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Assessing the Potential Environmental and Human Health Risks of Exposure to Surface Soils in Garatu Area near Minna, Nigeria

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ABSTRACT

The geochemistry of soils in Garatu area, part of Bida Sheet 184NE, Nigeria was investigated to evaluate elemental distribution patterns and their implications for environmental and human health. Surface soils were sampled in the area, and subjected to bulk chemical analysis using X-ray fluorescence (XRF) spectrometry. The median enrichment ratios of 2.0, 5.0, 6.2, 20 and 360 for Cu, V, Fe, Cr and Mo show that these elements are slightly too highly enriched relative to their upper crustal averages. The computed median *Igeo* values for these elements range from 0.42 to 7.91, indicating that the soils are moderately through strongly to extremely pollute. The oral hazard index (HI) for adults and children are 11.33 and 52.89 respectively. The HI for the dermal exposure scenario are 1.42 and 1.40 for adults and children, respectively. These values show a greater health risk for children through the oral pathway compared to the adult population. However, the risk is considered to be low for both populations via the dermal route. These findings provide the first detailed geochemical baseline for soil in the area, establishing a direct link between the parent rock composition and soil chemistry, which is crucial for environmental and human health risk assessments.

Keywords: Geochemistry, Medical Geology, Toxicity, Geogenic Contamination, Heavy Metals

INTRODUCTION

Soils formed from mafic rocks commonly contain high levels of essential and potentially toxic elements like chromium (Cr), nickel (Ni), and cobalt (Co) inherited from the parent rock. Mafic intrusion refers to igneous rock bodies that are rich in magnesium and iron and intrude into surrounding rocks, thereby shaping local geology and soil chemistry (Santos *et al.,* 2016). Significantly shape soil geochemistry and can lead to geogenic contamination (Tashakor *et al*., 2018). Geochemical characteristics describe the distribution and composition of chemical elements and minerals in soils, highlighting their origin, weathering, and enrichment processes (Santos *et al*., 2016). Such geochemical characteristics can threaten environmental quality and human health, especially in areas where soil and water are used for agriculture and domestic purposes (Tashakor *et al*., 2018). Environmental and human health implications refer to the effects of soil chemistry on ecosystem and human well-being, (Tashakor *et al*., 2018). Studying the geochemical traits of soil is vital for understanding element mobility, contamination pathways, and risks to local communities relying on these soils (Alloway, 2013; Kabata-Pendias, 2010). Most existing research focuses on the petrology of parent rocks (Woakes *et al*., 1987) or broad geochemical mapping (Lapworth *et al*., 2012). While regional soil geochemistry has been assessed, direct links between soil geochemistry in Garatu and environmental and human health remain unestablished. This study aims to investigate the geochemical characteristics of soils formed in Garatu and its environs, Nigeria, especially with respect to potentially toxic elements (PTEs) and to evaluate their implications for environmental quality and human health.

MATERIALS AND METHODS

The Study Area

The area is located around Garatu Village, south of Federal University of Technology Minna, Gidan Kwano, within Bida sheet 184NE. It lies within latitude 9°27′ to 9°29′N and longitude 6°24′ to 6°26′E with an approximate area of 13.70 km^2 along the Minna-Bida highway. It is generally a flat terrain, punctuated by more elevated ridges of mafic rocks (Figure 1). Agriculture is the dominant occupation, with the local people growing a variety of food crops. The area has a predominantly undulating landscape, with heights lying between 200 and 400 metres above sea level. The elevation topography influences the drainage set-ups, which are majorly controlled by the regional slope and geological formation. The drainage is mostly made up of ephemeral streams and a drainage system of seasonal rivers showing dendritic patterns because of the spatially variable resistance of underlying rocks. The existence of mafic intrusions in the region gives rise to some local variations in permeability, which in turn affect the configurations of groundwater flow and surface runoff. Minna and its surrounding areas, including Garatu, experience a tropical wet and dry climate. The wet season typically runs from April to October, with an annual rainfall ranging from 1,200 to 1,300 mm. The dry season, from November to March, is marked by the influence of the Harmattan wind, a dry and dusty north-easterly trade wind from the Sahara Desert, which can significantly lower humidity and temperatures. Average temperatures in the region generally range from 25°C to 30°C, though they can peak higher during the dry season.

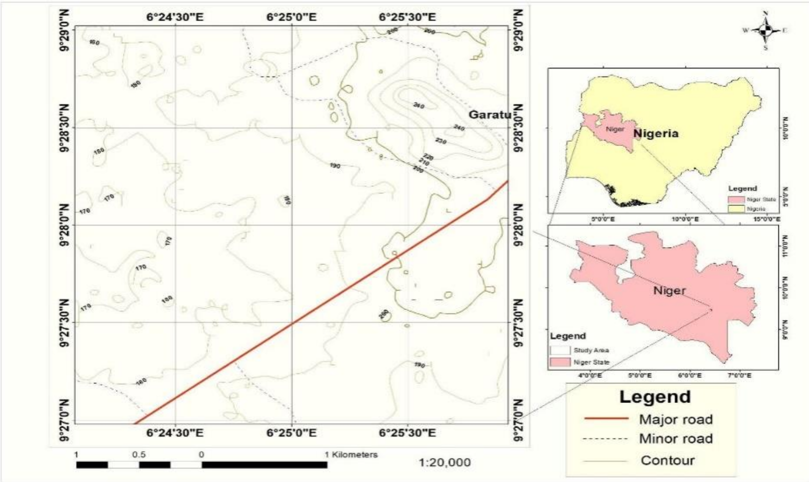

Figure 1: The Location of Garatu and its environs within the Bida Sheet 184NE, Nigeria

The settlement and land-use structure of the Garatu area reflects its rapid transition from a predominantly rural farming community into a peri-urban settlement influenced by the outward expansion of Minna metropolis, a trend clearly documented by Salami *et al*.(2020) who examined land-use and land-cover changes along the Kpakungu–Garatu urban corridor between 2000 and 2019. Their study shows that Garatu has undergone substantial changes as formerly agricultural and vegetation-dominated lands were progressively converted into residential layouts, commercial plots, access roads, and institutional uses in response to rising population pressure, housing demand, and rural–urban migration. As a result, settlement patterns in Garatu have shifted from scattered traditional homesteads surrounded by farmlands to denser, nucleated residential clusters characterized by mixed land uses, including small-scale commercial activities, informal housing developments, and newly planned estates. Geologically, the areas lies within the Central Nigeria Basement Complex, which is a part of the Pan-African mobile belt, sandwiched between the West African and Congo cratons. It is underlain by a suite of metasedimentary and igneous rocks, including migmatite, gneisses, granites and some localised ridges of gabbroic diorites.

Fieldwork and Sampling

Soil samples were taken using Global Positioning System (GPS) to take coordinates and elevations of sample locations. Samples were collected over the different lithologies in the study area. Nine sampling sites (three each from areas underlain by the three major lithologies) in the study area were selected for soil sampling. At each sampling station, three samples were collected at the apices of an equilateral triangle and made into a composite. The objective is to get a sample that represents the average or local variability of soil chemistry of the area that is being sampled. In order to collect a soil sample at depth for testing, the surface was cleared of litter, grass or debris from the sampling spot to expose the bare soil and approximately 1 Kg of soil was collected from the top 20 cm portion, using a plastic hand trowel into pre-labelled Ziploc backs.

Laboratory Work

Major and Trace Element composition of the soil samples was determined on fused glass beads on a Malvern PanAnalytical Epsilon 4 X-ray fluorescence (XRF) spectrometer. The samples were oven-dried at 100 °C for 1 hour. If a given dried sample is more than 40g, it will then be sub-sampled by a process known as "cone and quartering" so as to take a homogenous quantity of 40g for pulverisation.

The dried sample was pulverised using an agate pulverising machine (planetary micro mill pulverisette 7), for the powder sample to pass 75-mesh sieves. This was to ensure homogeneity of the samples. 0.6g of the pulverised sample was weighed into a platinum Crucible, 6g of Lithium Borax/Tetrabox (fusing flux). The mixture was thoroughly mixed to ensure homogeneity, then the crucible with the content was placed in a Fuse Bead machine (TheOx), which was heated at 1025 °C. This help in producing a bead, labelled and packaged, ready for the analysis.

Data Processing

Environmental quality and human health risks indices, based on two exposure scenarios were computed with respect to a suite of PTEs. The enrichment ratio (ER), which compares the concentration of a PTE in the soil to that in the background, was computed using the equation used by many previous workers, including Waziri (2014) and Waziri *et al*. (2023):

$$ER = \frac{Cn}{Bn}, \quad (1)$$

Where C_n is the concentration of an element in the soil and B_n is that in a background material (in this case, the upper continental crust average of Taylor and McLennan, 1995).

Similarly, the index of geoaccumulation (*Igeo*) was calculated according to the method of Muller (1969) as:

$$Igeo = \text{Log}_2 \left(\frac{Cn}{1.5Bn}\right) \quad (2)$$

The human health indices for the oral and dermal exposure routes were obtained using the methods described by Man *et al*. (2010) and later workers. For the oral exposure pathway, the average daily dose (ADD) was calculated as:

$$ADD_{ing} = \frac{\text{Csoil xIngR x CF xEF x ED}}{\text{BW X AT}} \quad (3)$$

For the dermal route of exposure, the same parameter is expressed as:

$$ADD_{dermal} = \frac{\text{Csoil xSA x AFsoilABS xEF x ED}}{\text{BW X AT}} \text{xCF} \quad (4)$$

Where C_{soil} is the concentration of a PTE in the studied soil, while other parameters in the equations are defined in Table1.

Table 1: Parameters Used in the Computation of Human Health Risks

S/N	Parameter	Children	Adult
1	Ingestion rate (IngR)	200 mg/day	100 mg/day
2	Exposure frequency (EF)	350 days	350 days
3	Exposure duration (ED)	6 years	24 years
4	Body weight (BW)	15 kg	70 kg
5	Average time (AT)	365days×ED	365days×ED
6	Conversion Factor (CF)	1×10^{-6} kg/mg	1×10^{-6} kg/mg
7	Surface area of skin (SA)	2800 cm^2	3300 cm^2
8	Skin adherence factor of soil(AF)	0.2 mg/cm^2	0.2 mg/cm^2
9	Dermal Absorption Factor (ABS)	0.001	0.001

The hazard quotient (HQ) for either pathway was obtained as:

$$HQi = \frac{\Sigma ADDi}{RfDi} \quad (5)$$

Where RfD_i refers to the reference dose for each element, obtained from USEPA (2000).

Finally, the overall hazard index (HI), which is an expression of the sum of the risk due to multiple contaminates for each of the exposure routes giving as:

$$HI = \sum HQi \quad (6)$$

RESULTS AND DISCUSSION

Environmental and Human Health Indices

In this section, data on the environmental and health indices are presented with a view to addressing concerns of the dangers associated with exposure to soils in Garatu area. The section explores the utility of enrichment ratios and indices of geoaccumulation to decipher the level of contamination of the soils with respect to a number of elements that are considered to be potential toxic to human beings and the ecological system. The second part attempts to quantify the health risks posed by some of these elements to the health of children and adult populations exposed to certain quantities of these soils over given time frames.

Environmental Pollution Indices

Table 2 presents the enrichment ratios (ER) of five elements considered to be of potential health effects on human health and the environment, together with the interpretations. For iron, the soils were found to be 2.93 to 11.31 times more enriched than the upper continental crust (UCC) abundance of the element, with a median enrichment of 6.16. The soils were to have 0.17 to 13.33 (median: 5.00) more vanadium than the UCC. In the case of chromium, the enrichment ratio ranges from 0.86 to 24.63, with a median enrichment of 20. The values for copper fall between 0.4 and 21.6, with a median of 2.0, while zinc is generally depleted (<1) in the soils. The most enriched element was found to be molybdenum, its ER values are in the range of 60 to 600 (median: 360) times higher than its UCC abundance.

Table 2: Enrichment and Depletion of Some Potentially Harmful Elements in Soils of Garatu

	Fe	V	Cr	Cu	Zn	Mo
	2.93	5.00	22.86	6.00	0.70	120.00
	3.33	11.67	2.37	5.60	0.42	140.00
	4.72	6.67	24.63	8.00	0.45	200.00
	6.96	6.83	21.14	21.60	0.54	180.00
	5.05	13.33	23.14	18.40	0.70	60.00
	8.55	4.50	22.46	1.68	0.68	113.33
	6.65	0.17	0.86	12.00	0.14	600.00
	7.32	0.33	14.29	2.00	0.17	360.00
	6.16	2.50	22.86	1.12	0.21	520.00
	11.31	4.50	17.14	1.36	0.28	406.67
	7.87	3.00	10.57	0.40	0.22	400.00
	4.04	11.67	17.14	1.12	0.14	533.33
	3.13	6.33	20.00	2.00	1.41	588.00
Min	2.93	0.17	0.86	0.40	0.14	60.00
Max	11.31	13.33	24.63	21.60	1.41	600.00
Median	6.16	5.00	20.00	2.00	0.42	360.00

Indices of Geoaccumulation

The computed indices of geoaccumulation (*Igeo*) for the earlier mentioned elements are presented in table 3, along with the interpretations. These results give a similar pattern to those of ER, again, showing that there is no pollution threat with respect to zinc in the soils of Garatu area. In the same vein, molybdenum has the highest *Igeo* values, in the range of 5.32 to 8.64, with a median of 7.91. Other *Igeo* values include 0.97 to 2.92 (median 2.04) for iron, -3.07 to 3.15 (median: 1.74) for vanadium, -0.81 to 4.04 (median: 3.74) for chromium and -1.91 to 3.85 (median: 0.42) for copper.

Table 3: Indices of Geoaccumulation (Igeo) For Some Potentially Harmful Elements in the Soil of Garatu

	Fe	V	Cr	Cu	Zn	Mo
	0.97	1.74	3.93	2.00	-1.09	6.32
	1.15	2.96	0.66	1.90	-1.83	6.54
	1.65	2.15	4.04	2.42	-1.73	7.06
	2.21	2.19	3.82	3.85	-1.49	6.91
	1.75	3.15	3.95	3.62	-1.09	5.32
	2.51	1.58	3.90	0.16	-1.15	6.24
	2.15	-3.17	-0.81	3.00	-3.41	8.64
	2.29	-2.17	3.25	0.42	-3.15	7.91
	2.04	0.74	3.93	-0.42	-2.83	8.44
	2.92	1.58	3.51	-0.14	-2.41	8.08
	2.39	1.00	2.82	-1.91	-2.78	8.06
	1.43	2.96	3.51	-0.42	-3.41	8.47
	1.06	2.08	3.74	0.42	-0.09	8.61
Min	0.97	-3.17	-0.81	-1.91	-3.41	5.32
Max	2.92	3.15	4.04	3.85	-0.09	8.64
Median	2.04	1.74	3.74	0.42	-1.83	7.91

Human Health Risk Assessment

The risk to human health as a result of exposure to the soils in Garatu area was estimated for oral and dermal exposure scenarios in respect of adults and children. It is aimed at the determining the potential for non-carcinogenic and carcinogenic health issues for the populations exposed to potentially toxic elements (PTEs) in the soils, namely, Fe, Cr, Cu and Zn, for which RfD are available. For the oral exposure pathway for adults, the results are presented in table 4 and these show that the average daily dose (ADD) for iron is 7.48 across the fourteen samples, while those for Cr, Cu and Zn are 0.021, 0.006 and 0.0012 respectively. The hazard quotients (HQ) for the four metals are 10.69, 0.64, 0.003 and 0.0009 for Fe, Cr, Cu and Zn respectively. The overall health index (HI) for the adult population through this route was found to be approximately 11.33, contributed mainly by the HQ for Fe. For the exposure of children through the ingestion route (table 5), the sum of ADDs is as high as 34.92 for Fe, followed 0.098 for Cr, 0.025 for Cu and 0.006 for Zn respectively. The HQ values for the four metals are 49.89 for Fe, 2.98 for Cr, 0.02 for Cu and 0.005 for Zn. These led to an overall health index for children exposed to the soils in the area of about 53.

Table 4: Oral Health Risk Assessment for Adults In Respect Of Four Metals in Soils of Garatu Area

	Fe	Cr	Cu	Zn	HI(ΣHQi)
	0.2813	0.00219	0.00041	0.00014	
	0.31906	0.00023	0.00038	8.2E-05	
	0.45281	0.00236	0.00055	8.8E-05	
	0.66762	0.00203	0.00148	0.0001	
	0.48424	0.00222	0.00126	0.00014	
	0.81977	0.00215	0.00012	0.00013	
	0.63792	8.2E-05	0.00082	2.7E-05	
	0.7023	0.00137	0.00014	3.3E-05	
	0.59116	0.00219	7.7E-05	4.1E-05	
	1.08498	0.00164	9.3E-05	5.5E-05	
	0.75462	0.00101	2.7E-05	4.2E-05	
	0.38708	0.00164	7.7E-05	2.7E-05	
	0.30028	0.00192	0.00014	0.00027	
ΣADDi	7.48313	0.02104	0.00557	0.00118	
HQi(ΣADDi/RfDi)	10.6902	0.63927	0.00342	0.00091	11.3338

Table 5: Oral Health Risk Assessment for Children In Respect Of Four Metals in Soils of Garatu Area

	Fe	Cr	Cu	Zn	HI(ΣHQi)
	1.312756654	0.01023	0.00192	0.00064	
	1.488923589	0.00106	0.00179	0.00038	
	2.113108974	0.01102	0.00256	0.00041	
	3.115561432	0.00946	0.0069	0.00049	
	2.259765711	0.01036	0.00588	0.00064	
	3.825594663	0.01005	0.00054	0.00061	
	2.97695293	0.00038	0.00384	0.00013	
	3.277420393	0.00639	0.00064	0.00015	
	2.75875632	0.01023	0.00036	0.00019	
	5.063234451	0.00767	0.00043	0.00026	

	Fe	Cr	Cu	Zn	HI(ΣHQi)
	3.521550206	0.00473	0.00013	0.0002	
	1.806381772	0.00767	0.00036	0.00013	
	1.401287246	0.00895	0.00064	0.00128	
ΣADDi	34.92129434	0.0982	0.02598	0.0055	
HQi(ΣADDi/RfDi)	49.88756334	2.98326	0.01598	0.00426	52.8911

Results for dermal exposure, which seek to identify the potential for cancer risk within the two populations are presented in tables 6 and 7 respectively for adults and children. For the adult population, the sum of ADDs is 0.98, 0.003, 0.0007 and 0.0002 for Fe, Cr, Cu and Zn in that order. The HQ values are 1.41, 0.004, 0.001 and 0.0002, with an overall HI of ≈1.42, which is again dominated by the HQ for Fe. In the case of children, the ADD values sum up to 0.97 for Fe, 0.003 for Cr, 0.0007 for Cu and 0.0002 for Zn respectively. The cancer health index for this group is very similar to that for the adults, at approximately 1.40, showing that for this pathway, the risk is relatively similar for both subjects.

Table 6: Dermal Health Risk Assessment for Adults In Respect Of Four Metals in Soils of Garatu Area

	Fe	Cr	Cu	Zn	HI(ΣHQi)
	0.03713226	0.00029	5.4E-05	1.8E-05	
	0.042115267	3E-05	5.1E-05	1.1E-05	
	0.059770797	0.00031	7.2E-05	1.2E-05	
	0.088125881	0.00027	0.0002	1.4E-05	
	0.063919087	0.00029	0.00017	1.8E-05	
	0.108209678	0.00028	1.5E-05	1.7E-05	
	0.08420524	1.1E-05	0.00011	3.6E-06	
	0.092704177	0.00018	1.8E-05	4.3E-06	
	0.078033393	0.00029	1E-05	5.4E-06	
	0.143217203	0.00022	1.2E-05	7.2E-06	
	0.099609563	0.00013	3.6E-06	5.6E-06	
	0.051094799	0.00022	1E-05	3.6E-06	
	0.039636411	0.00025	1.8E-05	3.6E-05	
ΣADDi	0.987773754	0.00278	0.00073	0.00016	
HQi(ΣADDi/RfDi)	1.411105363	0.003968	0.00105	0.000222	1.416346

Table 7: Dermal Health Risk Assessment for Children In Respect Of Four Metals in Soils of Garatu Area

	Fe	Cr	Cu	Zn	HI
	0.036757186	0.00029	5.4E-05	1.8E-05	
	0.04168986	3E-05	5E-05	1.1E-05	
	0.059167051	0.00031	7.2E-05	1.1E-05	
	0.08723572	0.00026	0.00019	1.4E-05	
	0.06327344	0.00029	0.00016	1.8E-05	
	0.107116651	0.00028	1.5E-05	1.7E-05	
	0.083354682	1.1E-05	0.00011	3.6E-06	
	0.091767771	0.00018	1.8E-05	4.3E-06	
	0.077245177	0.00029	1E-05	5.4E-06	
	0.141770565	0.00021	1.2E-05	7.2E-06	
	0.098603406	0.00013	3.6E-06	5.5E-06	
	0.05057869	0.00021	1E-05	3.6E-06	
	0.039236043	0.00025	1.8E-05	3.6E-05	
ΣADDi	0.977796242	0.00275	0.00073	0.00015	
HQi(ΣADDi/RfDi)	1.396851774	0.00393	0.00104	0.00022	1.40204

Discussion

To assess the environmental and human health risks from potentially harmful elements in the soils of Garatu area, enrichment ratios (ER), indices of geoaccumulation (*Igeo*) and health index (HI) were computed in this study. ER values were used to classify the elements in terms of enrichment or depletion, where a value < 1 means depletion, whereas > 1 shows enrichment (Waziri, 2012) relative to the crustal abundance of each element. Based on this, only Zn was found to be depleted in the soils, whereas Cu is enriched in about 46 % of the samples and either depleted or marginally enriched in the others. In all the samples, Fe, V, Cr and Mo are highly enriched, their median ER values are 6.16, 5, 20 and 360 respectively, thus indicating the potential for harm to human health and the environment. The Igeo values were interpreted according to the scheme of Muller (1969) and these again show that there is no risk with respect to Zn in the environment, while for Fe and V, values fall mainly between groups 2 and 3, indicating there is moderate to strong pollution with respect to the two elements. The risk is higher in terms of Cr, where the Igeo value lie within groups 3 and 4, suggesting strongly polluted soils. Most concerning is the data for Mo, whose values sit well above the 6th class, suggesting extreme levels of pollution.

The hazard quotients (HQ) and overall health hazard index (HI) of four metals for oral and dermal exposure scenarios were computed and the results haven presented at Tables 4-7. For the oral or ingestion exposure pathway, the results show that the HI for adults and children is 11.33 and 52.89, respectively. This means that the children exposed to the soils are ≈ 11 times more vulnerable, compared to adult populations. In the case of dermal contact exposure route, the HI values for adults and children are 1.42 and 1.40, respectively. In this case, the difference of the risk of adverse cancer effects between adults and children is very different. However, this still signifies substantial risk in terms of both non-carcinogenic and carcinogenic health effects for the two populations. This is because the estimated values are greater than the threshold of one that has been set by regulatory bodies (Awesome et al., 2017; Ondayo et al., 2023). The HI for adults and children for the two exposure scenarios in this study are strongly influenced by the HQ for Fe and the contribution of each of the metals for the two exposure routes decreases in the order Fe>Cr>Cu>Zn. The gradual transformation of the land in this area from nearly pure agricultural fields to its current state of intense human settlements (Salami *et al*., 2020), co-existing with farming, makes the results more relevant. An increased human population in the area means that more people, especially young children, get exposed to PTEs in the soil, mainly through their hand-to-mouth habits. This predisposes them to potential health implications related to ingestion and poisoning by toxic substances.

CONCLUSION

This work has aimed to investigate the geochemistry of soils in an area near Garatu, within the Bida Sheet 184NE, Nigeria, mainly focusing on the environment and human health implications of exposure to the soils. It was found that Cu is enriched in about 46 % of the samples and either depleted or marginally enriched in the others. In all the samples, Fe, V, Cr and Mo are highly enriched, thus indicating the potential for harm to human health and the environment. The *Igeo* values indicate no risk to the environment with respect to Zn, while for Fe and V, values fall mainly between groups 2 and 3, indicating moderate to strong pollution for both elements. The risk is higher in terms of Cr, where the *Igeo* value lie within groups 3 and 4, suggesting strongly polluted soils. Most concerning is the data for Mo, whose values sit well above the 6th class, suggesting extreme levels of pollution.

For the oral or ingestion exposure pathway, the results show that the HI for adults and children is 11.33 and 52.89, respectively. This means that the children exposed to the soils are ≈ 11 times more vulnerable, compared to adult populations. In the case of the dermal contact exposure route, the HI values for adults and children are 1.42 and 1.40, respectively. In this case, the risk of adverse cancer effects between adults and children is very different. However, this still signifies substantial risk in terms of both non-carcinogenic and carcinogenic health effects for the two populations. The HI for adults and children for the two exposure scenarios in this study are strongly influenced by the HQ for Fe, and the contribution of each of the metals for the two exposure routes decreases in the order Fe>Cr>Cu>Zn. Based on the findings of this work, it is recommended that further investigations should be carried out to provide more detailed information about the potential environmental and human health risks identified in the Garatu area. Specifically, it is recommended that studies be carried to ascertain the biogeoaccessibility of the potentially toxic elements in soils of the area. This will help in the computation of more useful hazard indices based on readily released fractions of PTEs, instead of the current practice of using total concentrations. Similarly, to assess the transfer of PTEs through the food chain, their distribution of food crops locally grown in the area should be studied.

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