Assessment and Evaluation of Enhanced Levels of Naturally Occurring Radionuclides Materials due to Gold Mining in Soil Samples obtained from Iperindo, Osun State, Southwestern, Nigeria

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Abstract: Two set of soil samples from Iperindo due to gold mining activities have been subjected to radiological investigation using a well calibrated NaI(Tl) detector. The first sets of soil samples were collected where the mining activities are taking place, the second sets of soil samples were collected where farming activities takes place. The radionuclide detected in both samples are majorly the singly occurring non series ^{40}K and decay series of ^{238}U, ^{232}Th, all of which belongs to the natural radionuclide, with traces of low quantity of Bismuth from the samples collected at the mining area. The mean activity concentrations obtained are 470.50 Bqkg^{-1}, 41.50 Bqkg^{-1} and 39.70 Bqkg^{-1} while 137.05 Bqkg^{-1}, 13.14 Bqkg^{-1} and 17.34 Bqkg^{-1} respectively. The mean absorbed dose rate and annual effective dose equivalent were also calculated with the obtained activities concentration. From the results, the activity concentrations from the mining site were higher than the world average value. This may be due to the exploration of gold in the area. Therefore, the mining activities in Iperindo may be considered being constitute radiological hazard to the local residents due to high concentration of uranium.

Keywords: Radionuclides, Gold-mining, Iperindo, Osun State

1 Introduction

Humans are continuously exposed to radiation from the environment due to some activities like exploration of soil, rock and ocean. Radiation can be of natural origin or man-made sources. The prominent natural radionuclide such as the singly occurring non series ^{40}K, and the decay series of ^{238}U and ^{232}Th are readily available in the Earth's crust and other environmental media, and these have been in existence since the ages of the Earth (NCRP, 1976, UNSCEAR, 2000). Enhanced levels of natural background radiation are encountered in many occupational settings most especially in all forms of underground mines extraction and processing, aircrew and workers exposed to radon in workplaces other than mines. The distribution of these radionuclides depends on the geological and geographical formation of such environment (UNSCEAR, 2008). Gamma radiation emitted by radionuclide from materials taken from the Earth's crust such as soil, rocks, and ores constitute external exposure while those contracted via inhalation and ingestion through foods and water constitutes internal exposure.

Mining is an extensive industry, and employment in the mining industry is changing in several ways for a variety of interrelated reasons among which include economic growth, politics, and technology, demographic and social factors. Activities related to the extraction and processing of ores have been reported to enhanced levels of naturally occurring radionuclides material (NORM) in products, by-products and wastes. The extraction and processing of radioactive ores are carried out in different countries throughout the world, and over the last few years, exposure to enhanced levels of NORM have become a focus of attention in the field of radiation protection (UNSCEAR, 2008). Gold mining had been on the increase owing to the quality and beauty of gold in several applications among which includes fashion, artwork, building, furniture and many more. Gold is

found deep within the Earth's crust and the extraction process involves a series of geological process. The raw materials, their by-products from processing and the end products produced may result to exposure in workplaces. The main potential sources of exposure in the extraction industries have been identified to be the natural radionuclides arising from the radioactive decay of the ^{238}U and ^{232}Th series (UNSCEAR, 2008). Radon is the main source of radiation exposure in most underground mining operations and out of the several isotopes of radon that exist ^{222}Rn dominates in terms of exposure to workers. Owing to the health risks associated with exposure to enhanced levels of NORM both externally and internally, several international bodies have adopted strong measures at minimizing the risk involved in radiation exposure.

In Nigeria, radiation monitoring started in the 1960's after the French carried out nuclear weapons tests in the Sahara Desert. Ever since, there had been an increased monitoring and awareness about radiation levels in air, soil and water and the implications on biological matter (Nwosu *et al.*, 1974; Akinloye and Olomo, 1995; Ugwu *et al.*, 2008; Akinloye *et al.*, 2012; Isola and Ajadi, 2015; Akinloye *et al.*, 2018 and many more). In addition, studies on radionuclide concentrations in mines have been extensively carried out (Jibiri and Esen, 2011; Abdulkarim and Umar, 2013). However, the gold mining activities in the Iperindo, Osun State has not been subjected to radiological investigation. As the residents of the gold mining environment may be exposed to radiation due to the presence of enhanced levels of NORM in the Earth's crust derived from mining operations without them been aware. Thus, this study aimed at investigating the enhanced levels of NORM in the soil samples obtained from gold mining areas of Iperindo, Osun State, Southwestern, Nigeria. This is necessary in order to have the quantitative and qualitative record of radiation level of the study area assayed.

2 MATERIALS AND METHODS

2.1 Geology of the Study Area

The study area is Iperindo in Atakunmosa East Local Government Area, Ilesa, Osun State (Figure 1). The area covers 238 km^2 and its geographical coordinates are $7^0$30' N and $4^0$49'E. The town is within the Precambrian Basement Complex of Southwestern, Nigeria, which is predominantly composed of migmatite, granitic, gnesis, quartzite and so on.

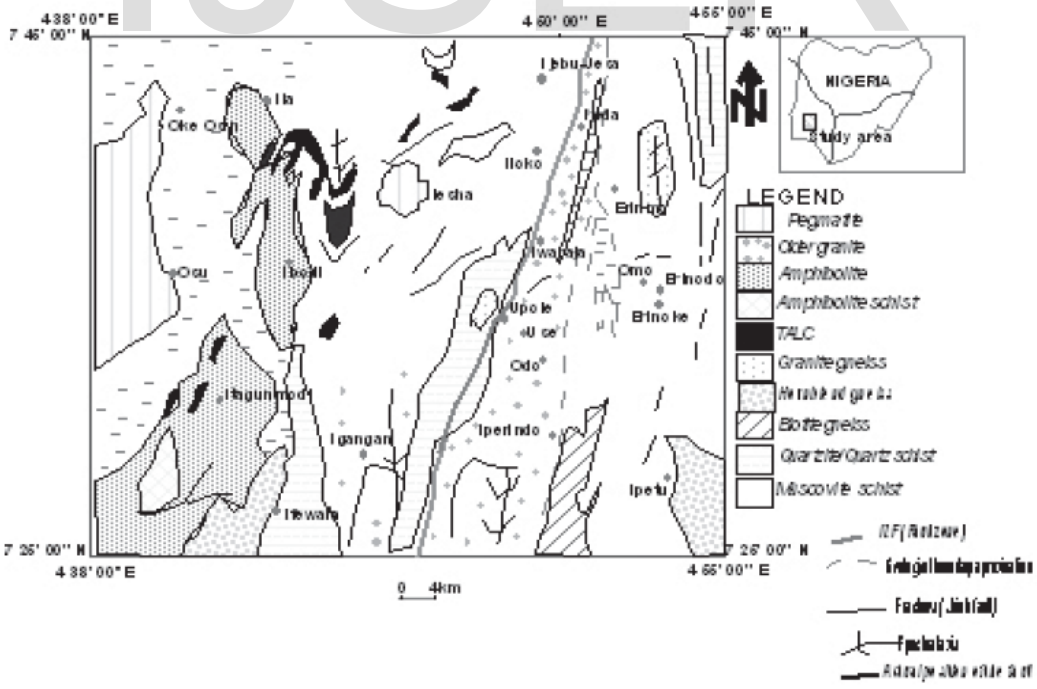

Figure 1: Map showing the location of the study area.

2.2 Sampling and Sample Preparation

The study area was stratified into two parts. The first part is where the mining activities are done. The second part is where farming activities takes place. This was done so as to have a good representative sampling of the area. Thirty soil samples were collected from each of the part to make a total of sixty samples. The samples were collect at depths ranging from 5 cm to 20 cm using a soil auger. Each sample collected was packed in a black polypropylene nylon, and were taken to the laboratory for further analysis. In the laboratory, the samples were air-dried at room temperature to remove the moisture content, pulverized and sieved through a 2 mm mesh. Thereafter, they were each packed in a plastic container that matches the geometry of the detector to be employed for gamma analysis and hermetically sealed for twenty eight days in order to attain radioactive secular equilibrium between radon and its decay products.

2.3 Sample Measurement

The samples were counted for a period of 36000 s, using a gamma spectrometry system with NaI(TI) as the detector. The scintillation detector, a 3x3 inch NaI(TI), product of Princeton Gamma Tech., USA was placed in a lead shield to reduce the effect of background radiation. Prior to the sample measurement, an empty container of the same geometry of the detector was counted for the same duration of time in order to determine the background gamma ray distribution. The gamma energies used for the estimation of radionuclide concentrations were ^{40}K at 1460.8 keV, ^{214}Bi at 1764.5 keV for ^{238}U and ^{208}Tl at 2614.7 keV for ^{232}Th. The samples activity concentration A (Bqkg^{-1}) was determined using Equation 1:

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

Where C_{net} is the net peak area, Pγ is the absolute gamma ray emission probability, ε is the full energy peak efficiency of the detector, t is the counting time, and m is sample mass.

2.4 Estimation of Radiological Parameters

The contribution of the primordial radionuclides identified in the samples to the absorbed dose rate due to external exposure (ADRA) was evaluated from the activity concentration of the radionuclide determined using Equation 2:

$$ADRA\ (\text{nGy}h^{-1}) = C_U A_U + C_{Th} A_{Th} + C_K A_K \quad (2)$$

Where C_U = 0.462, C_{Th} = 0.604, and C_K = 0.042 are the dose conversion factors and A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively (UNSCEAR, 2008).

The annual effective dose equivalent (AEDE) due to the radionuclides detected in the soil samples was estimated using Equation 3:

$$AEDE(\mu\text{Sv}y^{-1}) = ADRA \times O_f \times C_c \times T \quad (3)$$

Where ADRA is the absorbed dose rate due to external exposure, O_f is the outdoor occupancy factor (0.2), C_c is the dose conversion coefficient (0.7 SvGy^{-1}) and T is the time of exposure for a year (8760 h) (UNSCEAR, 2000).

Radium equivalent activity (Ra_{eq}) is used to assess the different mixtures of environmental materials and hazards associated with radionuclide contained in the soil samples when used as part of building materials. The radium equivalent measured in Bqkg^{-1} was calculated using Equation 4. (EC, 1999), where A_U, A_{Th} and A_K are as already define.

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \quad (4)$$

The hazard indices were also evaluated so as to quantify the external gamma radiation dose. It is a safety criterion for materials used for building purposes. External hazard index (H_{ex}) was calculated using Equation 5:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

The internal hazard index (H_{in}) further quantify the internal exposure to radon and its decay products when samples are used as part of building materials, and this was determined using Equation 6:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

The excess lifetime cancer risk (ELCR), a radiological indicator that quantifiestheprobabilityofdevelopingcanceroveralifeti meatagivenexposurelevelfrom the ingestion or inhalation of radionuclides. This was determined using Equation 7:

$$ELCR = AEDE \times D_l \times R_f \quad (7)$$

Where D_l is the average duration of life (70 y), and R_f is the risk factor (0.05 Sv^{-1}) obtain from ICRP (2007).

3 Results and Discussion

Tables 1 and 2 presents the results obtained for the radionuclides identified and activity concentrations in the analysed samples for both the gold mining and farming areas. The radionuclide detected are the singly occurring non series ^{40}K and decay series of ^{238}U, ^{232}Th, all of which belongs to the natural radionuclides. No artificial radionuclide was detected in all the samples assay. The values obtained for the activity concentration at the gold mining area range from 56.10 to 911.30 $Bqkg^{-1}$ with a mean value of 470.50 ± 12.10 $Bqkg^{-1}$ for ^{40}K, 8.50 to 90.10 $Bqkg^{-1}$ with a mean value of 41.50 ± 4.60 $Bqkg^{-1}$ for ^{238}U and 12.30 to 61.80 $Bqkg^{-1}$ with a mean value of 39.70 ± 2.70 $Bqkg^{-1}$ for ^{232}Th.The activity concentration at the farming area range from 60.92 to 213.06 $Bqkg^{-1}$ with a mean value of 137.05 ± 11.79 $Bqkg^{-1}$ for ^{40}K, 5.18 to 23.32 $Bqkg^{-1}$ with a mean value of 13.14 ± 2.42 $Bqkg^{-1}$ for ^{238}U and 5.68 to 38.35 $Bqkg^{-1}$ with a mean value of 17.34 ± 2.92 $Bqkg^{-1}$ for ^{232}Th.The results showed that the activity concentrations of the radionuclides obtained in the gold mining area are higher than that obtained from the farming area. This may be due to the distribution of radioactive dust generated from the mining processes and other related practices as residues due to conventional mining operations increases the concentrations of materials with enhanced levels of NORM (UNSCEAR, 2008).The variation may also be attributed to the geological and geographical formation of the Earth's crust that form part of the gold mining and farming area of Iperindo. The mean activity concentration obtained for the gold mining area are higher than the recommended mean of 420 $Bqkg^{-1}$, 33 $Bqkg^{-1}$ and 45 $Bqkg^{-1}$ for ^{40}K, ^{238}U and ^{232}Th respectively (UNSCEAR, 2000; 2008). Table 3 and Figure 2 present the comparison of the activity concentrations of the radionuclide identified in the present study with results obtained in similar study by researchers from other parts of the country and the world average.

The various radiological parameters estimated due to the activity concentration of the identified radionuclide in the soil samples are presented in Tables 4 and 5 for both the gold mining and farming areas. The estimated ADRA values for the gold mining area range from 29.76 to 99.30 $nGyh^{-1}$ with a mean value of 62.88 ± 4.25 $nGyh^{-1}$, while that of the farming area range from 14.00 to 37.17 $nGyh^{-1}$ with a mean value of 22.30 ± 3.37 $nGyh^{-1}$. The mean value obtained at the gold mining area is higher than the 59 $nGyh^{-1}$ reported by UNSCEAR (2008) and that of the farming area are found below the international value. The estimated AEDE for the gold mining area range from 36.49 to 121.81 μSvy^{-1} with a mean value of 77.11 ± 5.21 μSvy^{-1}, while that of the farming area range from 17.17 to 45.58 μSvy^{-1} with a mean value of 27.35 ± 4.14 μSvy^{-1}. The mean value obtained at the gold mining area is also higher than the 70 μSvy^{-1} obtained by UNSCAR (2000) and that of the farming area is less than the international value.

The values obtained for Ra_{eq} at the gold mining area range from 64.18 to 206.24 $Bqkg^{-1}$ with a mean value of 134.42 ± 9.36 $Bqkg^{-1}$. The obtained values for H_{ex} and H_{in} range from 0.17 to 0.56 $Bqkg^{-1}$ with a mean value of 0.36 ± 0.03 $Bqkg^{-1}$ and 0.22 to 0.80 $Bqkg^{-1}$ with a mean of 0.48 ± 0.04 $Bqkg^{-1}$ respectively. For the farming area, the Ra_{eq} values obtained range from 30.26 to 83.97 $Bqkg^{-1}$ with a mean value of 48.49 ± 7.50 $Bqkg^{-1}$. The obtained values for H_{ex} and H_{in} range from 0.08 to 0.23 $Bqkg^{-1}$ with a mean value of 0.13 ± 0.02 $Bqkg^{-1}$ and 0.10 to 0.29 $Bqkg^{-1}$ with a mean of 0.17 ± 0.03 $Bqkg^{-1}$ respectively.–The mean values obtained show that the radiation dose expected to be delivered both externally and internally to the occupants where these soil samples are used as part of building material does not exceed 370 $Bqkg^{-1}$ for Ra_{eq} and 1 $Bqkg^{-1}$ for H_{ex} and H_{in} as the recommended value (EC, 1999).The probability of any worker contracting cancer over a lifetime of exposure to radiation by the residents is therefore minimal, as the mean ELCR values at both the gold mining ($2.69 \pm 0.18\,x\,10^{-4}$) and farming area ($0.96 \pm 0.15\,x\,10^{-4}$) is lower than $1\,x\,10^{-4}$ recommended by international bodies.

Conclusion

The assessment of enhanced levels of NORM in soil samples from Iperindo have been studied using a well calibrated NaI(Tl) gamma ray spectrometry. The radionuclide detected are the singly occurring non

series ^{40}K and decay series of ^{238}U, ^{232}Th, all of which belongs to the natural radionuclides. No artificial radionuclide was detected in all the samples assayed. The results obtained showed that the distribution of natural radionuclides in the soil samples was not uniform. The mean activity concentrations obtained at the gold mining area are 470.50 $Bqkg^{-1}$, 41.50 $Bqkg^{-1}$ and 39.70 $Bqkg^{-1}$ while 137.05 $Bqkg^{-1}$, 13.14 $Bqkg^{-1}$ and 17.34 $Bqkg^{-1}$ were obtained at the farming area for ^{40}K, ^{238}U and ^{232}Th respectively. The results of the mean activity concentrations of ^{238}U and ^{40}K in the mining sites are higher than the world average and lower for the farming area. The mean ADRA and AEDE obtained are higher when compared with the world average. The mining activities in Iperindo may be considered to constitute radiological hazard to the local residents due to high concentration of uranium.

Table1: Activity concentrations ($Bqkg^{-1}$) of the radionuclides identified in the gold mining areas of Iperindo.

Sample Spot	^{40}K	^{238}U	^{232}Th
SP1	203.54 ± 22.01	18.15 ± 2.31	21.23 ± 3.54
SP2	445.21 ± 25.45	23.42 ± 2.15	12.25 ± 1.35
SP3	414.42 ± 4.61	30.31 ± 2.96	53.09 ± 2.02
SP4	613.06 ± 10.10	19.11 ± 7.76	52.48 ± 1.02
SP5	513.06 ± 7.93	50.12 ± 6.60	44.04 ± 2.28
SP6	256.12 ± 5.06	80.25 ± 1.03	52.14 ± 7.14
SP7	911.25 ± 28.23	90.13 ± 3.42	32.13 ± 5.45
SP8	271.22 ± 7.93	50.74 ± 5.32	35.91 ± 1.25
SP9	399.11 ± 8.63	43.32 ± 6.56	50.81 ± 3.71
SP10	379.28 ± 11.26	48.61 ± 9.24	28.32 ± 3.48
SP11	560.92 ± 15.33	65.21 ± 10.01	38.28 ± 3.51
SP12	234.05 ± 3.57	11.35 ± 1.73	46.55 ± 2.62
SP13	613.06 ± 7.93	60.12 ± 6.60	54.04 ± 2.28
SP14	277.13 ± 2.33	29.46 ± 0.57	48.68 ± 1.17
SP15	497.35 ± 8.65	23.93 ± 4.43	44.80 ± 1.22
SP16	690.66 ± 9.48	51.43 ± 7.76	52.06 ± 0.79
SP17	417.88 ± 6.53	10.19 ± 1.96	40.59 ± 1.84
SP18	498.61 ± 5.02	28.67 ± 3.45	15.35 ± 2.35
SP19	610.63 ± 20.15	8.54 ± 7.25	40.35 ± 5.28
SP20	583.51 ± 19.95	10.19 ± 3.59	61.75 ± 1.02
SP21	389.31 ± 16.25	50.28 ± 1.64	29.56 ± 2.17
SP22	600.17 ± 23.34	60.24 ± 4.65	18.32 ± 2.51
SP23	590.61 ± 1 6.23	51.05 ± 1.42	30.08 ± 3.21
SP24	540.52 ± 25.12	58.93 ± 6.48	27.61 ± 1.02
SP25	505.32 ± 17.02	55.34 ± 1.02	26.54 ± 2.27

SP26	479.53 ± 6.85	32.09 ± 1.05	34.02 ± 2.10
SP27	523.06 ± 6.93	45.12 ± 7.60	46.04 ± 2.28
SP28	389.11 ± 7.63	25.32 ± 4.56	52.81 ± 3.71
SP29	281.21 ± 5.39	51.72 ± 6.22	45.91 ± 4.10
SP30	625.06 ± 12.39	61.12 ± 8.60	54.04 ± 3.28
Range	**56.10 - 911.30**	**8.50 - 90.10**	**12.30 - 61.80**
Mean	**470.50 ± 12.20**	**41.50 ± 4.60**	**39.70 ± 2.70**

Table 2: Activity concentrations ($Bqkg^{-1}$) of the radionuclides identified in the farming area of Iperindo

Farming Spot	^{40}K	^{238}U	^{232}Th
FS1	112.82 ± 12.14	10.82 ± 1.9	12.13 ± 2.43
FS2	170.5 ± 16.00	7.15 ± 0.41	17.35 ± 2.57
FS3	85.53 ± 2.24	22.54 ± 3.86	38.35 ± 6.16
FS4	201.53 ± 23.12	10.51 ± 2.33	21.22 ± 3.35
FS5	150.45 ± 16.53	16.23 ± 2.14	25.25 ± 2.77
FS6	102.82 ± 8.04	6.28 ± 1.87	11.23 ± 1.78
FS7	156.45 ± 13.50	7.55 ± 0.56	19.15 ± 3.75
FS8	72.35 ± 4.42	21.54 ± 3.68	34.53 ± 5.16
FS9	211.54 ± 23.12	11.51 ± 3.23	19.22 ± 2.87
FS10	145.54 ± 14.35	12.31 ± 2.41	23.51 ± 1.97
FS11	92.31 ± 3.24	19.34 ± 2.65	20.19 ± 3.17
FS12	185.35 ± 21.01	9.23 ± 1.45	15.35 ± 2.33
FS13	135.34 ± 15.23	22.32 ± 2.41	17.15 ± 1.97
FS14	165.51 ± 16.68	6.13 ± 0.52	16.43 ± 2.81
FS15	81.35 ± 4.24	12.54 ± 2.86	32.51 ± 3.68
FS16	190.32 ± 18.13	10.11 ± 2.56	19.43 ± 3.08
FS17	155.04 ± 17.98	13.37 ± 2.81	27.03 ± 2.12
FS18	122.28 ± 7.04	5.18 ± 2.78	21.23 ± 1.78
FS19	156.45 ± 13.50	7.55 ± 0.56	19.15 ± 3.75
FS20	125.21 ± 5.06	12.25 ± 1.03	12.14 ± 3.18
FS21	99.11 ± 8.63	23.32 ± 6.56	8.81 ± 3.71
FS22	119.28 ± 10.26	18.61 ± 4.24	6.32 ± 3.48
FS23	60.92 ± 15.33	15.21 ± 5.01	9.28 ± 3.51
FS24	134.05 ± 3.57	11.35 ± 1.73	11.55 ± 2.62

FS25	213.06 ± 7.93	9.12 ± 2.14	14.04 ± 2.28
FS26	97.13 ± 2.33	18.46 ± 0.57	5.68 ± 1.17
FS27	95.53 ± 2.24	15.54 ± 3.86	9.35 ± 2.23
FS28	205.53 ± 23.12	10.51 ± 2.33	11.22 ± 3.35
FS29	165.45 ± 16.53	16.23 ± 2.14	12.25 ± 2.77
FS30	102.82 ± 8.04	13.28 ± 1.87	9.23 ± 1.78
Range	**60.92 - 213.06**	**5.18 - 23.32**	**5.68 - 38.35**
Mean	**137.05 ± 11.79**	**13.14 ± 2.42**	**17.34 ± 2.92**

Table 3: Comparison of mean activity concentrations ($Bqkg^{-1}$) obtained with that obtained in similar studies

References	Country	^{40}K	^{238}U	^{232}Th
UNSCEAR, 2000	World	420.00	33.00	45.00
Ademola and Ademonehin, 2010	Nigeria	240.20	13.3	40.0
Ademola and Obed, 2012	Nigeria	384.20	39.80	17.70
Innocent *et al.*, 2013	Nigeria	426.50	12.10	60.10
Present study (2019)	Nigeria	**470.60**	**41.50**	**39.70**

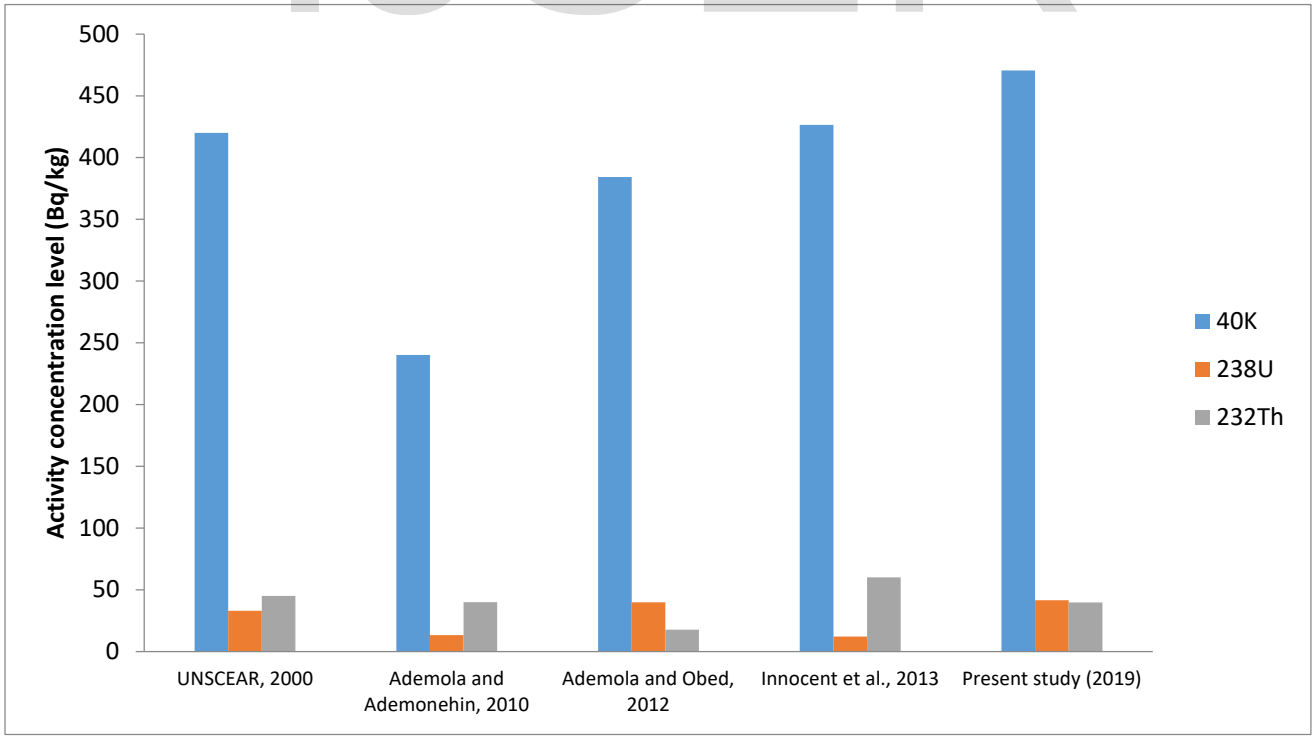

Figure 2: Chart showing the comparison of the mean activity concentration level obtained in the present study to that of similar studies.

Table 4: Estimated radiological parameters for the gold mining area of Iperindo

Sample Spot	ADRA (nGyh^{-1})	AEDE (μSvy^{-1})	Ra_{eq} ($Bqkg^{-1}$)	H_{ex} ($Bqkg^{-1}$)	H_{in} ($Bqkg^{-1}$)	ELCR ($x10^{-4}$)
SP1	29.76 ± 4.13	36.49 ± 5.07	64.18 ± 9.07	0.17 ± 0.02	0.22 ± 0.03	1.28 ± 0.18
SP2	36.92 ± 2.88	45.28 ± 3.53	75.22 ± 6.04	0.20 ± 0.02	0.27 ± 0.02	1.59 ± 0.12
SP3	63.48 ± 2.78	77.85 ± 3.41	138.14 ± 6.20	0.37 ± 0.02	0.45 ± 0.02	2.72 ± 0.12
SP4	66.28 ± 4.63	81.27 ± 5.67	141.36 ± 10.00	0.38 ± 0.03	0.43 ± 0.05	2.84 ± 0.20
SP5	71.30 ± 4.76	87.45 ± 5.84	152.60 ± 11.69	0.41 ± 0.03	0.55 ± 0.05	3.06 ± 0.21
SP6	70.93 ± 5.03	86.78 ± 6.94	159.13 ± 11.69	0.43 ± 0.03	0.65 ± 0.03	3.04 ± 0.22
SP7	99.32 ± 6.06	121.81 ± 7.43	206.24 ± 13.39	0.56 ± 0.04	0.80 ± 0.05	4.26 ± 0.26
SP8	56.52 ± 3.55	69.32 ± 4.35	122.98 ± 7.72	0.33 ± 0.02	0.47 ± 0.04	2.42 ± 0.15
SP9	67.47 ± 5.63	82.74 ± 6.91	146.71 ± 12.53	0.40 ± 0.03	0.51 ± 0.05	2.49 ± 0.24
SP10	55.49 ± 6.84	68.06 ± 8.39	118.31 ± 15.08	0.32 ± 0.04	0.45 ± 0.07	2.38 ± 0.29
SP11	76.81 ± 7.39	94.20 ± 9.06	163.14 ± 16.21	0.44 ± 0.04	0.62 ± 0.07	3.30 ± 0.32
SP12	43.23 ± 2.53	52.97 ± 3.14	95.94 ± 5.75	0.26 ± 0.02	0.66 ± 0.02	1.85 ± 0.11
SP13	86.16 ± 4.76	105.67 ± 5.84	184.60 ± 10.47	0.50 ± 0.03	0.66 ± 0.05	3.70 ± 0.20
SP14	54.65 ± 1.07	67.03 ± 1.31	120.41 ± 2.42	0.33 ± 0.01	0.40 ± 0.01	2.35 ± 0.05
SP15	59.00 ± 3.15	72.36 ± 3.86	126.29 ± 6.84	0.34 ± 0.02	0.41 ± 0.03	2.53 ± 0.13
SP16	84.21 ± 4.46	103.28 ± 5.47	179.06 ± 9.62	0.48 ± 0.03	0.62 ± 0.05	3.61 ± 0.19
SP17	46.78 ± 2.29	57.37 ± 2.81	100.41 ± 5.09	0.27 ± 0.01	0.30 ± 0.02	2.01 ± 0.10
SP18	43.46 ± 3.22	53.30 ± 3.95	89.01 ± 7.20	0.24 ± 0.02	0.32 ± 0.03	1.86 ± 0.13
SP19	53.96 ± 7.38	66.18 ± 9.06	113.26 ± 16.35	0.31 ± 0.04	0.33 ± 0.06	2.32 ± 0.32
SP20	66.51 ± 3.11	81.57 ± 3.82	143.42 ± 6.58	0.39 ± 0.02	0.41 ± 0.03	2.85 ± 0.13
SP21	57.43 ± 2.75	70.44 ± 3.37	122.53 ± 5.99	0.33 ± 0.02	0.47 ± 0.02	2.47 ± 0.12
SP22	64.10 ± 4.64	78.62 ± 5.69	132.65 ± 10.04	0.36 ± 0.03	0.52 ± 0.04	2.75 ± 0.20
SP23	66.56 ± 3.28	81.62 ± 4.02	139.54 ± 7.26	0.38 ± 0.02	0.51 ± 0.02	2.86 ± 0.14

SP24	66.60 ± 4.66	81.68 ± 5.72	140.03 ± 8.87	0.38 ± 0.03	0.54 ± 0.04	2.86 ± 0.20
SP25	62.82 ± 2.56	77.04 ± 3.14	132.20 ± 9.87	0.36 ± 0.02	0.51 ± 0.02	2.69 ± 0.11
SP26	55. 51 ± 2.04	68.08 ± 2.50	117.66 ± 4.58	0.32 ± 0.01	0.40 ± 0.02	2.38 ± 0.87
SP27	70.62 ± 5.18	86.61 ± 6.35	151.23 ± 11.39	0.41 ± 0.03	0.52 ± 0.05	3.03 ± 0.22
SP28	59.94 ± 4.67	73.50 ± 5.72	130.80 ± 10.45	0.35 ± 0.03	0.42 ± 0.04	2.57 ± 0.20
SP29	63.44 ± 5.62	77.80 ± 6.89	139.04 ± 12.60	0.38 ± 0.03	0.52 ± 0.05	2.72 ± 0.24
SP30	87.13 ± 6.47	106.85 ± 7.94	186.53 ± 14.24	0.50 ± 0.04	0.67 ± 0.06	3.73 ± 0.27
Range	**29.76 – 99.30**	**36.49 – 121.81**	**64.18 – 206.24**	**0.17 – 0.56**	**0.22 – 0.80**	**1.28 – 4.26**
Mean	**62.88 ± 4.25**	**77.11 ± 5.21**	**134.42 ± 9.36**	**0.36 ± 0.03**	**0.48 ± 0.04**	**2.69 ± 0.18**

Table 5: Estimated radiological parameters for the farming area of Iperindo

Farming Spot	**ADRA** $(\mathbf{nGy}h^{-1})$	**AEDE** $(\mu\mathbf{Sv}y^{-1})$	**Ra_{eq}** $(Bqkg^{-1})$	**H_{ex}** $(Bqkg^{-1})$	**H_{in}** $(Bqkg^{-1})$	**ELCR** $(x10^{-4})$
FS1	17.06 ± 2.86	20.92 ± 3.50	36.85 ± 6.31	0.10 ± 0.02	0.13 ± 0.02	0.73 ± 0.12
FS2	20.94 ± 2.41	25.69 ± 2.96	45.09 ± 5.32	0.12 ± 0.01	0.14 ± 0.02	0.90 ± 0.10
FS3	37.17 ± 5.60	45.58 ± 6.87	83.97 ± 12.84	0.23 ± 0.03	0.29 ± 0.05	1.60 ± 0.24
FS4	26.14 ± 4.09	32.05 ± 4.99	56.37 ± 8.90	0.15 ± 0.02	0,18 ± 0.03	1.12 ± 0.18
FS5	29.07 ± 3.36	35.65 ± 4.12	63.92 ± 7.37	0.17 ± 0.02	0.22 ± 0.03	1.25 ± 0.15
FS6	14.00 ± 2.27	17.17 ± 2.79	30.25 ± 5.03	0.08 ± 0.01	0.10 ± 0.02	0.60 ± 0.01
FS7	21.63 ± 3.09	26.52 ± 3.79	46.98 ± 6.96	0.13 ± 0.02	0.15 ± 0.02	0.93 ± 0.13
FS8	33.85 ± 5.00	41.50 ± 6.13	76.49 ± 11.40	0.21 ± 0.03	0.26 ± 0.04	1.45 ± 0.21
FS9	25.81 ± 4.19	31.65 ± 5.14	55.28 ± 9.11	0.15 ± 0.03	0.18 ± 0.03	1.11 ± 0.18
FS10	26.00 ± 2.90	31.88 ± 3.56	57.14 ± 6.33	0.15 ± 0.02	0.19 ± 0.02	1.12 ± 0.12
FS11	25.01 ± 3.27	30.66 ± 4.01	55.32 ± 7.43	0.15 ± 0.02	0.20 ± 0.03	1.07 ± 0.14
FS12	21.32 ± 2.95	26.14 ± 3.62	45.45 ± 6.40	0.12 ± 0.02	0.15 ± 0.02	0.92 ± 0.12
FS13	26.35 ± 2.94	32.32 ± 3.60	57.27 ± 6.40	0.16 ± 0.02	0.22 ± 0.02	1.13 ± 0.13
FS14	19.71 ± 2.63	24.16 ± 3.23	42.37 ± 5.82	0.11 ± 0.02	0.13 ± 0.02	0.85 ± 0.11
FS15	28.85 ± 3.72	35.37 ± 4.56	65.29 ± 8.45	0.18 ± 0.02	0.21 ± 0.02	0.24 ± 0.16
FS16	24.40 ± 3.80	29.92 ± 4.66	52.55 ± 8.36	0.14 ± 0.02	0.17 ± 0.03	1.05 ± 0.16
FS17	29.01 ± 3.33	35.58 ± 4.08	63.96 ± 7.23	0.18 ± 0.02	0.21 ± 0.03	1.25 ± 0.14
FS18	20.35 ± 2.65	24.95 ± 3.25	44.95 ± 5.87	0.12 ± 0.02	0.14 ± 0.02	0.87 ± 0.11
FS19	21.63 ± 3.09	26.52 ± 3.79	46.98 ± 6.96	0.13 ± 0.02	0.15 ± 0.02	0.93 ± 0.13
FS20	17.33 ± 2.60	21.25 ± 3.19	37.25 ± 5.97	0.10 ± 0.02	0.13 ± 0.02	0.74 ± 0.11
FS21	20.26 ± 5.63	24.84 ± 6.90	43.55 ± 12.53	0.12 ± 0.03	0.18 ± 0.05	0.87 ± 0.24
FS22	17.42 ± 4.49	21.36 ± 5.50	36.83 ± 10.01	0.10 ± 0.03	0.15 ± 0.04	0.75 ± 0.19
FS23	15.19 ± 5.07	18.63 ± 6.23	33.17 ± 11.21	0.09 ± 0.02	0.13 ± 0.04	0.65 ± 0.22

FS24	17.85 ± 2.53	21.89 ± 3.10	38.19 ± 5.75	0.10 ± 0.02	0.13 ± 0.02	0.77 ± 0.11
FS25	21.64 ± 2.69	26.54 ± 3.30	45.60 ± 6.01	0.12 ± 0.02	0.15 ± 0.02	0.93 ± 0.12
FS26	16.04 ± 1.06	19.66 ± 1.31	34.06 ± 2.42	0.09 ± 0.01	0.14 ± 0.01	0.69 ± 0.04
FS27	16.84 ± 3.22	20.65 ± 3.95	36.26 ± 7.22	0.10 ± 0.02	0.14 ± 0.03	0.72 ± 0.14
FS28	20.26 ± 4.07	24.85 ± 4.99	42.38 ± 8.90	0.11 ± 0.02	0.14 ± 0.03	0.87 ± 0.17
FS29	21.85 ± 3.35	26.79 ± 4.11	46.49 ± 7.37	0.13 ± 0.02	0.17 ± 0.03	0.94 ± 0.15
FS30	16.03 ± 2.27	19.66 ± 2.79	34.40 ± 5.03	0.10 ± 0.01	0.13 ± 0.02	0.67 ± 0.10
Range	**14.00 – 37.17**	**17.17 – 45.58**	**30.26 – 83.97**	**0.08 – 0.23**	**0.10 - 0.29**	**0.60 – 1.60**
Mean	**22.30 ± 3.37**	**27.35 ± 4.14**	**48.49 ± 7.50**	**0.13 ± 0.02**	**0.17 ± 0.03**	**0.96 ± 0.15**

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