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Assessment of radiological risk from the soils of artisanal mining areas of Anka, North West Nigeria

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Assessment of radiological risk was carried out on twenty soil samples collected from agricultural, mining and mine processing areas in Anka, Zamfara State, North Western Nigeria. The measurement of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K was performed using the gamma-ray spectrometer equipped with a high purity germanium detector. The values of the activity concentration of ^{226}Ra ranged from 24.69±4.26 to 82.20±15.62 Bqkg^{-1}, with a mean of 47.06±14.01 Bqkg^{-1}; ^{232}Th ranged from 22.52±3.44 to 159.47±16.81 Bqkg^{-1}, with a mean of 75.97±9.11; while ^{40}K ranged from 27.20±8.03 to 542.64±156.93 Bqkg^{-1}, with a mean of 216.02±62.37 Bqkg^{-1}. The concentration of the Radium equivalent in the study area ranged from 60.41 to 307.30 Bqkg^{-1}, with mean value of 172.33 Bqkg^{-1}. The absorbed dose rate in air was calculated and the values ranged between 26.80 and 135.02 nGyh^{-1}, with a mean of 76.64 nGyh^{-1}. The external hazard index was computed and the values ranged from 0.163 to 0.830, with a mean of 0.465. This value is within the safe limit of 1. The annual effective dose rate was calculated from the activity concentration with the minimum value of 32.87 µSvy^{-1}, while the maximum was 165.58 µSvy^{-1}, with a mean of 93.99 µSvy^{-1}, which is higher than the world average of 80 µSvy^{-1} but less than the recommended annual effective dose safe limit of 1 mSvy^{-1}. Therefore, the soil does not constitute radiological threat to the local population in the environment.

Key Words: Anka, artisanal mining, radioactivity, radiological, radionuclide, soil.

INTRODUCTION

Naturally occurring radionuclides within certain environmental matrix are able to assume hazardous radiological proportions as the activity concentrations of radioactive materials in the Earth's environment vary according to the geological formation. This is largely responsible for the uneven distribution of radionuclides and natural resources in the earth environment. The soil serves as a means of migration for transportation of radionuclides to the environment, it is considered the principal indicator to the radiological contamination in the

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in the environment (Elsaman et al., 2018).

A huge occurrence of about forty to fifty various types of untapped sub-terrain resources buried under the soil in Nigeria has been reported (Merem et al., 2017). Anka, is noted for crude mineral mining and processing by artisans alongside farming and cattle rearing (Salisu et al., 2016; Plumlee et al., 2013). Minerals, such as gold, copper, lead and zinc are mined and pre-processed in Anka and environs. These minerals deposits exist in alluvial and eluvia forms, with some occurring as vein within the meta-sediments of the area. Anka came under the radar following the discovery of rise in ill health and mortality rates amongst children in the isolated communities by health workers in the area. Investigation by Lo et al., (2012), suggested that the mining and processing of lead-rich ore inside villages in Anka led to soil contamination and that the polluted soil and ore dust were probably the main sources of lead exposure affecting children resident in ore-processing villages.

The environment where artisanal mining and processing activities are carried out is considered a major source of exposure to varying degrees of ionizing radiation. This radiation emanates from natural radionuclides present in rocks, soils, plants and water bodies and mining and mineral processing increase the concentration of the end products. The measurement of gamma radiation dose from environmental sources is of significance because radiation of natural origin is the principal contributing factor to the external dose globally (UNSCEAR, 1988).

Therefore, as the spread of radioactive elements in the earth environment is unequal and the concentration enhanced during mining activities, the knowledge of their level of concentration and distribution within the environment plays a major role in radiation safety. This work seeks to evaluate the activity concentrations and absorbed dose from ^{226}Ra, ^{232}Th and ^{40}K in the soils within artisanal mining and processing areas of Anka. It was recommended by Innocent et al., (2013), that periodic radiological assessment of proper radiation monitoring of the mining sites. Apart from complementing the previous findings, the result would be used to assess the radiological risk from natural radionuclides in the study area.

MATERIALS AND METHODS

Study area

With a population of 263,400 (Buba, 2016). Anka falls between latitude $11^0$51′N and $12^0$08′N, and longitude 5°51'E and 6°08'E. (Figure 1). However, samples were collected from mining and mine processing sites in Dareta, Abare, Dan Kampani and Daki Takwas. The Anka River is the main water body in the study area; it lies about one kilometer to the north of the town and numerous seasonal streams dissect the landscape, pouring into the major river, the Anka river (Figure 1).

The geology of Anka is characterized by the Anka schist belt that hosts the lead mineralization, and the lead-copper-silver-gold poly-metallic association. Anka is well known for artisanal gold exploitation for several decades and the mineral is hosted by schists, phyllites and quartzites associated with sub-regional structural elements subsidiary to the Anka fault (Waziri et al., 2013).

Sampling technique and sample preparation

Twenty (20) soil samples were systematically collected within 50 m from mining and mine processing sites as well as agricultural land. The samples were collected at an average depth of 10 cm. The samples were transferred to the Material Science laboratory at the Centre for Energy Research and Training, Zaria, where they were prepared. The samples were dried in an oven at about 120 to 150°C and ground into fine powder, using agate mortar and pestle, made of 99% silica to avoid contamination. The ground sample was sieved to 250 µm. 200 g of the prepared samples was packaged and transferred to the laboratory of National Institute for Radiation Protection and Research for laboratory analysis. The samples were weighed again, packaged and sealed in plastic cylindrical beakers, where they were stored for 28 days to allow for secular equilibrium between ^{238}U and ^{232}Th with their daughters, prior to the analysis.

Sample analysis

Sample analysis was undertaken at the National Institute of Radiation Protection and Research, University of Ibadan, Nigeria. Measurement of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K was carried out with the gamma-ray spectrometer equipped with a high purity germanium (HPGe) detector enclosed in a 10 cm cylindrical multilayer graded shield. The application of this method is based on the secular equilibrium between uranium and thorium with their daughter isotopes. Prior to the sample analysis, the background gamma radiation at the laboratory was measured with an empty sample container under similar environmental conditions. The value was later subtracted during the computation of the activity concentration.

Data analysis

Activity concentration

Calculations of number of counts per second for the photopeak and activity concentrations of each detected radionuclides was based on the concept secular equilibrium being. The activity concentration in Bqkg^{-1} (A) in the samples was obtained as follows (Uosif et al., 2015).

$$A = \frac{N_s}{\varepsilon \eta m} \quad (1)$$

Where, N_s is net counts per second (CPS) = (sample CPS – background CPS), ε is the abundance of the γ-line in a radionuclide, η is the measured efficiency for each gamma-line observed, and the mass of the sample in kilograms is denoted by m.

The 1764.8 keV of ^{214}Bi gamma line was used to determine the activity concentration of ^{226}Ra while the activity concentration of ^{232}Th was determined with 2614 keV of ^{208}Tl gamma line. The gamma line of ^{40}K was determined directly from 1460.8 keV gamma line.

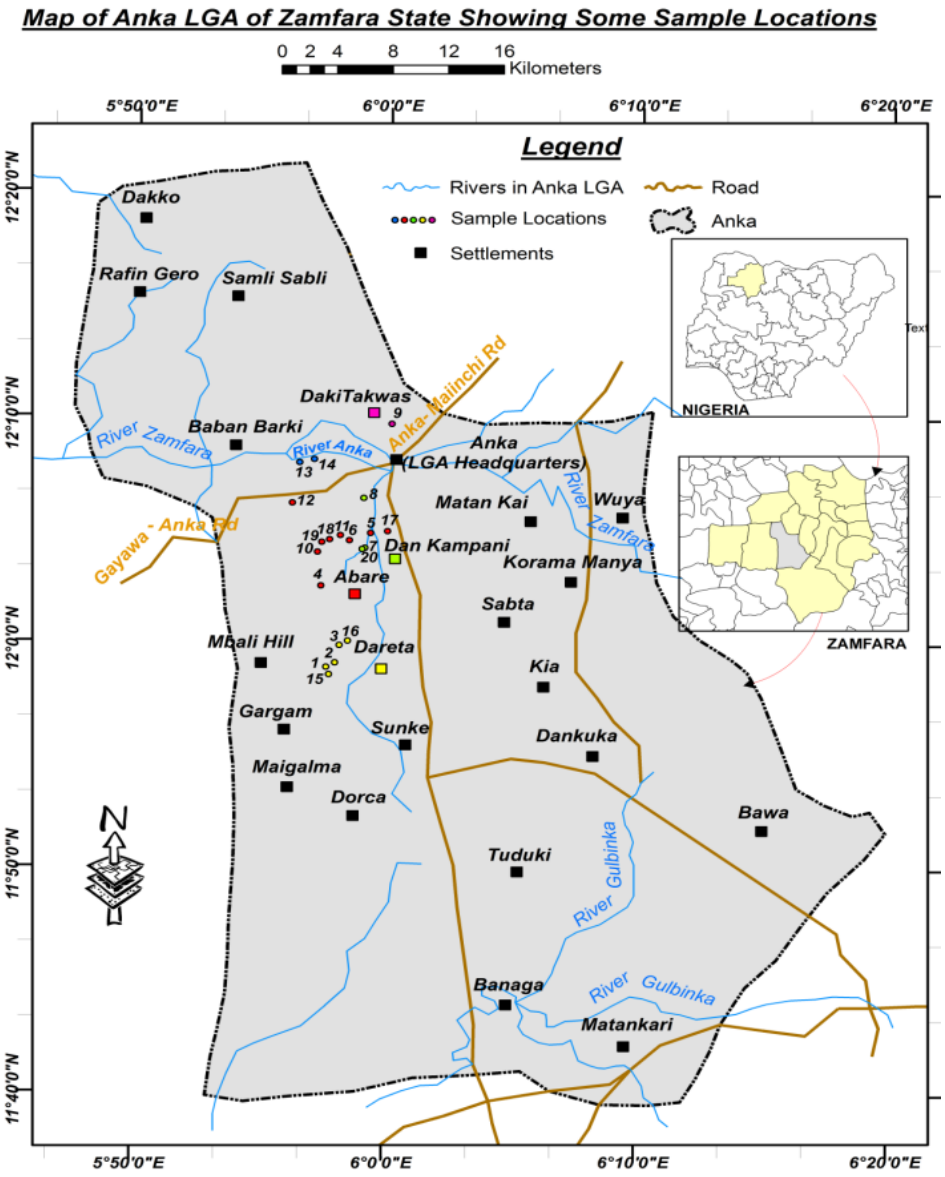

Figure 1. Map of Anka, Zamfara State, North Western Nigeria.

Radium equivalent (*Ra_{eq}*)

The radiological health effect can be determined by evaluating the radium equivalent effect because it is a measure of radiation hazard. This allows for uniformity in terms of radiation exposure and the comparison of the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K (Mohamed et al., 2016; Uosif et al., 2015). Ra_{eq} is evaluated on the basis that the gamma dose rate produced by 370 Bqkg^{-1} of ^{226}Ra, 259 Bqkg^{-1} of ^{232}Th and 4810 Bqkg^{-1} of ^{40}K is the same (Mohamed et al., 2016).

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

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

Calculation of absorbed dose rate (D)

The outdoor absorbed dose rate at a height of 1 m above the ground level from terrestrial sources of gamma radiation can be determined by measuring the specific activity concentrations of the ^{226}Ra, ^{232}Th and ^{40}K in soil samples using the formula (Mohamed et al., 2016)

$$D\ (nGy^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (3)$$

Where, D is given in nGy h^{-1}, A_{Ra}, A_{Th} and A_K are the specific

Table 1. Specific activity, radium equivalent, absorbed dose, Hazard index and annual equivalent dose rate for soil samples from Anka.

Sample code	Activity concentration (Bqkg^{-1})			Ra_{eq} (Bqkg^{-1})	Absorbed dose (nGyh^{-1})	H_{ex}	AEDR (μSvy^{-1})
	^{226}Ra	^{232}Th	^{40}K				
SL1	57.87±14.79	327.06±57.52	361.53±106.56	553.40	239.36±46.02	1.494	293.55
SL2	55.62±15.91	102.61±11.70	542.64±156.93	244.14	110.30±20.96	0.659	135.27
SL3	43.39±13.23	222.67±33.95	1052.34±305.67	442.84	198.42±39.36	1.196	243.34
SL4	31.40±6.29	325.22±45.23	342.19±100.49	522.81	225.21±34.42	1.412	276.20
SL5	26.11±8.19	22.52±3.44	27.20±8.03	60.41	26.80±6.20	0.163	32.87
SL6	24.69±4.26	39.02±7.30	173.55±50.51	93.85	42.21±8.48	0.253	51.77
SL7	54.55±13.80	55.66±7.91	174.39±50.75	147.57	66.09±13.27	0.399	81.06
SL8	42.46±10.58	346.99±50.49	794.38±231.38	599.82	262.32±45.03	1.620	321.71
SL9	60.10±15.03	88.47±11.75	332.73±96.46	212.23	74.31±13.70	0.573	116.60
SL10	47.06±12.79	34.59±4.84	106.52±31.09	104.73	95.08±18.06	0.283	57.73
SL11	28.28±14.27	54.62±7.40	184.79±53.83	104.73	47.08±10.13	0.283	65.93
SL12	34.84±15.35	64.25±8.43	439.55±127.23	120.62	53.76±13.31	0.326	89.81
SL13	54.53±14.51	73.32±8.56	194.63±56.56	160.56	73.23±17.49	0.434	89.81
SL14	53.02±14.32	111.16±11.84	123.70±36.18	174.36	77.59±14.23	0.471	95.16
SL15	75.38±16.72	362.30±35.49	542.16±159.20	221.50	96.79±15.28	0.598	118.71
SL16	31.17±13.82	209.07±36.53	940.66±274.38	635.22	276.26±35.80	1.715	338.81
SL17	17.99±1.24	92.43±12.25	85.91±25.57	402.57	179.90±39.89	1.087	220.63
SL18	23.84±3.48	193.14±25.76	508.27±148.88	156.78	67.72±9.04	0.423	83.05
SL19	51.05±10.69	63.33±8.52	299.24±86.71	339.17	148.87±23.38	0.916	182.57
SL20	18.72±2.02	234.62±32.90	761.69±221.86	164.65	74.31±13.70	0.445	91.14
Min	17.99±1.24	22.52±3.44	27.2±8.03	60.41	23.05±2.99	0.163	32.87
Max	75.38±16.72	362.30±57.52	1052.34±305.67	635.22	297.54±55.21	1.715	338.81
Mean	41.60±11.06	151.15±21.09	380.34±116.41	273.10	121.78±21.89	0.737	149.29

activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

External hazard index (H_{ex})

The external hazard index (H_{ex}) is widely used to reflect external exposure. It provides a solitary index that expresses the gamma yield from various combinations of ^{226}Ra, ^{232}Th and ^{40}K in the sample. It is defined as follows (Mohamed et al., 2016)

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

Annual effective dose rate (AEDR)

The Annual effective dose rate (μSv y$^{-1)}$ was computed as described by Mohamed et al., (2016). The evaluation of year-long effective dose rates, the conversion factor from absorbed dose in air to the effective dose (0.7 SvGy^{-1}) and outdoor occupancy factor (0.2) given by Durusoy and Yildirim (2017) and Mohamed et al. (2016).

$$\text{AEDR}\ (\mu Svy^{-1}) = D(\text{nGyh}^{-1}) \text{x}\ 8760\ (\text{hy}^{-1})\ \text{x}\ 0.14\ (\text{SvGy}^{-1})\ \text{x}\ 10^{-3} \quad (5)$$

RESULTS AND DISCUSSION

The measurement of the radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected from Anka was determined using the HPGe detector. These values including the Ra_{eq}, D, H_{ex} and *AEDR* are presented on Table 1. The values of the activity concentration of ^{226}Ra ranged from 17.99±1.24 (Abare) to 75.38±16.72 (Dareta) Bqkg^{-1}, with a mean of 41.60±11.06Bqkg^{-1}.

^{232}Th ranged from 22.52±3.44 Bqkg^{-1} (Abare) to 362.30±57.52 Bqkg^{-1} (Dareta), with a mean of 151.15±21.09; while ^{40}K ranged from 27.20±8.03 (Abare) to 1052.34±305.67Bqkg^{-1} (Dareta), with a mean of 380.34±116.41Bqkg^{-1}.

A summary of the activity concentraction of ^{226}Ra, ^{232}Th and ^{40}K is presented in Figure 2. Dareta accounted for the highest concentrations of ^{226}Ra, ^{232}Th and ^{40}K while Abare recorded the least values. Analysing the results obtained in this study, the mean activity concentrations for ^{226}Ra and ^{232}Th are higher than the world average of 35 Bqkg^{-1} and 30 Bqkg^{-1}, respectively (UNSCEAR, 2000).

The mean activity concentration of ^{40}K is lower than the world average of 400 Bqkg^{-1} (UNSCEAR, 2000). This generally suggests that the radioactivity concentration in the study area is higher than the world average.

The Ra_{eq} in the study area ranges from 60.41 to 635.22 Bqkg^{-1}, with mean value of 273.10 Bqkg^{-1}, which falls below the permissible limit of 370 Bqkg^{-1} set by

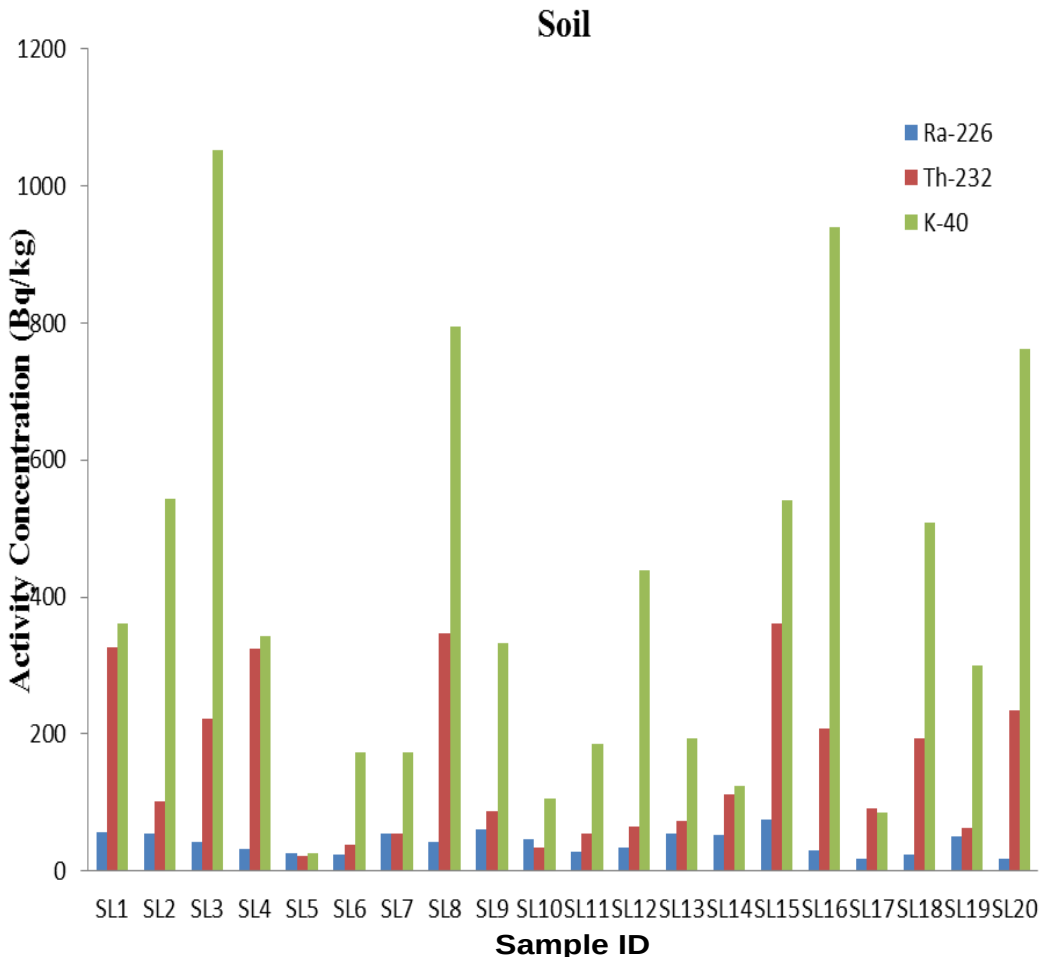

Figure 2. Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples of study sites.

Organization of Economic Cooperation Development (Miah et al., 2012).

The D in air values ranged between 23.05±2.99 $nGyh^{-1}$ and 297.54±55.21$nGyh^{-1}$, with a mean of 121.78±21.89 $nGyh^{-1}$. This value is higher than the world average value of 60 $nGyh^{-1}$(UNSCEAR, 2000), which indicates that the dose from the study area is higher than most places in the world.

The external hazard index values ranged from 0.163 to 1.715, with a mean of 0.737, which is less than the recommended limit of 1 (UNSCEAR, 2000). Generally, the radiation hazard in the study region can be assumed to be lower than the recommended limit but not insignificant as 33% of the sites showed high radiation hazard indices. The annual effective dose rate was calculated from the soil samples with the minimum value of 32.87 μSvy^{-1}. while the maximum was 338.81 μSvy^{-1}, with a mean of 149.29 μSvy^{-1}, which is higher than the world average of 80 μSvy^{-1}. This is less than 1 $mSvy^{-1}$, the limit on dose from public exposure.

Comparison of natural radioactivity levels in soils of Anka with those obtained from other studies within and outside Nigeria

A comparison of activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and Ra_{eq} from different studies around the world and the present study has been carried out and is summarized on Table 2. For ^{226}Ra (47.06±14.01 $Bqkg^{-1}$), the minimum average concentration was recorded in Utagunmodi, Nigeria (Ademola et al., 2013) while the maximum average value of 102.08±3.96 $Bqkg^{-1}$ obtained was reported in Kedah, Malaysia (Alzubaidi et al., 2016).

The minimum average concentration of ^{232}Th of 11.41±3.28 $Bqkg^{-1}$ was recorded at Suez Canal region, Egypt (Fares et al., 2017) and the maximum average of 155.36 $Bqkg^{-1}$ was recorded in Kaduna, Nigeria (Gyuk et al., 2017). For ^{40}K, the minimum value of 102.8 ± 12.1 $Bqkg^{-1}$ was reported in Utagunmodi, Nigeria while the maximum average of 505.1 ± 7.1 $Bqkg^{-1}$ was reported in Utagunmodi, Nigeria (mining site) Ademola et al., 2013).

Table 2. Comparison of activity concentration and radium equivalent for soil of Anka with those of other regions/countries.

Country/region	Activity concentration (Bqkg^{-1})			Ra_{eq} (Bqkg^{-1})	Reference
	Ra-226	Th-232	K-40		
Panipat, India	30.24 ± 0.53	29.89 ± 0.61	291.06 ± 0.57	93.41	Kumar et al. (2017)
Malnichera Bangladesh	55.25 ±4.68	125.27± 5.81	497.91±43.83	269.24±16.06	Miah et al. (2012)
Zamfara, Nigeria	12.12±1.37	60.117±1.98	426.51±9.67	-	Innocent et al. (2013)
Kaduna, Nigeria,	62.28	155.36	459.56	-	Gyuk et al. (2017)
Balad, Iraq	-	-	-	33.241	Assie et al. (2016)
Kedah, Malaysia	102.08±3.96	133.96±2.92	325.87±9.83	458.785	Alzubaidi et al. (2016)
Punjab, India	56.74	87.42	143.04	192.76	Singh et al. (2005)
Suez Canal, Egypt	11.63±3.35	11.41±3.28	327.65±80.05	52.15	Fares et al. (2017)
Tulkarem, Palestine	34.5	23.8	120.0	72.0	Thabayneh et al. (2012)
Utagunmodi, Nig. Mining site	8.8 ± 1.9 55.3 ± 1.2	17.5 ± 2.7 26.4 ± 2.7	102.8 ± 12.1 505.1 ± 7.1	31.75 132.14	Ademola et al. (2013)
World	35	30	400	-	UNSCEAR (2000)
This study	41.60±11.06	151.15±21.09	380.34±116.41	373.10	

Table 3. Comparison of absorbed dose, external hazard index and annual effective dose rate for soil of Anka with those of other regions.

Country/region	Absorbed dose (nGyh^{-1})	H_{ex}	AEDR (µSvy^{-1})	Reference
Panipat,India	44.16		54	Kumar et al. (2017)
Malnichera, Bangladesh	124.12±7.59	0.601	152.23±9.31	Miah et al. (2012)
Zamfara, Nigeria	59.70±2.23	-	73	Innocent et al. (2013)
Balad, Iraq,	17.558	0.089	70	Gyuk et al. (2017)
Kedah, Malaysia	141.62	0.859	168	Assie et al. (2016)
Punjab and Himachal Pradesh,India	-	0.52	87	Singh et al. (2005)
Egypt. Suez Canal	26.12	0.14	-	Fares et al. (2017)
Tulkarem, Palestine	35.5	0.30	44	Thabayneh et al. (2012)
Utagunmodi, Nig. Mining Site	20.4±2.1 66.3±4.1	0.11 0.36	132.62 439.73	Ademola et al. (2013)
World	57	-	-	UNSCEAR (2000)
This study	121.78	0.737	149.29	

A comparison of the average radium equivalent activity Ra_{eq} indicates that the minimum average of 33.241 Bqkg^{-1} was reported in Balad, Iraq [(Assie et al., 2016) whereas the maximum average of 458.785 Bqkg^{-1} was reported in Kedah, Malaysia (Alzubaidi et al., 2016).

Table 3 summarizes the comparison of absorbed dose, external hazard index and the annual effective dose rate obtained from different studies. The average minimum absorbed dose and external hazard index were recorded in Balad, Iraq with values of 17.558 nGyh^{-1} and 0.089 respectively (Assie et al., 2016). However, Kedah, Malaysia Alzubaidi (2016) recorded the average maximum value of 141.62 nGyh^{-1} for absorbed dose and 0.859 for external hazard index. The average minimum of annual effective dose rate of 30 µSvy^{-1} was recorded in Suez Canal region, Egypt (Fares, 2017) while the average maximum of 439.73 µSvy^{-1} was recorded for mining site, Utagunmodi, Nigeria (Ademola et al., 2013). The result by the latter is however not consistent with those obtained from other studies considering the level of activity concentration of natural radionuclides from which the annual effective dose rate is evaluated. The values would have been much lower and consistent with the result of this study.

Conclusion

The gamma-ray spectrometer equipped with a HPGe detector was used in the measurement of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K from soil samples in Anka, Zamfara State. From the result obtained in the

study area, the mean activity concentrations for ^{226}Ra and ^{232}Th are higher than the world average of 35 $Bqkg^{-1}$ and 30 $Bqkg^{-1}$, respectively (UNSCEAR, 2000). Generally, the radioactivity levels recorded in this study is higher than those recorded by Ademola et al. (2013) and Innocent et al. (2013) (Table 2). Hence, the increase in artisanal mining activities in the study area is increasing the external gamma radiation. The mean external hazard index was evaluated to be 0.737, which is less than the limit of 1. The annual effective dose rate is less than the limit on dose from public exposure (1 $mSvyr^{-1}$); this suggests that the risk of radiation hazard to humans and animals is insignificant. Hence, the soil does not constitute radiological threat to the local population in the environment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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