

# Evaluation of Radiological Hazards Associated with Some Selected Mining Sites in Niger State, Nigeria

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## Authors' contributions

*This work was carried out in collaboration among all authors. Authors IKS, MB, AM and MKK collected and prepared the field samples, participated in the laboratory procedures, performed the statistical analysis and wrote the draft of the manuscript. Authors IKS and MB also designed the study, contributed to the statistical analysis and supervised the analyses of the study. All authors read and approved the final manuscript.*

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## ABSTRACT

Evaluation of Radiological Hazards associated with some selected mining sites (ie Gadaeragi (GR), Maiwayo (MW) and Kataeragi (KR)) in Niger State, Nigeria was carried out using NaI (TI) Gamma ray spectroscopy. The results shows average activity concentration for  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in Gadaeragi mining site are  $8.05 \pm 0.14$  Bq/kg,  $14.60 \pm 0.30$  Bq/kg and  $20.62 \pm 14.62$  Bq/kg respectively. The result shows average activity concentration for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in Maiwayo mining site to be  $12.03 \pm 0.17$  Bq/kg,  $17.89 \pm 0.32$  Bq/kg and  $151.11 \pm 10.04$  Bq/kg respectively. Furthermore, the results shows average activity concentration for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in Kataeragi mining site are  $6.39 \pm 0.13$  Bq/kg,  $13.25 \pm 0.29$  Bq/kg and  $154.87 \pm 10.77$  Bq/kg respectively. The average activities concentration of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  for the three mining sites shows  $\text{MW} > \text{GR} > \text{KR}$ ,  $\text{MW} > \text{GR} > \text{KR}$  and  $\text{GR} > \text{KR} > \text{MW}$  respectively. The activity concentrations was found to be below worldwide accepted average values of 33 Bq/kg, 45 Bq/kg and 420 Bq/kg for  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  respectively. The Annual Effective Dose Equivalent for GR, MW and KR mining sites was found to be 0.16, 0.17 and 0.13 mSv/y respectively, which were below the 1.00 mSv/y threshold stipulated by UNSCEAR [1]. Therefore, the mining sites are safe in terms of radiological hazard. The entire environment is within the permissible dose limit for the workers of the mining sites and also for agriculture and construction buildings. Therefore, the mining sites are safe in terms of radiological hazard.

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## 1. INTRODUCTION

Naturally occurring radionuclide materials (NORM) in soil samples emits radiations which may pose external hazards to human and environment. The natural radioactivity in soil is caused principally by  $^{238}\text{U}$ ,  $^{235}\text{U}$ ,  $^{232}\text{Th}$ , and to a lesser extent by  $^{40}\text{K}$  and  $^{87}\text{Rb}$ . Radiation from these sources are generally of low doses but could pose health problems. In 1977, study by Advisory Committee on Biological Effects of Ionizing Radiation as well as the United Nations Scientific Committee on the Effects of Atomic Radiation report of 1977 have all shown that even low doses of radiation pose a human cancer risk three to four times higher than previously estimated. The estimated cancer risks for children exposed are also about twice as large as those for adults [2].

Radionuclide in natural environment may be acquired into the body unintentionally through inhalation, ingestion or absorption [2]. Subsequently, they are deposited at various sites in the body. The human body cannot sense exposure to radiation directly except at levels that are invariably lethal and therefore, it cannot provide defense against it. Because of the severity of this problem. The acceptable (safe) levels of radiation exposure and consequently radiation doses (maximum permissible doses - MPD) have been set by various bodies based on research findings in this field [3-7]. These bodies include the National Academy of Science/National Research Council Advisory Committee on Biological Effect of Ionizing Radiation (BEIR), International Commission on Radiological Protection (ICRP), National Council on Radiation Protection and Measurement (NCRP), International Commission on Radiation Units and Measurements (ICRU), United Nations Scientific Committee on Effect of Atomic Radiation [3], International Atomic Energy Agency [2] as well as World Health Organization (WHO).

Maximum permissible dose (MPD) for non-occupationally exposed individual is put at 1mSv/yr [1]. The higher doses, ionizing radiation is dangerous. It is therefore necessary to know the level of radiation within our living environment because of its health implications [1].

Radiation exposure carries a health risk, which help the regulatory bodies establish dose limit

and regulations that keep the exposure at acceptable or tolerable risk level, where it is unlikely to cause harm [8-10]. Nowadays, however, it is realized that a very large number of workers are exposed to natural sources of radiation, mainly in the mining industry. For certain occupations in the mining sector, inhaling radon gas dominates radiation exposure at work [11-14]. While the release of radon in underground uranium mining makes a substantial contribution to occupational exposure on the part of the nuclear industry, the annual average effective dose for a worker in the nuclear industry overall has decreased from 4.4 mSv in the 1970s to about 1 mSv today (Killeen, 1979).

However, the annual average effective dose to a coal miner is still about 2.4 mSv and for other miners about 3 mSv. The current estimate of the total number of monitored workers is about 23 million worldwide, of whom about 10 million are exposed to artificial sources (Killeen, 1979). Three out of four workers exposed to artificial sources work in the medical sector, with an annual effective dose per worker of 0.5 mSv (Killeen, 1979). Evaluation of the trends of the average annual effective dose per worker shows an increase in exposure from natural sources mainly due to mining and a decrease in exposure from artificial sources mainly because of the successful implementation of radiation protection measures (Killeen, 1979).

## 2. MATERIALS AND METHODS

A frame work for the protection of environment against the hazards of radiation from the solid minerals processing requires a logical methodology for proper assessing the dose ratio arising from the natural occurring radionuclide [15]. The methodology that was employed in carrying out this research work includes careful collections of soil samples from mining sites, transportation of the sealed samples to Ladoko Akintola University of Technology (LAUTECH), Ogbomosho, Physics department and then analysis of the samples which would generate result for interpretation.

Ten soil samples were each collected from three mining sites of Maiwayo, Gadaeregi and Kataeregi (making a total of thirty (30) soil samples) all in Niger State, Nigeria. Fig. 1 shows the map of the sampling points. The soil samples

were collected at depths 6- 8 cm. Each sample was placed in a labelled polythene bag sealed to avoid cross contamination of the samples during transportation to the LAUTECH University, Ogbomosho for laboratory analysis.

The soil samples were each oven dry at a temperature of 110°C to remove any moisture. The samples were then grinded into powder (using mortar and pestle) sieved (with a wire mesh with holes of thickness. 0.5 mm) and homogenized [16]. Each soil samples weighing 350 g were placed in hermitically sealed plastic beaker, sealed to prevent the escape of <sup>222</sup>Ra and <sup>220</sup>Rn and kept for 30 days to attain secular equilibrium [17].

The samples were each measured for 36000s (i.e.10 hours), NaI (TI) Gamma spectroscope detector. Prior to sample measurement, the detector was energy calibrated using <sup>137</sup>Cs (661.6 keV and <sup>60</sup>Co (1173.2 keV and 1332.4 keV). The detector efficiency was calibrated using a reference source consisting of radionuclides with known activity concentration: <sup>40</sup>K (578.4 Bq/kg), <sup>238</sup>U (20.9 Bq/kg) and <sup>232</sup>Th

(10.47 Bq/kg). The full energy peak efficiency ( $\epsilon$ ) was obtained using equation (1) [17].

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

where  $C_{net}$  is the net peak count for each radio nuclide present in the sample, after subtracting the back ground count from gross count,  $P_{\gamma}$  is the absolute gamma ray emission probability of the identified radio nuclide,  $\epsilon$  is the obtained full energy peak efficiency for each identified radio nuclide,  $m$  is sample mass and  $T$  is the counting time. The radionuclides and gamma energy links used are given in Table 1.

An empty container with the sample geometry as that of the sample container was measured for 36000s (10 hours) to obtain the back ground contribution, using the full energy peak efficiency in equation (1), the activity concentration (A) of the measured sample was obtained using equation (2) [17].

$$A = \frac{C_{net}}{P_{\gamma} \times \epsilon \times m \times T} \quad (2)$$

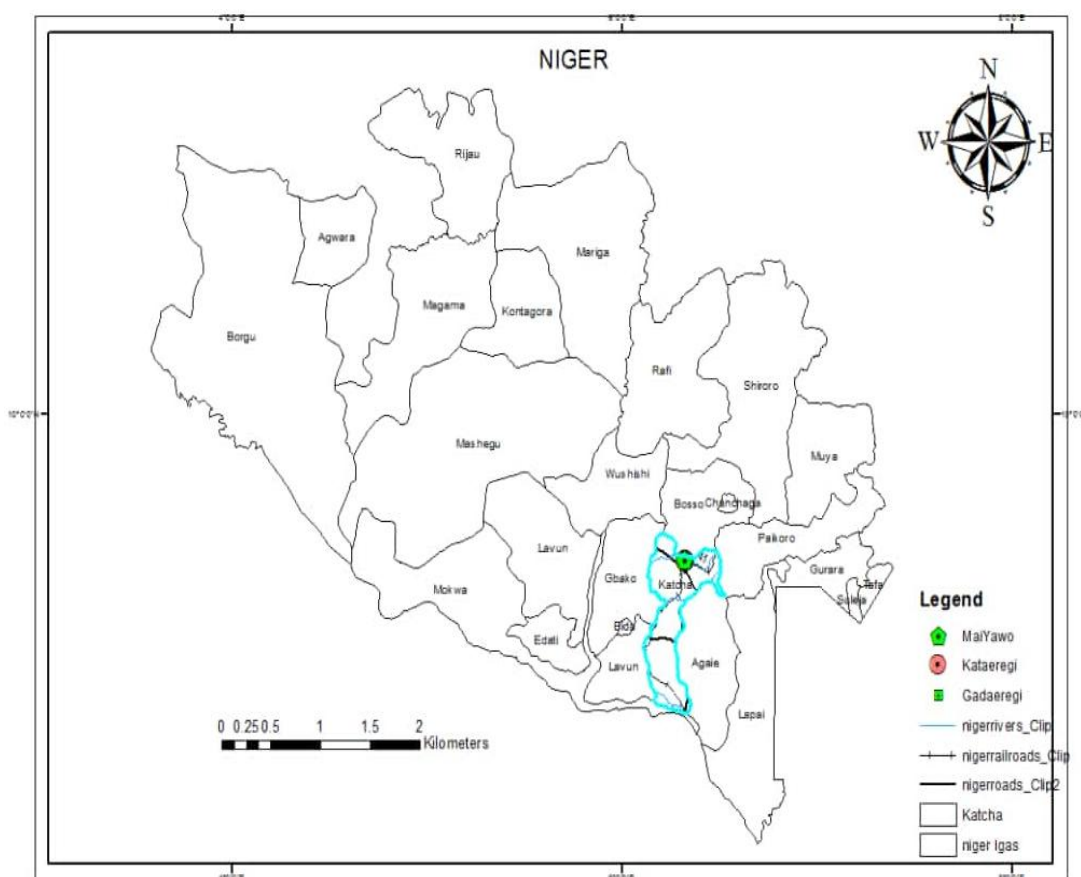


Fig. 1. Map of Niger State showing study area

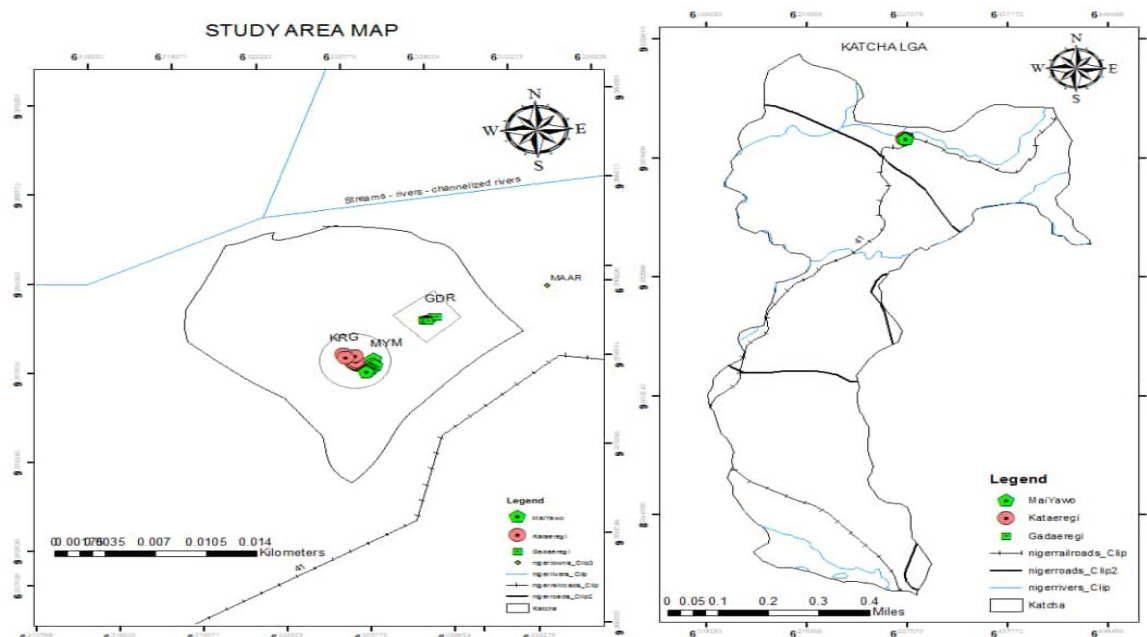


Fig. 2. Map of the study area and points

Table 1. Detected Radio nuclide and the gamma energy lines used for determination of activity

Nuclide of Interest	Detected Isotope	Gamma ray energy keV
$^{221}\text{Ra}$	$^{214}\text{Bi}$	1764.0
$^{232}\text{Th}$	$^{208}\text{Tl}$	2614.5
$^{40}\text{K}$	$^{40}\text{K}$	1460.0

## 2.1 Calibration and Background Radiation

In order to use gamma spectrometer to identify samples of unknown composition, its energy scales were calibrated, the calibration was performed using peak of known source such as  $^{137}\text{Cs}$  and  $^{60}\text{Co}$ . The efficiency calibration of the detector was also carried out using a reference source consisting of known radionuclide activities:  $^{40}\text{K}$  (578.4 Bq/kg),  $^{238}\text{U}$  (20.9 Bq/kg) and the standard sources are designed for the determination of natural radionuclides in environmental matrices. The source was prepared in a container that has the same geometry as the sample and counted for period of 36000s. The full energy peak efficiency was employed as it relates the peak area in the spectrum to amount of radioactivity present).

The gamma spectrometer system employed consists of a 3'x3' NaI(Tl) detector, a product of Princeton Gamma Tech, USA. The detector is house in a cylindrical lead shield to reduce the effect of background radiation. The detector was coupled to Gamma Spectacular (model Gs- 2000 Pro) multichannel analyzer and further linked to a

computer for display. Data acquisition and analysis of gamma-ray spectra were achieved using Thermanino software.

## 3. RESULTS AND DISCUSSION

### 3.1 Radiological Parameters

From the activity concentrations obtained using Equation 1, the following radiological parameters were used to explain whether exposure to radiations in the artisanal solid minerals mining areas may or may not affect human and the environment.

#### 3.1.1 Radium equivalent activity ( $Ra_{eq}$ )

Radium Equivalent Activity ( $Ra_{eq}$ ) is the weighted sum of hazards associated with  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ . This index presumes that 1, 0.7 and 13 Bq/kg of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ , respectively, produce equal terrestrial gamma dose rates [18]; stipulates a threshold of 370 Bq/kg for  $Ra_{eq}$  [15].  $Ra_{eq}$  was estimated using the equation (3)

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (3)$$

where  $A_{Ra}$ ,  $A_{Th}$  and  $A_K$  are the specific activity concentrations of  $^{226}Ra$ ,  $^{232}Th$  and  $^{40}K$ , respectively, in the soil samples.

### 3.1.2 Gamma radiation dose ( $D_R$ )

The gamma radiation dose or absorbed dose ( $D_R$ ) at 1 m above the ground was estimated using the equation [19]:

$$D_R = 0.46A_{Ra} + 0.60A_{Th} + 0.0417A_K \quad (4)$$

where  $D_R$  is the gamma radiation dose in nGy/h and the coefficients (0.462, 0.604 and 0.0417 in nGy/h per Bq/kg) are the dose conversion factors for  $^{226}Ra$ ,  $^{232}Th$  and  $^{40}K$ , respectively, as contained in the UNSCEAR [19] report.

### 3.1.3 Annual Effective Dose Equivalent (AEDE)

Annual Effective Dose Equivalent (AEDE) in mSv/y is estimated as the product 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 0.2 for outdoor exposure [20]. AEDE was computed using the equation:

$$AEDE = D \times 8760 \times 0.7 \times 0.2 \times 10^{-6} \quad (5)$$

ICRP [21] provided AEDE threshold of 1 mSv/y for public exposure.

### 3.1.4 Annual Gonadal Dose Equivalent (AGDE)

The annual gonadal dose equivalent (AGDE) is a measure of the dose received by the gonads (gamete producing organs) of exposed population in a year [22]:

$$AGDE(\mu Sv.y^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (6)$$

where  $A_{Ra}$ ,  $A_{Th}$  and  $A_K$  assume their respective definitions given before.

### 3.1.5 Activity Utilization Index (AUI)

Activity Utilization Index (AUI) is a parametric model used in determining NORM dose levels in the atmosphere from soil samples [23]. AUI was calculated from the specific activities of  $^{226}Ra$ ,  $^{232}Th$  and  $^{40}K$  in the sampled soils using the equation Osimobi et al., [23];

$$AUI = \left( \frac{A_{Ra}}{50Bq/kg} \right) f_{Ra} + \left( \frac{A_{Th}}{50Bq/kg} \right) f_{Th} + \left( \frac{A_K}{50Bq/kg} \right) f_K \quad (7)$$

where  $f_{Ra}$ ,  $f_{Th}$  and  $f_K$  having the numerical values of 0.462, 0.604 and 0.041, respectively, represent fragmentary supplements of  $^{226}Ra$ ,  $^{232}Th$  and  $^{40}K$  to the entire gamma dose [24].

### 3.1.6 External and internal hazard indices

External hazard index ( $H_{ex}$ ) is a parameter used for evaluating external exposure to gamma radiation in air. The maximum allowed value for  $H_{ex}$  is 1, which corresponds to the upper limit of  $Ra_{eq}$  (370 Bq/kg) [15]. Internal hazard index ( $H_{in}$ ), on the other hand, is a factor used to evaluate the hazardous effects of radon and its short lived progeny to the respiratory organs [15]. The threshold for  $H_{in}$  is also 1.

The external hazard index ( $H_{ex}$ ) and internal hazard index ( $H_{in}$ ) were estimated using the equations [23]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (8)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (9)$$

### 3.1.7 Representative gamma index ( $I_{\gamma r}$ )

Representative gamma index ( $I_{\gamma r}$ ) is used to evaluate the conformity of soil to dose standards set for building materials [25]. It categorizes materials that may induce radiological risk if deployed for construction [23].  $I_{\gamma r}$  was computed from the equation [23].

$$I_{\gamma r} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (10)$$

$I_{\gamma r}$  must be  $\leq 1$  to satisfy the given dose criteria. This corresponds to an annual effective dose below 1 mSv [23].

### 3.1.8 Excess lifetime Cancer Risk (ELCR)

Excess Lifetime Cancer Risk (ELCR) is a measure of the probability that a certain stochastic effect will occur in an individual exposed to low doses of ionizing radiation over a given period of time [26]. The most common radiation induced health effects are incidence of cancers and genetic effects. ELCR was estimated using the equation [27].

$$ELCR = AEDE \times DL \times RF \quad (11)$$

where DL is the average duration of human life (estimated to be 70 years) and RF is risk factor ( $Sv^{-1}$ ) or fatal cancer risk per Sievert. For stochastic effects, which produce low background radiation, the ICRP 60 stipulates RF value of 0.05 for public exposure [27].

### 3.2 Activity concentration of NORM

Specific activities of primordial radionuclide in the samples collected from Gadaeregi (GR) mining site along with the location coordinates are shown in Table 2. The activities concentrations of  $^{238}U$  varied from  $5.94 \pm 0.12$  Bq/kg to  $9.19 \pm 0.15$  Bq/kg with an average value of  $8.05 \pm 0.14$  Bq/kg. Specific activity values for  $^{232}Th$  ranged from  $11.42 \pm 0.27$  Bq/kg to  $16.98 \pm 0.32$  Bq/kg, with mean activity value of  $14.60 \pm 0.30$  Bq/kg.  $^{40}K$  show much higher activity values than  $^{226}Ra$  and  $^{232}Th$  which of course should be expected owing to the natural abundance of  $^{40}K$  in the soil. Activity concentration of  $^{40}K$  varied from  $152.29 \pm 13.49$  Bq/kg to  $231.53 \pm 18.34$  Bq/kg (Table 2). The average activity value for  $^{40}K$  in the investigated mining site was lower than the world mean value of 400 Bq/kg.

Specific activities of primordial radio nucleic in the sample collected from Maiwayo (MW) mining are shown in Table 3. Activity concentration of  $^{238}U$  varied from  $3.42 \pm 0.09$  Bq/kg to  $27.52 \pm 0.27$  Bq/kg with an average value of  $12.03 \pm 0.17$  Bq/kg. Specific activity values for  $^{232}Th$  ranged between  $7.04 \pm 0.21$  Bq/kg to  $35.47 \pm 0.27$  Bq/kg, with mean activity values of  $17.89 \pm 0.32$  Bq/kg.  $^{40}K$  show much higher activity values than  $^{226}Ra$  and  $^{232}Th$  which of course should be

expected owing to the natural abundance of  $^{40}K$  in the soil. Activity concentration of  $^{40}K$  varied from  $72.54 \pm 5.95$  Bq/kg to  $251.32 \pm 10.53$  Bq/kg (Table 3). The average activity value for  $^{40}K$  in the investigated mining site was lower than the world mean value of 400 Bq/kg.

Specific activities of primordial radio nucleic in the soil sample collected from Kateregi (KR) mining site are shown in Table 4. Activity concentration of  $^{238}U$  varied from  $3.58 \pm 0.10$  Bq/kg to  $11.94 \pm 0.18$  Bq/kg with an average value of  $6.39 \pm 0.13$  Bq/kg. Specific activity values for  $^{232}Th$  ranged between  $7.80 \pm 0.22$  Bq/kg to  $18.27 \pm 0.34$  Bq/kg, with mean activity value of  $13.25 \pm 0.29$  Bq/kg.  $^{40}K$  show much higher activity values than  $^{226}Ra$  and  $^{232}Th$  which of course should be expected owing to the natural abundance of  $^{40}K$  in the soil. Activity concentration of  $^{40}K$  varied from  $89.36 \pm 5.34$  Bq/kg to  $197.62 \pm 17.55$  Bq/kg with mean value of  $154.87 \pm 10.77$  Bq/kg (Table 4). The average activity value for  $^{40}K$  in the investigated mining site was lower than the world mean value of 400 Bq/kg.

#### 3.2.1 Computed radiological parameters

Computed  $Ra_{eq}$  radiological doses and other ratio hazard indices for Gadaeregi (GR) mining site are given in Table 5.  $Ra_{eq}$  varied from  $34.17 \pm 1.32$  Bq/kg $^{-1}$  to  $49.88 \pm 1.81$  Bq/kg $^{-1}$  with mean value of  $44.83 \pm 1.70$  Bq/kg $^{-1}$ . This value was below the recommended safe limit of 370 Bq/kg [28]. DR at 1 m above the ground varied from  $16.07$  nGy/h $^{-1}$  to  $23.43$  nGy/h with an average value of  $21.15$  nGy/h. AEDE – Annual Effective. Dose equivalent has the ranged from  $0.12$  mSv/y to  $0.17$  mSv/y with mean value of  $0.16$  mSv/y

**Table 2. Activity concentrations of NORM in soil samples collected from GR mining site**

Sample code	Activity concentration (Bq/kg)		
	$^{238}U$	$^{232}Th$	$^{40}K$
GR01	$9.19 \pm 0.15$	$14.88 \pm 0.30$	$224.17 \pm 16.79$
GR02	$9.11 \pm 0.15$	$14.80 \pm 0.30$	$231.53 \pm 18.34$
GR03	$9.15 \pm 0.15$	$16.73 \pm 0.32$	$218.29 \pm 15.63$
GR04	$6.87 \pm 0.13$	$16.98 \pm 0.32$	$210.24 \pm 17.05$
GR05	$8.14 \pm 0.15$	$14.16 \pm 0.30$	$208.20 \pm 15.92$
GR06	$9.14 \pm 0.15$	$14.66 \pm 0.30$	$211.50 \pm 11.91$
GR07	$8.73 \pm 0.15$	$14.28 \pm 0.30$	$224.31 \pm 15.40$
GR08	$5.94 \pm 0.12$	$13.92 \pm 0.29$	$197.44 \pm 10.18$
GR09	$8.11 \pm 0.15$	$14.12 \pm 0.30$	$188.19 \pm 11.48$
GR10	$6.11 \pm 0.13$	$11.42 \pm 0.27$	$152.29 \pm 13.49$
Min	$5.94 \pm 0.12$	$11.42 \pm 0.27$	$152.29 \pm 13.49$
Max	$9.19 \pm 0.15$	$16.98 \pm 0.32$	$231.53 \pm 18.34$
Average	$8.05 \pm 0.14$	$14.60 \pm 0.30$	$206.62 \pm 14.62$

**Table 3. Activity concentrations of NORM in soil samples collected from MW mining site**

Sample code	Activity concentration (Bq/kg)		
	<sup>238</sup> U	<sup>232</sup> Th	<sup>40</sup> K
MW11	5.14±0.12	11.19±0.26	151.01±11.91
MW12	7.57±0.14	12.89±0.28	126.13±9.22
MW13	8.46±0.15	11.31±0.27	124.25±7.46
MW14	7.49±0.14	12.39±0.28	122.83±6.03
MW15	7.90±0.14	11.84±0.27	139.42±14.31
MW16	26.78±0.26	34.30±0.46	214.09±15.97
MW17	22.27±0.26	35.47±0.47	228.43±12.11
MW18	27.52±0.27	34.54±0.46	251.32±10.53
MW19	3.42±0.09	7.90±0.22	81.03±6.87
MW20	3.70±0.10	7.04±0.21	72.54±5.95
Min	3.42±0.09	7.04±0.21	72.54±5.95
Max	27.52±0.27	35.47±0.47	251.32±10.53
Average	12.03±0.17	17.89±0.32	151.11±10.04

**Table 4. Activity concentrations of NORM in soil samples collected from KR mining site**

Sample code	Activity concentration (Bq/kg)		
	<sup>238</sup> U	<sup>232</sup> Th	<sup>40</sup> K
KR21	3.58±0.10	7.80±0.22	89.36±7.40
KR22	4.73±0.11	9.62±0.24	120.88±7.25
KR23	4.81±0.11	9.80±0.25	134.40±5.34
KR24	4.10±0.10	9.86±0.25	121.69±7.10
KR25	11.94±0.18	18.27±0.34	173.67±14.04
KR26	5.80±0.12	17.21±0.33	171.21±14.47
KR27	5.58±0.12	18.12±0.34	158.81±17.55
KR28	7.63±0.14	14.62±0.30	185.45±11.91
KR29	7.75±0.14	13.84±0.29	197.62±12.23
KR30	7.96±0.14	13.38±0.29	195.56±10.43
Min	3.58±0.10	7.80±0.22	89.36±5.34
Max	11.94±0.18	18.27±0.34	197.62±17.55
Average	6.39±0.13	13.25±0.29	154.87±10.77

AGDE ( $\mu\text{Sv y}^{-1}$ ) Annual Gonadal Dose equivalent (Table 5), it has range from  $114.43 \mu\text{Sv y}^{-1}$ , with mean average value of  $150.76 \mu\text{Sv y}^{-1}$ .

The computed  $R_{a_{eq}}$  radiological doses and other ratio hazard indices are given in Table 6,  $R_{a_{eq}}$  varied from  $19.35 + 0.86 \text{Bq/kg}^{-1}$  to  $96.26 + 2.15 \text{Bq/kg}^{-1}$  with mean value of  $49.24 + 1.39 \text{Bq/kg}^{-1}$ . This value was below the global upper limit of  $370 \text{Bq/kg}^{-1}$  (UNSCEAR, 2021). Dose rate at 1m above the ground varied from  $8.99 \text{nGy/h}$  to  $44.06 \text{nGy/h}$  with an average value of  $22.66 \text{nGy/h}$ . AEDE – Annual Effective Dose equivalent has the ranged from  $0.07 \text{mSv/y}$  to  $0.32 \text{mSv/y}$  with mean value of  $0.17 \text{mSv/y}$ . AGDE – Annual Gonadal Dose Equivalent (Table 6) it has ranged from  $63.64 \mu\text{Sv/y}$  to  $308.33 \mu\text{Sv/y}$ , with average value of  $159.37 \mu\text{Sv/y}$ .

Computed  $R_{a_{eq}}$  radiological doses and radiation hazard indices for Kataeregi mining site (KR) are

given in Table 7, i.e.  $R_{a_{eq}}$  varied from  $21.61 + 0.88 \text{Bq/kg}^{-1}$  to  $51.44 + 1.96 \text{Bq/kg}$  with mean value of  $37.26 + 1.36 \text{Bq/kg}$ . This value was below the global upper limit of  $370 \text{Bq/kg}$  UNSCEAR, [29]. Dose Rate at 1m above the ground varied from  $10.09 \text{nGy/h}$  to  $23.79 \text{nGy/h}$  with an average value of  $17.41 \text{nGy/h}$ .

In Table 5 (GR) mining site:-

The calculated AEDE values ranged between  $0.12 \text{mSv/y}$  to  $0.17 \text{mSv/y}$ , with mean value of  $0.16 \text{mSv/y}$ , which was lower than the  $1 \text{mSv/y}$  threshold recommended by ICRP [21] for public exposure. AGDE recorded values ranging from  $114.43 \mu\text{Sv/y}$  to  $166.7 \mu\text{Sv/y}$ , with mean value of  $150.76 \mu\text{Sv/y}$ .

Then, the values compacted for AUI ranged between  $0.66$  and  $0.96$ , with a mean of  $0.87$ . This satisfied the  $<2$  threshold, corresponding to AEDE below  $1 \text{mSv/y}$  for radiological safety [23].

Computed values for external hazard index  $H_{ex}$  and internal hazard index  $H_{in}$  ranged from 0.09 to 0.13 and 0.11 to 0.16 respectively, with the average values of 0.12 and 0.14 in sequence. Furthermore, calculated values for  $I_{yr}$  varied from 0.26 to 0.37, the computed mean  $I_{yr}$  of 0.34, which must be  $< 1$  to satisfy the given dose criteria. This corresponds to annual effective dose below 1mSv [30]. Similarly, the computed ELCR values for the Gadaeregi mining site varied from  $0.41 \times 10^{-3}$  to  $0.6 \times 10^{-3}$  with average value of  $0.54 \times 10^{-3}$ .

For Table 6 (MW) mining site:-

The calculated AEDE values ranged between 0.07 mSv/y to 0.32 mSv/y, with mean value of 0.17 mSv/y, which was lower than the 1mSv/y threshold recommended by ICRP [21] for public exposure. AGDE recorded values ranging from

63.64uSv/y to 308.33uSv/y, with mean value of 159.37uSv/y [24].

Then, the values compacted for AUI ranged between 0.36 and 1.74, with a mean of 0.90. The satisfied the  $< 2$  threshold, corresponding to AEDE below 1mSv/y for radiological safety [23]. Computed values for external hazard index  $H_{ex}$  and internal hazard index  $H_{in}$  ranged from 0.05 to 0.26 and 0.06 to 0.33 respectively, with the average values of 0.13 and 0.17 in sequence.

Furthermore, calculated values for  $I_{yr}$  varied from 0.14 to 0.70, the computed mean  $I_{yr}$  of 0.36, which must be  $< 1$  to satisfy the given dose criteria. This corresponds to annual effective dose below 1 mSv [23]. Similarly, the computed ELCR values for the Maiwayu mining site varied from  $0.23 \times 10^{-3}$  to  $1.13 \times 10^{-3}$  with average value of  $0.58 \times 10^{-3}$ .

**Table 5. Computed radiological parameters for GR mining site**

Sample code	$R_{a_{eq}}$ (Bq/kg)	D (nGy/h)	AEDE (mSv/y)	AGDE ( $\mu$ Sv/y)	AUI	$H_{ex}$	$H_{in}$	$I_{yr}$	ELCR ( $\times 10^{-3}$ )
GR01	47.73	22.58	0.17	160.98	0.93	0.13	0.15	0.36	0.58
GR02	48.10	22.80	0.17	162.71	0.94	0.13	0.15	0.36	0.59
GR03	49.88	23.43	0.17	166.75	0.95	0.13	0.16	0.37	0.60
GR04	47.34	22.20	0.16	158.22	0.90	0.13	0.15	0.36	0.57
GR05	44.42	21.00	0.15	149.72	0.86	0.12	0.14	0.33	0.54
GR06	46.39	21.90	0.16	155.93	0.90	0.13	0.15	0.35	0.56
GR07	46.42	22.01	0.16	157.10	0.91	0.13	0.15	0.35	0.57
GR08	41.05	19.39	0.14	138.54	0.79	0.11	0.13	0.31	0.50
GR09	42.79	20.12	0.15	143.17	0.82	0.12	0.14	0.32	0.52
GR10	34.17	16.07	0.12	114.43	0.66	0.09	0.11	0.26	0.41
Min	34.17	16.07	0.12	114.43	0.66	0.09	0.11	0.26	0.41
Max	49.88	23.43	0.17	166.75	0.95	0.13	0.16	0.37	0.60
Average	44.83	21.15	0.16	150.76	0.87	0.12	0.14	0.34	0.54

**Table 6. Computed radiological parameters for MW mining site**

Sample code	$R_{a_{eq}}$ (Bq/kg)	D (nGy/h)	AEDE (mSv/y)	AGDE ( $\mu$ Sv/y)	AUI	$H_{ex}$	$H_{in}$	$I_{yr}$	ELCR ( $\times 10^{-3}$ )
MW11	32.77	15.43	0.11	110.07	0.63	0.09	0.10	0.25	0.40
MW12	35.71	16.54	0.12	116.88	0.66	0.10	0.12	0.26	0.43
MW13	34.20	15.92	0.12	112.43	0.64	0.09	0.12	0.25	0.41
MW14	34.67	16.07	0.12	113.50	0.64	0.09	0.11	0.26	0.41
MW15	35.57	16.61	0.12	117.68	0.67	0.10	0.12	0.26	0.43
MW16	92.31	42.02	0.31	293.35	1.65	0.25	0.32	0.66	1.08
MW17	90.58	41.24	0.30	288.81	1.61	0.24	0.30	0.66	1.06
MW18	96.26	44.06	0.32	308.33	1.74	0.26	0.33	0.70	1.13
MW19	20.96	9.73	0.07	69.03	0.39	0.06	0.07	0.16	0.25
MW20	19.35	8.99	0.07	63.64	0.36	0.05	0.06	0.14	0.23
Min	19.35	8.99	0.07	63.64	0.36	0.05	0.06	0.14	0.23
Max	96.26	44.06	0.32	308.33	1.74	0.26	0.33	0.70	1.13
Average	49.24	22.66	0.17	159.37	0.90	0.13	0.17	0.36	0.58



**Table 7. Computed radiological parameters for KR mining site**

Sample code	Ra <sub>eq</sub> (Bq/kg)	D (nGy/h)	AEDE (mSv/y)	AGDE (μSv/y)	AUI	H <sub>ex</sub>	H <sub>in</sub>	I <sub>yr</sub>	ELCR (×10 <sup>3</sup> )
KR21	21.61	10.09	0.07	71.73	0.41	0.06	0.07	0.16	0.26
KR22	27.79	13.04	0.10	92.78	0.53	0.08	0.09	0.21	0.34
KR23	29.17	13.75	0.10	98.03	0.56	0.08	0.09	0.22	0.35
KR24	27.57	12.92	0.10	92.09	0.52	0.07	0.09	0.21	0.33
KR25	51.44	23.79	0.18	167.80	0.95	0.14	0.17	0.38	0.61
KR26	43.59	20.21	0.15	143.62	0.80	0.12	0.13	0.32	0.52
KR27	43.72	20.14	0.15	142.85	0.79	0.12	0.13	0.32	0.52
KR28	42.82	20.09	0.15	142.92	0.82	0.12	0.14	0.32	0.52
KR29	42.76	20.18	0.15	143.85	0.83	0.12	0.14	0.32	0.52
KR30	42.15	19.91	0.15	141.93	0.82	0.11	0.14	0.32	0.51
Min	21.61	10.09	0.07	71.73	0.41	0.06	0.07	0.16	0.26
Max	51.44	23.79	0.18	167.80	0.95	0.14	0.17	0.38	0.61
Average	37.26	17.41	0.13	123.76	0.70	0.10	0.12	0.28	0.45

For Table 7 (KR) mining site:-

The calculated AEDE values ranged between 0.07 mSv/y to 0.18 mSv/y, with mean value of 0.13 mSv/y, which was lower than the 1 mSv/y threshold recommended by ICRP [21] for public exposure. AGDE recorded values ranging from 71.73 uSv/y to 167.80 uSv/y, with mean value of 123.76 uSv/y.

Then, the values compacted for AUI ranged between 0.41 and 0.95, with a mean of 0.70. The satisfied the < 2 threshold, corresponding to AEDE below 1mSv/y for radiological safety [23]. Computed values for external hazard index H<sub>ex</sub> and internal hazard index H<sub>in</sub> ranged from 0.06 to 0.14 and 0.07 to 0.17 respectively, with the average values of 0.10 and 0.12 in sequence.

Furthermore, calculated values for 1 year varied from 0.16 to 0.38, the computed mean 1 year of 0.28, which must be < 1 to satisfy the given does criteria. This corresponds to annual effective dose below 1 mSv [23]. Similarly, the computed ELCR values for the Kataeregi mining site varied from 0.26×10<sup>-3</sup> to 0.61×10<sup>-3</sup> with average value of 0.45×10<sup>-3</sup>.

### 3.3 Discussion of Results

Results presented in Tables 2, 3 and 4 clearly showed spatial variation in activity concentrations which according to Kolo et al., [30], may be a result of geochemical and physiochemical characteristics of the radionuclide. However, despite the variations in the activity values, there appear to be an even distribution of primordial radionuclide across the mining site as depicted in

the frequency distribution histograms as shown in Fig. 2.

Mean activity concentration of <sup>238</sup>U was 8.05 + 0.14Bq/kg, while <sup>232</sup>Th recorded average specific activity of 14.60 + 0.30Bq/kg. These values were found to be lower than their respective global average of 35Bq/kg and 30Bq/kg respectively as documented by UNSEAR [31] for normal soils in (Table 2) Gadaeregi mining site.

Then in Table 3, Maiwayo (MW) mining site, mean activity concentration of <sup>238</sup>U was 12.03 + 0.17Bq/kg, while <sup>232</sup>Th recorded average specific activity of 17.89 + 0.32Bq/kg. These values were found to be lower than their respective global average of 35Bq/kg and 30Bq/kg respectively as documented by UNSEAR [1] for normal soils.

Furthermore, in the Table 4, Kataeregi (KR) mining site, mean activity concentration of <sup>238</sup>U was 6.39 + 0.13Bq/kg, while <sup>232</sup>Th recorded average specific activity of 13.25 + 0.29Bq/kg. These values were found to be below their respective global average of 35Bq/kg and 30Bq/kg respectively as documented by UNSEAR [1] for normal soils. This therefore, point to the likelihood of radioactive pollution Gadaeregi, Maiwayo and Kataeregi mining environment are within the permissible doses or global averages.

Gamma radiation dose D<sub>R</sub> characterization from the soil samples from Gadaeregi, Maiwayo and Kataeregi mining sites with average D<sub>R</sub> at 1m above the ground was calculated to be 21.15nGy/h, 22.66nGy/h and 17.41nGy/h respectively. Although this value appear to be relatively below the global average of 57nGy/h

documented by UNSCEAR [1], when compares moderately with results of similar studies around the world [32].

Calculated  $H_{ex}$  for the studies samples areas i.e. Gadaeragi, Maiwayo and Kataeragi varied between 0.09 to 0.13, 0.05 to 0.26 and 0.06 to 0.14, with a mean value of 0.12, 0.13 and 0.10. Although the average value was lower than the UNSCEAR [1] established threshold of unity. The calculated mean  $H_{in}$  value of Gadaeragi, Maiwayo and Kataeragi are 0.14, 0.17 and 0.12 were below the UNSCEAR 2021 threshold of unity. The studies areas sample were within the permissible dose rate.

The variation in the representation of gamma index  $I_{\gamma}$  obtained for the studies sample areas which represent about 100% of the studied samples recorded  $I_{\gamma}$  value below the recommended UNSCEAR threshold.

Computed average for ELCR for the studied areas are  $0.54 \times 10^{-3}$ ,  $0.58 \times 10^{-3}$  and  $0.45 \times 10^{-3}$ , which are higher than the global mean of  $0.29 \times 10^{-3}$  [26].

#### 4. CONCLUSIONS

The radiation exposure due to natural source of radiation in the soil samples of the three mining sites of Gadaeragi, Maiwayo and Kataeragi was determined using NaI (TI) Gamma ray spectroscopy, the results shows average activity concentration for  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in Gadaeragi mining site are  $8.05 \pm 0.14$  Bq/kg,  $14.60 \pm 0.30$  Bq/kg and  $20.62 \pm 14.62$  Bq/kg respectively. the result shows averages activity concentration for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in Maiwayo mining site and  $12.03 \pm 0.17$  Bq/kg,  $17.89 \pm 0.32$  Bq/kg and  $151.11 \pm 10.04$  Bq/kg respectively, furthermore, the shows average activity concentration for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in Kataeragi mining site are  $6.39 \pm 0.13$  Bq/kg,  $13.25 \pm 0.29$  Bq/kg and  $154.87 \pm 10.77$  Bq/kg respectively, then, the mean average of the three mining sites average activities concentration for  $^{232}\text{U}$ , MW>GR>KR, For  $^{232}\text{Th}$ , MW>GR>KR and For  $^{40}\text{K}$ , GR>KR> MW respectively. The activity concentrations was also found to below worldwide average values of  $45 \text{ Bq/kg}^{-1}$ ,  $33 \text{ Bq/kg}^{-1}$  and  $420 \text{ Bq/kg}^{-1}$  for  $^{232}\text{Th}$ ,  $^{238}\text{U}$  and  $^{40}\text{K}$  respectively.

The computed value of the average mean of annual effective dose equivalent for the three mining sites (i.e. Gadaeragi, Maiwayo, and

Kataeragi) are 0.16 mSv/y, 0.17mSv/y and 0.13mSv/y respective. The average annual effective dose equivalent obtained from this site are below the world wide average, which tells us that the environment is safe for all activities.

Therefore, the entire environments are within the permissible dose safe limits for the workers of the mining sites and also for agriculture and construction buildings.

#### 5. RECOMMENDATION

The study was conducted using soils samples from the three mining sites of Gadaeragi, Maiwayo and Kataeragi in Katcha Local Government Area of Niger State, North Central, and Nigeria. More study needs to be carried out on these mining sites within the surrounding areas to find out the activity concentration of the radionuclide constitutes in the environment. The three research mining sites of GR, MW and KR are all with average annual effective dose of 0.16 mSv/y, 0.17 mSv/y and 0.13 mSv/y are below the safety limit of 1.0 mSv/y as proposed by UNSCEAR, [1].

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#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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