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RESEARCH

Human health risks of metal contamination in Shallow Wells around waste dumpsites in Abeokuta Metropolis, Southwestern, Nigeria

Harvester O. Okoye · Abayomi O. Bankole · Adedayo O. Ayegbokiki · Abraham O. James · Afolashade R. Bankole · Damilola E. Oluyege

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Abstract Metal contamination in shallow wells through solid waste leaching is a serious environmental problem with contribution to global cancer cases. This paper evaluated the health risks of metals in shallow wells around dumpsites in the Abeokuta metropolis, Nigeria. Five dumpsites were purposively selected to sample twenty-five shallow wells. In situ and laboratory analyses for physico-chemical parameters, copper, lead, cadmium, iron, and chromium were conducted following the APHA standard procedure. Carcinogenic and non-carcinogenic risks for oral and dermal routes were evaluated for adult males and females, children, and infants. Findings revealed that all wells were acidic (pH = 5.82–6.48), with Fe and Cd concentrations above the established limits. The wells around Obada, Obantoko, and Saje dumpsites had high EC (up to 1200 μS/cm), Cu, and Pb concentrations above the permissible limits. Non-carcinogenic risks for oral ingestion were significant for all age groups (hazard index: HI > 1), and the significance level across dumping areas increased in the order: Saje > Obantoko > Obada > Idiaba > Lafenwa. All wells assessed in Saje and Obantoko recorded significant HI of dermal exposure for children and infants. Cancer risks were significant for all age groups (CR > 1.0E−04), and metal contributions followed: Cd > Cr > Pb. The overall trend of significant risks for non-carcinogenic and carcinogenic via oral and dermal routes is in the order of infant > children > adult female > adult male. This suggests that groundwater

Highlights

- Shallow wells around dumpsiteswere examined for metals contamination from leachate.
- Non-carcinogenic oral anddermal risks were evaluated for different age groups.
- Oral and dermal cancer risks wereevaluated for adults, children, and infants.
- Children and infants havehigher significant non-cancer risks for oral ingestions.
- Cancer risks are significantfor all age groups, and Cd contributes the most risks.

H. O. Okoye (✉) · A. O. Ayegbokiki
Institute of Food Security, Environmental Resources and Agricultural Research (IFSERAR), Federal University of Agriculture Abeokuta, Abeokuta, Nigeria
e-mail: okoyeho@funaab.edu.ng

A. O. Bankole (✉)
Department of Water Resources Management and Agrometeorology, Federal University of Agriculture Abeokuta, Abeokuta, Nigeria
e-mail: bankoleabayomi3@gmail.com

A. O. Bankole · A. O. James · A. R. Bankole
Department of Civil and Environmental Engineering, Faculty of Engineering, Sao Paulo State University (UNESP), Bauru Campus, Sao Paulo, Brazil

A. O. James
Department of Environmental Management and Toxicology, Federal University of Agriculture Abeokuta, Abeokuta, Nigeria

D. E. Oluyege
Early Warning System and Geospatial Laboratory, Federal University of Agriculture Abeokuta, Abeokuta, Nigeria

users within the studied areas may experience diverse illnesses or cancer in their lifetime, particularly children and infants.

Keywords Abeokuta metropolis · Dumpsites · Health risks · Metal contamination · Leachates · Shallow well

Introduction

Globally, there is a growing concern around water security issues due to the pollution of water sources, particularly groundwater that provides nearly 50% of all domestic water needs including drinking water (Carrard et al., 2019; UNESCO, 2022). Unlike surface water, groundwater pollution is not often practically reversible especially for non-degradable contaminants such as metals and persistent organic pollutants (Berkowitz et al., 2014; Ravenscroft & Lytton, 2022). These pollutants may impact the groundwater quality and render it unfit for direct human use. This poses potential health risks to humans and may adversely affect the realization of the United Nations Sustainable Development Goals (SDGs) by 2030, particularly SDG 6 (Ezbakhe, 2018; Taka et al., 2021; UNESCO, 2019).

Generally, obliteration of groundwater quality stems from (1) the characteristic of the aquifers through the leaching of geologic components (Bankole et al., 2022) and (2) the process of recharge which may contain elevated concentrations of various chemical components that are leached as water trickles through polluted surfaces (Bankole et al., 2020; Bodrud-Doza et al., 2020; Parameswari & Padmini, 2018). Improperly disposed municipal and industrial solid wastes can negatively impact the quality of soil, air, and water and as well affect public health adversely with their inherent chemical components and pathogenic organisms (Ogundele et al., 2018; Ojekunle et al., 2022; Olujimi et al., 2016). The vulnerability of groundwater to pollutants such as heavy metals (lead, cadmium, arsenic, etc.) may be significant in developing countries and particularly Nigeria due to the pervasiveness of the open dumping practice of solid wastes, being the prominent means of solid waste disposal (Ojekunle et al., 2020; Sharma et al., 2018; Talang & Sirivithayapakorn, 2021). This has festered because of inadequate funding and low budget allocation for solid waste management (Abdel-Shafy & Mansour, 2018; Ochuko, 2014).

Open dumping, although not environmentally friendly, is a waste disposal method, where waste is disposed off on bare ground, without a barrier from the surrounding ambience and the general public or any form of processing, such as sorting and recycling (Ojekunle et al., 2022). As a result of the lack of containment infrastructure and abatement measures, polluting trace elements such as cadmium, lead, and chromium and other pollutants like nitrate from fecal waste and wastewater are collected through hydrokinetic energy in the form of leachates (Ahmed et al., 2019; Selvam et al., 2017). This portends a potential pollution risk to groundwater resources as it is capable of penetrating the soil layers and sometimes facilitated by run-off to reach the water-bearing aquifers, thus polluting the groundwater (Ojekunle et al., 2020; Olujimi et al., 2016). Repeated exposure to these pollutants from day-to-day use of polluted water poses serious health risks owing to their carcinogenic, toxic, and non-degradable nature (Bankole et al., 2022; Krishna & Mohan, 2014; Mahmood et al., 2018; Naz et al., 2016; Olayinka et al., 2017).

For instance, the detection of trace elements such as As, Cd, Co, Cu, Mn, Ni, Pb, and Zn in groundwater aquifers (about 10% (w/w)) has been reported in Germany and Netherlands, and the pathway was linked to anthropogenic activities (Riedel et al., 2022). This suggests the possibility of increased risk of groundwater pollution and the resultant public health consequences from protracted exposures. Health risk assessment had shown the vulnerability of both adults and children to oral and dermal exposure, although prevalent in the latter (Bodrud-Doza et al., 2020). A range of pathological conditions (cancer, cardiovascular disease, nervous system disorder, hypertension, reproductive effects) has been linked to repeated exposure to elevated concentrations of trace elements (Nkpaa et al., 2018; Rahman et al., 2018; Zhang et al., 2016). Specifically, intake of excessive quantities of Fe in water could lead to hemochromatosis (precursor to organ damage), weight loss, and musculoskeletal pains (Ahmed et al., 2019; Kohgo et al., 2008).

In Nigeria, groundwater is mostly exploited for domestic water needs (Carrard et al., 2019; Healy et al., 2020; Villar, 2016), and shallow wells are the cheapest means of water provision (Danert & Healy, 2021). The exploitation is heightened by the steady rise in population growth which imposes further constraints on dwindling budgetary provisions on water supply infrastructure and facilities for the underserved population (Danert & Healy, 2021; WHO, 2019). Thus, this has made shallow wells a common sight in urban Nigeria (Agava et al., 2018). Anand et al. (2021) noted that groundwater of this nature readily comes under attack from on-site excreta disposal systems, animal wastes, and open dumping and poses a significant high risk to the health of users (MacDonald & Pieper, 2017).

Similarly, the metropolitan areas of Abeokuta in Ogun State, Nigeria, are fast developing, and this could be attributed to ingress from the neighboring mega city such as Lagos State, due to congestion of the latter. Furthermore, Ogun State being the state with the highest number of tertiary institutions in the country, the accompanying large-scale development in the metropolis could be accountable for the steady rise in population. Aside from the benefit of economic prosperity, this comes with the complex challenges of urban sprawl with the attendant adverse effect of environmental blight (indiscriminate waste dumping, open defecation, and open burning) (Vitorino de Souza Melaré et al., 2017), being some of the anthropogenic sources of groundwater pollution. In this instance, groundwater quality comes under serious threat of being useful for its intended purpose. Considering that groundwater is used directly without advanced treatment or any form of treatment, which is typical of Nigeria (Yadav et al., 2019), it becomes essential to monitor the groundwater quality for the sake of public health and contingent intervention in an established case of pollution.

In recent times, growing concern on the potential human health risk posed by the increasing level of groundwater pollution has received huge attention. In this regard, many studies had been conducted in the area of human health risks (Adimalla & Li, 2019; Barzegar et al., 2019; Chen et al., 2020; Qasemi et al., 2022; Rahman et al., 2018; Su et al., 2018; Tabassum et al., 2019; Towfiqul Islam et al., 2017; Zakir et al., 2020). Studies have also been conducted on the concentrations of trace metals and physico-chemical parameters in dumpsites in the southwestern region of Nigeria (Aboyeji & Eigbokhan, 2016; Abul, 2010; Oyelami et al., 2013). Moreover, groundwater suitability assessment and mapping of aquifers within the Abeokuta Formation were conducted by Bankole et al. (2022), in relation to human health risk exposure. Nonetheless, the latest edition of the United Nations World Water Development Report raises concern on the lack of data on groundwater (UNESCO, 2022), which suggests a clear case of limited explorative studies on groundwater quality.

Also, considering the fact that the health risks of residents living in close proximity to dumpsites are seldomly reported (Ojekunle et al., 2022), coupled with the likely increase in dumpsites, drawing from the growing ingress, it becomes imperative to monitor the groundwater quality and evaluate the human health risks potential around the developing areas within the Abeokuta metropolis in Ogun State, Nigeria.

Therefore, the objectives of this study are to (a) evaluate the concentrations of heavy metals in groundwater sources around selected dumpsites in the Abeokuta metropolis; (b) evaluate the effect of long-term exposure (oral and dermal) to groundwater around the dumpsites, using human health risk index; and (c) establish the suitability (or otherwise) of water quality for direct human use and domestic purposes.

Materials and methods

Description of the study area

Abeokuta is the largest urban center and the capital of Ogun State, Southwestern Nigeria, which covers a landmass of about 879 km^2 and lies between latitude 7° 10′–7° 15′ N and longitude 3° 17′–3° 26′ E (Fig. 1). The area is characterized by a tropical climate, having distinct wet (April–October) and dry (November–March) seasons (Odjegba et al., 2021), with an annual temperature of 23–32 °C and annual rainfall of 1200–1500 mm. The geological settings of the Abeokuta metropolis consist of a crystallized pre-Cambrian basement complex mainly made of igneous and metamorphic rocks with visible outcrops, which is responsible for the poor water-bearing potential (Orebiyi et al., 2008). Part of the metropolis also consists of transition zones to the sedimentary Abeokuta Formation (Bankole et al., 2022). The metropolis has a dendritic drainage and is drained by a major river (Ogun River) that passes through the city center (Adekitan & Bankole, 2019). This made shallow and deep wells the major means of groundwater exploitation in the Abeokuta metropolis.

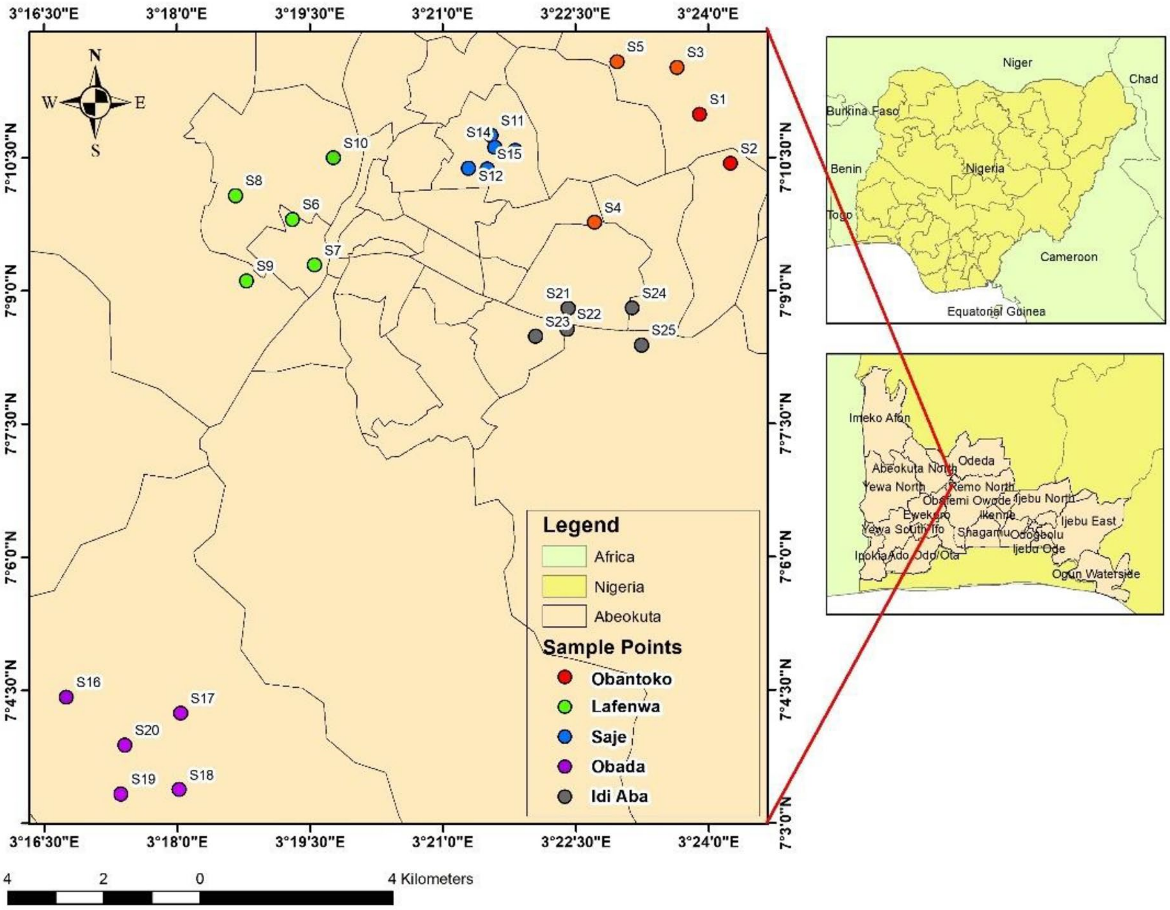

Fig. 1 Map of the study area showing the sampling sites

Abeokuta is built in between the center of Lagos-Ibadan extended urban region and forms part of the larger metropolitan economic area. This strategic location, matched with the presence of diverse local resources, rapid population growth, and enhanced political status, has generated dynamic economic activities. The population of the city is growing rapidly mainly due to its proximity to the most populous city in Nigeria (Lagos), economic prospects, and rural–urban migration. A few large-scale industrial establishments, as well as trading, personal, finance, and insurance services, comprise the local economy. Abeokuta is also an agricultural trade center with a dedicated agricultural cargo airport as an exporting point for various commodities, such as food crops (cassava, maize, etc.) and cash crops (cashew, palm oil, etc.).

Sample collection and analysis

A total of twenty-five (25) wells were randomly sampled around five purposively selected open dumpsites within the Abeokuta metropolis in May 2022. The month of May is usually a rainy season (or a wet month) in Nigeria. This factor tends to influence the pollution of the water table and, consequently, the wells (or shallow wells). The selection of the dumpsites was based on the size of the dumpsites and the volume of waste generated (five biggest and well-known dumpsites) (Ojo et al., 2022). The selected dumpsite locations were Idi-aba, Lafenwa, Obada, Obantoko, and Saje.

Five water samples were collected from wells situated at a maximum of 500 m away from each dumpsite. All sampled wells were georeferenced using a geographical positioning system (GPS). In situ analysis was carried out to determine the pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS) of sampled wells, using HI 98130 combo tester and VIVOSUN pH meter. The meters were calibrated using standard buffer 7.0 solution, pre-rinsed with deionized water before and after sampling. Samples for laboratory analysis (to determine the concentration of selected metals) were collected in a sterilized well-labeled 2-L plastic bottles, properly rinsed with deionized water followed by sampled water before the sample collection.

Afterward, 2.5 mL of concentrated nitric acid was added to water samples to ensure that the samples were kept in their natural state, and the samples were stored in ice cubes and transported to the laboratory for further analysis. The concentration of selected metals (copper (Cu), lead (Pb), cadmium (Cd), iron (Fe), and chromium (Cr)) was analyzed using standard APHA methods. The selection of metals was premised on past studies on metal occurrences in Abeokuta (Adekunle et al., 2013; Aladejana & Talabi, 2013; Babalola et al., 2005; Bankole et al., 2022; Taiwo, 2012; Taiwo et al., 2020). All samples were digested with nitric: perchloric acid 1:1. The water samples were analyzed using an atomic absorption spectrophotometer (AAS, 210/211VGP (Buck Scientific, E. Norwalk, CT, USA)). The equipment was properly calibrated using a prepared metal stock solution (100 mg/L). All analysis was carried out in triplicate for quality assurance and quality control.

Human health risk assessment

The human health risk (HHR) assessment is used to determine the risk level of substances to human health. The carcinogenic and non-carcinogenic risks of metals in groundwater sources were developed using the methods described by the US Environmental Protection Agency (USEPA, 1989; USEPA, 2004). Recently, HHR has been adopted by researchers to critically assess the exposure level to pollutants with severe health implications (carcinogenic and non-carcinogenic), such evaluations have also cut across different age groups (toddlers, teenagers, adults, etc.) and exposure routes (oral and dermal) (Adimalla, 2018; Adimalla & Li, 2019; Akshitha et al., 2022; Bankole et al., 2022; Gao et al., 2020; Ijumulana et al., 2021; Nyambura et al., 2020; Sohrabi et al., 2021; Wang et al., 2021). Notably, most health risk–based studies have been conducted in parts (i.e., evaluation of different age groups for only one route or evaluation of both dermal and oral routes but one or two age groups). Therefore, this study evaluated the carcinogenic and non-carcinogenic risks for both dermal and oral ingestion for infants, children, and adults (male and female). This is to ensure that adequate information that would enhance public health protection and promote sustainable groundwater management in the Abeokuta metropolis is proffered by this study.

Non-carcinogenic risks

The computation of the oral and dermal ingestion non-carcinogenic risks of metals for the selected age groups was carried out using the steps below:

The chronic daily intake (CDI) for oral and dermal ingestion was computed using Eqs. (1) and (2).

$$\mathrm{CDIoral} = \frac{C \times \mathrm{IR} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT}} \tag{1}$$

$$\mathrm{CDIdermal} = \frac{C \times K \times \mathrm{SA} \times \mathrm{ET} \times \mathrm{ED} \times \mathrm{EF} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}} \tag{2}$$

where CDI oral is the chronic daily intake of metals through oral ingestion of water (mg kg^{-1} day^{-1}); CDI dermal is the chronic daily intake of metals through dermal ingestion of water (mg kg^{-1} day^{-1}); C is the concentration of metals in water (mg L^{-1}); IR is the Ingestion rate of water (L day^{-1}); ED is the exposure duration (years); ET is the exposure time in hour/event; EF is the exposure frequency (day year^{-1}); K is the Permeability coefficient (cm/h); CF is the conversion factor in L/cm^3; AT is the average time of exposure = ED for non-carcinogenic effects, while AT = 60 years for carcinogenic effects in adult male, 63 years for an adult female, 6 years for a child, and 1 year for an infant; and SA is the skin surface area (cm^2). This is estimated for different age groups, using Eq. (3):

$$\mathrm{SA} = 239 \times \mathrm{H}0.417 \times \mathrm{BW}0.517 \tag{3}$$

H is the height of different age groups and sex (cm). BW is the body weight (kg).

Afterward, the hazard quotients (HQs) of individual parameters were computed for the oral and dermal ingestion for the selected age groups using Eqs. (4) and (5).

$$\text{Hazard Quotient}_{\text{oral}} = \frac{\text{CDI}_{\text{oral}}}{\text{RfD}_{\text{oral}}} \tag{4}$$

$$\text{Hazard Quotient}_{\text{dermal}} = \frac{\text{CDI}_{\text{dermal}}}{\text{RfD}_{\text{dermal}}} \tag{5}$$

where CDI = chronic daily intake of metals in water (mg kg^{-1} day^{-1}), RfD_{oral} is the reference dose for oral ingestion (mg kg^{-1} day^{-1}), and RfD_{dermal} is the reference dose for dermal ingestion (mg kg^{-1} day^{-1}).

If hazard quotient (HQ) > 1, there is a non-carcinogenic adverse effect, while if HQ < 1, there is no adverse effect.

Finally, the non-carcinogenic hazard index (HI) for oral and dermal ingestion was achieved by summing up the hazard quotients (HQ) as shown in Eqs. (6) and (7):

$$\text{HI}_{\text{oral}} = \sum_{i=1}^{n} \text{HQ}_{\text{oral}}\ i = 1 \ldots ..n \tag{6}$$

$$\text{HI}_{\text{dermal}} = \sum_{i=1}^{n} \text{HQ}_{\text{dermal}}\ i = 1 \ldots ..n \tag{7}$$

where n is the number of elements observed.

Cancer risk (CR)

The cancer risks of the age groups through the oral and dermal ingestion routes were computed using Eqs. (8) and (9).

$$\text{CRoral} = \text{CDIoral} \times \text{SF} \tag{8}$$

$$\text{CRdermal} = \text{CDIdermal} \times \text{SF} \tag{9}$$

where CDI_{oral} and CDI_{dermal} are the chronic daily intake of metals in water through oral and dermal routes, respectively (mg kg^{-1} day^{-1}). SF = cancer slope factor (mg^{-1} kg^{-1} day^{-1}); SF of Cd = 15, Cr = 0.42, and Pb = 0.0085 was used for the computation according to the California Office of Environmental Health Hazard Assessment (OEHHA, 2019).

If CR > 1×10^{-4}, there is a carcinogenic adverse effect, while CR < 1×10^{-4} indicates no carcinogenic adverse effect.

The detailed information and values used in computing the non-carcinogenic and carcinogenic risks of the oral and dermal ingestion routes, for the selected age groups, are summarized in Table 1.

Digital elevation model (DEM) analysis

The application of geographical information system (GIS) has been leveraged to demystify the patterns of water pollution and spatial distribution of pollutants within a given geographical extent. Digital elevation model (DEM) map has been used in studies to understand the role of relief (elevation) and groundwater (well) pollution (Bankole et al., 2022; Ijumulana et al., 2021; Paramasivam & Venkatramanan, 2019). In this study, DEM map was generated from the GIS environment (ArcGIS 10.1 and ArcScene). The elevation data (digital elevation model in a tile form) was collected by the shuttle radar topography mission (STRM) from the US Geological Survey's Earth Explorer website. The downloaded tiles were mosaicked to generate the DEM for the metropolis and transferred to the ArcScene environment to protrude the elevation contours for the sampled areas.

Result and discussion

Summary of water quality results

Identifying the water quality status through detailed laboratory testing is essential to determine its suitability for diverse purposes, particularly for drinking purpose. The descriptive statistics of the laboratory results of physico-chemical and heavy metal concentration in groundwater sources around open dumpsites in the Abeokuta metropolis are presented in Table 2. Generally, all sampled wells were slightly acidic, with mean pH values of 6.24, 6.36, and 6.11 for the wells at Idi-aba, Lafenwa, and Obada respectively. The pH values of the wells decreased in the order of Lafenwa > Idi-aba > Obada > Obantoko > Saje. All wells sampled had pH values below the lower threshold established by the WHO (2011, 2017). Groundwater pH level is an indicator of the ability of trace metals to dissolve in the water sources and the potential to interact with acidic or alkaline materials (Bodrud-Doza et al., 2020).

Sampled wells around dumpsites at Idi-aba, Lafenwa, and Obada recorded electrical conductivity (EC) and total dissolved solids (TDS) mean values of 132.00 µS/cm and 35.68 mg/L, 76 µS/cm and

Table 1 Summary of assumed values used to calculate the non-carcinogenic human health risks and cancer risks of metals due to dermal and oral ingestion

Parameter	Unit	Oral values				Dermal values				Reference
		M	F	C	I	M	F	C	I	
Concentration of heavy metals	mg L^{-1}									
Ingestion rate	L day^{-1}	2	2	1	0.75					Taiwo et al. (2020)
Exposure frequency (EF	Days $year^{-1}$	365	365	365	365	350	350	350	350	USEPA (2004)
Exposure duration (ED)	Year	30	30	6	1	30	30	6	1	USEPA (2004)
Conversion factor (CF)	L cm^{-3}					0.001	0.001	0.001	0.001	USEPA (2004)
Average body weight (BW)	kg	72	63	18	5	72	63	18	5	
Average Time (AT)	Day	10,950	10,950	2190	365	31,500	31,500	2100	350	
Exposure time (ET)	Hour/event					0.58	0.58	0.58	0.58	USEPA (2004)
Permeability coefficient (K)	cm/h					Cd, Cr, Fe & Cu = 0.001; Pb = 0.0001				USEPA (2004)
Reference dose-oral (RfD oral)	mg kg^{-1} day^{-1}					Cu = 0.04, Pb = 0.0035, Fe = 0.7, Cd = 0.001, Cr = 0.003				Akshitha et al. (2022), Ozoko et al. (2022)
Reference dose-dermal (RfD dermal)	mg kg^{-1} day^{-1}					Cu = 0.012, Pb = 0.00042, Fe = 0.3, Cd = 0.000025, Cr = 0.000015				Khalili et al. (2019), Tripathee et al. (2016)
Cancer slope factor	mg kg^{-1} day^{-1}					Cd = 15, Cr = 0.42, Pb = 0.0085				OEHHA (2019)
Height	cm					165.9	156.4	114.5*	58.75*	
Life expectancy	year	60	63	61.5*	61.5*	60	63	61.5*	61.5*	
Skin surface area (SA)	cm^2					18,378.69	16,804.61	7689.45	3002.21	USEPA (2004)

M adult male, *F* adult female, *C* children, *I* infant

*indicates mean for male and female

Table 2 Water quality concentrations in water samples collected around selected dumpsites in the Abeokuta metropolis

Parameters		Sample area/dumpsite Location					WHO standard
		Idi-aba	Lafenwa	Obada	Obantoko	Saje	
pH	Mean	6.24	6.36	6.11	6.00	5.95	6.5–8.5
	SD	0.10	0.09	0.09	0.08	0.13	
EC	Mean	132.00	76.00	550.80	618.00	1200	1000 µS/cm
	SD	3.54	2.55	35.44	9.57	16.55	
TDS	Mean	35.68	35.94	275.4	308.70	777.42	500 mg/L
	SD	5.24	1.04	17.72	5.64	18.29	
Fe	Mean	1.220	0.576	1.280	1.380	1.604	0.300 mg/L
	SD	0.402	0.052	0.264	0.303	1.018	
Cu	Mean	2.004	1.248	2.018	2.802	3.156	2.000 mg/L
	SD	0.136	0.234	0.158	0.262	0.220	
Pb	Mean	0.007	0.005	0.011	0.016	0.096	0.010 mg/L
	SD	0.007	0.002	0.003	0.001	0.006	
Cd	Mean	0.056	0.052	0.059	0.100	0.244	0.003 mg/L
	SD	0.005	0.003	0.002	0.026	0.199	
Cr	Mean	0.004	0.006	0.007	0.021	0.040	0.050 mg/L
	SD	0.001	0.002	0.002	0.006	0.037	

35.94 mg/L, and 550.80 µS/cm and 275.4 mg/L, respectively. The mean EC and TDS concentration of groundwater sources near the dumpsites at Obantoko and Saje were 618.00 µS/cm and 308.70 mg/L and 1200 µS/cm and 777.42 mg/L, respectively (as shown in Table 2). High EC is an indicator of dissolved salt and organic pollution load in groundwater (Wagh et al., 2020). All sampled groundwater sources at Saje have EC and TDS concentrations above the threshold of 1000 µS/cm and 500 mg/L. The probable cause of high EC around the Saje dumpsite could be attributed to run-off and percolation of leachate caused by a high volume of waste generated at the dumpsite. Saje dumpsite is the largest dumpsite in Abeokuta, with about 119 km^2 of landmass (Ojo et al., 2022). Additionally, the dumpsite is located on an abandoned mine site; therefore, leachate concentration in the vicinity of the dumpsite may be higher than other dumpsites' areas. The high groundwater table could influence groundwater flow in the area and consequently the leachate transport within the aquifers. This could cause an inflow of ions (anion) and dissolved organic matter from the dumpsite leachate. Higher EC values (884–1510 µS/cm) were reported by Odipe et al. (2018) in their study that investigated the impact of solid waste leachate on groundwater contamination at the Ijemikin waste dumpsite environ, Ondo State, Nigeria.

The mean concentrations of iron in groundwater sources around dumpsites located at Idi-aba, Lafenwa, Obada, Obantoko, and Saje were 1.220 mg/L, 0.576 mg/L, 1.280 mg/L, 1.380 mg/L, and 1.604 mg/L, respectively. Similarly, groundwater sources around the Saje dumpsite recorded the highest Fe concentration, against other sources. The result revealed that the mean iron concentrations in all wells were above the WHO permissible limit of 0.30 mg/L (as shown in Table 2). High iron concentration in water could cause coloration of water. The lowest and highest values recorded at all sampled wells were below the iron concentrations (1.430–36.333 mg/L) found in wells around the Kurata dumpsite in Sango, Ogun State, Nigeria, by Ojekunle et al. (2022) and the concentration (1.20–17.60 mg/L) found in leachate from municipal solid waste landfill in Gohagoda, Sri Lanka, by Dharmarathne and Gunatilake (2013).

The mean concentrations of copper (Cu) in the water samples collected from wells around the dumpsites increased from 1.248 mg/L (Lafenwa) to 2.004 mg/L (Idi-aba), 2.018 mg/L (Obada), and 2.802 mg/L (Obantoko), and the highest value (3.156 mg/L) was recorded at the well around the Saje dumpsite. All wells around the dumpsite at Lafenwa recorded Cu values below the established limit of 2.0 mg/L by WHO (2011, 2017). Two wells each at Idi-aba and Obada recorded values above the limit, while all the wells in Obantoko and Saje have Cu concentrations above the limit, and the highest was recorded in this study. Although copper is needed for body metabolism, exposure to high Cu content poses adverse effects (Taiwo et al., 2020) to human. The results show that the users of groundwater sources around dumpsites in Saje, Obantoko, and the sampled wells with high Cu content in Idi-aba and Obada are vulnerable to health implications such as cardiovascular disease, immune system and increased infection rate, headache, and kidney failure. This result supports the findings of Araya et al. (2007) and Manne et al. (2022).

Similarly, wells around the dumpsite at Saje recorded the highest mean lead concentration (0.096 mg/L), followed by wells around the dumpsites at Obantoko (0.016 mg/L) and Obada (0.011 mg/L). As shown in Table 2, all wells around the dumpsites at Saje and Obantoko have values above the established standard, including three (3) wells at Obada. All wells around dumpsites at Lafenwa and Idi-Aba had lead concentrations below the established limit of 0.010 mg/L by the WHO. Lead is a non-essential element for humans and an established carcinogen. Lead occurs in groundwater as suspended organic matter or as precipitate ($PbCO_3$ and Pb_2O). The high concentration of lead in most of the wells could be attributed to leachates from wastes deposited at dumpsites, such as battery cells, dye, and medical equipment, percolating into the aquiferous layers. Exposure to high lead concentration in water could impair infant mental development and cause increased blood pressure, kidney damage, and cardiovascular diseases, among other severe health conditions. Several studies such as Alam et al. (2020), Ojekunle et al. (2022), and Taiwo et al. (2010), among others, are in line with the result of this study.

All wells assessed in this study recorded cadmium concentration above the established limit of 0.003 mg/L (WHO, 2011, 2017). The highest cadmium concentration was recorded at the Saje dumpsite (0.244 mg/L), and the mean concentration at the remaining dumpsites followed the order Obantoko > Obada > Idi-Aba > Lafenwa. Lower Cd concentration (0.024 mg/L) was reported by Ojekunle et al. (2022) in their study that assessed the risks of metals in groundwater sources around the Kurakuta dumpsite, Ogun State. Landfill leachate through indiscriminate waste disposal and incineration, intensive agricultural activities, and industrial activities has been implicated as the major anthropogenic source of cadmium in the environment, aside from the natural occurrence through rock weathering in black shale rocks (Mahajan et al., 2022). Studies have emphasized leachate as one of the major contributors to high Cd concentration in groundwater (Bankole et al., 2022; Ojekunle et al., 2022; Troudi et al., 2020). High Cd concentrations in drinking water are deposited in the kidney over time, causing renal damage (Huang et al., 2021; Kubier et al., 2019). Endocrine disruption, development of malignant cells, and calcium homeostasis are the severe consequences of high Cd exposure (Ali et al., 2013), with renal tubule being the most common consequence (Bernard, 2004).

Chromium (Cr) concentration in all wells assessed was below the established standard of 0.050 mg/L. The mean concentration increased in the order of Saje > Obantoko > Obada > Lafenwa > Idi-aba (as shown in Table 2). Cr occurs in two forms in the environment: Cr III and Cr VI, with Cr III being a micronutrient and insoluble in water (Zhao et al., 2016). Cr (Cr VI) is highly stable, mobile, and soluble in groundwater, with a very high carcinogenic effect on human health, even at a very low concentration (Beukes et al., 2017; Zhao et al., 2016). Although Cr occurrence in groundwater is often from rock-water interaction and anthropogenic activities, the impact of the latter has been prominent in the findings of most studies (Gedamy, 2015; Salman & Elnazer, 2020; Tiwari et al., 2019). The use of Cr-containing material in different industrial activities including metallurgy, paint, paper pulp, steel production, petroleum refining, and electroplating, which are often disposed off into the environment, could introduce Cr into the groundwater aquifer. Most importantly, leachate of solid waste from open dumpsites could easily influence the concentration of Cr in groundwater aquifers; hence, its monitoring is of essential interest.

The overall high metal concentration in wells around the Saje dumpsite is envisaged and could be attributed to the influence of previous mining activities before the spot was converted into a dumpsite. Nevertheless, the general high concentration of metals in wells around other dumpsites (Obantoko, Idi-aba, Lafenwa, and Obada), coupled with the acidic pH concentration of the water samples, suggests that the leaching of the solid wastes has seriously polluted the shallow water sources in the vicinity, with probable high metal mobility (due to acidic pH). Therefore, it is essential to evaluate the probable non-carcinogenic and carcinogenic effects of the water sources for both oral and dermal routes, across different age groups: infant, children, and adult male and female.

Non-carcinogenic health risks

Evaluation of potential health risks is critical to determine the suitability of water sources for drinking and other domestic uses. The non-carcinogenic risks of the heavy metals were determined by evaluating the oral and dermal hazard index for infants, children, and adult males and females. The hazard index (HI) value greater than 1 indicates that water users within the study area may experience diverse non-carcinogenic health complications ranging from headaches to renal damage, by either oral or dermal usage. On the other hand, a hazard index value of less than one implies that groundwater users in the study area will have no consequential health effects. The result of non-carcinogenic HI of oral and dermal routes for the age groups is presented in Table 3. The results are sectionalized into oral and dermal routes.

Table 3 Hazard Index values for oral and dermal ingestion for age groups

Dumpsites	Samples	HI oral				HI dermal			
		Adult male	Adult female	Children	Infant	Adult male	Adult female	Children	Infant
Obantoko	S1	5.00	5.67	10.01	27.03	0.80	0.83	1.34	1.88
	S2	4.19	4.75	8.37	22.60	0.62	0.64	1.04	1.47
	S3	4.36	4.95	8.72	23.55	0.69	0.72	1.16	1.63
	S4	6.49	7.36	12.99	35.06	1.15	1.18	1.92	2.70
	S5	5.45	6.17	10.89	29.41	0.91	0.94	1.53	2.15
Lafenwa	S6	2.33	2.64	4.65	12.56	0.38	0.39	0.63	0.88
	S7	2.29	2.59	4.57	12.35	0.37	0.38	0.61	0.86
	S8	2.15	2.44	4.30	11.60	0.36	0.37	0.61	0.85
	S9	2.61	2.96	5.22	14.10	0.41	0.42	0.68	0.95
	S10	2.82	3.20	5.64	15.23	0.44	0.46	0.74	1.04
Saje	S11	18.12	20.55	36.24	98.69	3.91	4.04	6.54	9.20
	S12	15.30	17.35	30.60	82.62	3.15	3.25	5.27	7.41
	S13	6.24	7.07	12.47	33.68	0.97	1.00	1.62	2.28
	S14	5.71	6.48	11.43	30.86	0.71	0.74	1.19	1.67
	S15	5.39	6.11	10.78	29.10	0.65	0.68	1.09	1.54
Obada	S16	2.98	3.38	5.96	16.09	0.41	0.42	0.69	0.96
	S17	3.16	3.59	6.33	17.08	0.44	0.45	0.73	1.03
	S18	3.22	3.65	6.43	17.37	0.45	0.47	0.76	1.07
	S19	3.52	3.99	7.04	19.01	0.48	0.50	0.81	1.14
	S20	3.41	3.87	6.82	18.42	0.47	0.48	0.78	1.10
Idi-aba	S21	2.83	3.21	5.66	15.28	0.37	0.38	0.61	0.86
	S22	2.89	3.27	5.77	15.58	0.38	0.39	0.63	0.88
	S23	3.01	3.41	6.02	16.26	0.38	0.40	0.64	0.90
	S24	3.59	4.07	7.18	19.38	0.47	0.48	0.78	1.10
	S25	3.15	3.57	6.29	16.99	0.40	0.41	0.67	0.94
Min		2.15	2.44	4.30	11.60	0.36	0.37	0.61	0.85
Max		18.12	20.55	36.24	98.69	3.91	4.04	6.54	9.20
Mean		4.81	5.45	9.62	26.00	0.79	0.82	1.32	1.86

Oral ingestion

The hazard index for oral ingestion (HI oral) for adult males and females, children, and infants is presented in this section. Notably, all sample points evaluated recorded significant HI values (HI > 1) for all the age groups. HI oral values for adult males and females, children, and infants range from 2.15–18.12, 2.44–20.55, 4.30–36.24, and 11.60–98.69, respectively.

The higher risk values for children and infants compared to the adults were expected considering that children's immune systems are more fragile. A similar trend of higher non-carcinogenic risks via the oral route in children and infants was recorded in the study of Akshitha et al. (2022) and Gao et al. (2020). Likewise, adult females recorded higher oral ingestion risks than adult males, which corroborates the assertion of Gao et al. (2020) that gender plays a critical role in the vulnerability to non-carcinogenic risks, by evaluating the human health risks of nitrate contamination in shallow groundwater sources in Eastern China. The minimum and maximum risks for oral ingestion for all age groups were recorded at Lafenwa (S8) and Saje (S11) as shown in Table 3. HI values of wells across the dumpsites environ increased in the order of Lafenwa < Idi-aba < Obada < Obantoko < Saje. This result showed that groundwater aquifers around the dumpsites in the Abeokuta metropolis have been seriously polluted by leachates, and users are vulnerable to diverse health consequences, particularly children and infants.

The maximum HI recorded in the wells assessed is higher than the values recorded in shallow groundwater sources around the mining site at Anhui Province, China (Jiang et al., 2021), and Degohlan village, Western Iran (Rezaei et al., 2019). Meanwhile, Nyambura et al. (2020) evaluated the probable health risks of metals (Pb, Cd, and Ni) from groundwater sources in Kilimambogo, Kenya, and the study recorded mean non-carcinogenic risks of 272.0 for adults and 133.1 for children, although the reasons why the risk in adults is higher than in children were not clarified by the authors. Also, Ojekunle et al. (2022) recorded extremely high mean HI values for adults (1809), children (5427), and infants (8140) in their study that assessed cancer and non-cancer risks of metal contamination in wells around the Kurata dumpsite, Sango, Ogun State, Nigeria.

Dermal ingestion

The values of hazard index (HI) through dermal ingestion are presented in Table 3. The HI dermal for adults male and female across the sample sites ranges from 0.36–3.91 and 0.37–4.04, respectively. All wells at Idi-aba, Lafenwa, and Obada have no significant risks, while one sample point at Obantoko (S4) was significant for male and female adults. Two wells around the Saje dumpsite (S11 and S12) were significant for males, and three wells (S11, S12, and S13) have HI values above 1.0 for adult females. This shows that both adult males and females are likely to experience severe health consequences by using the water from the wells for domestic or aesthetic purposes.

All groundwater sources around the dumpsites at Idi-aba, Lafenwa, and Obada recorded a similar trend of no significant risks for children, while significant risks were recorded by all wells in Obantoko and Saje. The minimum and maximum HI dermal values for children were recorded at wells S7 (0.61), S8 (0.61), S21 (0.61), and S11 (6.54), respectively. The difference in the number of significant risks of wells in Obantoko between adults and children could be attributed to the fact that non-significant HI values for adults are close to one (1). Jiang et al. (2021) recorded lower non-carcinogenic risks of metal through the dermal route for children in their study on groundwater contamination from mining sites in China. This implies that bathing children or other aesthetic uses of water from the studied wells and the environs of Obantoko and Saje dumpsites are not advisable unless treated. Children who are exposed to untreated contaminated water could experience acute or severe health problems, including skin irritations.

The non-carcinogenic risks for infants via the dermal route at Lafenwa and Idi-aba sample sites were non-significant, except for one well each (S10 and S24) with significant non-carcinogenic risks (HI > 1), as shown in Table 3. In contrast, only one well at Obada (S16) recorded non-significant risks (HI < 1), but other wells have significant risks (HI > 1) ranging from 1.03 to 1.14. All wells around Obantoko and Saje dumpsites recorded significant risks for infants with HI values of 1.47–2.70 and 1.54–9.20, respectively.

The overall percentage of wells with significant risks for oral and dermal ingestions for all age groups is presented in Fig. 2. All sampled wells have significant risks for oral ingestion for adult males and females, children, and infants. The percentage of sampled wells with significant non-cancer risks (HI > 1) for dermal exposure is 12% for adult males, 16% for adult females, 40% for children, and 64% for infants (as shown in Fig. 2). Considering the HI dermal values, the vulnerability to non-carcinogenic health risks via dermal ingestion followed a similar pattern to the risks of oral ingestion, with infants being the most vulnerable and adult males being the least at risk. Meanwhile, the trend of the percentage of significant wells decreases from infant to adult male (infant > children > adult female > adult male). Adimalla (2018) reported 55.67%, 63.40%, and 92.27% of wells with significant non-carcinogenic risks for adult males and females and children, due to contamination of groundwater sources in the semi-arid region of South India.

Cancer risk (CR)

The cancer risks (CRs) of metals (Pb, Cd, and Cr) in sampled wells are shown in Table 4. The CR significant level as recommended by the US Environmental Protection Agency is 1.0E − 04. Overall, CR for all the sampled wells was significant across all age groups for both oral and dermal ingestion routes. The highest CR for adult males and females, children, and infants through oral ingestion was recorded at Saje S11 (2.10E − 01, 2.38E − 01, 4.20E − 01, and 1.14, respectively). Higher cancer risks for oral ingestion were reported for both adults (30.64E − 02—highest value) and children (7.43E02) by Nyambura et al. (2020). The same well (S11) recorded the highest dermal risk (CR) values for all age groups: male (1.12E − 03), female (1.16E − 03), children (1.88E − 03), and infant (2.64E − 03). Similar trend of non-carcinogenic risks (infant > children > female > male) was observed for cancer risk exposure (CR) through both oral and dermal routes.

The cancer risk contribution of the metals (Cd, Cr, and Pb) to all age groups for the entire sampled wells is presented in Fig. 3. The order of toxicity was Cd > Cr > Pb for all the age groups assessed in this study. Cadmium recorded over 99% toxicity contribution for adult males and females and infants, while about 97% was recorded for children. Cadmium is a highly toxic element and is mostly found in groundwater systems (Kubier et al., 2019, 2020). Health consequences of exposure to cadmium aside from cancer include gastrointestinal diseases, chronic anemia, and calcium homeostasis (Alam et al., 2020; Ali et al., 2013). Improper sewage and solid waste management has been attributed to high cadmium content in groundwater sources in different parts of the world (Mahajan et al., 2022; Troudi et al., 2020). Therefore, cadmium-containing substances should be stopped from being discarded/dumped at open dumpsites in the Abeokuta metropolis.

Studies have established the impact of seasonal variations on groundwater quality and pollution level (Khawla & Mohamed, 2020; Owamah, 2020; Sahu et al., 2020; Wagh et al., 2018). Gao et al. (2020) established the influence of seasonal variation (wet and dry seasons) on the overall health risks of groundwater sources within the Karst geological

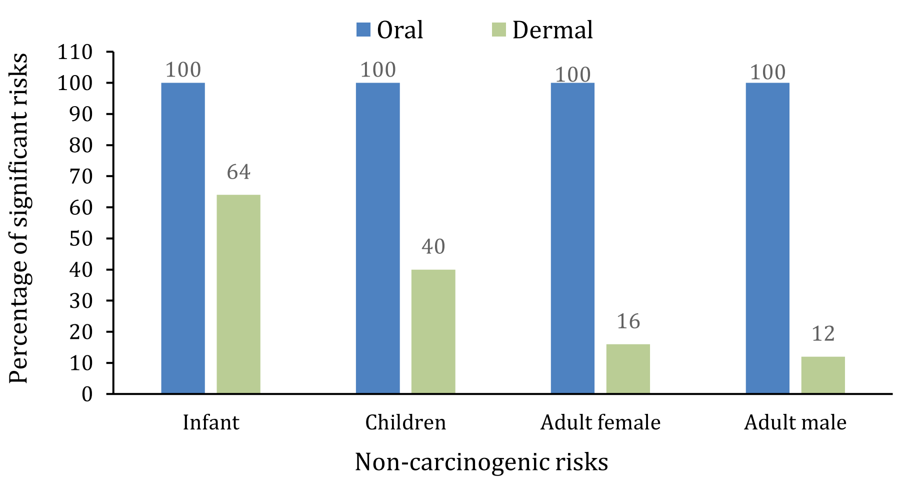

Fig. 2 Percentage of samples with significant non-carcinogenic HI for all age groups

Table 4 Cancer risk values for oral and dermal ingestion for the age groups

Dumpsite location	Samples code	CR oral values				CR dermal values			
		Adult male	Adult female	Children	Infant	Adult male	Adult female	Children	Infant
Obantoko	S1	3.86E−02	4.38E−02	7.72E−02	2.08E−01	2.06E−04	2.12E−04	3.44E−04	4.84E−04
	S2	3.35E−02	3.80E−02	6.70E−02	1.81E−01	1.78E−04	1.84E−04	2.99E−04	4.20E−04
	S3	3.36E−02	3.81E−02	6.71E−02	1.81E−01	1.79E−04	1.85E−04	2.99E−04	4.21E−04
	S4	5.95E−02	6.74E−02	1.19E−01	3.21E−01	3.17E−04	3.27E−04	5.31E−04	7.46E−04
	S5	4.45E−02	5.04E−02	8.89E−02	2.40E−01	2.37E−04	2.45E−04	3.97E−04	5.57E−04
Lafenwa	S6	2.13E−02	2.42E−02	4.26E−02	1.15E−01	1.14E−04	1.17E−04	1.90E−04	2.67E−04
	S7	2.13E−02	2.42E−02	4.26E−02	1.15E−01	1.14E−04	1.17E−04	1.90E−04	2.67E−04
	S8	2.05E−02	2.32E−02	4.10E−02	1.11E−01	1.09E−04	1.13E−04	1.83E−04	2.57E−04
	S9	2.18E−02	2.47E−02	4.35E−02	1.18E−01	1.16E−04	1.20E−04	1.94E−04	2.73E−04
	S10	2.43E−02	2.75E−02	4.85E−02	1.31E−01	1.29E−04	1.34E−04	2.16E−04	3.04E−04
Saje	S11	2.10E−01	2.38E−01	4.20E−01	1.14	1.12E−03	1.16E−03	1.88E−03	2.64E−03
	S12	1.74E−01	1.97E−01	3.48E−01	9.40E−01	9.28E−04	9.58E−04	1.55E−03	2.18E−03
	S13	4.54E−02	5.14E−02	9.07E−02	2.45E−01	2.42E−04	2.50E−04	4.04E−04	5.68E−04
	S14	4.18E−02	4.74E−02	8.36E−02	2.26E−01	2.23E−04	2.30E−04	3.73E−04	5.24E−04
	S15	3.84E−02	4.36E−02	7.69E−02	2.08E−01	2.05E−04	2.11E−04	3.43E−04	4.82E−04
Obada	S16	2.38E−02	2.70E−02	4.76E−02	1.29E−01	1.27E−04	1.31E−04	2.12E−04	2.98E−04
	S17	2.43E−02	2.75E−02	4.85E−02	1.31E−01	1.29E−04	1.33E−04	2.16E−04	3.04E−04
	S18	2.47E−02	2.80E−02	4.94E−02	1.33E−01	1.32E−04	1.36E−04	2.20E−04	3.09E−04
	S19	2.59E−02	2.94E−02	5.19E−02	1.40E−01	1.38E−04	1.43E−04	2.31E−04	3.25E−04
	S20	2.55E−02	2.89E−02	5.10E−02	1.38E−01	1.36E−04	1.40E−04	2.28E−04	3.20E−04
Idi-aba	S21	2.17E−02	2.46E−02	4.34E−02	1.17E−01	1.16E−04	1.19E−04	1.94E−04	2.72E−04
	S22	2.21E−02	2.51E−02	4.43E−02	1.19E−01	1.18E−04	1.22E−04	1.97E−04	2.77E−04
	S23	2.25E−02	2.56E−02	4.51E−02	1.22E−01	1.20E−04	1.24E−04	2.01E−04	2.83E−04
	S24	2.67E−02	3.03E−02	5.35E−02	1.44E−01	1.43E−04	1.47E−04	2.38E−04	3.35E−04
	S25	2.34E−02	2.65E−02	4.68E−02	1.26E−01	1.25E−04	1.29E−04	2.09E−04	2.93E−04
Min		2.05E−02	2.32E−02	4.10E−02	1.11E−01	1.09E−04	1.13E−04	1.83E−04	2.57E−04
Max		2.10E−01	2.38E−01	4.20E−01	1.14E+00	1.12E−03	1.16E−03	1.88E−03	2.64E−03
Mean		4.28E−02	4.85E−02	8.55E−02	2.31E−01	2.28E−04	2.35E−04	3.81E−04	5.36E−04

unit in Eastern China. Authors related the high hazard quotient and spatial spread during the wet season to the impact of seasonal variation. Considering that groundwater pollution could be influenced by run-off during the rainy season, it could be assumed that the sampling period (wet season) contributed to the high and significant cancer and non-carcinogenic risks recorded in this study. Nevertheless, the results have clearly shown that poor solid waste management through uncontrolled open dumpsites in the Abeokuta metropolis has greatly impacted the groundwater system of the fast-growing city.

Also, it could be argued that higher concentration is expected in the dry season due to low precipitation, which could possibly increase the metal concentration since the leaching process is continuous. Future studies are advised to evaluate the health risks at a wider distance and across different seasons, to ascertain the extent of pollution in the Abeokuta metropolis.

This study has shown that the users of the sampled and neighboring wells in the dumpsite environ are highly susceptible to different kinds of cancer and cancer-related illnesses (recurring flu, skin irritation, development of malignant cells, hormonal disruption, kidney failure, etc.), either by drinking the water without treatment or via daily domestic routines that involve water. Additionally, the extremely high risks for children and infants are an urgent call for drastic and holistic measures to tackle the poor solid waste management in the entire Abeokuta metropolis and build a healthy environment. Appropriate sustainable groundwater management approach and remediation technologies are urgently needed to reduce the contamination rate and curb further spread within the aquiferous units across the metropolis. Notably, the impact of past mining activity on the Saje dumpsite and its environment has been made obvious with the results of the metals, non-carcinogenic risks, and cancer risks for all the age groups, with well S11 being the overall highly polluted well assessed. This assertion is similar to the conclusion of Jiang et al. (2021) that mining activities and solid waste leachate impact the metals risks of shallow groundwater sources in Northern Anhui, China. Furthermore, soil/aquifer remediation measures for cadmium should be adopted to curtail the current pollution level and future consequences.

Digital elevation model

The digital elevation model (DEM) generated for the study area as presented in Fig. 4 shows that the metropolis has a higher elevation toward the northeastern part (Obantoko) and decreases southward (toward Obada), with the western part having a lower elevation compared to the eastern part (Idi-aba). Also, the location of the Ogun River and its channels is obviously depicted by the lowest elevation in the metropolis (deep blue pattern).

Considering that Obada has the second highest level of metal pollution and significant health risks (dermal and oral routes), it could be assumed that the low elevation and proximity to the downstream of the Ogun River influenced the pollution of shallow wells in the area, since pollutants are expected to be washed downstream across the river channel. The elevated metal concentration and significant risks of shallow wells in Saje could be traced to the

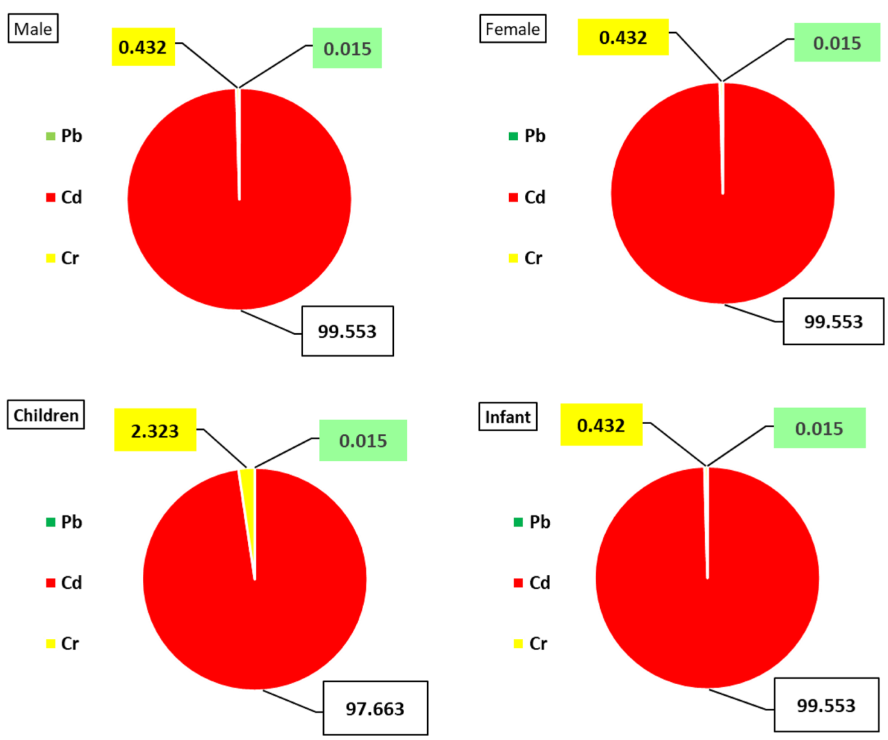

Fig. 3 Percentage toxicity of metals and contribution to cancer risks for all age groups

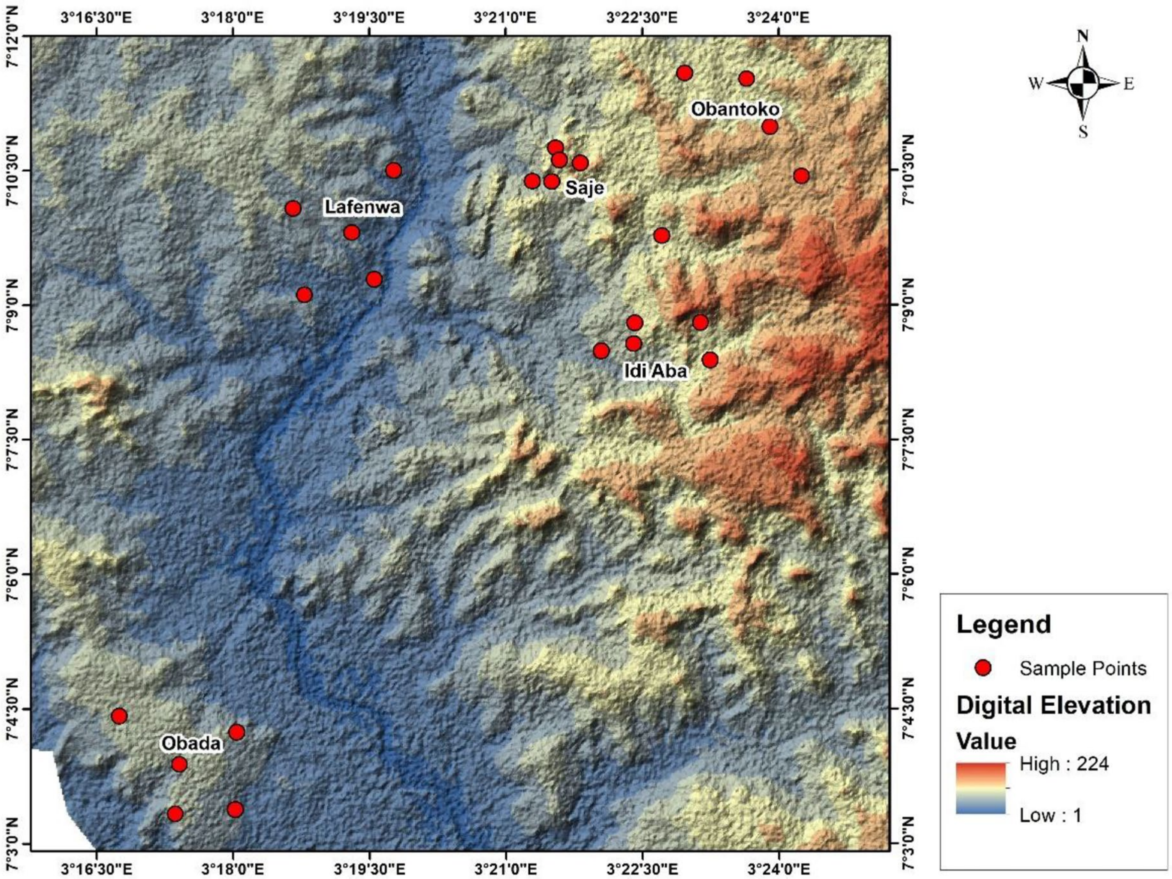

Fig. 4 Digital elevation model (DEM map) of the study area showing the sampling points

past mining activities in the area. This is similar to the established pattern between the elevation of parts of Ogun State and the spatial distribution of health risks and metals in groundwater sources by Bankole et al. (2022)

Conclusion

This study evaluated the non-carcinogenic and cancer risks of metal contamination of shallow wells due to leachates from dumpsites in the Abeokuta metropolis, Southwestern Nigeria. Five open dumpsites were selected within Abeokuta Metropolis based on their sizes, and twenty-five (25) groundwater samples were collected from shallow wells within 500 m distance from the dumpsites for laboratory testing and evaluation of risks. Human health risks through oral and dermal exposure for four age groups were evaluated. The laboratory water quality results show that all wells were acidic pH with high iron and cadmium, while the wells around Obantoko and Saje had high Cu and Pb concentrations above the established standards, including a few wells at Obada. The highest electrical conductivity and TDS were recorded at the wells at Saje.

Non-carcinogenic health risks of metals for oral ingestion were significant for all age groups, across the dumpsites in the order of Lafenwa < Idi-aba < Obada < Obantoko < Saje. HI increases from adult males to females and children, while infants have more vulnerability with the highest risk value of 98.69. Fewer samples recorded significant risks of dermal exposure for adult males and females, but all wells around Saje and Obantoko dumpsites have dermal HI > 1 for children and infants. Cancer risks for all wells across the age groups were significant (CR > 1.0E – 04) for both oral ingestion and dermal routes. The metal contribution to cancer risks in the study area for all age groups is in the order of Cd > Cr > Pb. The trend of significant non-carcinogenic and carcinogenic risks for oral and dermal ingestion is as follows: infant > children > adult female > adult male. The results show a high level of metal contamination and risks in the sampled wells with possible extension to other parts of the Abeokuta metropolis and portends the development of cancers by users in their lifetime. Urgent drastic and holistic remediation technologies are highly recommended while Government should encourage a containment management strategy in the interim and relocation of dumpsites far away from the metropolis as a lasting solution, to reduce groundwater contamination.

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Author contribution All authors have significantly contributed to the success of this research from the conceptualizing phase to the final manuscript preparation. Research methodology designs were performed by Harvester O. Okoye and Bankole O. Abayomi. Material preparation, data collection, and analysis were performed by Harvester O. Okoye, Adedayo O. Ayegbokiki, Bankole O. Abayomi, and Damilola E. Oluyege. The first draft of the manuscript was written by Harvester O. Okoye, Bankole O. Abayomi, Abraham O. James, and Afolashade R. Bankole. All authors reviewed and commented on the draft manuscript and approved the final manuscript.

Data availability The authors hereby declare that all data generated or analyzed during this study are included in this article.

Declarations

Ethical responsibilities of authors All authors have read, understood, and complied as applicable with the statement on "Ethical responsibilities of authors" as found in the Instructions for authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Competing interests The authors declare no competing interests.

Conflict of interest All authors declare no conflict of interests.

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