Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 04-2024
DOI: 10.5281/zenodo.10953095

EVALUATION OF NATURAL RADIOACTIVITY AND HAZARD INDICES IN ITAGUNMODI AND IPERINDO GOLD MINES, OSUN STATE, NIGERIA

KUGBERE EMUMEJAYE *
Department of Physics, Delta State University of Science & Technology, Ozoro, Nigeria.
*Corresponding Author Email: ekugbere@gmail.com

J. A. AMUOFU
Department of Science Laboratory Technology, Delta State University of Science & Technology, Ozoro, Nigeria.

A. O. MUSTAPHA
Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria.

A. M. GBADEBO
Department of Geology, Federal University of Agriculture, Abeokuta, Nigeria.

Abstract

Mining activities worldwide have culminated in the production of large quantities of tailings, which include significant amounts of naturally occurring radionuclides. Hence, this research was done to quantify the levels of radioactivity and hazard indices present in the soil and rock samples from the gold mines located in Itagunmodi and Iperindo, Osun State. Forty samples were collected and analyzed using a well-calibrated NaI(Tl) detector system. The mean radioactivity of 40K, 226Ra, and 232Th in soil samples from the Itagunmodi gold mine were 372.07 ± 24.32, 45.25 ± 4.41, and 155.92 ± 8.78 Bq/kg respectively. The average values (in Bq/kg) for 40K, 232Th, and 226Ra in soil from the Iperindo mine were 1315.79 ± 9.67, 444.28 ± 5.55, and 22.87 ± 3.61, respectively. Whereas for the rock samples, the average values for 40K, 232Th, and 226Ra were 569.41 ± 27.24, 233.30 ± 11.38, and 24.67 ± 5.58, respectively. The hazard indices values suggest that the soil and rock samples from Iperindo exhibit higher average values overall, whereas the E_{eff} values for both mining areas were below the global mean. The findings of this study indicate that there are radiological issues for both the miners and the general population in the vicinity.

Keywords: Gold Mining, Nigeria, Radionuclides, Radioactivity, Soil, Rock.

1. INTRODUCTION

The constant and inevitable exposure of humans to ionizing radiation from environmental sources is an intrinsic characteristic of existence on Earth [1]. The extraction and refinement of natural resources, including coal, gold, petroleum, and others, have been conducted since ancient times and continue to be pursued for the betterment of humanity. While the extraction and refinement of these resources offer advantages to humanity, they have also resulted in detrimental environmental consequences, including air pollution, soil and water contamination, and land degradation [2 – 4]. Globally, the mining business has led to the accumulation of substantial quantities of tailings, which include elevated levels of natural radionuclides. This has raised significant health concerns among the population residing in and around mining sites [5 – 6].

Miners can potentially encounter ionizing radiation, either internally or externally, throughout several phases of mining. The main source of outdoor exposure arises from gamma-emitting radioactive substances that exist in trace quantities in soil and sediment. These radioactive substances largely come from the decay series of 238U and 232Th, as well as 40K. Internal exposures occur when individuals inhale radon, thoron, and other radioactive substances present in the air or take in dust containing these substances [5,7-8]. Individuals residing close to the mining sites may potentially encounter radionuclides, which can infiltrate their bodies via the use of polluted drinking water or the ingestion of contaminated food. Furthermore, the general populace may encounter possible risks due to the utilization of wastes and mining fluids in activities such as construction and irrigation [8-9].

Assessments of the radiological impact on humans caused by natural radioactive elements in mines and the environment have been extensively researched in many countries around the globe [8,10-15]. However, there has been a scarcity of research conducted in this particular field of study. Hence, this study attempts to estimate radiological exposures to individuals dwelling in the area and artisanal miners who have no regard for safety in their operations. Also, this research aimed to evaluate hazard indices arising from the presence of natural radionuclides in the gold mines.

2. MATERIALS AND METHODS

2.1 Location and geology of the study area

The research locations encompass parts of the two Local Government Areas: Atakumosa West and Atakunmosa East. The Itagunmodi and Iperindo gold mining communities are notable in this study area. Smaller villages surround these communities.

Itagunmodi is located in the Nigerian basement complex, specifically in the equatorial rainforest region of Africa, between latitudes 7.5°N and longitude 4.6°E, and latitude 7.60°N and longitude 4.70°E. Different lithologies make up the basement complex: low-grade sediment-dominated schist, polymetamorphic migmatite gneiss with varying compositions, and granitic rocks with varying compositions from sync tectonic to late tectonic [16]. The rock assemblage comprises amphibolites, hornblende gneiss, and granite gneiss. Amphibolite rock types are abundant in the research area, with large areas of dark-colored amphibolites visible in streams and river channels [17]. The soil in these locations is distinctly red because of the presence of hematite and migmatite, which are released during the weathering process of amphibolites and contribute to the formation of the soil.

The mine contains a conspicuous upper stratum distinguished by a profusion of lofty and robust bamboo trees. This layer also includes an evergreen canopy and a highly dense undergrowth composed of crawling and climbing vines.

Situated approximately 18 kilometers south of Ilesa, the Iperindo-odo gold field is accessible to the town via a paved road. It is positioned between latitude 7.45^0 N and longitude 4.80^0 E, and latitude 7.55^0 N and longitude 4.85^0 E.

The primary gold deposit at Iperindo consists of quartz-carbonate veins containing gold, which are concentrated along a secondary fault within biotite gneiss and mica schist. The present description of the goldmine consists of ancient excavations that are arranged in a parallel manner and stretch in a north-northeast orientation. Gold is found in association with pyrite, pyrrhotite, small amounts of chalcopyrite, galena, sphalerite, migmatite, and ilmenite [18].

The gold-field area has a dendritic pattern in its central and western regions. The western highlands serve as the source of multiple tributaries in the area. The rivers Ora, Osun, Owena, Mukuro, and Obudu are among those included. The initial pair of rivers follow a north-western course, serving as offshoots to the Osun and Shasha rivers, respectively. A trench drainage pattern has formed within the subparallel ridges. The main rivers travel in a southern direction, accompanied by smaller tributaries that join them at around 90-degree angles. All the water that flows from this area is channeled towards the Egun and Oni rivers in the western and eastern directions of Iperindo, respectively [19].

2.2 Sample collection and preparation

Forty samples of rock and soil were gathered from various mining sites within the study area. The soil samples were taken on-site at a depth of 5 – 10 cm and stored in plastic containers. Similarly, eleven rock samples were collected at different locations in the Iperindo mine with the aid of a hammer and were each packaged in clean polythene bags. Every sample container was meticulously labeled to guarantee the appropriate handling of the materials. The samples underwent the processes of air-drying, crushing, and homogenization. Subsequently, the specimens were enclosed in containers, securely sealed, and kept for a duration of 30 days to achieve a steady balance between 226Ra and its disintegration byproducts before performing gamma-ray spectrometry.

2.3 Gamma spectroscopy

The soil samples underwent analysis with a meticulously calibrated gamma-ray detector system, specifically the sodium-iodide (thallium-activated) detector. This analysis took place in the Radiation and Health Laboratory, which is part of the Department of Physics at the Federal University of Agriculture, Abeokuta. The counting length was set at 10800 seconds (3 hours). This duration was found to be adequate for the detector to collect a spectrum with clear and well-defined peaks of interest. The Multichannel Analyzer (MCA) technique was employed to compute the areas under each photopeak. These areas correspond to the quantities of radioactive nuclei in a certain sample, measured in counts. The regions of interest were precisely identified based on the spectra and used to compute the complete counts corresponding to the 3 main peaks at 1460 keV, 1764 keV, and 2624 keV for 40K, 214Bi, and 208Tl, respectively. The peaks exhibited energy ranges of 160–190, 200–235, and 295–335 keV, respectively. The count for the background was determined by counting a container that possessed the same dimensions as the ones used for the analysis of the soil and rocks samples, filled with purified water, hermetically sealed, and kept for 30 days. The net area, derived by eliminating the background counts, was associated with the radioactivity concentration of 40K, 232Th, and 226Ra.

2.3.1 Quantification of activity concentration and determination of radiation exposure levels in samples

The radioactivity concentrations of 226Ra and 232Th were determined using the prominent peaks in 1764 keV for 214Bi and 2624 keV for 208Tl, respectively. The equation (1) provides the analytical expression utilized for calculating the radioactivity concentrations in Bq/kg [11,20].

$$A = R/(B * T * S * M) \tag{1}$$

where S is the detection efficiency of the system, A represents radioactivity concentration, R indicates the total count of radionuclides in the samples, B is the probability of γ-ray emission, S is the detection efficiency of the system, T is the duration of sample counting, and M is the mass of sample in kilogram.

2.4 External gamma dose rate in air (D)

D in air, measured one meter from the ground up, for the soil and rock samples were determined by applying Equation (2) to the activity concentrations [1,8].

$$D = X_{Th}.A_{Th} + Y_{Ra}.A_{Ra} + Z_K.A_K \tag{2}$$

The variables ATh, ARa, and AK are the radioactivity concentrations (measured in Bq/kg) of 232Th, 226Ra, and 40K, respectively. The conversion factors for D of 232Th, 226Ra, and 40K are XTh, YRa, and ZK, respectively. The XTh, YRa, and ZK values in nGy/h/Bqkg-1 are 033.3/50, 42.9/100, and 4.2/100, respectively.

2.5 Average annual effective dose (E_{eff})

E_{eff} to the general population, based on D in the air, was determined by utilizing a dose conversion factor of 0.7 Sv/Gy and an outdoor occupancy factor of 0.2 for the exposure to ambient gamma rays, as defined in Equation (3) [1,21].

$$E_{eff} = D \times 8760 \times 0.7 \times 0.2 \times 10^{-6} \tag{3}$$

where E_{eff} is in mSv.

2.6 Radium equivalent activity (REA)

The idea of radium equivalent activity provides a means to quantify the gamma radiation emitted by various combinations of 238U, 232Th, and 40K in a substance [22]. The REA of soil samples, measured in becquerel per kilogram, was evaluated to estimate the possible risk of natural radioactivity that could be in construction materials. This evaluation was done using Equation (4) [1,23-25].

$$REA = G_1 A_{Ra} + G_2 A_{Th} + G_3 A_K \tag{4}$$

where G_1, G_2, and G_3 are 1, 1.43, and 0.077 respectively.

2.7 External hazard index (EHI)

EHI was employed to evaluate the extent of gamma radiation hazard associated with the inherent radionuclides found in certain building materials. The estimate of the eternal hazard index (EHI) is determined by utilizing Equation (5) [26,27].

$$EHI = CF_1 A_{Ra} + CF_2 A_{Th} + CF_3 A_K \qquad (5)$$

where CF_1, CF_2 *and* CF_3 are 1/370, 1/259 and 1/4810 respectively. The external gamma radiation risk is deemed minor when the value of the EHI is below 1.

2.8 Internal hazard index (IHI)

IHI caused by radon and its offspring could pose a significant risk to the respiratory system. It was calculated by utilizing Equation (6) [28].

$$IHI = X_1 A_{Ra} + X_2 A_{Th} + X_3 A_K \qquad (6)$$

where X_1, X_2 and X_3 are 1/185,1/259 and 1/4810 respectively. For the materials obtained from sites to be considered safe for constructing houses, the IHI value must be less than one.

2.9 Gamma index (GAI)

GAI serves as a screening technique to classify construction materials. It is hypothesized that the activity concentrations of 200 Bqkg-1 of 232Th, 300 Bqkg-1 of 226Ra, and 3000 Bqkg-1 of 40K result in equivalent gamma dose rates Equation 7 can be used to compute the gamma index [1,28].

$$GAI = Y_1 A_{Ra} + Y_2 A_{Th} + Y_3 A_K \qquad (7)$$

where Y_1, Y_2 and Y_3 are 1/300,1/200 and 1/3000 respectively.

2.10 Annual gonadal dose equivalent (AGDE)

Equation 8 was used to compute AGDE resulting from the radioactivity of 40K, 226Ra, and 232Th [27].

$$\boldsymbol{AGDE}(\boldsymbol{\mu Svy}^{-1}) = Z_1 A_{Ra} + Z_2 A_{Th} + Z_3 A_K \qquad (8)$$

where Z_1, Z_2 and Z_3 are 3.09,4.18 and 0.314 respectively.

2.11 Excess life-time cancer risk

Equation (9) was utilized to compute the excess life-time cancer risk resulting from the radioactivity of 40K, 226Ra, and 232Th [5,29]

$$\mathrm{ELCR} = E_{eff} * \mathrm{DL} * \mathrm{F} \qquad (9)$$

DL represents the lifespan, which is assumed to be seventy years, and F denotes the likelihood of developing deadly cancer (in Sv^{-1}). For stochastic impacts, the value of F is assumed to be 0.05 for the overall population [30].

3. RESULTS AND DISCUSSION

The results from the analysis of soil samples of gold mining locations in Itagunmodi are shown in Table 1. The average radioactivity level of 226Ra is 45.25 ± 25.29 Bq/kg, with a range of 6.08–60.51 Bq/kg and that of 232Th is 155.92 ± 8.72 Bq/kg, falling within the range of BD–668.93 Bq/kg. Whereas the average radioactivity level of 40K is 372.07 ± 24.32 Bq/kg, with a range of 90.62–886.57 Bq/kg. These values are higher than the global averages of 33 and 45 Bq/kg for 226Ra and 232Th respectively, however, the activity concentrations of these radionuclides are still below the limits of 1000 Bq/kg for 226Ra and 232Th, and 100,000 Bq/kg for 40K in materials such as tailings and soil, which are considered significant [1,31].

Table 2 presents the averages and ranges of radioactivity levels found in soil samples from the gold mining locations in Iperindo. The average radioactivity level of 226Ra is 22.87 ± 3.61 Bq/kg within a range of 2.61–42.17 Bq/kg and that of 232Th is 444.28 ±5.55 Bq/kg within the range of 277.03–716.38 Bq/kg. Similarly, the average radioactivity level of 40K is 1315.79 ± 9.67 Bq/kg within the range of 582.53–1732.55 Bq/kg.

Table 1: Activity levels of radionuclides in soil samples from Itagunmodi and environs

Sample	Activity concentration (Bq/kg)			
	^{40}K	^{226}Ra	^{232}Th	
IG1	446.42 ± 21.19	15.44 ± 4.33	24.41 ± 12.78	
IG2	218.64 ± 26.86	43.99 ± 3.72	64.19 ± 13.07	
IG3	247.87 ± 22.50	52.81 ± 2.69	37.11 ± 11.21	
IG4	357.72 ± 30.86	21.34 ± 5.52	BD	
IG5	362.01 ± 26.06	6.86 ± 1.52	195.10 ± 6.72	
IG6	582.29 ± 18.54	27.02 ± 3.98	113.90 ± 15.20	
IG7	361.06 ± 19.82	36.93 ± 3.52	155.67 ± 20.79	
IT1	284.13 ± 29.30	20.93 ± 5.58	BD	
IT2	219.06 ± 32.99	10.05 ± 6.02	7.06 ± 10.26	
IT3	271.62 ± 27.30	9.53 ± 4.71	100.46 ± 8.87	
IT4	315.98 ± 22.32	15.33 ± 4.06	135.68 ± 6.87	
IT5	886.57 ± 10.94	47.01 ± 4.72	668.93 ± 1.46	
IT6	90.62 ± 46.48	3.00 ± 2.35	107.62 ± 6.23	
IT7	504.28 ± 18.79	11.80 ± 4.39	240.40 ± 5.82	
EE1	383.29 ± 17.69	52.66 ± 7.20	227.85 ± 3.48	
EE2	297.93 ± 25.18	6.08 ± 3.49	121.68 ± 7.20	
EE3	436.72 ± 21.47	13.89 ± 5.85	131.80 ± 9.05	
EE4	431.08 ± 19.54	60.51 ± 5.77	474.78 ± 1.52	
Average	**372.07 ± 24.32**	**45.25 ± 4.41**	**155.92 ± 8.78**	
World Average	**400**	**33**	**45**	**[1]**

BD - Below detection limit; IT – Itagunmodi; EE - Eepe

The levels of 226Ra, 232Th, and 40K are greater than the global averages of 33, 45, and 420 Bq/kg, respectively [1]. However, the levels of activity are below the permissible limitations set by IAEA [31]. These limits are 1000 Bq/kg for 226Ra and 232Th, and 100,000 Bq/kg for 40K in materials that are considered significant.

Table 2 represents the mean and range of activity concentrations found in rock samples collected from the Iperindo gold mines. The average activity concentration of 226Ra is 24.67 ± 5.58 Bq/kg within the range of BD–62.91 Bq/kg. The average activity concentration of 232Th is 233.30 ± 11.38 Bq/kg, with a range of 69.56–622.81 Bq/kg. The average activity concentration of 40K is 569.41 ± 27.24 Bq/kg, with a range of 109.42–2331.81 Bq/kg. The average values of 226Ra, 232Th, and 40K exceed the global average values, but they fall below the acceptable limits of 1000 Bq/kg for 226Ra and 232Th, and 100,000 Bq/kg for 40K [31].

The ratios of the radioactivity concentrations of primordial radionuclides were calculated for the soil and rock samples. The ranges and mean values obtained are presented in Table 3. The ratios ^{226}Ra/^{40}K and ^{232}Th/^{40}K are less than 1, indicating that the activity concentrations of ^{40}K are higher than those of ^{226}Ra and ^{232}Th and, in some cases, several orders of magnitude higher. The ^{232}Th/^{226}Ra ratio is higher than 1 in all the soil and rock samples from both mining sites. For the soil samples, the mean ^{232}Th concentrations are about 3 times higher than the concentrations of ^{226}Ra. This result indicates that ^{232}Th is somewhat enhanced in the soil of the Iperindo mining site when compared with ^{226}Ra. These ratios conform with the reports for the Ijero and Itagunmodi mining sites [5].

The values of absorbed dose rate, annual effective dose, radium equivalent, external hazard index, internal hazard index, GAI, annual gonadal dose equivalent, and excess lifetime cancer risk obtained in this study are presented in Table 4.

The measured D in air of all the examined samples varied between 18.21 and 558.76 nGy/h. The average absorbed dose rates for soil were 130.32 ± 10.15 and 360.46 ± 12.36 nGy/h for Itagunmodi and Iperindo mines, respectively. In Iperindo mines, the average D for rock samples

Table 2: Radioactivity concentrations of 40K, 232Th and 226Ra in soil and rock samples from Iperindo gold mines

Sample	**Activity concentration (Bq/kg)**			
	^{40}K	**^{226}Ra**	**^{232}Th**	
Rock				
RIP 1	109.42 ± 56.21	16.60 ± 6.25	136.69 ± 14.25	
RIP2	130.04 ± 39.49	29.14 ± 4.31	69.56 ± 20.20	
RIP 3	147.03 ± 36.42	30.59 ± 5.07	218.05 ± 12.10	
RIP 4	261.06 ± 28.79	8.88 ± 6.54	200.76 ± 13.15	
RIP 5	478.20 ± 18.62	0.68 ± 0.13	214.99 ± 10.18	
RIP 6	308.37 ± 22.30	37.82 ± 5.61	222.11 ± 9.15	
RIP 7	189.49 ± 43.13	8.87 ± 4.46	152.96 ± 12.89	
RIP 8	615.28 ± 15.05	26.73 ± 4.90	318.73 ± 7.03	
RIP 9	2331.81 ± 4.68	62.91 ± 3.90	622.81 ± 2.90	
RIP 10	1413.50 ± 7.98	21.90 ± 4.77	225.16 ± 11.02	
RIP 11	279.26 ± 26.93	27.21 ± 6.16	184.48 ± 12.32	
Average Soil	**569.41 ± 27.24**	**24.67 ± 5.58**	**233.30 ± 11.38**	
SIP 1	1505.70 ± 8.36	35.89 ± 3.52	512.98 ± 3.99	
SIP 2	1110.22 ± 10.22	4.05 ± 0.65	308.56 ± 7.86	
SIP 3	1170.88 ± 9.86	42.17 ± 4.46	402.12 ± 4.75	

SIP 4	902.79 ± 11.40	19.97 ± 4.67	457.04 ± 5.10	
SIP 5	1720.41 ± 7.29	21.90 ± 6.42	716.38 ± 3.41	
SIP 6	1720.41 ± 7.29	32.04 ± 5.97	694.00 ± 2.85	
SIP 7	1669.47 ± 7.81	2.61 ± 0.56	536.37 ± 4.16	
SIP 8	1062.92 ± 10.48	36.86 ± 3.65	333.98 ± 6.59	
SIP 9	1295.83 ± 8.32	29.62 ± 4.42	277.03 ± 8.13	
SIP 10	1732.55 ± 6.76	9.93± 4.79	330.93 ± 6.42	
SIP 11	582.53 ± 18.61	3.57 ± 0.55	317.71 ± 7.83	
Average	**1315.79 ± 9.67**	**22.87 ± 3.61**	**444.28 ± 5.55**	
World average	400	33	45	[1]

Table 3: Means, ranges, and radioactivity concentration ratios of natural radionuclides in soil and rock samples of Itagunmodi and Iperindo gold mining sites

Radionuclide	**Itagunmodi**		**Iperindo**			
	Soil		**Soil**		**Rock**	
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**
^{226}Ra(Bq/kg)	3.00-60.51	45.25	2.61-42.17	22.87	0.68-62.91	24.67
^{232}Th(Bq/kg)	BD-668.93	155.92	277.03-716.38	444.28	69.56-622.81	233.30
^{40}K(Bq/kg)	90.62-886.57	372.07	582.53-1732.55	1315.79	109.42-2331.81	569.41
^{232}Th/^{226}Ra	BD-35.87	9.60	9.06-205.51	47.59	2.38-316.16	38.05
^{232}Th/^{40}K	BD- 1.19	0.41	0.19-0.55	0.35	0.16-1.48	0.69
^{226}Ra/ ^{40}K	0.02-0.21	0.07	0.0015-0.036	0.02	BD-0.22	0.09

Was 189.85 ± 15.23 nGy/h. The mean D measured for the soil at both mining locations exceeds the global average value of 58 nGy/h for the Earth's crust. The average D in the soil samples from Itagunmodi and Iperindo mining sites is 2.25 and 6.21 times higher than the world average of 58 nGy/h, respectively [1]. The study findings indicate that the soil at the Itagunmodi and Iperindo mining sites exhibited a somewhat elevated amount of radioactivity.

D obtained for all the samples ranged from 0.02 to 0.69 mSvy^{-1}. The average values obtained are 0.16 and 0.44 mSvy-1 for the soil of Itagunmodi and Iperindo mining sites, respectively. The value obtained for rock samples from Iperindo mines is 0.23 mSvy^{-1}. The mean E_{eff} calculated for soil and rock exceed the average yearly effective dose of 0.07 mSvy-1 reported globally for outdoor exposure of the general public [1] but lower than the 0.91 mSvy^{-1} obtained for soils and rocks at a gold mine in Ghana, as documented in literature [11].

The computed radium equivalent activity (REA) for all the samples varied between 37.01 and 1178.80 Bq/kg. The greatest mean equivalent activity of 758.33 ± 21.32 Bq/kg was obtained from the soil samples collected from Iperindo (Table 4). The maximum radium equivalent activity calculated in this study exceeds the upper limit of 370 Bq/kg. In addition, the mean values for soil and rock samples from both mining sites were above the acceptable threshold for soil and rock, except for the soil from the Itagunmodi gold mining site. This reveals that if the soil and rocks of the mining sites are used as house building components, occupants of such buildings may face a substantial radiation health risk [1].

The average value for the external hazard index, which is less than one., indicates no significant radiation health risk arising from soil samples from Itagunmodi, while the means of 2.05 and 1.09 for soil and rock, respectively, from Iperindo mines are greater than unity, which implies a possible health risk. The values obtained in the current study varied between 0.10 and 3.18. It can then be inferred that the radiation hazards at the mining sites in Iperindo can be considered significant.

Table 4: Hazard indices of soil and rock of Itagunmodi and Iperindo gold mining sites

Radiological index	Itagunmodi		Iperindo			
	Soil		Soil		Rock	
	Range	Mean	Range	Mean	Range	Mean
D (nGy/h)	18.21-502.91	130.32	237.59-558.76	360.46	64.29-539.72	189.85
E_{eff} (mSv/y)	0.02-0.62	0.16	0.29-0.69	0.44	0.08-0.67	0.23
REA	37.01-1071.85	276.91	502.75-1178.80	758.33	138.62-1133.08	402.07
EHI	0.10-2.89	0.75	1.36-3.18	2.05	0.37-3.06	1.09
IHI	0.13-3.02	0.82	1.37-3.24	2.11	0.45-3.23	1.15
GAI	0.14-3.08	0.99	1.79-4.23	2.73	0.49-4.10	1.44
AGDE(µSv/y)	129.35-3219.77	846.73	1521.97-3602.35	2337.28	421.64-3529.93	1230.02
ELCR	0.08-2.16	0.56	1.02-2.40	1.55	0.28-2.32	0.81

Similarly, the IHI had values ranging from 0.13 to 3.24. The mean for soil samples from Itagunmodi is 0.82, which is lower than unity, indicating no significant radiation hazard, while 2.11 and 1.15 are the respective means for soil and rock samples from Iperindo mine. The values exceed 1, indicating that if these materials are utilized in construction, they could potentially offer internal risks owing to radon and its offspring [11].

The values obtained for the gamma representative index (GAI) for soil and rock samples varied between 0.14 to 4.23. The average value for soil samples from Itagunmodi is 0.99 ± 0.11, which is below the recommended limit of unity. Hence, the utilization of this soil as a construction material does not pose an identifiable radiation risk. For soil and rock samples from Iperindo mine, the means are 2.73 ± 0.74 and 1.44 ± 0.09, respectively. These results are more than the recommended threshold of unity, suggesting that the utilization of these materials may result in a range of respiratory and exterior ailments [1].

AGDE values were in the range of 129.35 to 3602.35µSv/y. The average value for soil samples from Itagunmodi is 846.73 ± 31.25 µSv/y, exceeding the recommended threshold of 300 µSv/y. The average radiation levels for soil and rock samples obtained from Iperindo mine are 2337.28 ± 26.56 and 1230.02 ± 14.68 µSv/y, respectively. The recorded values above the recommended threshold of 300 µSv/y, indicating a potential risk to the reproductive organs of both miners and individuals residing in the research locations. The calculated excess life cancer risk values in the current study were found to exceed the global average standard of 0.29x10-3. This suggests that individuals exposed to this radiation may have the likelihood of developing cancer over their lifetime due to tissue ionization [1].

4. STATISTICAL ANALYSIS

In this section, further statistical analysis is performed to investigate whether the soil samples from both locations (Itagunmodi and Iperindo) differs statistically. To achieve this, the Minitab statistical software is utilized. In particular, the One-Way Analysis of Variance (ANOVA) was employed to check the significant difference between the soil samples with the radioactivity concentration of ^{40}K, ^{232}Th, and ^{226}Ra in IG, IT and EE environs. On the other hand, the independent sample *t*-test was used to investigate the statistical difference between the rock and soil samples in Iperindo community. The results of the analyses are shown in Tables (5-10) and Figures (3-5).

Table 5: The One-Way ANOVA of the soil samples with the radioactivity concentration of ^{40}K

Null hypothesis:	All means are equal				
Alternative hypothesis:	At least one mean is different				
Significance level:	α = 0.05				
Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	2	1187	593.3	0.02	0.983
Error	15	506999	33799.9		
Total	17	508185			

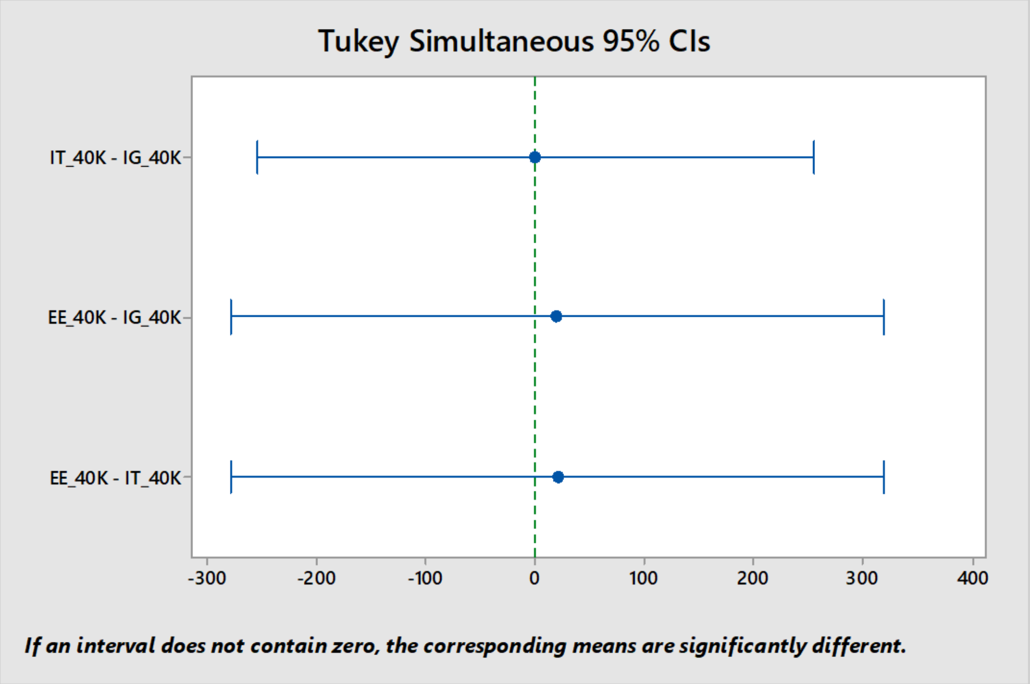

Figure 3: Tukey Simultaneous 95% CIs showing the significant difference between soil samples with the radioactivity concentration of ^{40}K in IG, IT and EE environs

Table 6: The One-Way ANOVA of the soil samples with the radioactivity concentration of ^{226}Ra

Null hypothesis:	All means are equal				
Alternative hypothesis:	At least one mean is different				
Significance level:	α = 0.05				
Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	2	866.3	433.2	1.28	0.306
Error	15	5069.5	338.0		
Total	17	5935.8			

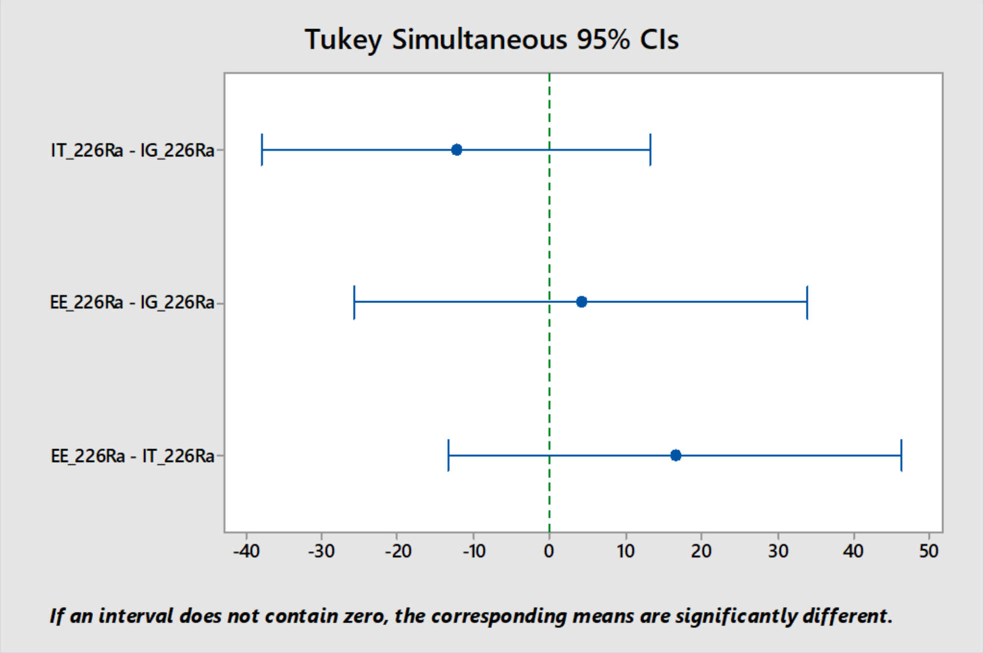

Figure 4: Tukey Simultaneous 95% CIs showing the significant difference between soil samples with the radioactivity concentration of ^{226}Ra in IG, IT and EE environs

Table 7: The One-Way ANOVA of the soil samples with the radioactivity concentration of ^{232}Th

Null hypothesis:	All means are equal				
Alternative hypothesis:	At least one mean is different				
Significance level:	α = 0.05				
Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	2	58964	29482	1.00	0.396
Error	13	384974	29613		
Total	15	443939			

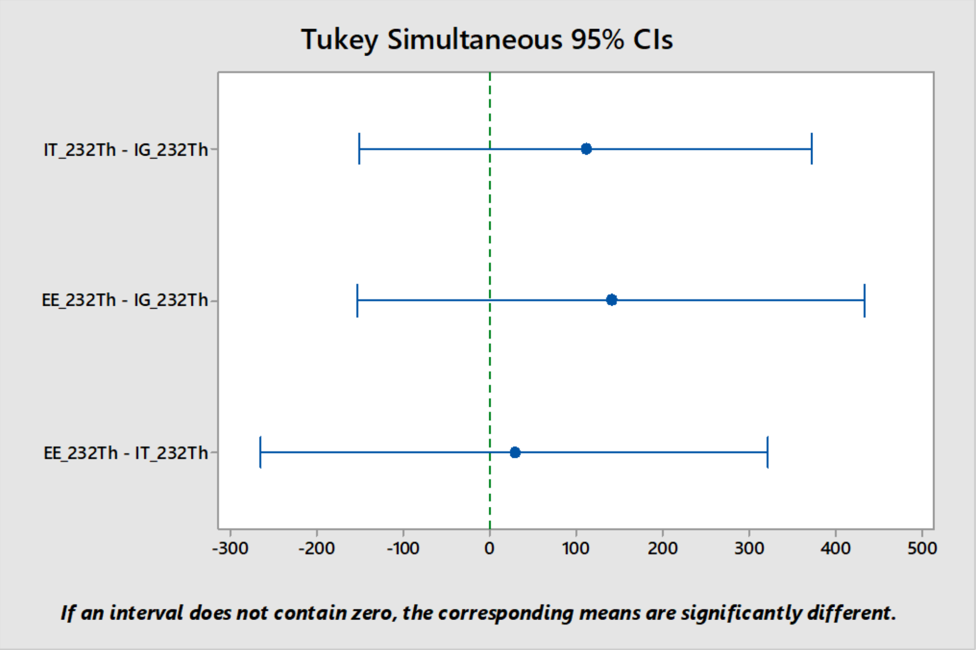

Figure 5: Tukey Simultaneous 95% CIs showing the significant difference between soil samples with the radioactivity concentration of ^{232}Th in IG, IT and EE environs

From Tables 5-7, the ANOVA tables reveal a *p*-value of 0.983, 0.306 and 0.396, for the soil samples with the radioactivity concentration of ^{40}K, ^{226}Ra and ^{232}Th, respectively, at 95% confidence interval. Since the *p*-values are greater than 0.05 alpha level of significance, we do not reject the null hypothesis. Thus, we conclude that there is no significant difference in the means of the soil samples with the radioactivity concentration of ^{40}K, ^{226}Ra and ^{232}Th from IG, IT and EE environs. These results are also validated by the plots of the Tukey simultaneous 95% CIs as shown in Figures 3-5. Since all the intervals in Figures 3-5 contain zero, it suggests that the corresponding means does not differ statistically.

Furthermore, Tables 8-10 show the independent sample t-test for the rock and soil samples with the radioactivity concentration of ^{40}K, ^{226}Ra and ^{232}Th, respectively, in Iperindo Environ

Table 8: Independent Sample T-Test for the rock and soil samples with the radioactivity concentration of ^{40}K in Iperindo Environ

	N	Mean	St Dev	SE Mean
RIP_40K	11	569	693	209
SIP_40K	11	1316	387	117
Difference =		μ (RIP_40K) - μ (SIP_40K)		
Estimate for difference:		-746		
95% CI for difference:		(-1257, -236)		
T-Test of difference = 0 (vs ≠): T-Value = -3.12 P-Value = 0.007 DF = 15				

Table 9: Independent Sample T-Test for the rock and soil samples with the radioactivity concentration of ^{226}Ra in Iperindo Environ

	N	Mean	St Dev	SE Mean
RIP_226Ra	11	24.7	16.9	5.1
SIP_226Ra	11	21.7	14.7	4.4
Difference =		μ (RIP_226Ra) - μ (SIP_226Ra)		
Estimate for difference:		2.97		
95% CI for difference:		(-11.16, 17.11)		
T-Test of difference = 0 (vs ≠): T-Value = 0.44 P-Value = 0.664 DF = 19				

Table 10: Independent Sample T-Test for the rock and soil samples with the radioactivity concentration of ^{232}Th in Iperindo Environ

	N	Mean	St Dev	SE Mean
RIP_232Th	11	233	143	43
SIP_232Th	11	444	155	47
Difference =		μ (RIP_232Th) - μ (SIP_232Th)		
Estimate for difference:		-211.0		
95% CI for difference:		(-344.1, -77.9)		
T-Test of difference = 0 (vs ≠): T-Value = -3.32 P-Value = 0.004 DF = 19				

Tables 8 and 10 revealed that there are significant differences between the rock and soil samples with the radioactivity concentration of ^{40}K and ^{232}Th, since at 95% confidence interval, the *p*-values are less than 0.05 alpha level of significance. Whereas Table 9 indicates that there is no significant difference between the rock and soil samples with the radioactivity concentration of ^{226}Ra, since at 95% confidence interval, the *p*-value is greater than 0.05 alpha level of significance.

5. CONCLUSION

Except in soil samples from Itagunmodi and its environs, the radioactivity levels of 40K, 226Ra, and 232Th radionuclides are higher compared to the global average. Potassium-40 and thorium-232 concentrations in the samples from Iperindo mining site were greater than the world average except for ^{226}Ra. REA, EHI, IHI, ELCR, and GAI were all evaluated and found to have higher average values for soil and rock samples from Iperindo than for soil samples from Itagunmodi mining sites. D, E_{ff}, and AGDE values exceeded the world average values except for E_{ff} values for both mining sites. The hazard indices evaluated in the examined samples exceed the global average. Consequently, the artisanal mining operations will have a detrimental impact on the radiological condition of the environment. Based on the findings of this study, it may be inferred that there are substantial radiological risks to individuals in that area, namely those who are working and living in Iperindo.

Acknowledgement

We wish to thank the Department of Physics, Federal University of Agriculture, Abeokuta for making the Radiation laboratory available for the samples analysis.

References

1) United Nations Scientific Committee on Effects of Atomic Radiation (2000) Dose assessment methodologies UNSCEAR Report to the General Assembly (New York: UNSCEAR).

2) Hilson G. (2002) “An overview of land use conflicts in mining communities”. Land Use Policy, 19, 65-73.

3) Hossain D, Gorman D, Chapelle B, Mann W, Saal R, Penton G. (2013) Impact of the mining industry on the mental health of landholders and rural communities in southwest Queensland. Aust. Psychiatry, 21,32-37.

4) Nakazawa, K., Nagafuchi, O., Kawakami, T., Inoue, T., Yokota, K., Serikawa, Y., Cyio, B. and Elvince, R. (2016) Human health risk assessment of mercury vapor around artisanal small-scale gold mining area, Palu city, Central Sulawesi, Indonesia. Ecotoxicol Environ Saf., 124, 155-162.

5) Isinkaye, O.M. (2013) Natural radioactivity levels and the radiological health implications of tailing enriched soil and sediment samples around two mining sites in Southwest Nigeria. Radiation Protection and Environment, 36(3), 122-127.

6) Paiva, I., Marques, R., Santos, M., Reis, M., Prudêncio, M.I., Waerenborgh, J.C., Dias, M.I., Russo, D., Cardoso, G., Vieira, B.J.C., Carvalho, E., Rosa, C., Lobarinhas, D., Diamantino, C. and Pinto, R. (2019) Naturally occurring radioactive material and risk assessment of tailings of polymetallic and Ra/U mines from legacy sites” Chemosphere, 223, 171-179.

7) UNSCEAR (2008) Sources, effects and risks of ionizing radiation. United Nations Scientific Committee on the effects of Atomic Radiation. Exposures from natural sources, 2000 report to General Assembly, Annex B, New York.

8) Odumo, O.B., Mustapha, A.O., Patel, J.P. and Angeyo, H.K. (2011) Multielemental Analysis of Migori (Southwest, Kenya) Artisanal Gold Mine Ores and Sediments by EDX-Ray Fluorescence Technique: Implications of Occupational Exposure and Environmental Impact, Bull environ Contam Toxicol., 86, 484-489.

9) Odumo, O.B., Mustapha, A.O., Patel J.P. and Angeyo, H.K. (2011b) Energy Dispersive X – Ray Fluorescence Analysis of Mine Waters from The Migori Gold Mining Belt in Southern Nyanza, Kenya, Bull environ Contam Toxicol., 87, 260-271.

10) Mustapha, A.O., Mbuzukongira, P. and Mangala, M.J. (2007) Occupational Radiation Exposure of Artisans Mining Columbite-Tantalite in The Eastern Democratic Republic of Congo, Journal of Radiological Protection, 27, 187-195.

11) Faanu, A, Adukpo, O. K., Tettey-Larbi, L, Lawluvi, H., Kpeglo, D. O, Darko, E. O, Emi-Reynolds, G, Awudu, R. A, Kansaana, C, Amoah, P. A, Efa, A. O, Ibrahim, A. D, Agyeman, B, Kpodzro, R and Agyeman, L. (2016) Natural radioactivity levels in soils, rocks and water at a mining concession of Perseus gold mine and surrounding towns in Central Region of Ghana, SpringerPlus, 98, 1-16

12) Pires, D. O., Rio, M.A., Amaral, E. C. S., Fernandes, H. M. and Rochedo, E. R. R. (2002) Environmental radiological impact associated with non-uranium mining industries: A proposal for screening criteria J. Environ. Radioact., 59, 1-17.

13) Sam, A.K. and Awad, A.A.M.M. (2000) Radiological Evaluation of Gold Mining activities in Ariab (Eastern Sudan), Radiation Protection Dosimetry, 88 (4), 335-340.

14) Darko, E.O., Tetteh, G.K. and Akaho, E.H. (2005) Occupational radiation exposure to norms in a gold mine. Radiat Prot Dosimetry, 114, 538-545.

15) Wymer, D.G. and Botha, J.C. (2001) Managing the environmental impacts of low activity wastes from the South African gold mining industry. Session 51-1. In: Eighth International Conference on Environmental Management, Bruges,Belgium, 30 September-4 October; 2001.

16) Arogunjo, A.M. (2007) Heavy Metal Composition of Some Solid Minerals in Nigeria and their Health Implications to the Environment. Pak J Biol Sci,10, 4438-4443.

17) Oyinloye, O. O. (2012) Geology and Geotectonic Setting of the Basement Complex Rocks in Southwestern Nigeria: Implications on Provenance and Evolution. In: Dar IA, Editor. Earth and Environmental Sciences (online). Rijeka, Croatia: Intech. http://www.scirp.org/journal/jmmce (1 July 2015)

18) TML (Tropical Mines Limited). (1996) A Pre-Investment Study of the Primary Goldmine-Odo Ijesa (Primary) Gold Deposit Report (2), 1-12.

19) Gbadebo, A. M. and Ekwue, Y. A. (2014) Heavy Metal Contamination in Tailings and Rock Samples from an Abandoned Goldmine in Southwestern Nigeria. Environ Monit Assess,186, 165-174.

20) Ebaid, Y.Y. (2010) Use of gamma-ray spectrometry for uranium isotopic analysis of environmental samples. Rom. J Phys ,55(1–2), 69-74.

21) Mehra, R., Singh, S., Singh, K. (2009) Analysis of 226Ra,232Th and 40K in soil samples for the assessment of the average effective dose. Indian J Phys, 83, 1031-1037.

22) Frame, P. 2006. Radium Equivalent (online). Health Physics Society: http//hps.org/.

23) Yasir, M., Ab Majid, A. and Yahaya, R. Study of natural radionuclides and its radiation hazard index in Malaysia building materials. Radioanalytical and Nuclear Chemistry 273 (2007) 539-541.

24) Tawalbeh, A.A., Samat, S.B. and Yasir, M.S. Radionuclides Level and its Radiation Hazard Index in Some Drinks Consumed in the Central Zone of Malaysia. Sains Malaysiana 42(3) (2013) 319-323.

25) Xinwei, L., Lingquig, W., Xiaodan, J., Leipeng, Y. and Gelian, D. Specific activity and hazards of Archeozoic–Cambrian rock samples collected from the Weibei area of Xhaanxi, China. Radiat Prot Dosim 118(3) (2006) 352-359.

26) Beretka, J. and Mathew, P.J. (1985) Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys, 48, 87-95.

27) Tufail, M., Iqbal, M. and Mirza, S. (2000) Radiation Doses due to The Natural Radioactivity in Pakistan Marble. Radioprotection, 35, 299-310.

28) Hasan, M., Chaity, A., Imrose, J., Abu, H.M., Ali, M and Paul, D. (2020) Assessment of Natural Radioactivity and Radiological Analysis of Soil and Brick Samples Used as Building Materials in Bangladesh. Inter J. of Scientific and Engineering Research, 11, 860-869.

29) Asaduzzaman, K.H., Mannan, F., Khandaker, M.U., Farook, M.S., Elkezza, A., Amin, Y.B.M. (2015) Assessment of Natural Radioactivity Levels and Potential Radiological Risks of Common Building Materials Used in Bangladeshi Dwellings. PLoS ONE 10(10).

30) International Commission on Radiological Protection (ICRP). (1991) Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Pergamon Press, Oxford.

31) IAEA (1996) International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of radiation Sources, Safety Series No. 115 (Vienna: IAEA).