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RESEARCH ARTICLE

Potentially toxic element contamination and risk assessment of borehole water within a landfill in the Nnewi metropolis

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Abstract: Borehole water has been used as a vital source of water for many communities. The pollution of these boreholes by potentially toxic elements using unlined solid waste dumpsites has posed a significant risk to the populace living around the dumpsite. This study investigates the environmental impact of potentially toxic elements on borehole water within the vicinity of an unlined dumpsite in the Nnewi metropolis. The upstream and downstream samples (16 each) were collected in wet and dry seasons. The potentially toxic elements analysis wasperformed using the methods of the American Public Health Association (APHA) under the required conditions. The quality of the boreholes was assessed using the World Health Organisation (WHO) acceptable limits for drinking water. The risk assessment was estimated for carcinogenic and non-carcinogenic risks using ingestion and dermal routes. The results show that the borehole water wascontaminated with potentially toxic elements through leachate infiltration, which exceeded the WHO permissible limits for drinking water at both locations and seasons. The upstream borehole samples were more contaminated than the downstream samples for both seasons, due to their proximity to the pollution source. The hazard indices of the ingestion and dermal routes showed that the borehole water poses serious cancer and non-cancer health risks for both locations. The results revealed that children are more susceptible to cancer and non-carcinogenic health threats than adults for both locations and seasons. The pollution indices of borehole water for wet season (9.028 and 5.728) and dry season (7.107 and 5.328) for upstream and downstream samples respectively, were polluted and the pollution was higher in the wet season. The borehole water samples were unsuitable for drinking water and should be treated before use.

Keywords: potentially toxic elements, borehole, contamination, Nnewi, health risk

1 Introduction

Groundwater has always been a major source of water for the residents of Nnewi in Anambra State. The populace normally depends on groundwater for drinking and other domestic purposes. Groundwater quality can be altered because of human activities, which can change the physicochemical characteristics of the water [1,2]. Human activities such as unsanitary landfills, poor soakaway systems and indiscriminate dumping of refuse can have negative consequences on the quality of the underground water [3]. Unsanitary landfills are the most common waste disposal practiseused in Anambra State, Nigeria [4–6].

The increase in population growth, urbanisation and industrialisation has also increased the volume of waste generated in Anambra State [7]. Poor allocations for waste management have negatively impacted waste management activities [7]. This method of waste practice has led to environmental pollution, which can pose a severe health risk to the populace [8–15]. The unregulated leachates coming from this unlined dumpsite tend to infiltrate the soil and thereby pollute the soil and groundwater due to the migration of pollutants [16–19].

Leachates from these dumpsites according to researchers constitute a major source of potentially toxic elements pollution to the groundwater and its environment [20–24]. Wastes such as electronic products, paint waste and automobile batteries deposited in the refuse dump, tend to increase the volume of potentially toxic elements in dumpsites, which can be toxic to the environment [25]. Open burning of wastes using unlined dumpsite is a common practise usually done to reduce the quantity of waste [6]. The by-products left after the burning can pose a risk to the underground water and public health [25].

Potentially toxic elements are adsorbed into soils and water bodies, which when exposed to the human body, results ina severe threat to human health [12, 26]. Recently, the contamination and potential risk of underground water have been investigated [27–29].

Some heavy metals such as Pb and Hg, are toxic and can induce cancer in the human body when they exceed their threshold limits [22, 26, 29, 30]. Exposure to potentially toxic elements toxicity can cause brain damage, dermatitis, anaemia and death in humans [26, 31].

Health-associated risks caused by the use of unlined dumpsites call for a complete assessment of the effect of unlined waste dumpsites on the environment [6]. Many researchers have reported groundwater pollution through leachates from dumpsites [25, 32–34]. However, few studies have been conductedon potentially toxic elements pollution of underground water from landfill leachates in the Nnewi metropolis [6, 35]. The previous studies on the underground water quality in Nnewi only focused on the levels of potentially toxic elements and pollution indices of the water and did not evaluate the risk assessment involved in the use of the water by the residents.

Therefore, in this research work, the impact of solid waste leachates on potentially toxic elements contamination of groundwater quality was studied around the Okpunoeze dumpsite in the Nnewi metropolis. Cancer and non–cancer health risks were also estimated using dermal and ingestion routes on the populace.The metal pollution index of the borehole water was also determined. The findings of this work will be a valuable tool for policy makers on better ways to prevent underground water pollution using improved waste disposal methods.

2 Materials and methods

2.1 Sampling area

The sampling area (Figure 1) is located around the OkpunoezeOtolo dumpsite in Nnewi, Anambra State. Nnewi is located within the tropical rainforest region of Nigeria [36]. Nnewi is a major town in Anambra State known for its manufacturing activities, which has led to the rapid growth of the city [36, 37]. Open dumpsites are the predominant waste disposal method practised in the area [1]. The dumping site is located at the following latitude of 6°00’43.4”N and longitude of 6°54’28.2”E [37]. Two distinct seasons are observed, dry and wet. Nnewi has an annual rainfall of about 2000 mm [38]. Wastes disposed of in the landfill are predominantly solid waste from industries, hospitals, markets, workshops and households, which are located around the dumpsite [1].

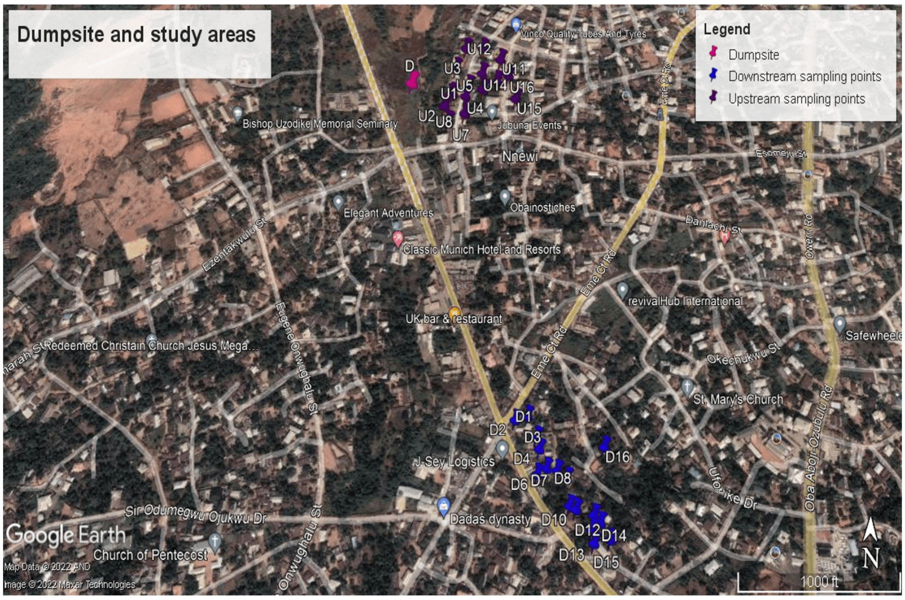

Figure 1 Map of sampling areas

The Nnewi metropolis lies beneath Nanka Formation, consisting of loose and friable sands [35]. The lithology of the area is composed of sandstones, which are porous and allow for infiltrating leachates into the aquiferous system [35]. The average depth to the water table in the study area is about 110 m and the average static water level is 120 m [39].

2.2 Sampling of borehole water samples

Borehole water samples (16 each) were collected during the morning hours (9 - 10 am) from the upstream and downstream locations for 4 months (May-August 2018) for the wet season, and 3 months (December 2018 - February 2019) in the dry season [1]. The downstream samples were collected 685 - 935 m away from the upstream samples, which are located around the dumpsite [37]. Properly washed and rinsed glass sample bottles were used for sample collection from the selected locations. The sampled borehole water was homogenised to form a composite sample [37]. Acidification of the samples was done with 10% HNO_3 [1]. The water samples were brought in an ice chest, before being stored at 4°C in the refrigerator [37].

2.3 Chemicals and reagents

All chemicals used were of high analytical reagent grade, which were purchased from Sigma-Aldrich, USA.

2.4 Sample preparation and potentially toxic elements analysis

The potentially toxic elements analyses of the samples were carried out using standard methods [40]. 100 mL of the borehole water samples were transferred into a 250 mL glass beaker. Concentrated HNO_3(6 mL) was added and it was heated using a hot plate until the volume was reduced to 20mL. The mixture was allowed to cool and filtered. It was made up to the 100 mL mark using deionized water. The samples were aspirated into the oxidizing air-acetylene flame using an Agilent 240-FS Atomic Absorption Spectrophotometer. The sensitivity for 1% absorption was observed after the samples were aspirated. The potentially toxic elements analyses was analysed for nickel (Ni), iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), arsenic (As),cobalt (Co), manganese (Mn), zinc (Zn) and copper (Cu).

A standard solution containing 1000 ppm of 2% HNO_3 was used to prepare the spiking experiments and calibrationstandards [33]. Two working standards for each potentially toxic elements were prepared from these standards. A standard calibration curve was obtained by running a prepared standard solution of each potentially toxic element [33].

2.5 Quality control

The blank samples and certified reference materials (CRM) were analyzed to ensure the accuracy, reliability and reproducibility of the results [33]. The results were found within ±5% of the certified values and a recovery rate between 93.4 and 101.2%. The analyses were performed in triplicate with the mean values recorded [37].

2.6 Health risk assessment

The potential health risk of the borehole water on the residents was assessed using ingestion and dermal exposure assessment, which was expressed using Equations 1 and 2 [41].

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

$$\mathrm{CDD_{derm}} = \frac{\mathrm{C \times SA \times SAF \times DAF \times ED \times EF}}{\mathrm{BW \times AT}} \times \mathrm{CF} \tag{2}$$

Where $\mathrm{CDD_{ing}}$ and $\mathrm{CDD_{derm}}$ represent the chronic daily dose of ingestion and dermal contact (mg/kg/day). The exposure parameters used are presented in Table 1. For non-carcinogenic risks, the hazard quotients (HQs) for ingestion and dermal contact wereevaluated using Equations 3 and 4 [42, 43]. The hazard index (HI) was evaluated using Equation 5. The HQ or HI $<$ 1, signifies no risk, while the HQ or HI $1\geq$ signifies risk.

Table 1 Parameters for health risk assessment

Parameters	Unit	Adult	Child	Reference
Concentration of metals (C)	mg/L	-	-	-
Ingestion rate (IR)	L/day	2.5	0.78	[41]
Exposure duration (ED)	years	20	6	[45]
Exposure frequency (EF)	days/year	365	365	[45]
Average time (AT) non-cancer	days	7300	2190	[41]
Average time (AT) cancer	days	25550	25550	
Body weight (BW)	kg	70	15	[45]
Surface area (SA)	cm^2	6032	2373	[45]
Skin adherence factor (SAF)	mg/cm^2	0.07	0.2	[46]
Dermal absorption factor (DAF)	-	0.001	0.001	[41]
Conversion factor (CF)	-	1E-06	1E-06	[41]

$$\mathrm{HQ} = \frac{\mathrm{CDD_{ing}}}{\mathrm{RfD}} \tag{3}$$

$$\mathrm{HQ} = \frac{\mathrm{CDD_{derm}}}{\mathrm{RfD}} \tag{4}$$

$$\mathrm{HI} = \sum \mathrm{HQs} \tag{5}$$

The cancer risks (CR) and HI in the boreholewater were estimated using Equations 6, 7 and 8 [44].

$$\mathrm{CR} = \mathrm{CDD_{ing}} \times \mathrm{SF} \tag{6}$$

$$\mathrm{CR} = \mathrm{CDD_{derm}} \times \mathrm{SF} \tag{7}$$

$$\mathrm{HI} = \sum \mathrm{CDDs} \tag{8}$$

Table 2 shows the reference doses and slope factors for the potentially toxic elements.

Table 2 Reference doses and cancer slope factors for non-carcinogenic and carcinogenic risks

Potentially toxic elements (mg/L)	Reference doses (RfD)		Slope factors (SF)		Reference
	Dermal	Ingestion	Dermal	Ingestion	
Zinc	0.06	0.3	-	-	[47]
Arsenic	0.000123	0.0003	3.66	1.5	[47]
Lead	0.000524	0.0014	-	0.0085	[47]
Iron	0.7	0.7	-	-	[47]
Nickel	0.00054	0.02	4.25	0.91	[47]
Manganese	0.014	0.014	-	-	[47]
Chromium	0.003	0.003	2	0.5	[47]
Cobalt	0.02	0.03	-	-	[47]
Cadmium	0.000025	0.001	-	6.3	[47]
Copper	0.012	0.04	-	-	[47]

2.7 Metal Pollution Index (MPI)

MPI represents the sum of the ratio between the analysed parameters and their corresponding national standard values [48]. The rating is a value between 0 and 1 [48].

$$\mathrm{MPI} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \left[\frac{\mathrm{Ci}}{\mathrm{MAC}} \right] \tag{9}$$

Where Ci = mean concentration, MAC = maximum allowable concentration.

2.8 Statistical evaluation

Correlation analyses between upstream and downstream samples on the levels of potentially toxic elements in the borehole water were performed. The relationships between the parameters were evaluated using a hierarchical cluster dendogram. SPSS version 23 software was used for the analysis.

3 Results and discussion

3.1 Potentially toxic elements analyses

Table 3 shows the potentially toxic elements parameters of the borehole water samples. The borehole samples showed different levels of potentially toxic elements characteristics in both study areas. The values of the mean potentially toxic elements parameters were compared with WHO standard limits (Figure 2).

Table 3 Potentially toxic elements level in the borehole water

Metals	Wet Season				Dry Season				[49]
	Upstream		Downstream		Upstream		Downstream		
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	
Zn	1.38–1.58	1.478±0.08	1.14–1.37	1.245± 0.09	1.18–1.31	1.23±0.07	1.12–1.24	1.187±0.06	3
As	0.01–0.02	0.013±0.01	ND–0.01	0.008± 0.00	0.01–0.01	0.01±0.00	ND–0.01	0.007±0.00	0.01
Pb	ND–0.02	0.018±0.00	ND–0.02	0.01± 0.01	0.01–0.02	0.013±0.01	ND–0.01	0.007±0.00	0.01
Fe	0.28–0.36	0.308±0.04	0.22–0.25	0.235±0.01	0.24–0.31	0.267±0.04	0.17–0.24	0.207±0.04	0.3
Ni	0.04–0.07	0.05±0.02	ND–0.04	0.023±0.02	0.05–0.06	0.053±0.01	0.03–0.05	0.037±0.01	0.07
Mn	0.37–0.45	0.4±0.04	0.10–0.34	0.265± 0.11	0.32–0.38	0.347±0.03	0.22–0.33	0.277±0.06	0.4
Cr	0.03–0.05	0.043±0.01	0.01–0.04	0.03± 0.01	0.03–0.04	0.033±0.01	0.01–0.03	0.023±0.01	0.05
Co	0.03–0.05	0.04±0.01	0.02–0.04	0.03± 0.01	0.03–0.04	0.037±0.01	0.02–0.03	0.023±0.01	-
Cd	ND–0.01	0.005±0.00	ND–0.01	0.003±0.00	ND–0.01	0.003±0.00	ND–0.01	0.003±0.00	0.003
Cu	0.37–0.48	0.433±0.05	0.32–0.48	0.383±0.07	0.41–0.47	0.443±0.03	0.28–0.37	0.32±0.05	2

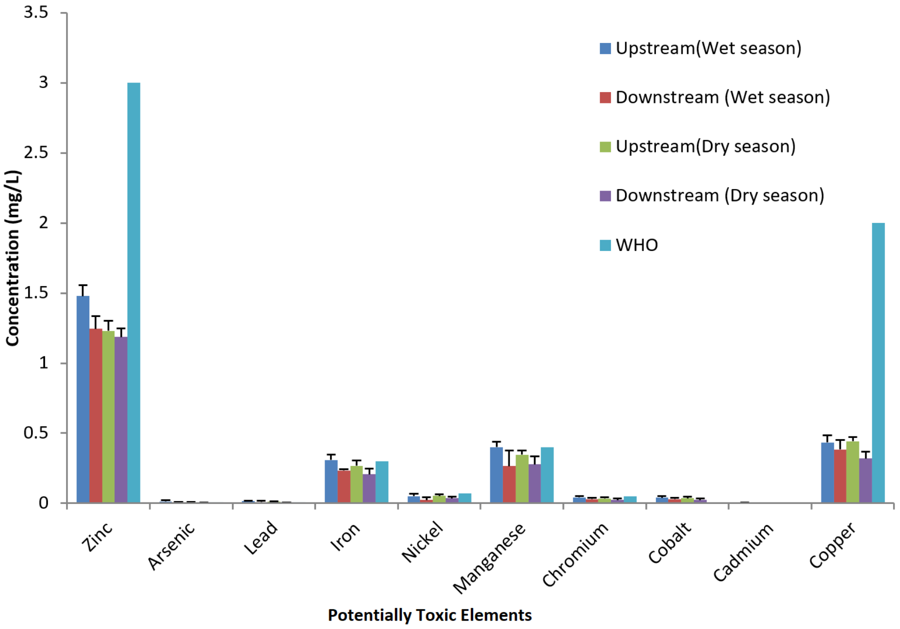

Figure 2 Seasonal variation of mean potentially toxic elements parameters for both study areas

The mean concentration of Zn ranged from 1.23 mg/L – 1.478 mg/L for upstream samples for both seasons. In the downstream samples, the mean values ranged from 1.187 – 1.245 mg/L for both seasons. The Zn values for the upstream sample were higher than the downstream values, possibly due to infiltration of the leachates from the dumpsite, which were closer to the upstream locations. The Zn levels were below the WHO permissible limit (3 mg/L) for drinking water. The values were lower than 1.79 mg/L and 10.8 mg/L which werereported [25, 34]. The Zn values obtained from this study were higher than the values obtained [33].

The As values for both seasons ranged from 0.01 - 0.013 mg/L for the upstream samples, while the downstream samples ranged from 0.007 – 0.008 mg/L for both seasons. The As values in the upstream samples were equal to or greater than the WHO maximum allowable limit of 0.01mg/L for both seasons. Higher values of arsenic higher than the study samples werereported [29, 34, 50]. The values of As reported in this study were similar [25, 32].

The mean values of Pb in the upstream location ranged from 0.013 to 0.018mg/L for both seasons, while the downstream values ranged from 0.01 – 0.007 mg/L. The values were equal to or greater than the WHO threshold limit of 0.01mg/L, except for the downstream value in the dry season, which was lower than the WHO limit. The high values of Pb could be attributed to the disposal of lead batteries, pipes, and paints at the refuse dump [33, 34]. The values obtained from this study were similar [29, 33]. High values of Pb higher than this study was obtained [25, 32, 33].

The Fe values for the upstream values ranged from 0.267 – 0.308 mg/L for both seasons, while the downstream values ranged from 0.207 – 0.237 mg/L respectively, which were above the permissible limit of 0.30 mg/L. The mean value for the upstream samples during the wet season was the only mean value that exceeded the WHO permissible limits. High values of Fe in water can be attributed to the oxidation of metal wastes in the dumpsites [35]. The upstream samples were higher than the downstream samples for both seasons. The values in this study were lower than obtained reports [32, 33, 51]. The values in this study were higher than the values obtained by [29, 34].

The mean values of Ni for the upstream samples for both seasons ranged from 0.05 - 0.053 mg/L. The downstream samples ranged from 0.023 – 0.037 mg/L for both locations. The values were lower than the threshold limit of 0.07 mg/L for both locations in both seasons. The upstream location values were higher than the downstream locations for both seasons.The Ni values in this study were similar [32]. The Ni values from this study were higher than the reported work [29].

The mean values of Mn for the upstream samples ranged from 0.347 – 0.4 mg/L, while they ranged from 0265 – 0.277 mg/L for the downstream samples for both seasons. The upstream sample value in the wet season was the only Mn value equal to the WHO threshold, while the rest were within the limit. The values from this study were higher than the obtained value [32] and were lower than the values [52].

The mean values of Cr for the upstream samples ranged from 0.033 – 0.043 mg/L, while the downstream values ranged from 0.023 – 0.03 mg/L for both seasons. These values were below the permissible limit of the WHO. The values in this study were similar [33]. The mean values of chromium obtained in this study were lower than the results obtained [25, 29, 51].

The mean values of Co for the upstream samples for both seasons ranged from 0.03 – 0.04 mg/L, while the downstream sample values ranged from 0.023 – 0.03 mg/L. These values were lower than the results obtained [53, 54].

The mean values for Cd ranged from 0.003 - 0.005 mg/L for the upstream samples and 0.003 0.003 mg/L for the downstream samples for both seasons. The Cd values were either equal to or greater than the threshold limit by the WHO for both locations and seasons. Cadmium could be linked with the dispersal of potentially toxic elements produced from electronic wastes disposed of in the dumpsite [34]. Similar values of Cd were reported [33, 34]. The values were higher than the reported work [29] and lower than obtained work [25, 52].

The mean values for Cu in the upstream sample ranged from 0.443 – 0.443 mg/L for both seasons, while they ranged from 0.32 – 0.383 mg/L in the downstream samples in both seasons. These values were below the WHO permissible limits of 2 mg/L. The values were higher than the values obtained [25, 32, 33, 35] and lower than the value obtained [34].

The order of maximum concentrations followed this order for the wet season: Zn > Cu>Mn>Fe>Ni > Cr >Co >Pb>As > Cd for the upstream samples,and Zn > Cu >Mn> Fe>Cr>Co>Ni >Pb>As>Cd for the downstream samples. The dry season followed this order: Zn > Co >Mn> Fe > Ni > Co > Cr>Pb> As > Cd for the upstream samples and Zn > Co >Mn> Fe > Ni >Cr > Co >As >Pb> Cd for the downstream samples.

The correlation values of the potentially toxic elements parameters (Table 4) for the borehole water samples indicated a strong positive correlation between upstream and downstream samples during the wet season (r = 0.998, P = 0.000) and dry season (r = 0.995, P = 0.000). The correlation study values between the wet and dry season upstream values (r = 0.998, P = 0.000) and downstream values (r = -0.999, P = 0.000) showed astrong positivelinear relationship [37]. The strong correlation observed in the study areas indicates that the pollution are of a similar source [37]. The pollutant source was linked to anthropogenic activities such as the discharge of leachates from the unlined dumpsite [37]. The p-values are all less than 0.05 ($p < 0.05$), which implies that the potentially toxic elements characteristics are significant, and are dependent on the extent of accumulation of pollutants in the borehole water samples in both seasons [37].

Therefore, the study suggests that the levels of potentially toxic elements obtained were attributed to leachate percolation through the unlined refuse dump. The upstream sample's results were predominantly higher than the results of the downstream samples for both locations and seasons. This is due to the infiltration of pollutants from the leachates because of its proximity to the dumpsite [44].

Table 4 Pearsons correlation between study area parameters across both seasons

	Upstream samples (Wet season)	Downstream samples (Wet season)	Upstream samples (Dry season)	Downstream samples (Dry season)
Upstream samples (Wet season)	1			
Downstream samples (Wet season)	0.998**	1		
Upstream samples (Dry season)	0.998**	0.997**	1	
Downstream samples (Dry season)	0.999**	0.999**	0.995**	1

Note: ** Correlation is significant at the 0.01 level (2-tailed)

3.2 Non-carcinogenic risk via ingestion route

The non-carcinogenic risk values through the ingestion route are shown in Table 5. The hazard index values for the upstream locations were greater than those for the downstream locations for both seasons. This trend shows that the child's HI values were predominantly greater than the adult's HI, which implies that the children are at a higher risk than the adult [32, 34]. The HI values for the upstream location were greater than the downstream location because of its proximity to the dumpsite.

3.3 Carcinogenic risk through ingestion routes

The carcinogenic risk values lower than 1.0E-06 are a negligible risk, while values above 1.0E-04 represent a potential threat likely to humans [41]. Table 6 shows the carcinogenic risk values through the ingestion route. The cancer risk values of lead for adults and children were below the carcinogenic threshold, while the cancer risk values for Cr, Cd, As and Ni were higher than the threshold limit indicating cancer threat. Generally, the HI values for both age categories were above the threshold value of 1.0E-04, which indicates a potential cancer risk to

Table 5 Hazard quotient of non-carcinogenic risks through the ingestion route

Parameters	Adults				Children			
	Wet season		Dry season		Wet season		Dry season	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Zn	0.1476	0.1244	0.1229	0.1186	0.2457	0.2069	0.2044	0.1973
As	1.2985	0.7991	0.9989	0.6992	2.1607	1.3297	1.6621	1.1635
Pb	0.3853	0.214	0.2783	0.5244	0.6411	0.3562	0.463	0.2493
Fe	0.0132	0.0101	0.0114	0.0089	0.0219	0.0167	0.019	0.0147
Ni	0.0749	0.0345	0.0794	0.0554	0.1247	0.0573	0.1321	0.0922
Mn	0.8562	0.5672	0.7427	0.5929	1.4247	0.9438	1.2359	0.9866
Cr	0.4295	0.2997	0.3296	0.0005	0.7147	0.4986	0.5485	0.3823
Co	0.04	0.03	0.037	0.023	0.0665	0.0499	0.0615	0.0382
Cd	0.1498	0.0899	0.0899	0.0899	0.2493	0.1496	0.1496	0.1496
Cu	0.3244	0.2869	0.3319	0.2397	0.5398	0.4774	0.5522	0.3989
HI	3.7194	2.4558	3.022	2.3525	6.1891	4.0861	5.0283	3.6726

the population. The child's cancer risk values were higher than those of the adult, indicating that the children are more exposed to cancer threats [34, 55]. Moreover, for both age categories, Ni has a higher potential cancer threat compared to other potentially toxic elements. The HI for the upstream samples was greater than that for the downstream locations due to their closeness to the dumpsite.

Table 6 Carcinogenic risks via ingestion route

Parameters	Adults				Children			
	Wet season		Dry season		Wet season		Dry season	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
As	2E-04	1E-04	1E-04	9E-05	8E-05	5E-05	6E-05	4E-05
Pb	1E-06	7E-07	9E-07	5E-07	7E-07	4E-07	5E-07	3E-07
Ni	4E-04	2E-04	4E-04	3E-04	2E-04	9E-05	2E-04	1E-04
Cr	2E-04	1E-04	1E-04	1E-04	9E-05	6E-05	7E-05	5E-05
Cd	3E-04	2E-04	2E-04	2E-04	1E-04	8E-05	8E-05	8E-05
HI	1E-03	6E-04	8E-04	6E-04	5E-04	3E-04	4E-04	3E-04

3.4 Non-carcinogenic health risk via dermal contact

Table 7 shows the non-carcinogenic health risk values through dermal contact. The other potentially toxic elements' HQ values were all lower than 1. The HI values for the adult were higher than 1 for the upstream location during the wet season. The child HI values were all higher than 1, with the upstream location greater than the downstream samples. Children are more exposed to non-carcinogenic related risks than adults because of higher HI values [34].

Table 7 Hazard quotient of non-carcinogenic risks through the dermal route

Parameters	Adults				Children			
	Wet season		Dry season		Wet season		Dry season	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Zn	0.1247	0.105	0.1038	0.1001	0.7474	0.6295	0.622	0.6002
As	0.5349	0.3292	0.4115	0.288	3.2066	1.9733	2.4666	1.7267
Pb	0.1739	0.0966	0.1256	0.0676	1.0422	0.579	0.7527	0.4053
Fe	0.0022	0.0017	0.0019	0.0015	0.0133	0.0102	0.0116	0.009
Ni	0.4686	0.2156	0.4967	0.3468	2.8092	1.2922	2.9778	2.0788
Mn	0.1446	0.0958	0.1254	0.1001	0.8668	0.5743	0.752	0.6003
Cr	0.0725	0.0506	0.0557	0.0388	0.4349	0.3034	0.3337	0.2326
Co	0.0101	0.0076	0.0094	0.0058	0.0607	0.0455	0.0561	0.0349
Cd	1.0122	0.6073	0.6073	0.6073	6.0679	3.6408	3.6408	3.6408
Cu	0.1826	0.1615	0.1868	0.135	1.0948	0.9683	1.12	0.8091
HI	2.7263	1.6709	2.1241	1.691	16.3438	10.0165	12.7333	10.1377

3.5 Carcinogenic risk through dermal contact

The carcinogenic risk values via dermal contact with potentially toxic elements are shown in Table 8. The carcinogenic risk values through dermal routes were above the threshold value of 1.0E-04 for the potentially toxic elements calculated. The HI values were all above the threshold limit. The upstream values were greater than the downstream values because of leachate infiltration into the dumpsite [32]. The HI for the children was higher than that of adults, which makes them more susceptible to cancer risk through dermal contact. A similar trend was reported [34].

Table 8 Carcinogenic risks through the dermal route

Parameters	Adults				Children			
	Wet season		Dry season		Wet season		Dry season	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
As	7E-05	4E-05	5E-05	4E-05	1E-04	8E-05	1E-04	7E-05
Ni	3E-04	1E-04	3E-04	2E-04	6E-04	3E-04	6E-04	4E-04
Cr	1E-04	9E-05	1E-04	7E-05	2E-04	2E-04	2E-04	1E-04
HI	5E-04	3E-04	5E-04	3E-04	9E-04	5E-04	9E-04	6E-04

3.6 Metal pollution index

The potentially toxic elements pollution index of the borehole water samples for the wet and dry seasons is shown in Table 9. The values showed that the pollution index was beyond the critical value of 1, and hence, cannot be used for specific purposes without any special treatment. The potentially toxic elements pollution index for the wet season was 9.028 and 5.782, while the dry seasonwas 7.107 and 5.328 for the upstream and downstream respectively. The potentially toxic elements pollution index for the wet season was higher than the dry season in both locations because of the percolation of leachates from the refuse dump aided by rainfall. The upstream samples pollution index was higher than the downstream samples, which was attributed to the infiltration of more leachates due to proximity to the refuse dump. Therefore, the borehole water samples should not be used for domestic purposes without special treatment.

Table 9 Metal pollution index of borehole samples

Parameters	Wet season		Dry season	
	Upstream	Downstream	Upstream	Downstream
Zinc	0.493	0.415	0.41	0.396
Arsenic	1.25	0.8	1	0.7
Lead	1.8	1	1.3	0.7
Iron	1.027	0.783	0.89	0.69
Nickel	0.714	0.329	0.757	0.529
Manganese	1	0.663	0.868	0.693
Chromium	0.86	0.6	0.66	0.46
Cobalt	-	-	-	-
Cadmium	1.667	1	1	1
Copper	0.217	0.192	0.222	0.16
$\sum$ MPI	9.028	5.782	7.107	5.328

3.7 Cluster analysis of potentially toxic elements

The potentially toxic elements parameters that had similar characteristics were grouped using dendogram hierarchical cluster [7]. The hierarchical cluster dendrogram (HCA) showed four distinct clusters (Figure 3). Ni was grouped into the first cluster, while Zn and Cd were grouped into the fourth cluster. Co and Cu were grouped into the second cluster. The As, Pb, Fe, Cr and Mn were grouped into the third cluster. The cluster showed that Ni is not influenced by any other elements assessed, while As is influenced by Pb, Fe, Cr and Mn. The observed clustering could be linked to the anthropogenic sources of the potentially toxic elements in the leachates of the refuse dump [34].

4 Conclusion

The results of the study area showed that the upstream and downstream boreholes were contaminated with different concentrations of potentially toxic elements through the infiltration of the leachates from the unlined dumpsite. The results revealed that Cd was above the WHO limit across both locations. The Mn and Fe values for the upstream samples in the wet season were above the WHO permissible limit. The As mean values in the upstream samples in both seasons were above the WHO limit. The Pb values were above the WHO threshold limit, except for the downstream sample values in the dry season. The overall results obtained showed that both borehole water samples do not meet the WHO standard for drinking water. The upstream sample's potentially toxic elements' levels were greater than that of the downstream samples, because of leachate infiltration linked to their proximity to the dumpsite. The wet

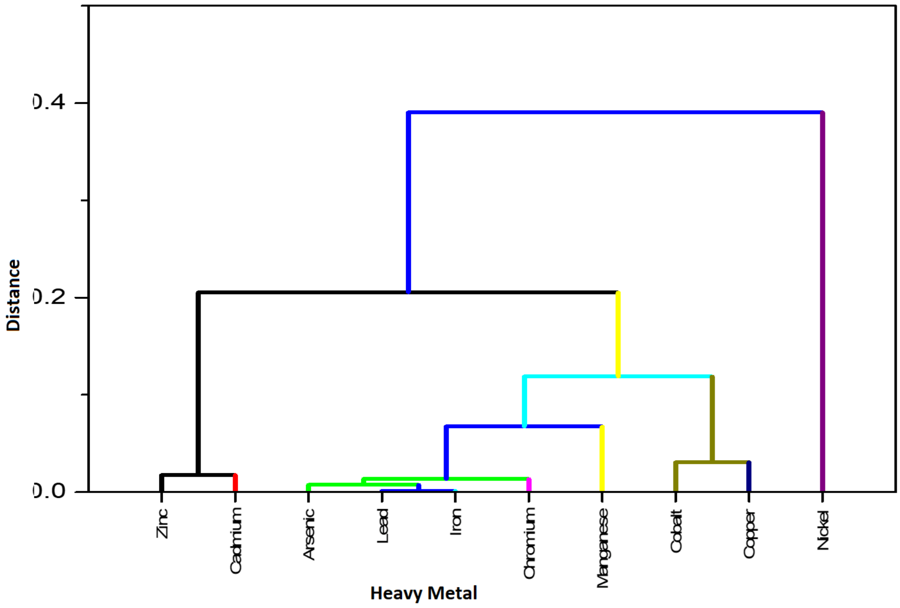

Figure 3 Hierarchical cluster dendrogram of the potentially toxic elements (heavy metals)

season concentrations were higher than those during the dry season because of the runoff of leachates from the unlined dumpsite. Carcinogenic and non-carcinogenic risks through ingestion and dermal contact with potentially toxic elements pose serious health-related risks to the population, of which children are more vulnerable than adults. The pollution indices showed that the borehole water samples were polluted and should be treated before use. Routine monitoring of the borehole water around the dumpsite area should be encouraged to curtail health-related risks from exposure to potentially toxic elements toxicity. The government should adopt an efficient waste management system that involves constructing sanitary dumpsite that will prevent leachate infiltration from the environment.

Author contribution

All authors have read and approved the manuscript. CCA: Writing- Original draft preparation, Conceptualization, Methodology; PAC: Reviewing and Editing, Data curation; HOA: Investigation, Supervision and Validation; VCE: Methodology, Data curation, Software; HOC: Visualization, Conceptualization. The final manuscript was read and approved by all authors.

Availability of data

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

All authors have read, understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors.

Disclosure statement

No potential conflict of interest is reported by the authors.

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