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Full Length Research Article

HEAVY METALS AND NATURAL RADIOACTIVITY CONCENTRATION IN SOILS FROM SELECTED MINING AREAS IN BOSSO LOCAL GOVERNMENT, NIGER STATE, NIGERIA

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ABSTRACT
Activity concentration of naturally occurring radioactive materials (NORMs) and Heavy Metals (HMs) concentration in the soil samples of two artisanal mining areas in Bosso local government, Niger State, were estimated using gamma spectrometry with NaI(TI) detector and flame atomic absorption spectro-photometry. The mean activity concentration of ^{40}K ranged from 250± 7 to 433± 6 Bq kg^{-1} in the soil samples. ^{226}Ra ranged from 12± 0.5 to 25± 2 Bq kg^{-1}, and ^{232}Th ranged from 25± 2 to 11± 1 Bq kg^{-1}. The Annual effective dose (AED) ranged from 26.02 to 39.54 $\mu Sv/year$ and the absorbed gamma dose rate ranged from 21 to 32.24 nGy/year. The results suggest that the soil radioactivity in the study area, although enhance by the mining and farming activities, are not significant to cause harm to human health considering that the effective doses estimated were lower than the world average of 70 $\mu Sv/year$ recommended by UNSCEAR, 2000. The radium equivalent (Ra_{eq}), internal hazard index (H_{in}), and external hazard index (H_{ex}) were estimated and their mean fell within the acceptable limit recommended by ICRP, 2007. The HM concentration of Zn, Pb, Cd, Cu, Ni, and Fe in the soils were evaluated and their associated health risk were estimated. The results, when compared with the Canadian Environmental Quality Guidelines (CEQG) indicated that all the metals were far below the standards and the soil samples from the artisanal mining sites are said to be safe for building and construction.

Keywords: Radionuclide, heavy metal, gamma spectrometry, flame absorption spectro-photometer, activity concentration.

INTRODUCTION

Natural radionuclide (^{226}Ra, ^{232}Th, and ^{40}K) and their decay products which originated from the earth crust about 4.6 billion years ago, are generally the cause of natural radioactivity found in the environment at varying concentration (Kolapo & Omoboyede, 2018; Najam et al., 2015). These natural radiations are present everywhere in the environment and man is continuously being exposed to them either knowingly or unknowingly (Shabana & Kinsara, 2014) . Naturally occurring radioactive materials (NORMs) are found in different spheres of the environment: soil, water, air, food, and in humans and to a large extent plants consumed as food contain ^{226}Ra, ^{232}Th, and ^{40}K in different proportions (WHO, 2011). For this reason, terrestrial radionuclides are found alongside other pollutants in the environment such as HMs produced as a result of human activities, such as industrial activities, application of fertilizers and pesticides used in agriculture, municipal waste, automobile exhust (Järup, 2003; Kolapo & Omoboyede, 2018; Umar et al., 2023). Therefore, most of the radioactivity in the environment whether NORMs or Technologically Enhanced Naturally Occurring Radioactive Materials (TENORMs) is linked to the geology and soil type (Al-Mashhadani et al., 2014)(UNSCEAR, 2000). Radionuclides can be transported from soil to plants/vegetable via sedimentation process, dust particles deposition, plants root uptake and finally to man via the food chain by either direct ingestion, inhalation or breathing. In line with this, soil is an important component in the environment for the assessment of radiation risk to man and animals (Ademola & Obed, 2012; Kolapo & Omoboyede, 2018; Muhammad et al., 2020).

Anthropogenic processes like mining, smelting and farming are the sources of the HM pollution of the soil. The largest producers of heavy metals in the environment are the chemical and metallurgical industries (Suciu et al., 2008). High concentrations of HMs are typically the product of human activity, whereas very low concentrations of HMs are typically found in the environment naturally.

All trace elements (Co, Cr, Cu, Mn, Mo, Ni, Se, and Zn) are toxic to living organisms at high concentrations, but few are essential for the growth of plants and animals at very low concentrations, whereas Ag, As, Ba, Cd, Hg, Pb, Sb, and Th have no known essential use but cause toxicity above certain tolerance threshold . Deficiencies of these essential metals in both animals and plants could lead to diseases and subsequent death. The most potentially hazardous HMs (As, Cd, Cr, Hg, Pb, and Zn) exist in the soil as contaminants (Salbu et al., 2013; Umar et al., 2023; Uosif et al., 2013). This implies that monitoring the rate of HMs concentration in soil is paramount, as this contaminate water sources (groundwater and surface water) (Korashy & El-Kadi, 2008), and food chain, hence, affecting man, plants and animals, respectively (Boukhalfa, 2007). Many researchers across different countries of the world have reported the concentrations of NORMs, TENORMs and heavy metals as could be seen in (Abdul Hamid et al., 2020; Kolapo & Omoboyede, 2018; Korashy & El-Kadi, 2008; Muhammad & Abbasi, 2025; Najam et al., 2015; Salbu et al., 2013; Uosif et al., 2013; Zorer et al., 2009).

This research examines the concentrations of NORMs and HMs in order to assess their environmental risk of exposure in the soils of Pina in Bosso local government area of Niger, Nigeria. Due to the excessive artisanal activities of miners in the area of study, the research aims to examine the radiological effects of HM and

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NORMs in the soil within Pina mining area.

Table 1. Sample identification information

Sample ID	Sample Location	North	East
P1	Pina	006°45'38.3"	09°42'55.9"
P2	Pina	006°45'37.6"	09°42'54.4"
P3	Pina	006°45'37.0"	09°42'53.0"
P4	Pina	006°45'37.1"	09°42'51.7"
P5	Pina	006°45'37.1"	09°42'50.5"
MI	Maitumbi	006° 37'12.9"	09° 39'08.7"
MII	Maitumbi	006°37'11.3"	09°39' 09.1"
MIII	Maitumbi	006°37'09.9"	09°39'09.2"
MIV	Maitumbi	006° 37' 08.2"	09° 39'09.3"
MV	Maitumbi	006° 37'06.6"	09°39'09.0"

MATERIALS AND METHODS

The materials/equipment/reagents that were used to perform this research are as follows:

1. Flame absorption spectrophotometer
2. Sodium Iodide detector NaI(Tl)
3. GPS
4. Polythene containers
5. Drying oven
6. Sieve (2 mm size)
7. Acid digestion reagent based on the EPA 3050B protocol (HNO_3, HCL, and H_2O_2)
8. Volumetric flasks and digestion vessels.

Area of Study

This study was conducted at two artisanal mining locations (Maikunkele and Maitumbi) in Bosso local government area of Niger State, Nigeria. The area is situated in a complex basement that is characterized by a vast deposit of gneiss and granite rocks that date back to the Precambrian epoch, as well as gold deposits that have been mined in various sections of Maitumbi, particularly in the Pina district. The land mass of this area is roughly 884 hectares, and it is located between Latitudes 9°31' and 9° 40' North and Longitudes 6°29' and 6°35' East. Figure 1 displays the location of the study areas and sample collecting locations, while Table 1 displays the sample identifying information.

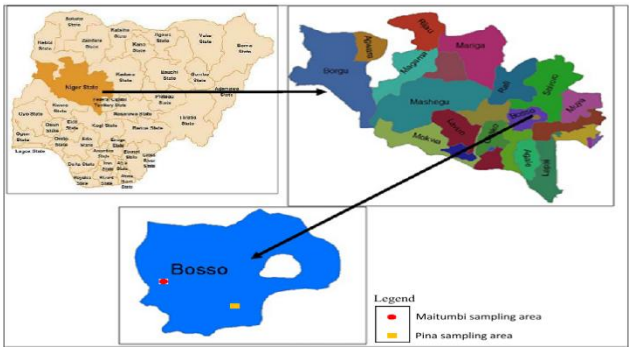

Figure 1. Map of Niger State showing the sampling areas in Bosso local government area (Modified from (Ajayi et al., 2015)).

Samples Collection and Preparation

Ten (10) samples were obtained from the two areas of study, Pina and Maitumbi artisanal mining sites. Using the systematic profiling sampling technique depicted in Figure 1. Soil samples were collected in the summer of 2024 (IAEA TECDOC-1415, 2004). The polluted mining regions were separated into 12 cells, each of which was further separated by a grid. Soil samples weighing 1 kg each were taken from the nodes of each intersecting grid at a depth of 15 cm (Figure 2), and the samples from each cell were merged to create a single composite sample. The materials were crushed and sieved through a 1 mm mesh screen after been oven dried for 24 hours at 100 °C to remove all moisture content. To achieve secular equilibrium, samples were kept for about 30 days.

Using a range of standard solutions with different concentrations, the concentration of six HMs (Zn, Pb, Cd, Ni, Cu, and Fe) were determined in the soil samples using the flame Atomic Absorption Spectroscopy (FAAS). Throughout the work, de-ionized, double-distilled water devoid of metals was utilized. Samples of the fine soil (<2 mm) fraction that had been sieved and air-dried were analyzed, and the results were adjusted for moisture content. Using Test Methods for Evaluating Solid Waste, Physical/Chemical method 3050 B was used to extract HMs from the soil samples (1 g) (EPA, 1999). This process removes all of the HMs and breaks down the majority of the organic stuff. Following digestion, the Shimadzu AA-6800 atomic absorption spectro-photometer was used to measure the total amounts of Cd, Pb, Cu, Ni, Cr, Mn, Zn, and Fe in soil samples. HMs risk assessment in soil from two artisanal mining areas were carried out on a child and an adult using the standard values presented in Table 2.

Procedure for Gamma Ray Spectrometry

Prior to the start of gamma spectrometry, the background-count was obtained by measuring an empty container, which had the same geometry as that of the detector for 36,000 s. The samples were subsequently examined at Ladoke Akintola University of Technology (LAUTECH) radiation lab by utilizing a 3 x 3 inch NaI (Tl) detector (model number GS-2000 Pro multichannel analyzer). A program called Thermo was used to collect and analyze data from the gamma ray spectrum. For analysis, the sealed soil samples were sequentially put on the detector. To ascertain the activity concentrations in the soil, each soil sample was counted at equal intervals of time as the empty container (36000 s) to produce a complete gamma-ray energy spectrum. The entire energy peaks

of interest were ^{137}Cs (661.7 keV), ^{212}Pb (238.6 keV), ^{228}Ac (911.1 keV), and ^{208}Tl (2614.7 keV) for the detection of ^{232}Th, and ^{214}Pb (295.3 keV) and ^{214}Bi (1764.5 keV) for ^{226}Ra (^{238}U). The activity concentration was determined using the specific full energy peak of 1460.0 keV of ^{40}K (Oumar Bobbo et al., 2019; Ziajahromi et al., 2015). The activity concentration of each soil sample was calculated using equation (1):

$$A = \frac{C_{net}}{P_\gamma \times \varepsilon \times m \times t} \quad (1)$$

where Pγ is the probability of gamma-ray emission, ε is the efficiency of the radionuclide's full energy peak, m is the mass of the soil samples, t is the counting time in seconds, and Cnet is the net peak count for each radionuclide in the sample after subtracting the background count from the gross count (Asgharizadeh et al., 2012).

Estimation of radium equivalent activity

Understanding the activity of gamma radiation emissions from a radiation source is necessary to estimate radiological effects on the environment. The gamma outputs from a sample that comprises a mixture of many radiation sources, such as potassium, thorium, and (sometimes referred to as the parent of radium), are referred to as radium equivalent (Raeq). The expression for the radium equivalent activity is found in equation (2) (Asgharizadeh et al., 2011):

$$\mathrm{Ra_{eq}} = \mathrm{A_{Ra}} + 1.43\mathrm{A_{Th}} + 0.077\mathrm{A_K} \quad (2)$$

where the independent activities of ^{226}Ra, ^{232}Th, and ^{40}K are denoted by the letters A_Ra, A_Th,
and A_K, respectively.

Equation (2) states that for 1 Bq kg^{-1} of ^{226}Ra, 0.07 Bq kg^{-1} of ^{232}Th, and 13 Bq kg^{-1} of ^{40}K, respectively, the gamma-ray dosage rate is the same (Beretka & Mathew, 1985).

For safe use in building materials and other household applications, the maximum $\mathrm{Ra_{eq}}$ in soil must be less than 370 Bq kg^{-1} in order to maintain the external dose rate at less than 15 mGy y^{-1} (ICRP, 2007a).

Estimation of external hazard index (H_{ex})

The external hazard index (H_{ex}) is a criterion for calculating the consequences of radiation exposure from soil samples collected outside the body. Equation (3) (Nations, 2011), where A_{Ra}, A_{Th} and A_K have meanings similar to those in equation (2), can be used to determine the H_{ex} index.

$$\mathrm{H_{ex}} = \frac{\mathrm{A_{Ra}}}{370} + \frac{\mathrm{A_{Th}}}{259} + \frac{\mathrm{A_K}}{4810} \leq 1 \quad (3)$$

Estimation of internal hazard index ($\mathrm{H_{in}}$)

Equation (4) provides the internal hazard index criterion, which is used to assess the effects of radiation sources, such as carcinogenic radon gas and its decay products or any other gamma-emitting radionuclide, when inhaled or consumed within the body (Nations, 2011). Equation (2) and the definitions of A_{Ra}, A_{Th} and A_K are similar.

$$\mathrm{H_{in}} = \frac{\mathrm{A_{Ra}}}{185} + \frac{\mathrm{A_{Th}}}{259} + \frac{\mathrm{A_K}}{4810} \leq 1 \quad (4)$$

Estimation of gamma radiation hazard index ($\mathrm{I_{\gamma r}}$)

Another dose threshold is the representative level index, sometimes referred to as the gamma radiation hazard index expressed in Equation (5) with A_{Ra}, A_{Th} and A_K (Bq kg^{-1}) maintaining their usual meanings, while indicating whether or not a certain dose condition is met (Fares et al., 2011).

$$\mathrm{I_{\gamma r}} = \frac{\mathrm{A_{Ra}}}{300} + \frac{\mathrm{A_{Th}}}{200} + \frac{\mathrm{A_K}}{3000} \quad (5)$$

Estimation of absorbed gamma dose rate in air (D)

Equation (6) was employed to determine the amount of gamma radiation in air that was absorbed from the radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) at a height of 1 m above the ground surface.

$$\mathrm{D} = 0.462 \times \mathrm{A_{R_a}} + 0.604 \times \mathrm{A_{T_h}} + 0.0417 \times \mathrm{A_K} \quad (6)$$

Annual effective dose

This index measures the effects of irradiation of the human body on annual basis from NORMs existing in the soil. According to the UNSCEAR, 2000 (UNSCEAR, 2000), the AED can be calculated using equation (7):

$$\mathrm{AED} = \mathrm{D} \times 8760 \times 0.2 \times 0.7 \times 10^{-3} \quad (7)$$

where 0.7 (Sv/Gy) is the conversion coefficient from the absorbed dose in air to the effective dose absorbed by an adult, 0.2 is the outdoor (or indoor) occupancy factor, D is the absorbed gamma radiation dose rate (nGy/h), and 8760 (h/y) is equal to 360 days × 24 hours in a year.

HMs risk assessment

Humans are constantly exposed to both natural radiation and heavy metals (HMs) from the soil through ingestion, dust inhalation through the mouth, nose, and skin contact (Cheng et al., 2014)(Ferreira-Baptista & De Miguel, 2005). Equations (8), (9), (10), (11) and (12) can be used to compute the health risk assessment of HMs.

$$AD_{\mathrm{ingt.}} = \frac{\mathrm{C \times IngtR \times EF \times ED}}{\mathrm{BW \times AT}} 10^{-6} \quad (8)$$

$$\mathrm{AD_{inht.}} = \frac{\mathrm{C \times InhtR \times EF \times ED}}{\mathrm{PEF \times BW \times AT}} \quad (9)$$

$$\mathrm{AD_{dermal}} = \frac{\mathrm{C \times SA \times SL \times ABS \times EF \times ED}}{\mathrm{BW \times AT}} 10^{-6} \quad (10)$$

$$\mathrm{HQ} = \mathrm{ADI_{dermal}} \quad (11)$$

$$\mathrm{HI} = \mathrm{HQ_{Zn}} + \mathrm{HQ_{Pb}} + \mathrm{HQ_{Cd}} + \mathrm{HQ_{Ni}} \quad (12)$$

where $\mathrm{AD_{ingt}}$, $\mathrm{AD_{inht}}$, and $\mathrm{AD_{dermal}}$ are the average daily intake of metals from soil ingestion, inhalation and dermal absorption in mg/kg.day; InhtR and IngtR are the inhalation and ingestion rate of soil (mg/day, m^3/day), metal concentration in soil (mg/kg) is denoted by C, exposure frequency (day/year) by EF, and exposure duration (year) by ED. PEF is the emission factor (m^3/kg); SA is the irradiated skin surface area (cm^2); AF is the adherence factor (mg/cm^2.day); ABS is the dermal absorption factor (no unit); BW is the body weight of the irradiated individual (kg); and AT is the average time taken (day). The outcomes of these computations are shown in Table 2. To generate a hazard quotient (HQ) for none-cancer risk, the estimated doses for each element and exposure pathway were then divided by the corresponding reference dose values (RD) (mg/kg.day). For carcinogens, the dose is then multiplied by the corresponding slope factor (SF) (mg/kg.day)-1 to generate a cancer risk. The hazard index and cancer risk of HMs were estimated using this method. Furthermore, the hazard index is the sum of all HQ (Zheng et al., 2010). It means there is no risk for H< 1. As H rises, so does risk (Epa, 2002).

The hazard index and cancer risk of HMs were estimated using this method. Furthermore, the hazard index is the sum of all HQ (Zheng et al., 2010). It means there is no risk for H< 1. As H rises, so does risk (Epa, 2002). The acceptable amount of risk is between 10^{-6}-10^{-4} (Ferreira-Baptista & De Miguel, 2005). The cancer risk and hazard indices for adults and children living in the mining area are examined in this report. The evaluation's parameters are shown in Table 2.

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Table 2. Standard reference parameters for risk assessment of HMs in soil (Cheng et al., 2014)(Ferreira-Baptista & De Miguel, 2005)(USEPA, 2001)

S/N	Parameter	Symbol	Value	Unit
1	Soil ingestion rate	IngtR.	200 (child), 100 (adult)	mg/day
2	Exposure frequency	EF.	350	day/year
3	Soil inhalation rate	InhtR.	7.6 (child), 20 (adult)	m^3/day
4	Exposure rate	ED.	70 [6 (child) for non-cancer effects]	year
5	Skin area	SA.	860 (child), 1530 (adult)	cm^2
6	Skin adherence factor	SL.	0.2(child), 0.07(adult)	$mgcm^2$
7	Dermal absorption factor	ABS.	0.006 (Pb), 0.14 (Cd), 0.1 (Cu), 0.02 (Zn), 0.05 (Hg), 0.03 (As)	—
8	Particle emission factor	PEF.	1.36×10^9	m^3/kg
9	Body weight	BW.	15 (child), 70 (adult)	Kg
10	Averaging time	AT.	ED 365 days for non-carcinogens 70 365 days for carcinogens	Day
11	Chronic reference dose	RfD.	Ingestion RfD: 3.50×10^{-3} (Pb), 1.00×10^{-3} (Cd), 4.00×10^{-2} (Cu), 3.00×10^{-1} (Zn), 3.00×10^{-4} (Hg),3.00×10^{-4} (As) Inhalation RfD: 3.52×10^{-3} (Pb), 2.86×10^{-5}(Cd), 4.02×10^{-2} (Cu), 3.00×10^{-1} (Zn), 8.57×10^{-5} (Hg), 3.01×10^{-4} (As) Dermal RfD: 5.25×10^{-4} (Pb), 1.00×10^{-5} (Cd), 1.20×10^{-2} (Cu), 6.00×10^{-2} (Zn), 2.10×10^{-5}(Hg), 1.23×10^{-4} (As)	$mgkg^{-1}day^{-1}$
12	Carcinogenic slope factor	SF.	Ingestion SF:1.5 (As) Inhalation SF:15.1 (As) Dermal SF:3.66 (As)	$mgkg^{-1}day^{-1}$

RESULTS AND DISCUSSION

The average activity concentration in the soil samples from the research sites is displayed in Table 1. It is evident that every sample taken from the study locations had a high activity content of ^{40}K; the average was 343.7± 9.5 Bq kg^{-1}, with a range of 250± 7 to 433 ± 6 Bq kg^{-1}. The substantial granite rock deposits and the overuse of fertilizers by artisanal farmers to increase agricultural yields, which are evident in the research locations, may be the causes of the high ^{40}K content in Table 2. This concentration was higher than the global mean (Table 2). The average activity concentration of ^{226}Ra is 19.7± 1.07 Bq kg^{-1}, with a range of 12 ± 0.5 to 25 ± 2.

With an average of 6.9± 1.29, the activity concentration of ^{232}Th ranges from 25 ± 2 to 11 ± 1. This finding indicates that the soil samples' 226Ra and ^{232}Th activity concentrations were negligible. Table 3 shows that these concentration values (^{226}Ra and ^{232}Th) were below the global average. The average AED was determined to be 33.85 μSv/year, with a range of 26.02 to 39.54 μSv/year. With an average of 27.60 nGy/year, the absorbed gamma dose rate varied from 21 to 32.24 nGy/year (Figure 2).

The acceptable limit is reached by the average Ra_{eq} of 56.03, as shown in Figure 3. However, the average external danger index is 0.15, which is once more inside the permissible range. According to Figure 4, the average internal hazard index is 0.20, which is likewise below the acceptable limit of 1 (ICRP, 2007b).

The samples of soil collected at a depth of 15 cm each from the artisanal mining site (Maikunkel, and Pina) were analyzed for the presence of HM concentrations. Background concentration level of the Canadian environmental quality (CEQG) guidelines was used as shown in Table 3. With Cu having the highest concentration, it is evident that the HM concentrations were consistently much below the CEQG standard. The outcomes of the risk assessment are displayed in Table 5. Table 5 for children and Table 6 for adults show the findings of the health risk assessment of heavy metals (HMs) in the soil from the artisanal mining regions. The findings make it clear that youngsters are more at risk from HMs in the soil than adults are for non-cancer risk. However, for both children and adults, the hazard indices (HIs) lead to soil decreases in the order Pb<Z<Cu<Fe<Cd<Ni (Table 5 and 6).

There was also no calculation of the cancer risk for adults or children since soil samples from the artisanal mining regions in this study did not include arsenic (As), the most carcinogenic heavy metal.

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Table 3: Average activity concentration of Radionuclides in the soil samples

Sample ID		Activity concentration (Bq kg^{-1})		
		^{40}K	^{232}Ra	^{232}Th
PI		433 ± 6	21 ± 1	7 ± 2
PII		423 ± 6	21 ± 1	7 ± 2
PIII		428 ± 6	22 ± 1	7 ± 2
PIV		397± 14	18 ± 1	11 ± 1
PV		396± 14	18 ±1	11 ± 1
M1		250± 7	20 ±2	5 ± 1
M2		260 ± 7	25 ± 2	5 ± 1
M3		297± 11	24 ± 0.7	4 ± 1
M4		293± 10	16 ± 0.5	4 ± 1
M5		260± 14	12 ± 0.5	8 ±0.9
	Average (this study)	**343.7± 9.5**	**19.7± 1.07**	**6.9± 1.29**
World avearge (UNSCEAR, 2000)		**400**	**35**	**30**

Table 4: Mean concentration of HMs in soil (mgkg^{-1})

Sample ID	Concentration of HMs					
	Zn	**Pb**	**Cd**	**Ni**	**Cu**	**Fe**
S1	0.15	0.47	0.52	1.06	0.25	0.18
S2	0.03	0.17	0.07	0.62	0.04	0.48
S3	0.04	0.42	0.01	0.77	0.06	0.59
S4	0.03	0.46	0.52	1.06	0.08	0.67
S5	0.03	0.39	0.33	0.95	0.08	0.54
PI	0.19	0.35	0.3	0.92	0.08	0.49
PII	0.2	0.35	0.37	0.77	0.09	0.51
PIII	0.87	0.03	0.02	0.05	0.41	0.29
PIV	0.97	0.05	0.03	0.04	0.54	0.19
PV	0.43	0.03	0.07	0.06	0.30	0.15
Average	**0.29**	**0.27**	**0.22**	**0.63**	**0.19**	**0.41**
CEQG Threshold	**200**	**70**	**14**	**50**	**63**	–

CEQG: Canadian Environmental Quality Guidelines

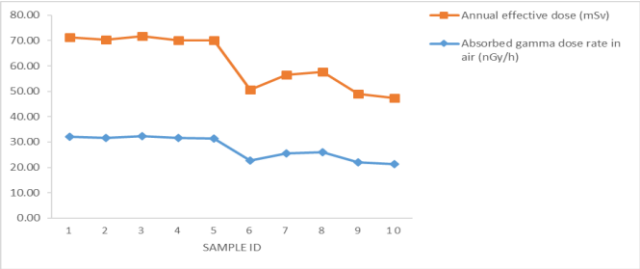

Figure 2. Annual effective dose and absorbed gamma dose rate in air for the study areas

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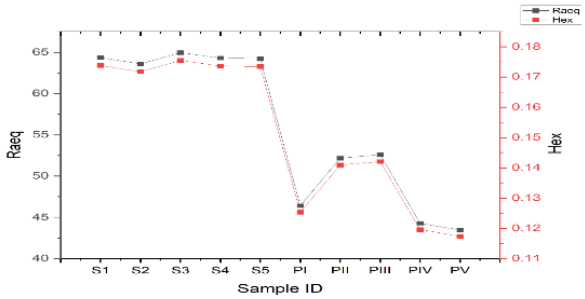

Figure 3. Mean Radium equivalent and external hazard index

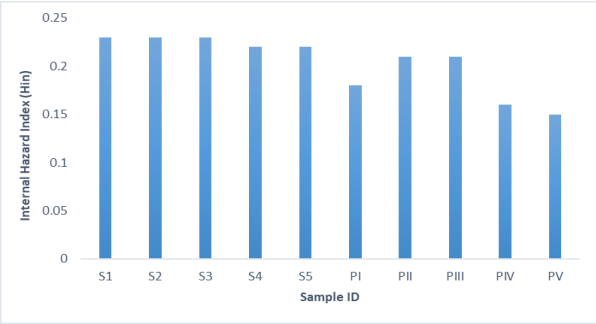

Figure 4. Internal hazard index for the study areas

Table 5. The daily doses, hazard quotient, hazard indices, and cancer risk of heavy metals present in soil samples from Maikunkele and Pina aritisanal mining areas for child

Element		ADingt	ADinht	Ddermal	HQing	HQinh	HQdermal	HI
Zn	Min.	3.84E-07	2.82E-10	6.60E-09	1.28E-06	9.40E-10	1.10E-07	1.39E-06
	Max.	1.24E-05	9.12E-09	2.13E-07	4.13E-05	3.04E-08	3.56E-06	4.49E-05
	Mean	3.76E-06	2.76E-09	6.47E-08	1.25E-05	9.21E-09	1.08E-06	1.36E-05
Pb	Min.	3.84E-07	2.82E-10	1.98E-09	1.10E-10	9.40E-10	3.30E-08	3.40E-08
	Max.	5.88E-06	4.32E-09	3.03E-08	1.68E-09	1.44E-08	5.06E-07	5.22E-07
	Mean	3.32E-06	2.44E-09	1.72E-08	9.50E-10	8.15E-09	2.86E-07	2.95E-07
Cd	Min.	3.84E-07	2.82E-10	1.98E-09	1.10E-10	9.40E-10	3.30E-08	3.40E-08
	Max.	6.65E-06	4.89E-09	8.00E-07	6.65E-03	1.63E-08	1.33E-05	6.66E-03
	Mean	2.53E-06	1.86E-09	2.19E-07	1.79E-03	6.19E-09	3.66E-06	1.79E-03
Ni	Min.	1.28E-07	9.40E-11	1.98E-09	1.10E-10	3.13E-10	3.30E-08	3.40E-08
	Max.	6.65E-06	4.89E-09	8.00E-07	6.65E-03	1.63E-08	1.33E-05	6.66E-03
	Mean	3.42E-06	2.51E-09	4.12E-07	3.42E-03	8.38E-09	6.86E-06	3.43E-03
Cu	Min.	1.28E-07	9.40E-11	1.54E-08	1.28E-04	3.13E-10	2.57E-07	1.28E-04

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	Max.	6.65E-06	4.89E-09	8.00E-07	6.65E-03	1.63E-08	1.33E-05	6.66E-03
	Mean	2.64E-06	1.94E-09	3.17E-07	2.64E-03	6.46E-09	5.29E-06	2.64E-03
Fe	Min.	2.56E-07	1.88E-10	3.08E-08	2.56E-04	6.27E-10	5.13E-07	2.56E-04
	Max.	1.36E-05	9.97E-09	5.70E-07	4.73E-03	3.32E-08	9.49E-06	4.74E-03
	Mean	6.39E-06	4.70E-09	2.87E-07	1.06E-03	1.57E-08	4.79E-06	1.07E-03

Table 6. The daily doses, hazard quotient, hazard indices, and cancer risk of heavy metals present in soil samples from Maikunkele and Pina artisanal mining areas for adult

Element		**ADingt**	**ADinht**	**Ddermal**	**HQing**	**HQinh**	**HQdermal**	**HI**
Zn	Min.	4.11E-08	3.02E-11	8.80E-10	1.37E-07	1.01E-10	1.47E-08	1.52E-07
	Max.	1.33E-06	9.77E-10	2.85E-08	4.43E-06	3.26E-09	4.74E-07	4.91E-06
	Mean	4.03E-07	2.96E-10	8.63E-09	1.34E-06	9.87E-10	1.44E-07	1.49E-06
Pb	Min.	4.11E-08	3.02E-11	2.64E-10	1.17E-11	1.01E-10	4.40E-09	4.51E-09
	Max.	6.30E-07	4.63E-10	4.05E-09	1.80E-10	1.54E-09	6.75E-08	6.92E-08
	Mean	3.56E-07	2.62E-10	2.29E-09	1.02E-10	8.73E-10	3.81E-08	3.91E-08
Cd	Min.	4.11E-08	3.02E-11	2.64E-10	1.17E-11	1.01E-10	4.40E-09	4.51E-09
	Max.	7.12E-07	6.58E-10	1.07E-07	7.12E-04	2.19E-09	1.78E-06	7.14E-04
	Mean	2.71E-07	8.28E-10	2.93E-08	1.92E-04	2.76E-09	4.88E-07	1.92E-04
Ni	Min.	1.37E-08	3.02E-11	2.64E-10	1.17E-11	1.01E-10	4.40E-09	4.51E-09
	Max.	7.12E-07	4.89E-09	1.07E-07	7.12E-04	1.63E-08	1.78E-06	7.14E-04
	Mean	3.66E-07	1.97E-09	5.49E-08	3.66E-04	6.56E-09	9.16E-07	3.67E-04
Cu	Min.	1.37E-08	9.40E-11	2.05E-09	1.37E-05	3.13E-10	3.42E-08	1.37E-05
	Max.	7.12E-07	4.89E-09	1.07E-07	7.12E-04	1.63E-08	1.78E-06	7.14E-04
	Mean	2.83E-07	1.94E-09	4.24E-08	2.83E-04	6.46E-09	7.06E-07	2.83E-04
Fe	Min.	2.74E-08	1.88E-10	4.11E-09	2.74E-05	6.27E-10	6.85E-08	2.75E-05
	Max.	1.45E-06	3.48E-09	7.60E-08	5.07E-04	1.16E-08	1.27E-06	5.08E-04
	Mean	6.85E-07	1.02E-09	3.83E-08	1.14E-04	3.39E-09	6.39E-07	1.15E-04

The samples of soil collected at a depth of 15 cm each from the artisanal mining site (Maikunkel, and Pina) were analyzed for the presence of HM concentrations. Background concentration level of the Canadian environmental quality (CEQG) guidelines was used as shown in Table 3. It can be seen that the HM concentrations in all cases were far lower than the CEQG limit, with Cu having the highest concentration. Table 5 shows the results of the risk assessment. The health risk assessment results of HMs in the soil from the artisanal mining areas is presented in Table 5 for children and Table 6 for adult, respectively. It is evident from the results that for non-cancer risk, the risk of HMs in the soil in children is more than that in adults. This is due to higher exposure relative to total body weight, increased physiological sensitivity and often more ingestion due to behavioral factors. However, the hazard indices (HIs) results in soil decreases in the order Pb<Z<Cu<Fe<Cd<Ni for both children and adults (Table 5 and 6). In addition, the most carcinogenic HM, Arsenic (As) was not detected in the soil samples from the artisanal mining areas in this study, hence, there was no cancer risk estimation for both children and adults.

Conclusions

The HMs (Zn, Pb, Cd, Ni, Cu, and Fe) and naturally occurring radioactive elements (^{226}Ra, ^{232}Th, and ^{40}K) were investigated. With the exception of ^{40}K, which might have been caused by the artisanal farmers' excessive use of NPK fertilizers and active mining operations in the research areas, it was discovered that the mean activity concentration of NORMs was lower than the global average. The soil samples from the artisanal mining locations, however, were deemed safe for use in building and construction because the HMs concentration was significantly lower than the CEQG standards when compared to the worldwide standard.

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