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Health Risk Assessment of Heavy Metals in Groundwater Around Some E-Waste Dumpsites from Three States in Southwestern Nigeria

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ABSTRACT

Background and Objective: The e-waste dumpsites, among others, are eye sore in many developing countries, with damaging effects on public health and the environment. Although e-waste dumpsites are sparse, the few ones that exist may contain high levels of heavy metals released into the environment. Therefore, carcinogenic and non-carcinogenic health risks posed by heavy metals are used to determine the quality of groundwater in the study area. **Materials and Methods:** Thirty samples of groundwater from the hand-dug wells were collected, with five samples from each of the six stations. The elemental analysis of some toxic heavy metals was performed using an atomic absorption spectrophotometer. The data preparation and arrangement were carried out using Microsoft Excel. **Results:** None of the heavy metals were detected in samples of groundwater from Karakata Market, Akure. The results of the carcinogenic and non-carcinogenic tests for adults and children showed that hazard quotient and hazard index values were below one in all the pathways like inhalation, ingestion and dermal. This implies that the heavy metals posed no carcinogenic or non-carcinogenic threat to the inhabitants of the study area. The total cancer risks due to ingestion and inhalation revealed that ingestion was the principal exposure pathway. The total cancer risk for children and adults was within the acceptable limits of the United States Environmental Protection Agency and the World Health Organization. **Conclusion:** The study indicated that all the results were below the limit recommended. Therefore, no environmental or health risk is expected in the study areas. However, no matter how small the environmental and health risks may be, long-term exposure to heavy metals may be detrimental to human health.

KEYWORDS

Carcinogenic, dumpsite, ecological, e-waste, heavy metals, non-carcinogenic

INTRODUCTION

The E-waste contains multiple toxic components, such as heavy metals, that are capable of causing hazardous effects on humans and the environment[1]. The e-waste causes a prominent environmental challenge because of its heterogeneous mixture of heavy metals, metalloids, plastics and glass. Mishra *et al.*[2] applied a solid-state route for the characterization of e-waste and the extraction of some

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metals; this technique is not effective enough to eliminate heavy metals from the environment. The residents living close to e-waste dumpsites are exposed to these hazardous elements or chemicals through different exposure pathways, including ingestion, inhalation and dermal contact[3]. People living around e-waste dumpsites and waste recycling sites have a high risk of exposure to heavy metals. The groups of people most vulnerable to hazardous e-waste heavy metals and chemicals are infants and children living around e-waste dumpsites.

Lead is a highly hazardous metal that has no benefit to human body in whatever quantity; accumulation of lead in human body damages the central nervous system which can lead to behavioral problems in children, including lowering of intelligence[4]. Heavy metals can enter human body through inhalation of particulates from burning e-waste and through the ingestion of contaminated water when they are leached into groundwater[5].

Inhalation of cadmium metal or cadmium oxide poses the greatest threat due to its extreme toxicity; only 5-8% of cadmium is absorbed into the digestive tract when ingested. However, there are a number of dietary and extra-intestinal factors that can improve the gastrointestinal absorption of the metal when ingested. For instance, tobacco smoking easily causes the gastrointestinal absorption of about 40% of cadmium when ingested. Cadmium is easily transported through the blood, but the liver and kidneys retain about 50-75% of the metal[6]. Although cadmium has various harmful consequences, the most prevalent ones in humans are kidney damage resulting from chronic exposure and testicular damage from acute exposure. Cadmium is also toxic to the liver, as well as vascular tissue and bone[6]. Acute inhalation of Cd may cause a variety of symptoms, including lung irritation and injury, nausea, vomiting, diarrhea and lethargy. Deficits in cognition, learning behavior and neuromotor skills are being attributed to exposure to Cd in children[4]. Chromium (VI) as a carcinogen has been reported by ecologists as a toxin to plants. The view has been that chemicals containing chromium (VI) may cause cancer, but recent research revealed that micronuclei and genomic instability of the chromium (VI) may prevent cancer development[5].

Water is one of the essentials that support all plant and animal life and generally, water comes from natural sources, including rivers, streams and groundwater, like hand-dug wells and bore-hole water. According to Deda *et al.*[7], 30% of clean water in nature is groundwater and 53% of the world's population is dependent on groundwater for drinking and domestic use.

The assessment of the health risks posed by heavy metals in groundwater has received considerable attention. The well-being of the impacted people is strongly influenced by the quality of water[8]. Comparing the mean concentrations of heavy metals present in the groundwater with the WHO[9] standard is not enough to determine the appropriateness of the drinking water. Therefore, finding the potential effects of the pollutants in the groundwater on human health is crucial for an accurate assessment of the water quality in a given area[10]. Evaluating the potential health impact of water in areas where e-waste dumpsites are located is vital for health risk assessment. Although ingestion is the most prevalent exposure mechanism, skin contact and inhalation were also taken into account in this investigation. This is because the main ways that people are exposed to heavy metals are through food, drink, inhaled aerosol particles and dust[10]. This research work aims to assess the carcinogenic and non-carcinogenic health risks of heavy metals in groundwater around e-waste dumpsites pose to children and adults in the three exposure pathways. The results of this study may educate the inhabitants of the communities around the e-waste dumpsites to come up with a protective measure and to avoid indiscriminate disposal of e-waste in residential areas.

MATERIALS AND METHODS

The study was carried out from July to August, 2021 when the precipitation is always at its peak in Southwest Nigeria.

Site description: Nigeria's Southwestern geopolitical zone includes the states of Ekiti, Lagos, Ondo, Oyo, Ogun and Osun with a total landmass area of 77,818 km^2 and the region has a population of about 45 million people around 22% of a total population of the country[11]. Lagos state is the most densely populated area because it has the biggest commercial city in Nigeria. The territory is located between Longitude 2°311 and 6°001 East and Latitude 6°211 and 8° 371 North. The region is bounded in the north by the states of Kwara and Kogi, in the south by the Gulf of Guinea, in the East by Edo and Delta states and in the west by the Republic of Benin. The climate in the region is tropical, with distinct wet and dry seasons. Precipitation during the rainy season ranges between 150 and 3000 mm per year, whereas the temperature during the dry season is between 21 and 34°C.

Sample collection and preparation: The study was carried out in some States in Southwestern Nigeria, including Lagos, Oyo and Ondo State. The dumpsites considered for the study in Lagos were situated in Alaba Market, Westminster Electronic Market and Ikeja Computer Village. In Oyo State, two dumpsites were considered for this study and they are located in Ogunpa and Iwo road electronic markets, while the only electronic dumpsite considered for study in Ondo State is located in Karakata electronic markets. Groundwater samples were collected from the hand-dug wells around residential areas at a distance of 100-300 m from each e-waste dumpsite from July to August, 2021. This period is the peak of rainy season in the Southwest when the water table is generally high. The groundwater samples were collected inside a sterile non-radioactive 75 Cl plastic container and labeled according to the sampling wells. The samples were taken to the laboratory for preparation before analyzing the levels of cadmium, cobalt, chromium, copper, nickel, lead and zinc in the samples.

As 50 mL of each water sample was measured using a cylinder and transferred into a Kjeldahl flask and 20 mL of aqua regia (a mixture of concentrated HCl acid and HNO_3 acid in a ratio of 3:1) was added. The mixture was digested on a hot plate for 2 hrs in a fume cupboard until the brown fume disappeared. After cooling, the digested material was filtered into a 50 mL standard flask and thereafter, distilled water was added to the mark of the 50 mL flask. This was then transferred into a clean plastic bottle and analyzed for metal content using the Bulk Scientific 210 Atomic Absorption Spectrophotometer (AAS). The following heavy metal concentrations were determined: Cd, Co, Cu, Cr, Ni, Pb and Zn.

Exposure assessment: The average daily intakes (ADI mg/kg/day) were determined by the following Equation according to Nfor *et al.*[12]:

$$ADI_{ing} = \frac{C \times IR_{ing} \times ED \times CF}{BW \times AT} \quad (1)$$

The inhalation pathway of heavy metals through media particulates (dust) was calculated by using:

$$ADI_{inh} = \frac{C \times IR_{inh} \times EF \times ED}{BW \times AT \times PEF} \quad (2)$$

The dermal pathway of heavy metal through skin contact was determined by using:

$$ADI_{derm} = \frac{C \times SA \times SAF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (3)$$

Where, BW represents the body weight, EF is exposure frequency, ED is exposure duration, IR_{ing} is ingestion rate, IR_{inh} is inhalation rate, SA is skin surface area, SAF is soil adherent factor, FE is dermal exposure ratio, PEF is particulate emission factor, CF is conversion factor and AT is indicates the average time.

Table 1: Reference Dose (RfD) in (mg/kg/day) and Cancer Slope Factor (CSF_D) for different heavy metals

Heavy metal	RfD_O	RfD_D	RfD_I	CSF_O	CSF_D	CSF_I
Pb	3.60E-03	-	-	8.50E-03	-	4.20E-02
Cd	5.00E-04	5.00E-04	5.70E-05	-	-	6.30E+00
Cr	3.00E-03	-	3.00E-05	5.00E-01	-	4.10E+01
Co	2.00E-02	5.70E-06	3.70E-06	-	-	9.80E+00
Ni	2.00E02	5.60E-03	-	-	-	-
Cu	3.70E-02	2.40E-02	-	-	-	-
Zn	3.00E-01	7.50E-02	-	-	-	-

Source: Nfor *et al.*[12] and Kamunda *et al.*[13]

Non-carcinogenic risk assessment: The hazard quotient (HQ) was calculated using Eq. 4[10,13]:

$$HQ = \frac{ADI}{RfD} \tag{4}$$

where, RfD is the reference dose of the i-th potentially heavy metal (mg/kg/day). The overall non-carcinogenic effect on the public ΣHQ values for individual heavy metals is defined as Hazard Index (HI) for several heavy metals estimated total non-carcinogenic effect caused by exposure to multiple heavy metals in water and expressed according to US Environmental Protection Agency (EPA) guidelines for health risk assessment as adopted by Mohammadi *et al.*[10]:

$$HI = \sum HQ = \sum \frac{ADI}{RfD} \tag{5}$$

Carcinogenic risk assessment: The carcinogenic risk is expressed as:

$$CR = ADI \times SF \tag{6}$$

where, CR is the unit less probability of an individual developing cancer over a lifetime, the ADI (mg/kg/day) and SF are the average daily intake and the carcinogenicity slope factor (per mg/kg/day), respectively, for individual heavy metals. The total excess lifetime cancer risk for an individual was calculated from the average contribution of individual heavy metals for all the pathways. The values of reference dose (RfD) and the cancer slope factor (SF) used to calculate the non-carcinogen and carcinogenic risk assessments are presented in Table 1.

Statistical analysis: The data preparation and arrangement were carried out using Microsoft Excel. The data analysis was performed by using SPSS 20.0 statistical software.

RESULTS AND DISCUSSION

Non-carcinogenic risk assessment in groundwater: The RfDing value in water for both adults and children was taken into consideration in this study. The results of the average daily intake (ADI) for non-carcinogenic risk in the study area was presented in Table 2 for both children and adults. The highest exposures of children were found in Cu (1.73E-07) and Zn (1.73E-07) at Alaba Market, with a decreasing order of Zn>Cu>Cr>Pb>Ni>Cd and the decreasing order for the pathway was ingestion>dermal>inhalation. The decreasing order of exposure for adults was Cr>Zn>Cu>Pb>Ni>Cd. Similarly, the highest average daily intake obtained in the Westminster Market showed Cu (1.43E-07) for children and Zn (1.71E-08) for adults, with the decreasing order Cu>Zn>Cr>Cd>Ni. Furthermore, Cr was the most commonly consumed heavy metal in children (1.35E-07) and adults (1.61E-08) in the Computer Village. The decreasing order of intake was Cr>Zn>Cu>Pb>Cd. In Ogunpa, Pb has the highest intake of

Table 2: Average daily intake (ADI) (mg/kg/day) of non-carcinogenic risk assessment in groundwater

Station		Receptor pathway	Cd	Co	Cr	Cu	Ni	Pb	Zn	Total
Alaba Market	Child	Ingestion	2.30E-08	0.00E+00	1.16E-07	1.53E-07	2.55E-08	6.39E-08	1.53E-07	5.34E-07
		Inhalation	8.85E-13	0.00E+00	6.19E-12	5.90E-12	9.83E-13	2.45E-12	5.90E-12	2.23E-11
		Dermal	2.94E-09	0.00E+00	2.06E-08	1.96E-08	3.27E-09	8.18E-09	1.96E-08	7.42E-08
		Total	2.59E-08	0.00E+00	1.37E-07	1.73E-07	2.88E-08	7.21E-08	1.73E-07	6.09E-07
	Adult	Ingestion	2.47E-09	0.00E+00	1.73E-08	1.64E-08	2.74E-09	6.85E-09	1.64E-08	6.22E-08
		Inhalation	3.79E-13	0.00E+00	2.66E-12	2.53E-12	4.12E-13	1.05E-12	2.53E-12	9.56E-12
		Dermal	6.10E-10	0.00E+00	4.27E-09	4.07E-09	6.78E-10	1.69E-09	4.07E-09	1.54E-08
		Total	3.08E-09	0.00E+00	2.16E-08	2.05E-08	3.42E-09	8.54E-09	2.05E-08	7.76E-08
Westminster	Child	Ingestion	2.55E-08	0.00E+00	6.64E-08	1.27E-07	1.91E-08	4.85E-08	9.46E-08	3.81E-07
		Inhalation	9.83E-13	0.00E+00	2.55E-12	4.91E-12	7.37E-13	1.82E-12	3.63E-12	1.46E-11
		Dermal	3.28E-09	0.00E+00	8.52E-09	1.63E-08	2.45E-09	6.22E-09	1.21E-08	4.89E-08
		Total	2.88E-08	0.00E+00	7.49E-08	1.43E-07	2.16E-08	5.47E-08	1.07E-07	4.30E-07
	Adult	Ingestion	2.74E-09	0.00E+00	7.12E-09	1.37E-08	2.05E-09	5.21E-09	1.01E-08	3.38E-08
		Inhalation	4.12E-13	0.00E+00	1.10E-12	2.11E-11	3.16E-13	8.01E-13	1.56E-12	2.53E-11
		Dermal	6.78E-10	0.00E+00	1.76E-09	3.39E-09	5.09E-10	1.28E-09	2.51E-09	1.01E-08
		Total	3.42E-09	0.00E+00	1.76E-09	1.71E-08	2.56E-09	6.49E-09	1.26E-08	4.40E-08
Computer Village	Child	Ingestion	4.16E-08	0.00E+00	1.20E-07	6.39E-08	0.00E+00	3.32E-08	8.43E-08	3.43E-07
		Inhalation	1.59E-12	0.00E+00	4.62E-12	2.45E-12	0.00E+00	1.27E-12	3.24E-12	1.32E-11
		Dermal	5.32E-09	0.00E+00	1.53E-08	8.18E-09	0.00E+00	4.25E-09	1.08E-08	4.39E-08
		Total	4.69E-08	0.00E+00	1.35E-07	7.21E-08	0.00E+00	3.75E-08	9.51E-08	3.87E-07
	Adult	Ingestion	4.45E-09	0.00E+00	1.29E-08	6.85E-09	0.00E+00	3.56E-09	9.04E-09	3.68E-08
		Inhalation	6.85E-13	0.00E+00	1.98E-12	1.05E-12	0.00E+00	5.48E-12	1.39E-12	1.06E-11
		Dermal	1.10E-09	0.00E+00	3.19E-09	1.69E-09	0.00E+00	8.82E-10	2.23E-09	9.09E-09
		Total	5.55E-09	0.00E+00	1.61E-08	8.54E-09	0.00E+00	4.45E-09	1.13E-08	4.59E-08
Ogunpa	Child	Ingestion	3.83E-08	1.27E-08	3.07E-08	8.95E-08	8.94E-08	1.38E-07	4.34E-08	4.42E-07
		Inhalation	1.26E-13	4.21E-14	1.01E-13	2.95E-13	2.95E-13	4.55E-13	1.43E-13	1.46E-12
		Dermal	4.21E-10	1.40E-10	3.37E-10	9.82E-10	9.83E-10	1.52E-09	4.77E-10	4.86E-09
		Total	3.87E-08	1.28E-08	3.10E-08	9.05E-08	9.04E-08	1.40E-07	4.39E-08	4.47E-07
	Adult	Ingestion	4.11E-09	1.37E-09	3.29E-09	9.59E-09	9.59E-09	1.48E-08	4.66E-09	4.74E-08
		Inhalation	2.71E-13	9.03E-14	2.17E-13	6.32E-13	6.32E-13	9.75E-13	3.07E-13	3.12E-12
		Dermal	1.02E-09	3.39E-10	8.14E-10	2.27E-09	2.33E-09	3.66E-09	1.15E-09	1.16E-08
		Total	5.13E-09	1.71E-09	4.10E-09	1.19E-08	1.19E-08	1.85E-08	5.81E-09	5.90E-08
Iwo Road	Child	Ingestion	2.05E-08	0.00E+00	2.55E-08	2.81E-08	8.95E-08	6.90E-08	2.55E-08	2.58E-07
		Inhalation	6.74E-14	0.00E+00	8.43E-14	9.27E-14	2.95E-13	2.28E-13	8.43E-14	8.52E-13
		Dermal	2.25E-10	0.00E+00	2.81E-10	3.08E-10	9.58E-10	7.58E-10	2.81E-10	2.81E-09
		Total	2.07E-08	0.00E+00	2.58E-08	2.84E-08	9.05E-08	6.98E-08	2.58E-08	2.61E-07
	Adult	Ingestion	2.19E-09	0.00E+00	2.74E-09	3.01E-09	9.59E-09	7.40E-09	2.74E-09	2.77E-08
		Inhalation	1.45E-13	0.00E+00	1.81E-13	1.99E-13	6.32E-13	4.88E-13	1.81E-13	1.83E-12
		Dermal	7.86E-09	1.71E-09	7.52E-09	1.52E-08	2.39E-08	2.76E-08	9.23E-09	9.30E-08
		Total	2.07E-08	0.00E+00	2.58E-08	2.84E-08	9.05E-08	6.98E-08	2.58E-08	1.21E-07

heavy metal (1.40E-07) for children and (1.85E-08) for adults. The order of decreasing metals was Pb>Cu>Ni>Zn>Cd>Cr>Co. Similarly, Ni has the highest intake in children among the heavy metals. In addition, Ni exhibited the highest value of (9.05E-08) for children and (9.05E-08) for adults in groundwater around the Iwo road e-waste dumpsite. The decreasing trend in the risk from heavy metals was Ni>Pb>Cu>Cr>Zn>Cd. It was observed that the average daily intakes were higher in children than in adults in all the selected e-waste dumpsites. However, the average daily intake of heavy metals in the study was less than the world's permissible limit WHO[9]. Therefore, the results showed similarity to the values reported by Adewoyin *et al.*[14]. Furthermore, it was observed that ingestion is the most common pathway through which humans are exposed to heavy metals in groundwater. However, Adeyemi and Ojekunle[15] reported that the highest value of 1.19E-03 was found in Cu, while 1.01E-02 was recorded in Mn for infants in Ota, Ogun State. In Sagamu, the highest dose of 1.51E-02 was obtained in Pb for adults and 1.14E-03 was obtained in Cd for children. Although reports by these authors showed higher values, the trend of exposure to heavy metals in groundwater was similar to the present study.

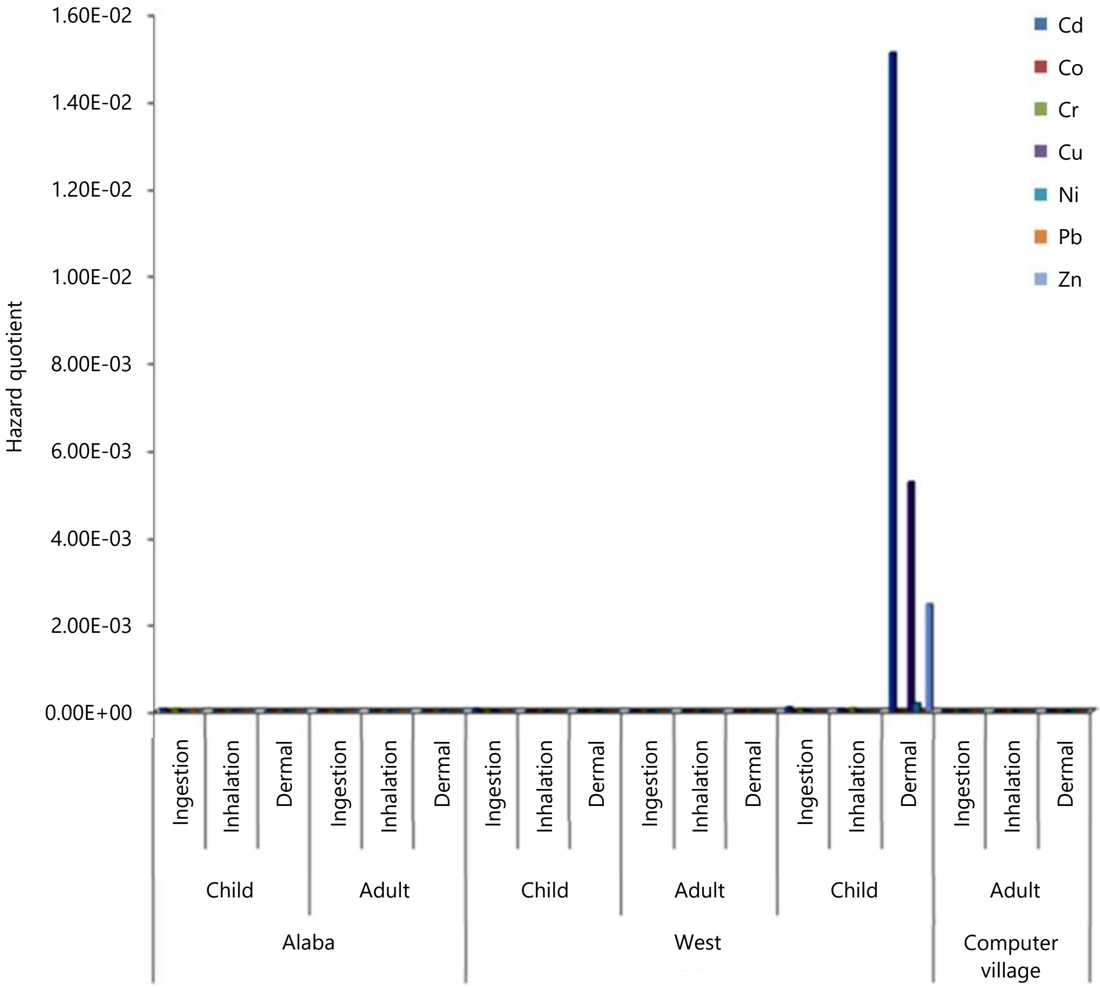

Fig. 1: Hazard quotient (HQ) due to heavy metals in groundwater around e-waste dumpsites in Ibadan

Hazard quotient (HQ) and hazard index (HI): Figure 1 and 2 depicted the summary of the hazard quotient for the heavy metals in the study. In Alaba Market, the respective hazard quotients for children and adults were 1.23E-04 and 1.09E-07, while the hazard indices for children and adults were 1.25E-04 and 1.49E-05, respectively and the main heavy metal exposure for kids and adults in Alaba Market was chromium (Cr). The HQ for children and adults in Westminster Market were 9.76E-05 and 6.72E-08, respectively, while the HI were 9.95E-05 and 1.15E-05, respectively and the main component of the groundwater pollutant was Cd. Children and adults at Computer village had HQ of 2.08E-02 and 6.00E-08, respectively, while HI were 2.32E-02 and 2.57E-05, respectively and the primary contributing element was Cd in the dermal pathway. Children living around the e-waste dumpsite in Computer village are exposed to the highest HQ and HI levels. In Iwo Road, the HQ and HI for children and adults were 8.89E-08 and 1.82E-08, respectively, while the HQ and HI were 7.46E-05 and 9.46E-06, respectively. In Ogunpa Market, HQ was 1.51E-07 and 3.09E-08 for children and adults, respectively, while HI was 1.59E-04 and 7.64E-05. However, because the HQ and HI were less than one (1), it was observed that the mean values of the hazard quotient and hazard index computed for Cd, Co, Cr, Cu, Ni, Pb and Zn in the groundwater around the e-waste dumpsites were below the permissible limits for drinking water.

Carcinogenic risk assessment in groundwater: Similar calculations were made to determine the carcinogenic risk for adults and children using the average daily intake (ADI) for carcinogenic risk values. Table 3 depicts the results for the computed ADI in Alaba Market, Westminster, Computer Village, Ogunpa and Iwo Road. Figure 3 and 4 display the groundwater carcinogenic risk levels. Alaba Market, Westminster Market and computer village's cancer risk (CR) values are shown in Fig. 3, whereas Ogunpa and Iwo Road

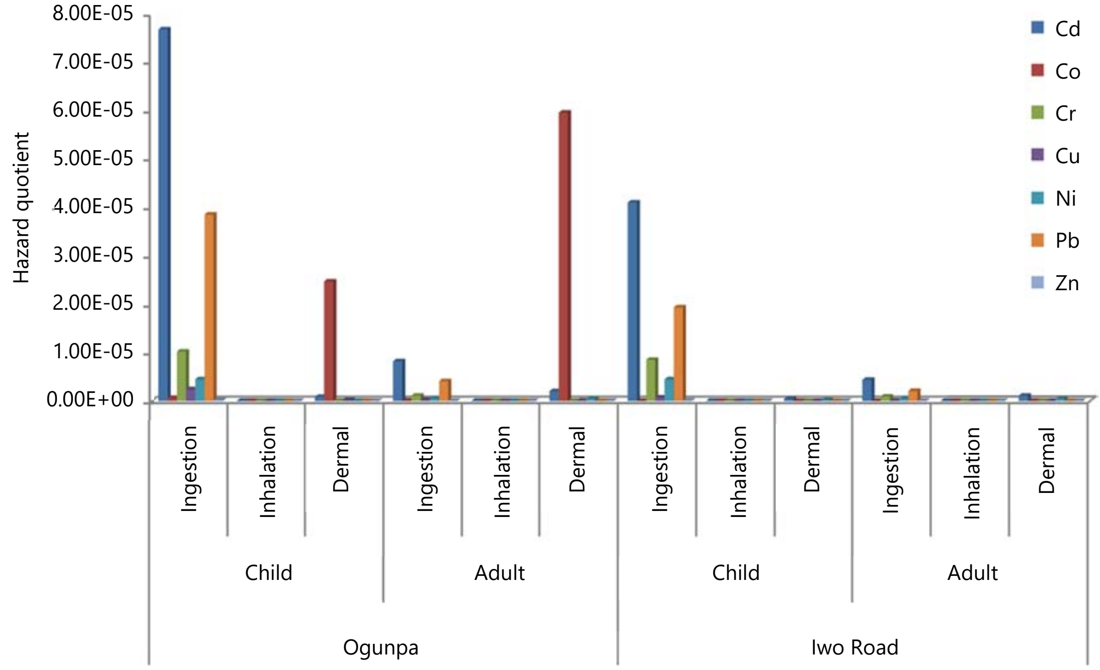

Fig. 2: Hazard quotients (HQ) due to heavy metals in groundwater around e-waste dumpsites in Lagos

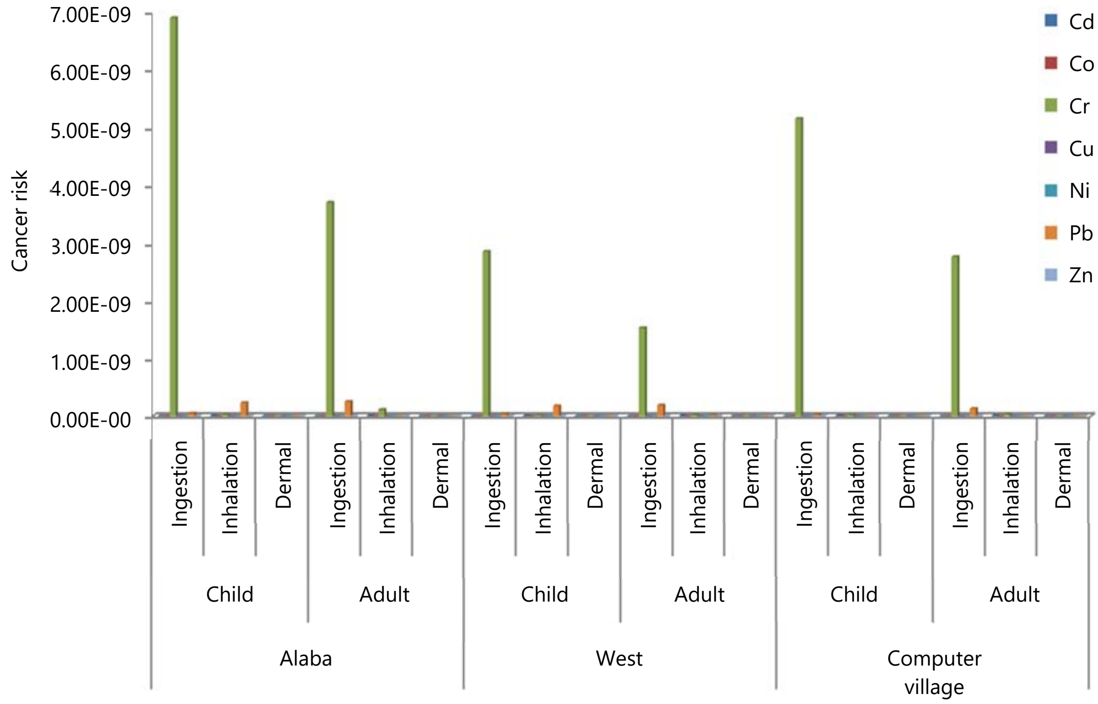

Fig. 3: Cancer risk values for heavy metals in children and adults in groundwater around e-waste dumpsites in Lagos

market's CR graph is shown in Fig. 4. Oral ingestion and inhalation were used to calculate the carcinogenic risk. In Table 3, children are more likely to develop cancer from ingesting Cr than adults, whereas Fig. 3 and 4 demonstrate that adults are more likely to develop cancer from ingesting Pb. Additionally, adults had higher CR inhalations than kids did for all the heavy metals taken into account, but they were still below the threshold. According to estimates, the combined extra lifetime cancer risk from the investigated carcinogenic heavy metals was 7.20E-09 for children and 4.06E-09 for adults in Alaba Market, 3.07E-09

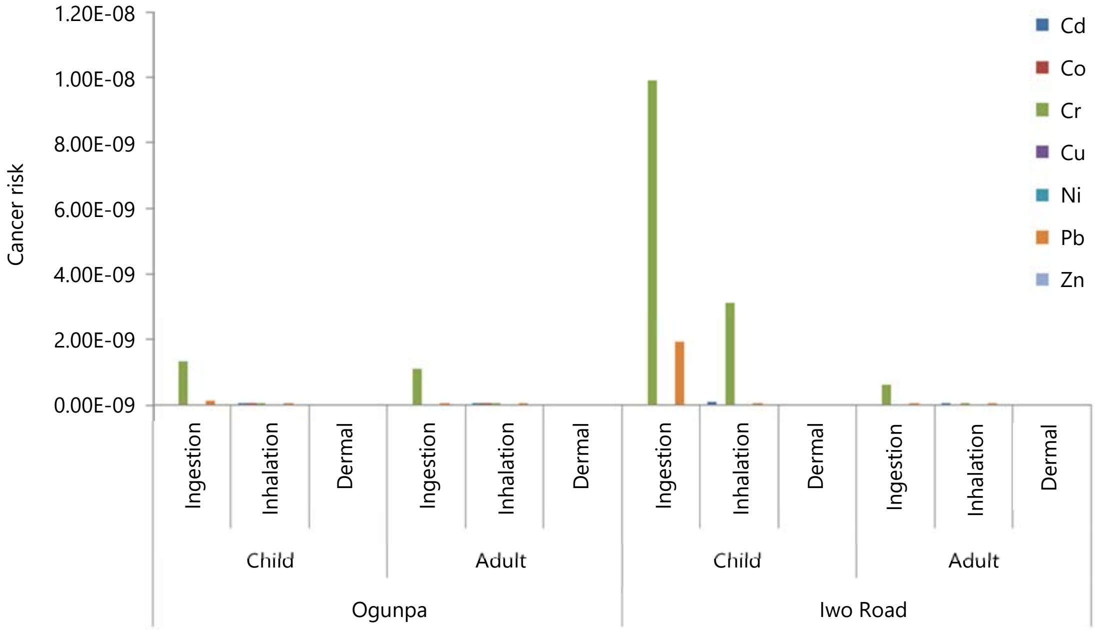

Fig. 4: Cancer risk values for heavy metals in children and adults in groundwater around e-waste dumpsite in Ibadan

and 1.75E-09 in Westminster Market and 5.19 E-09 and 2.93 E-09 in Ikeja Computer Village. For children and adults in Ogunpa, the values of the total excess lifetime cancer risk were 1.48E-09 and 1.20E-09, respectively, while in Iwo Road, the values were 9.92E-07 and 6.34E-10. Heavy metals' total excess lifetime cancer risk under 1×10^{-6} is seen as negligible and can be disregarded, while a total excess lifetime cancer risk beyond 1×10^{-4} is regarded as hazardous and problematic. The permissible limit for all heavy metals across all exposure routes is 1×10^{-5} [10]. Both the estimates of the cancer risk for adults and children in this study fell within the USEPA threshold.

Although Cd, Cr and Pb were the main contributors to the contamination for cutaneous and oral absorption in both children and adults, the trending order of heavy metals in groundwater varied from one dumpsite to another. The health risk due to inhalation was insignificant. However, the Hazard Indices obtained from all the study locations were below the USEPA's non-carcinogenic risk limit for both children and adults. This indicated that the exposure of the individuals in the study locations was insignificant. However, Olagunju *et al.*[16] result was a high hazard quotient (HQ>1) but HI<1 for oral and dermal exposure for children was not in agreement with the present study. Consequently, the results of the present study were in agreement with the trend of Nasrabadi's[17] report. Furthermore, the findings of the current investigation demonstrated that the cumulative ingestion and inhalation exposure pathways in the study areas' groundwater did not pose a cancer danger to the locals living close to e-waste dumpsites. However, close attention must be paid to the presence of Cr and Pb in the oral ingestion pathway. The Chromium (VI) compounds are categorized as human carcinogens in the respiratory system, which can result in lung, nose and nasal sinus cancer[18]. It is potentially carcinogenic when consumed orally in significant doses and is mutagenic when breathed in[6]. Environmental exposure to chromium (VI) has a detrimental effect on pregnancy outcomes and, as a result, has a knock-on effect on two generations' health, leading to increased pregnancy loss, spontaneous miscarriages and low birth rates[19]. Early pregnancy appears to be a very dangerous phase for fetal exposure to Cr[20]. Exposure to lead (Pb) has been linked to an increased risk of bladder, stomach and lung cancer in a variety of human groups, despite the fact that there is very limited evidence linking lead (Pb) to cancer[21]. Lung and stomach cancer have the strongest epidemiological evidence and they are weakly but persistently linked to jobs and sectors that

Table 3: Average daily Intake (ADI) (mg/kg/day) for carcinogenic risk for children and adults

Station		Receptor pathway	Cd	Co	Cr	Cu	Ni	Pb	Zn	Total
Alaba Market	Child	Ingestion	1.99E-09	ND	1.38E-08	1.32E-08	2.19E-09	5.48E-09	1.32E-08	4.99E-08
		Inhalation	7.59E-14	ND	5.31E-13	5.06E-13	8.43E-14	2.11E-13	5.06E-13	1.91E-12
		Dermal	2.53E-10	ND	1.77E-09	1.69E-09	2.81E-10	7.02E-10	1.68E-09	6.38E-09
		Total	2.24E-09	ND	1.56E-08	1.49E-08	2.47E-09	6.18E-09	1.49E-08	5.62E-08
	Adult	Ingestion	1.06E-09	ND	7.40E-09	7.05E-09	1.17E-09	2.94E-09	7.05E-09	2.67E-08
		Inhalation	1.63E-13	ND	1.14E-12	1.08E-12	1.81E-13	4.52E-13	1.08E-12	4.10E-12
		Dermal	2.61E-10	ND	1.83E-09	1.74E-09	2.90E-10	7.27E-10	1.74E-09	6.59E-09
		Total	1.32E-09	ND	9.23E-09	8.79E-09	1.46E-09	3.67E-09	8.79E-09	3.33E-08
Westminster	Child	Ingestion	2.19E-09	ND	5.69E-09	1.09E-08	1.64E-09	4.16E-09	8.11E-09	3.27E-08
		Inhalation	8.43E-14	ND	2.19E-13	4.21E-13	6.32E-14	1.61E-13	3.12E-13	1.26E-12
		Dermal	2.81E-10	ND	7.30E-10	1.40E-09	2.11E-10	5.33E-10	1.04E-09	4.20E-09
		Total	2.47E-09	ND	6.42E-09	1.23E-08	1.85E-09	4.69E-09	9.15E-09	3.69E-08
	Adult	Ingestion	1.17E-09	ND	3.05E-09	5.87E-09	8.81E-10	2.23E-09	4.34E-09	1.75E-08
		Inhalation	1.81E-13	ND	4.70E-13	9.03E-13	1.35E-13	3.42E-13	6.68E-13	2.70E-12
		Dermal	2.91E-10	ND	7.56E-10	1.45E-09	2.18E-10	5.52E-10	1.08E-09	4.35E-09
		Total	1.46E-09	ND	3.81E-09	7.32E-09	1.10E-09	2.78E-09	5.42E-09	2.19E-08
Computer village	Child	Ingestion	3.56E-09	ND	1.03E-08	5.47E-09	0.00E+00	2.84E-09	7.23E-09	2.94E-08
		Inhalation	1.36E-13	ND	3.96E-13	2.11E-13	0.00E+00	1.10E-13	2.78E-13	1.13E-12
		Dermal	4.56E-10	ND	1.32E-09	7.02E-10	0.00E+00	3.65E-10	9.26E-10	3.77E-09
		Total	4.02E-09	ND	1.16E-08	6.17E-09	0.00E+00	3.21E-09	8.16E-09	3.32E-08
	Adult	Ingestion	1.91E-09	ND	5.52E-09	2.94E-09	0.00E+00	1.53E-09	3.87E-09	1.58E-08
		Inhalation	2.94E-13	ND	8.49E-13	4.52E-13	0.00E+00	2.35E-13	5.96E-13	2.43E-12
		Dermal	4.73E-10	ND	1.37E-09	7.27E-10	0.00E+00	3.78E-10	9.59E-10	3.91E-09
		Total	2.38E-09	ND	6.89E-09	3.67E-09	0.00E+00	1.91E09	4.83E09	1.97E-08
Ogunpa	Child	Ingestion	3.28E-09	1.10E-09	2.63E-09	7.67E-09	7.67E-09	1.18E-08	3.72E-09	3.79E-08
		Inhalation	1.47E-12	4.91E-13	1.18E-12	3.44E-12	3.44E-12	5.31E-12	1.67E-12	1.70E-11
		Dermal	4.91E-09	1.64E-09	3.93E-09	1.15E-08	1.14E-08	1.76E-08	5.56E-09	5.65E-08
		Total	8.19E-09	2.74E-09	6.56E-09	1.92E-08	1.91E-08	2.94E-08	9.28E-09	9.44E-08
	Adult	Ingestion	1.76E-09	5.87E-10	1.41E-09	4.11E-09	4.11E-09	6.34E-09	2.00E-09	2.03E-08
		Inhalation	6.32E-13	2.11E-13	5.06E-13	1.48E-12	1.48E-12	2.28E-12	7.17E-13	7.31E-12
		Dermal	4.36E-10	1.48E-10	3.48E-10	1.02E-09	1.02E-09	1.57E-09	4.94E-10	5.04E-09
		Total	2.20E-09	7.35E-10	1.76E-09	5.13E-09	5.13E-09	7.91E-09	2.49E-09	2.54E-08
Iwo Road	Child	Ingestion	1.75E-09	0.00E+00	2.20E-09	2.41E-09	7.67E-09	5.91E-09	2.19E-09	2.21E-08
		Inhalation	7.87E-13	0.00E+00	9.83E-13	1.01E-12	3.44E-12	2.65E-12	9.83E-13	9.85E-12
		Dermal	2.62E-09	0.00E+00	3.27E-09	3.60E-09	1.15E-08	8.84E-09	3.27E-09	3.31E-08
		Total	4.37E-09	0.00E+00	5.47E-09	6.01E-09	1.92E-08	1.48E-08	5.46E-09	5.52E-08
	Adult	Ingestion	9.39E-10	0.00E+00	1.17E-09	1.29E-09	4.11E-09	3.17E-09	1.17E-09	1.18E-08
		Inhalation	3.37E-13	0.00E+00	4.21E-13	4.64E-13	1.48E-12	1.14E-12	4.21E-13	4.26E-12
		Dermal	2.32E-10	0.00E+00	2.91E-10	3.19E-10	1.02E-09	7.85E-10	2.91E-10	2.94E-09
		Total	1.17E-09	0.00E+00	1.46E-09	1.61E-09	5.13E-09	3.96E-09	1.46E-09	1.48E-08

ND: Not detected

expose workers to lead or lead compounds. The International Agency for Research on Cancer has classified Pb as a Group 2B carcinogen, meaning it may cause cancer in humans[22]. The Pb has also been suspected of being an enzyme inhibitor that harms the kidneys and interferes with fertility[23]. It has been established that children under the age of six and expecting mothers, are especially susceptible to the harmful effects of Pb on their health[23].

CONCLUSION

Electronic electrical equipment consists of several hazardous substances, which include heavy metals. In Nigeria, as in many other developing nations, obsolete or end-of-life electronics are discarded indiscriminately in landfills and incinerators and informally recycled. These pose a serious threat to the quality of groundwater since the increased concentration of heavy metals in the environment decreases the capacity of the soil to retain them, so they leach into the groundwater. This study assessed the health risk of exposure to heavy metals from e-waste dumpsites in some states in southwestern Nigeria. The results from this study reveal that the hazard quotient and hazard risk are less than one for all heavy metals analyzed. Therefore, the people living around these e-waste dumpsites are not at risk of possible cancer. The total cancer risk for children and adults was within the acceptable limits of the United States Environmental Protection Agency (USEPA) and World Health Organization (WHO) (10^{-6} to 10^{-4}). However, no matter how small the environmental and health risks may be, long exposure to heavy metals may be detrimental to human health due to the revealed level of pollution. Immediate preventative and corrective steps must be taken in order to stop the spread of heavy metal contamination.

SIGNIFICANCE STATEMENT

The main objectives of this study are to identify the heavy metals content of Cd, Co, Cr, Cu, Ni, Pb and Zn and, assess their potential health risk on groundwater from hand-dug wells around e-waste dumpsites and neighboring communities in Southwestern Nigeria. The results of the non-carcinogenic for adults and children showed that hazard quotient (HQ) and hazard index (HI) values were below the WHO permissible limit of one in all the pathways. Also, the cancer risk of groundwater was below the range of 10^{-6} to 10^{-4} which indicated that the heavy metals identified do not pose a carcinogenic risk to the inhabitants of the communities around the e-waste dumpsites as at the time this research was carried out.

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