0.0009	0.0005	0.0236	0.0438
	Zn	0.0110	0.0061	0.0367	0.1021	0.0082	0.0046	0.0272	0.0758	0.0107	0.0060	0.0356	0.0992
	Fe	0.0330	0.0184	0.0471	0.0000	0.0339	0.0189	0.0485	0.0000	0.0355	0.0198	0.0507	0.0000
HI				11.7360	603.8958			17.3772	927.6050			20.4337	1090.9763
Children	Pb	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0020	0.0000	0.5714	0.0000
	Cr	0.0100	0.0056	3.3333	93.3333	0.0080	0.0045	2.6667	74.6667	0.0093	0.0052	3.1111	87.1111
	Cd	0.0213	0.0119	21.3333	1194.6667	0.0340	0.0190	34.0000	1904.0000	0.0400	0.0224	40.0000	2240.0000
	Cu	0.0020	0.0011	0.0500	0.0933	0.0013	0.0007	0.0333	0.0622	0.0020	0.0011	0.0500	0.0933
	Zn	0.0233	0.0131	0.0778	0.2178	0.0173	0.0097	0.0578	0.1618	0.0227	0.0127	0.0756	0.2116
	Fe	0.0700	0.0392	0.1000	0.0000	0.0720	0.0403	0.1029	0.0000	0.0753	0.0422	0.1076	0.0000
HI				24.8944	1288.3111			36.8606	1978.8907			43.9157	2327.4160

Cancer Risk Index

Receptors	Metals	W1		W2		W3	
		CRI_{ing}	CRI_{derm}	CRI_{ing}	CRI_{derm}	CRI_{ing}	CRI_{derm}
Adult	Pb	0	0	0	0	0	0
	Cr	0.002357	0.0525	0.001886	0.042	0.0022	0.049
	Cd	0.061349	0.03416	0.097774	0.054443	0.115029	0.06405

Children	Pb	0	0	0	0	0.000017	0
	Cr	0.005	0.112	0.004	0.0896	0.004667	0.104533
	Cd	0.130133	0.072875	0.2074	0.116144	0.244	0.13664

DISCUSSION

Physicochemical Characteristics of Surface and Groundwater

The results of the physicochemical parameters of surface and groundwater samples collected from the Aba Eku landfill vicinity are presented in Tables 1 and 2. The recorded values were compared with World Health Organization (WHO, 2022) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2021) guidelines.

Water temperature ranged from 29.6–36.0 °C in surface water and 28.0–29.2 °C in groundwater. Elevated temperature at site S3 may result from microbial degradation and oxidation processes within the landfill leachate, consistent with findings by Zhao *et al*. (2023) in subtropical landfills where exothermic decomposition elevated water temperature near waste cells.

The pH values ranged between 5.1–8.6 for surface water and 6.7–8.3 for groundwater, indicating slightly acidic to alkaline conditions. Elevated pH values at S3 and W3 may reflect bicarbonate buffering and ammonia release from organic waste decomposition. Similar patterns were reported by Anwar *et al*. (2024) in a Malaysian municipal landfill, where alkaline leachates raised groundwater pH beyond WHO limits. Acidic pH values at S1 suggest early leachate generation stages, which typically produce organic acids during waste fermentation.

Electrical conductivity ranged from 1.26–7.10 µS/cm in surface water and 1.12–2.70 µS/cm in groundwater. The highest EC values at S3 indicate increased ionic load, possibly due to mineral dissolution and leachate infiltration. Total dissolved solids (TDS) remained below WHO limits (500 mg/L), implying partial dilution by rainfall and surface runoff.

Turbidity levels, however, were notably elevated in surface water (1.00–8.73 NTU) compared to groundwater (0.07–0.54 NTU), exceeding WHO limits at S3. High turbidity correlates with surface runoff and suspended organic matter mobilization from the waste body. A similar relationship between turbidity and landfill proximity was observed in the Lagos Olusosun landfill study by Ojo *et al*. (2023).

Dissolved oxygen concentrations were substantially elevated, ranging 16.23–59.02 mg/L in surface water and 11.67–20.42 mg/L in groundwater, exceeding the WHO minimum (6 mg/L). The unusually high DO may be attributed to algal photosynthesis and turbulence during sample collection.

BOD$_5$ values exceeded permissible limits (< 5 mg/L) at all sites, ranging 15.15–31.01 mg/L, suggesting substantial organic loading and microbial activity. Elevated BOD$_5$ levels align with leachate-affected waters rich in biodegradable organics, as noted by Li *et al*. (2024) in a leachate-impacted aquifer study in China.

Water hardness ranged from 574–685 mg/L (surface) and 296–724 mg/L (groundwater), far above the 500 mg/L limit, classifying the water as "very hard." Hardness increase may result from Ca^{2+} and Mg^{2+} leaching from concrete debris and soils near the dumpsite (Abdulsalam *et al*., 2011). Excessive hardness affects taste and scaling properties and can enhance metal mobility through complexation.

Alkalinity values ranged 252–700 mg/L (surface) and 36–64 mg/L (groundwater). The marked rise in surface water alkalinity near S3 signifies strong buffering capacity due to carbonate and bicarbonate ions derived from decomposition gases. Similar observations were made by Rahman *et al*. (2022) in Bangladesh, indicating that elevated alkalinity often accompanies high ammonia and bicarbonate levels in landfill leachate.

Heavy Metal Concentrations

Heavy-metal concentrations in the studied waters (Tables 3 and 4) showed that Fe, Cd, and Cr exceeded WHO (2022) limits at several locations, while Pb remained below detectable limits in most samples. Surface water Fe ranged from 1.20–4.72 mg/L, exceeding WHO's limit (2.0 mg/L) at S2–S3. Groundwater Fe values (1.05–1.13 mg/L) were within limits but indicated upward trends. High Fe may stem from corrosion of metallic wastes and reduction of ferric oxides under anaerobic leachate conditions. Cadmium concentrations in both surface and groundwater (0.32–0.72 mg/L) exceeded the WHO limit (0.003 mg/L), confirming strong leachate influence. Cadmium's toxicity even at trace levels highlights potential long-term health risks, corroborated by Okoye *et al*. (2024) who reported similar exceedances near Nigerian dumpsites. Chromium (Cr) concentrations values of 0.12–0.22 mg/L surpassed the WHO limit (0.05 mg/L), suggesting improper disposal of metal-plated waste and tanned leather residues. For Lead (Pb) it was below detection (< 0.001 mg/L), possibly due to limited industrial waste inflow. These findings indicate clear evidence of leachate migration into surrounding hydrological systems, consistent with patterns documented in Miletić *et al*. (2023), where heavy-metal plumes extended up to 2 km from landfill boundaries.

Non-Carcinogenic Risk Assessment

The Hazard Quotient (HQ) and Hazard Index (HI) values for both adults and children through ingestion and dermal exposure pathways (Tables 5 and 6) showed that Cd and Cr had HQ > 1 in nearly all samples, implying potential non-carcinogenic risks.

For children, HI values ranged from 31.32–53.54 (surface water) and 24.89–43.92 (groundwater), substantially higher than for adults (14.76–25.24 in surface water; 11.73–20.43 in groundwater). These findings confirm that children are more vulnerable due to lower body weight and higher intake per unit mass. Comparable results were reported in El-Said *et al*. (2024), where Cd and Cr exposure through drinking water posed significant risks to children in peri-urban communities.

Carcinogenic Risk Assessment

The Cancer Risk Index (CRI) values for Cd and Cr in both surface and groundwater samples exceeded the USEPA acceptable range (10^{-6}–10^{-4}), particularly for children. Cd exposure yielded CR values up to 2.9×10^{-1}, while Cr ranged from 7.7×10^{-2} in surface water to 1.0×10^{-1} in groundwater, indicating potential long-term carcinogenic effects.

Pb carcinogenic risk remained negligible due to low concentrations. Elevated Cd and Cr risks can be linked to improper waste sorting and disposal of batteries, paints, and tannery residues. Similar cancer-risk patterns were reported by Zhou *et al*. (2023) in East Asian landfill zones and Osae *et al*. (2023) in Ghana.

Statistical Correlation and Source Implication

Correlation analysis revealed strong positive relationships between EC, hardness, and Cd (r > 0.8), suggesting common geochemical sources such as leachate infiltration. Moderate correlations between Fe and Cr indicate mixed anthropogenic and lithogenic origins. Such patterns align with multivariate analyses performed by Adeyemi *et al*. (2024) using PCA and cluster methods for source apportionment in landfill-impacted aquifers.

Implications for Water Quality and Public Health

The observed physicochemical and heavy-metal contamination patterns indicate that the Aba Eku landfill is a significant contributor to both surface and groundwater degradation. Long-term consumption or use of contaminated water poses risks of renal dysfunction, neurological disorders, and carcinogenesis, especially among children.

These results reinforce the need for immediate remedial interventions such as installing leachate-collection systems, periodic water-quality monitoring, and community sensitization. Similar mitigation frameworks have proven effective in other developing-country contexts (Osei and Manandhar, 2023).

CONCLUSION AND RECOMMENDATION

Conclusion

This study evaluated the impact of the Aba Eku landfill site on the quality of surface and groundwater within Ona Ara Local Government, Ibadan, Nigeria, and assessed potential human health risks associated with heavy-metal contamination. The analysis revealed that several physicochemical parameters including pH, BOD_5, hardness, alkalinity, and turbidity exceeded WHO (2022) and NSDWQ (2021) permissible limits, indicating the influence of leachate percolation and pollutant migration from the landfill.

Heavy-metal analysis showed elevated levels of Fe, Cd, and Cr, with Cd and Cr particularly exceeding international safety thresholds in both surface and groundwater. Health risk assessment indicated non-carcinogenic (HQ, HI > 1) and carcinogenic risks (CRI > 10^{-4}) for these metals, with children more vulnerable than adults due to higher exposure per body mass.

The results confirm that the Aba Eku landfill has significantly compromised the quality of surrounding water resources and poses tangible risks to public health, especially for nearby communities reliant on shallow wells and streams for domestic use. These findings align with global evidence showing that poorly engineered landfills in developing nations contribute disproportionately to heavy-metal pollution and health hazards (Li *et al*., 2024; Ojo *et al*., 2023; Anwar *et al*., 2024).

Recommendations

To mitigate the identified environmental and public health risks, the following actions are recommended:

1. Implementation of an Engineered Landfill Design:

The current open-dump configuration should be upgraded to a sanitary landfill system with engineered liners, leachate collection, and gas management infrastructure. Such designs have proven effective in leachate containment and pollution control (Osei and Manandhar, 2023).

2. Regular Environmental Monitoring:

Establish a long-term water-quality surveillance program using geospatial and remote sensing tools to detect pollutant plumes and assess temporal variations. Integration of AI-based models can enhance predictive monitoring (Rahman *et al*., 2024).

3. Provision of Safe Water Alternatives:

Communities within a 2 km radius of the landfill should be supplied with treated municipal or borehole water sourced from uncontaminated aquifers. Periodic testing must be mandated by local environmental agencies.

4. Public Health Education and Risk Communication:

Local residents should be educated on the dangers of using untreated well or surface water. Awareness programs should emphasize water boiling, filtration, and avoidance of irrigation with contaminated sources.

5. Policy Enforcement and Waste Segregation:

The Oyo State Environmental Protection Agency (OYSEPA) should enforce stricter controls on waste segregation at source particularly hazardous materials such as batteries, paints, and industrial sludges to reduce heavy-metal input into municipal waste streams.

6. Future Research:

Future studies should incorporate isotopic or geochemical tracing to identify pollutant transport pathways, as well as ecotoxicological assessments on local biota to determine the broader ecosystem impacts of landfill leachate.

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