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Radiological Implications of Artisanal Gold Mining Activities in Gababiyu, Minna Metropolis, Nigeria

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ABSTRACT

Radiological contamination of the atmosphere and human environment due to anthropogenic activities has been associated with significant human health challenges. 12 surface soil samples collected at random from Gababiyu artisanal gold mining site in Minna were assessed for their radiological contents using gamma spectrometric technique which employs NaI (Tl) detector. Specific activities of ^{226}Ra, ^{232}Th and ^{40}K ranged from 10.27±2.88 to 61.45±4.68 Bq kg^{-1}, 32.67±1.93 to 83.00±2.24 Bq kg^{-1} and 82.48±3.00 to 281.65±9.49 Bq kg^{-1} respectively, with mean values of 31.92±6.41, 63.57±2.67 and 198.91±1.38 Bq kg^{-1} in sequence. Computed average absorbed dose rate at 1 m above ground was 61.44 nGy h^{-1} with corresponding mean annual dose equivalent of 0.07 mSv y^{-1} and average excess lifetime cancer risk of 0.26 × 10^{-3}. These values were all below respective safety limits set by UNSCEAR. Results of this investigation indicated minimal radiological risk associated with mining in the artisanal goldmine in Minna Metropolis.

Keywords: Artisanal gold mining**,** NaI(Tl) detector**,** dose, Gababiyu**,** Nigeria.

INTRODUCTION

The world inhabited by man is naturally radioactive. Naturally occurring radionuclides are present everywhere and all living and non-living things are exposed to radiations (Odumo *et al.*, 2009). Naturally occurring radionuclides are nuclides that undergo spontaneous radioactive decay and emit mass-energy. The decay process occurs spontaneously and repeatedly until a stable nuclide is formed (Long *et al.*, 2012). Such radionuclides are generally termed “Naturally Occurring Radioactive Materials (NORM)”. NORM refers to the primordial radionuclides of potassium (^{40}K), uranium (^{238}U and ^{235}U and their daughters), and thorium (^{232}Th and its daughters) synthesised during the creation of the solar system (IAEA, 2003). These primordial radionuclides are still in existence today due to their long half-lives in comparison with the age of the earth. They also emit gamma rays of sufficient intensity for gamma-ray mapping (IAEA, 2003).

Exposure to ionising radiation emitted by individual radionuclides of NORM pose radiological risk to humans and the environment (Alharbi, 2016). Radiation

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exposure can induce a range of effects in humans. The nature and probability of the effect depends on the radiation dose received by an individual. The effect may be somatic, occurring only in the exposed individual or genetic, occurring in the descendants of the exposed individual (NYSDH, 2007). Through proper regulations, such exposure can be controlled to ensure adequate protection to the environment and occupationally exposed people.

Elevated level of NORM in the environment may result from the activities and industrial processes related to the extraction and processing of ores (UNEP, 2016), such as uranium mining and milling, metal mining and smelting, phosphate production, coal mining and power generation from coal burning, oil and gas drilling, rare earth and titanium oxide industries, zirconium and ceramic industries and applications using isotopes of Radium and Thorium (UNEP, 2016).

Artisanal (small-scale) mining is an activity that encompasses small, medium, informal, legal and illegal miners who use rudimentary methods and processes to extract mineral resources (Sabo *et al.,* 2018). Environmental and health issues are risks associated with artisanal gold-mining, mining processes incite depletion of the environment such as land degradation, de-vegetation, air and water pollutions and loss of aquatic organisms (Ako *et al.*, 2014). Toxic matter discharged into the environment poses health risks to miners, their families and surrounding communities (Azubike, 2011; Ako *et al.*, 2014).

Associated with mining and mineral processing are potential adverse health risks that are more significant to occupationally exposed individuals. However, certain exposures and their associated risks may disperse via environmental pathways to the general population (Candeias *et al.*, 2018). According to the World Nuclear Association (WNA), radiation protection standards assumes that for any radiation dose, no matter how small, involves a possible risk to human health (WNA, 2014; Njinga *et al.*, 2015). Therefore, there is need to investigate the activity concentration of NORM in the artisanal goldmine in Gababiyu area of Minna Metropolis. This will yield radiological parameters to ascertain the radiological risk associated with small-scale mining in the region.

The study area (Gababiyu artisanal goldmine) is located in Minna Metropolis (Figure 1), off the City’s Eastern bye pass, after the M.I Wushishi Estate. The area is also the site proposed for the El-Amin University. The area is part of Minna Sheet 164 and falls within the Basement Complex Terrain of Nigeria (Ahmed *et al.,* 2019).

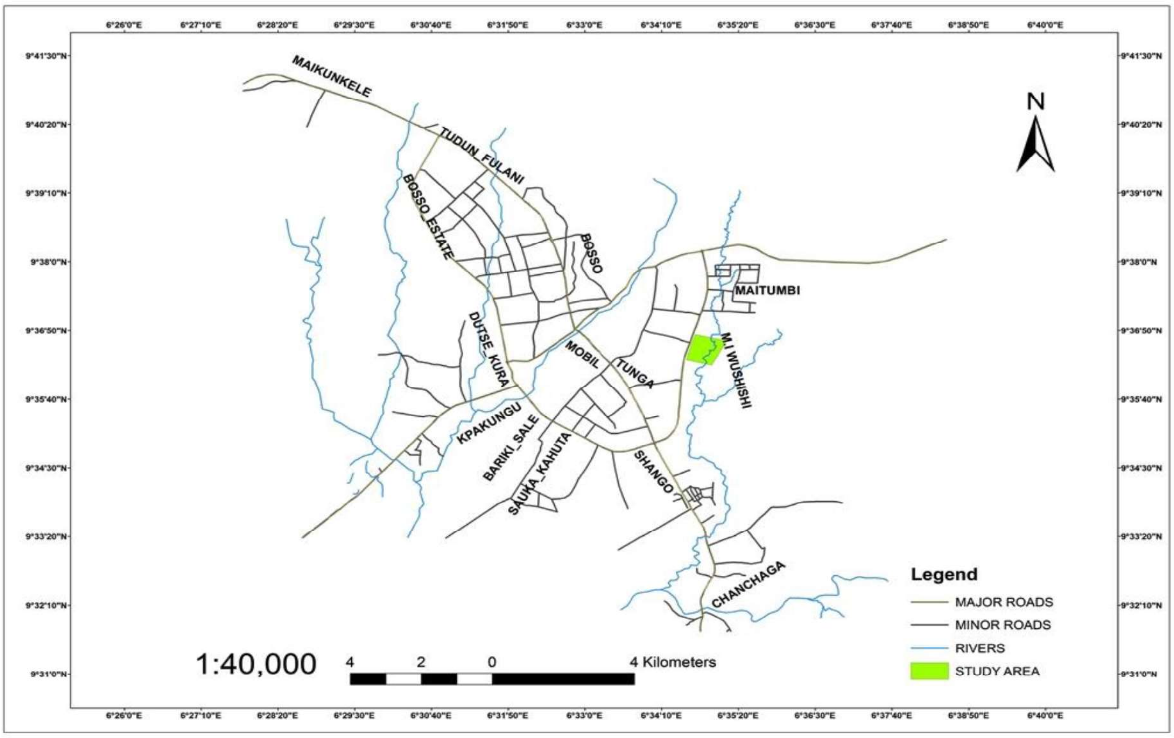

Fig. 1**:** Location map of the study area in Minna Metropolis (ArcGIS 10.1, 2012)

METHODOLOGY

Sample Collection and Preparation

Twelve (12) representative soil samples were randomly collected around the artisanal gold mine (Figure 1). All samples collected were cleared of any stones, pebbles and shrubs, and about 1 kg of each sample was packed neatly into well labelled polyethylene bags and conveyed to the laboratory for preparation.

Each of the soil samples were openly dried at room temperature in the laboratory and crushed using agate mortar and pestle. The crushed samples were sieved using a BSS 63 sieve to obtain homogeneous fine grain. Radon-impermeable cylindrical plastic containers selected based on the volume of the detector vessel (7.6 cm by 7.6 cm geometry) were used to package 300 g of the sieved sample. Ensuring the containment was air-tight to prevent radon-222 (^{222}Rn) from escaping, the packaging in each case was triple sealed. The sealing process was done by smearing of the inner rim of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps between lid and container, and tight-sealing lid-container with masking adhesive tape.

Radon and its short-lived progenies were allowed to reach secular radioactive equilibrium by storing the samples for 30 days prior to gamma spectroscopy measurements (Veiga *et al.*, 2006; Ademola *et al.*, 2014).

Gamma Spectrometric Analysis

To determine the activity concentration of NORM in the soil samples, gamma spectrometric analysis was carried out using a 7.6 cm by 7.6 cm NaI (Tl) detector which has energy resolution of 72% at 661.16 keV peak of

^{137}Cs. The crystal is optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1 kV external source. The detector is enclosed in a 6 cm lead shield with cadmium and copper sheets to minimize the effects of background and scattered radiation. The data acquisition software is Maestro by Camberra Nuclear Products. Each of the samples was measured for a period of 29000 seconds. The activity concentrations were computed using the equation (Njinga *et al.*, 2015):

$$\mathrm{A}\ (\mathrm{Bq.kg^{-1}}) = \frac{\mathrm{C_n}}{\mathrm{I_{(\gamma)}}\varepsilon\mathrm{MT}} \qquad (1)$$

where: A = activity concentration of a particular radionuclide in the sample, C_n = net count rate, $I_{(\gamma)}$ = emission probability of a specific energy photo peak, T = time for collecting the spectrum of the sample and M = mass of the sample.

Calibration and Efficiency Determinations

Calibration of the detector for energy and efficiency was done with two calibration point sources, ^{137}Cs and ^{60}Co before analysis. The standards used to check for the calibration are the IAEA gamma spectrometric reference materials RGU-1 for ^{226}Ra (^{214}Bi peak), RGTh-1 for ^{232}Th (^{208}Ti peak) and RGK-1 for ^{40}K. The energy peaks for the region of interest (ROI) used to compute the activity concentrations of ^{226}Ra ^{232}Th and ^{40}K are given in Table 1.

Table 1: Spectral energy windows used in the analysis

Isotope	Gamma Energy (Kev)	Energy Window (Kev)
^{226}Ra	1764.0	1620-1820
^{232}Th	2614.5	2480-2820
^{40}K	1460.0	1380-1550

Radiation hazard indices

The following hazard indices were computed from the measured activities of ^{226}Ra ^{232}Th and ^{40}K in the studied soil samples:

Radium Equivalent Activity (Ra_{eq})

The Radium Equivalent Activity (Ra_{eq}) was estimated using the equation (Ibrahiem, 1999; Munyaradzi *et al.*, 2018):

$$\mathrm{Ra_{eq}} = \left(\frac{\mathrm{Ra_A}}{370} + \frac{\mathrm{Th_A}}{259} + \frac{\mathrm{K_A}}{4810}\right) 370\ \mathrm{Bq/Kg} \qquad (2)$$

where: Ra_A, Th_A and K_A are respectively the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}k in the soil samples.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) stipulates a threshold of 370 Bq/kg for (Ra_{eq}) (UNSCEAR, 2000; Suleiman *et al.*, 2018). This threshold activity corresponds to gamma radiation dose of 1.5 mGy/y.

Gamma Radiation Dose (D)

The gamma radiation dose (D) 1 m above ground was calculated by applying conversion factors of 0.462, 0.604 and 0.0417 for ^{226}Ra, ^{232}Th and ^{40}K respectively to convert their activity concentrations into dose rates using the equation (UNSCEAR, 2000; Munyaradzi *et al.*, 2018):

$$\mathrm{D} = 0.462\mathrm{Ra_A} + 0.604\ \mathrm{Th_A} + 0.0417\mathrm{K_A} \qquad (3)$$

where: D is the gamma radiation dose in nGy/h and Ra_A, Th_A and K_A are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in sequence.

Annual Effective Dose Equivalent (AEDE)

Annual Effective Dose Equivalent (AEDE) in mSv/y is estimated as products of the gamma radiation dose, D (nGy/h), time in a year (8760 hours), dose conversion factor of 0.7 Sv/Gy and occupancy factor of 20 % (0.2) for outdoor exposure (accounting for the duration the miners spend on the field in a year), using the equation (UNSCEAR, 2000; Taskin *et al.*, 2009):

$$\mathrm{AEDE} = \mathrm{D} \times 8760 \times 0.7 \times 0.2 \times 10^{-6} \quad (4)$$

External and Internal Hazard Indices

The external hazard index (H_{ex}) and internal hazard index (H_{in}) were estimated using the equations (Berekta and Mathew, 1985; Ademola *et al.*, 2014):

$$\mathrm{H_{ex}} = \frac{\mathrm{Ra_A}}{370} + \frac{\mathrm{Th_A}}{259} + \frac{\mathrm{K_A}}{4810} \leq 1 \quad (5)$$

$$\mathrm{H_{in}} = \frac{\mathrm{Ra_A}}{185} + \frac{\mathrm{Th_A}}{259} + \frac{\mathrm{K_A}}{4810} \leq 1 \quad (6)$$

For radiological safety, UNSCEAR stipulates a threshold of unity for both H_{ex} and $H_{in.}$

Excess lifetime Cancer Risk (ELCR)

Excess lifetime Cancer Risk (ELCR) was estimated using the equation (Taskin *et al.*, 2009; Munyaradzi, Anna and Makondelele, 2018):

$$\mathrm{ELCR} = \mathrm{AEDE} \times \mathrm{DL} \times \mathrm{RF} \quad (7)$$

where AEDE is the annual effective Dose Equivalent computed from Eq. (4), DL = the average duration of human life (estimated to be 70 years) and RF = the risk factor (Sv^{-1}). For stochastic effects, which produce low background radiation, the ICRP 60 stipulates a value of 0.05 Sv^{-1} for RF and a threshold of 0.29 × 10^{-3} for ELCR for the public exposure (Taskin *et al.*, 2009; Munyaradzi *et al.*, 2018).

RESULTS

The activity concentrations of naturally occurring radionuclides (^{226}Ra ^{232}Th and ^{40}K) in soil samples collected from Gababiyu artisanal goldmine are presented in Table 2. The computed radiation hazard indices are presented in columns 5 to 10 of Table 2. Distribution of ^{226}Ra ^{232}Th and ^{40}K across the soil samples are displayed on bar chart in Figure 2.

The specific activity concentration of ^{226}Ra varies from 10.27±2.88 to 61.45±4.68 Bq/kg, ^{232}Th specific activity ranges from 32.67±1.93 to 83.00±2.24 Bq/kg, while the activity concentration of ^{40}K varies from 82.48±3.00 to 281.65±9.49 Bq/kg. Radium equivalent activity (Ra_{eq}) ranges from 96.74 to 176.25 Bq/kg. Gamma absorbed dose 1 m from the ground (D) varies from 44.02 to 78.01 nGy/h. Annual Effective Dose Equivalent (AEDE) varies from 0.05 to 0.09 mSv/y with a mean of 0.07 mSv/y. The external hazard index (H_{ex}) varies from 0.26 to 0.48 while the internal hazard index (H_{in}) varies from 0.32 to 0.61. Excess Lifetime Cancer Risk (ELCR) estimated varies from 1.90×10^{-4} to 3.3×10^{-4} with a mean of 2.6×10^{-4}.

Table 2: Activity concentrations and radiation hazard indices of soil samples collected from Gababiyu artisanal goldmine

Sample	Activity concentrations (Bq/kg)				Radiological hazard parameters				
	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}	D (nGy/h)	AEDE (mSv/y)	H_{ex} ≤ 1	H_{in} ≤ 1	ELCR ($\times10^{-3}$)
GM01	10.27±2.88	60.12±0.31	183.84±8.56	110.39	48.72	0.06	0.30	0.33	0.21
GM02	19.18±2.80	48.21±0.94	144.85±5.47	99.27	44.02	0.05	0.27	0.32	0.19
GM03	25.05±0.92	63.62±0.20	233.34±8.85	133.99	59.73	0.07	0.36	0.43	0.25
GM04	28.33±1.08	32.67±1.93	281.65±9.49	96.74	44.57	0.05	0.26	0.34	0.19
GM05	34.52±2.00	68.10±0.98	168.77±6.76	144.90	64.12	0.08	0.39	0.48	0.27
GM06	17.50±2.24	78.76±1.53	277.74±7.94	151.51	67.24	0.08	0.41	0.46	0.28
GM07	22.22±1.68	68.34±1.42	135.46±6.06	130.37	57.19	0.07	0.35	0.41	0.24
GM08	33.52±2.60	60.43±2.01	82.48±3.00	126.29	55.43	0.07	0.34	0.43	0.23
GM09	38.48±3.00	66.33±1.34	247.06±6.86	152.36	68.14	0.08	0.41	0.52	0.29
GM10	51.06±3.80	73.41±1.61	232.26±5.68	173.92	77.62	0.09	0.47	0.61	0.33
GM11	61.45±4.68	59.88±2.08	189.57±2.63	161.68	72.47	0.09	0.44	0.60	0.31
GM12	41.40±4.44	83.00±2.24	209.90±5.63	176.25	78.01	0.09	0.48	0.59	0.33
Min.	10.27±2.88	32.67±1.93	82.48±3.00	96.74	44.02	0.05	0.26	0.32	0.19
Max.	61.45±4.68	83.00±2.24	281.65±9.49	176.25	78.01	0.09	0.48	0.61	0.33
Mean	31.92±6.41	63.57±2.67	198.91±1.38	138.14	61.44	0.07	0.37	0.46	0.26

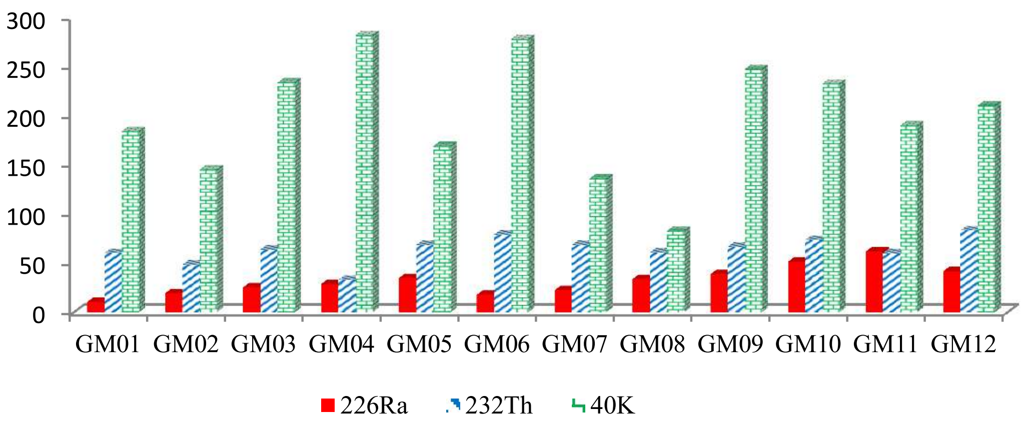

Fig. 2: Distribution of NORM across the soil samples

DISCUSSION

The specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the studied soil samples varied with mean values of 31.92±6.41, 63.57±2.67 and 198.91±1.38 Bq/kg in sequence. Global average values documented by UNSCEAR are 35 Bq/kg for ^{226}Ra, 30 Bq/kg for ^{232}Th and 400 Bq/kg for

^{40}K (Oluwaseyi *et al.,* 2017; UNSCEAR, 2000). Mean values for ^{226}Ra and ^{40}K are below UNSCEAR recorded average while that of ^{232}Th is twice above the recommended average. The distribution of ^{226}Ra, ^{232}Th and ^{40}K shown in figure 2 with unequal height of the bars depicting uneven concentration for the NORM (^{226}Ra, ^{232}Th and ^{40}K) across the region agrees with existing literature. Radium equivalent activity (Ra_{eq}) varies with mean of 138.14 Bq/kg that is below the 370.00 Bq/kg threshold recommended by UNSCEAR (2000).

Gamma absorbed dose 1 m from the ground (D) varies with 61.44 nGy/h mean yielding an Annual Effective Dose Equivalent (AEDE) with 0.07 mSv/y mean, that is far below the 1.00 mSv/y threshold value recommended for occupational exposure by UNSCEAR. Therefore, indicating minimal radiological risk associated with artisanal gold mining in the area.

The external and internal hazard indices (H_{ex} and H_{in}) indicated minimal radiological risk as they varied with mean values of 0.37 and 0.46 respectively. These values are below unity, implying an overall minimal risk to the artisanal gold miners and populace of surrounding communities.

Excess Lifetime Cancer Risk (ELCR) estimated varies with a mean of 2.6×10^{-4} that is slightly below the global recommended threshold of 2.9×10^{-4} (Taskin *et al.*, 2009; Munyaradzi *et al.*, 2018). Hence, indicating minimal cancer risk.

Conclusion

Human activities incite radiological contamination of the environment which results to significant human health challenges. Soil samples from artisanal gold mining environment in Gababiyu were assessed for their radiological contents. Average specific activity values for ^{226}Ra, ^{232}Th and ^{40}K were 31.92±6.41, 63.57±2.67 and 198.91±1.38 Bq/kg in sequence. These values except for ^{232}Th were below the safety limits stipulated by UNSCEAR. However, computed radiological hazard parameters for the studied soil samples were all within the safety limits for occupational exposure. Thus, the radiological impact of artisanal gold mining in the study area bears minimal significance.

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