ENVIRONMENTAL RADIOACTIVITY AROUND A SOUTHWEST NIGERIA MINING SITE AND ITS IMPACT ON THE POPULACE

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Abstract. In this study, we quantify specific activity of ^{238}U, ^{232}Th, and ^{40}K, from soils, water, and vegetables around limestone mining sites because of the dense urban settlement with high agricultural activities around the area. Annual effective dose (*AED*) was evaluated and used to estimate radiological hazard impact. Mean values of internal radiation hazard index (H_{in}) for soils, water, and vegetation are calculated and compared with those from literatures. The estimated mean excess lifetime cancer risk (*ELCR*) was obtained, too. The values of *ELCR* are under the world average value as recommended by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) one of the world regulatory bodies. For this reason, health related issues may occur at long time of living in this environment.

Key words: Radionuclides, annual effective dose, cancer risk, health hazard index, dose rate.

INTRODUCTION

Mining activities around a densely populated area may be a source of environmental radioactivity concern today. Exposure to naturally occurring radioactive materials (NORM) can be through various means like the soil, water, and vegetation [6]. Currently, humans are exposed to naturally occurring radioactive materials present in the Earth's crust [24] and also in the atmosphere due to human activities [2]. Thus, in the scientific community it has been accepted that natural radiation accounts for the greatest part of public radiation exposure. Some of the dietary pathways (vegetation and water) become contaminated [19] with radioactive materials found around them. This may be a result of man-made applications of nuclear materials or of those naturally present in the Earth crust or the atmosphere.

From the radiobiological point of view, the most important radionuclides, emitting gamma radiation, are of ^{238}U-series ($t_{1/2} = 4.47 \times 10^9$ years), ^{232}Th-series ($t_{1/2} = 1.41 \times 10^9$ years) and ^{40}K ($t_{1/2} = 1.28 \times 10^9$ years) [25] with their progenies. In addition, nuclear accidents may cause various radiobiological effects in both human

Received: August 2023;
in final form October 2023.

and non-human species, e.g., animals and plants [31]. In general, the average annual effective dose for an individual due to natural background radiation has been estimated to be approximately 2.4 mSv [26]. Fatal radiobiological health hazards posed by human activities, especially in the area of research, industrial activities, energy generation, medical application of nuclear facilities, oil and gas extraction and production, have attracted great concern and tremendous interest over the years in the field of radiation protection [7]. Human-stimulated radiation varies for different locations depending upon the variation of radionuclide concentration in the soil, water, and vegetation. Areas where the natural background radiations are higher than normal were referred to as high background radiation and some of these areas are found around Sagamu (Nigeria) cement factory [1, 22]. Therefore, wherever the sources of radiation exposure to the environment, it is a concern and needed to be monitored.

Soil features, geological formations, and human activities (such as mining) related to radiations and radioactivity are important factors that may enhanced the background levels of natural radiation [5]. Many years of mining activities around Sagamu community (with reasonable great population), has produced contaminated water supplies, poor agricultural land with unusual high levels of natural radioactive elements, such as ^{238}U, ^{228}Th, and ^{40}K and contributed greatly to the radioactivity pollution of the environment affecting also the biotic systems of plants, animals, soil, water, and air around the area [12]. As a matter of fact, the accumulation of these radioelements contributes to both the internal and external radiation doses over period of time and these may lead to health problems such as cancer depending on the organ affected [8, 17, 18].

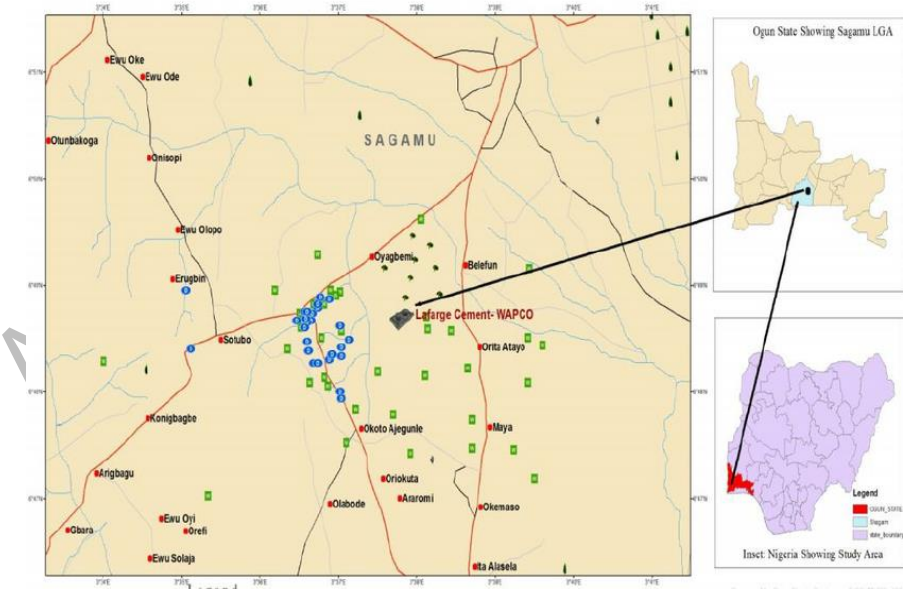

Fig. 1. The map of Sagamu, Ogun state, Nigeria, showing the cement company [32].

This study evaluates the concentration of ^{238}U, ^{232}Th, ^{40}K, and around a mining site near one of the Sagamu community in the Southwestern part of Nigeria, determines the effective radiation dose to the population and computes the radiological parameters evaluating the related health issues in this area.

MATERIALS AND METHODS

SAMPLING AREA

In the year 2022, the population of Sagamu was about 355,900 people. The projected population of Sagamu by National Population Commission of Nigeria (NPCN) and National Bureau of Statistics (NBS) was 228,382 at 2007 with population density of 605.6 per km^2 with an increment of 3.35 % per year. It covers a span of total area of 614 km^2. The climate pattern in the area is a subset of the humid tropical region, characterized by relative high temperature [1] apparent absence of cold session, low pressure, and high relative humidity. Sagamu (Fig. 1) is situated at latitude 6.8322 °N, longitude 3.6319 °E and 65 m above the sea level [23]. The major occupation of the people of Sagamu is farming. The crops grown in this area include sweet potatoes, yam, maize, cane sugar, cassava, plantain, kola nut, cocoa, rubber, and palm oil. The region is underlain with major deposit of limestone which is used for the production of cement [13].

COLLECTION OF THE SAMPLES

Water, soil, and vegetation samples (15 each) were collected from around the mining site for about 1 km into the town of Sagamu to get a thorough outline of how the pollution from the cement factory have affected the populace through the agricultural products, drinking water, etc.

Soil sampling and analysis

The soil samples were collected at a depth of 15 cm below the ground level and kept in a labeled plastic container. Each of these samples was dried for about four weeks till a constant weight have been obtained. Samples were pulverized in the laboratory and sieved by a 1 mm sieve. The samples were weighed to 720 g and placed in labeled sealed plastic containers for four weeks to allow the secular equilibrium between ^{238}U and ^{232}Th and their corresponding progenies. The soil samples were analyzed for activity concentrations of ^{238}U, ^{232}Th, and ^{40}K using high purity germanium (HPGe) gamma spectrometer detector.

Water sampling and analysis

The samples were collected from the water supply available in the area water well. The collected water was placed in pre-washed 75 cL plastics bottle containers fully filled and taken to the laboratory. The collected samples were acidified by the addition of 0.5 mL of concentrated HNO_3 per liter to prevent adsorption or loss of radium isotopes around the walls of the sampling bottles. The samples are then stored in a standard Marinelli beaker for four weeks tightly closed in order to give room for secular equilibrium between ^{238}U, ^{232}Th and their progenies. The water samples were analyzed for activity concentrations of ^{238}U, ^{232}Th, and ^{40}K using high purity germanium (HPGe) gamma spectrometer detector.

Vegetation sampling and analysis

The vegetation samples were collected in polyethylene bags and dried in a well-ventilated room to avoid direct sunlight radiation. Then, the samples were pulverized and sieved by l mm sieve to remove stones and organic parts. The samples were weighed to 150 g and placed in labeled sealed plastic containers to prevent escape of ^{222}Rn and ^{220}Rn before taking it to the laboratory. The samples were kept in Marinelli beakers for 28 days to attain secular equilibrium between ^{232}Th, ^{238}U, ^{40}K and their progeny [2]. The vegetable samples were analyzed for activity concentrations of ^{238}U, ^{232}Th, and ^{40}K using high purity germanium (HPGe) gamma spectrometer detector. A p-type closed end co-axial detector (Model BE 3825, Canberra, USA) of dimensions 70 mm diameter and 25 mm length with an active area 3,800 mm^2 having 38 % relative efficiency was used. The spectrum was analyzed using a 16 K multi-channel analyzer connected to a computer using GENIE-2000 software. Quality assured standard materials procured from IAEA were used for the calibration of the detector.

ASSOCIATED RADIOLOGICAL PARAMETERS

The associated radiobiological parameters such as absorbed dose rate, annual effective dose, and internal and external radiation hazard index are needed for the evaluation of the hazard level of the radioactivity of the area studied.

Absorbed dose rate (D_0)

Effects of gamma radiation are normally expressed in terms of the absorbed dose rate in air, which originate from radioactive sources in the soil. The activity concentrations in soil correspond to the total absorbed dose rate in air at 1 m above the ground level. This was calculated using equation (1) [27]:

$$D_0(\text{nGy h}^{-1}) = 0.427A_{\text{U}} + 0.622A_{\text{Th}} + 0.0432A_{\text{K}} \quad (1)$$

where, $A_{\text{U}}, A_{\text{Th}}$ and A_{K} are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K, respectively, in Bq/kg, and D_0 is the absorbed dose rate in air.

Annual effective dose (D_E)

The annual effective dose received by the population was calculated using the equation (2) and a conversion factor of 0.7 SvGy^{-1} [2, 4, 9, 30]:

$$D_E(\text{mSv y}^{-1}) = D_0\ (\text{nGy h}^{-1}) \times 0.25 \times 8{,}760 \times 0.7\ (\text{SvG y}^{-1}) \times 10^{-6} \quad (2)$$

where, 0.25 is equivalent to 6 hours spent outdoor daily and 8,760 is the number of hours in a year.

External radiation hazard index (H_{ex})

The external radiation hazard index (Bq/kg) due to natural radionuclides of ^{238}U, ^{232}Th, and ^{40}K is defined in terms of external or outdoor radiation hazard index.

This index must be less than unity, in order to keep the radiation hazard insignificant. The external hazard index was calculated using the expression below [16]:

$$H_{ex} = A_U/370 + A_{Th}/259 + A_K/4{,}810 \quad (3)$$

where, A_U, A_{Th} and A_K are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K, respectively, in Bq/kg.

Internal radiation hazard index (H_{in})

The internal radiation hazard index (Bq/kg) originating from short lived radon will be calculated as follows [16]:

$$H_{in} = A_U/185 + A_{Th}/259 + A_K/4{,}810 \quad (4)$$

Excess lifetime cancer risk (*ELCR*)

Excess lifetime cancer risk (*ELCR*) was evaluated according to equation (5) below [10, 15, 20, 23]. This will enable estimate the potential carcinogenic effects of the long-term bases:

$$ELCR = AED \times DL \times RF \quad (5)$$

where *ELCR* is the excess lifetime cancer risk a dimensionless quantity, *AED* is the annual effective dose (mSv/y), *DL* is the duration of life (70 years) [29, 14] and *RF* is the fatal cancer risk factor (Sv^{-1}) (0.05 for the public).

ACTIVITY MEASUREMENT

For the samples collected, gamma spectra were accumulated for a counting times 8 hours for each sample and the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K

were obtained from the count rates from photo-peaks of interest. For ^{238}U, the photo-peaks considered were those of ^{214}Pb and ^{214}Bi of energies 295.21 keV and 609.31 keV, respectively. For ^{232}Th the photo-peaks considered were those of ^{212}Pb, ^{228}Ac, and ^{208}Tl of energies 238.63 keV, 911.21 keV, and 2,614.55 keV, respectively. The activity concentration of ^{40}K was determined from its photo-peak of energy 1,460.8 keV. Activity concentration in water and soil samples was determined using equations (6) and (7).

$$A(\mathrm{Bq/kg}) = \frac{KC}{t \times m \times \varepsilon \times P_\gamma} \quad (6)$$

$$A(\mathrm{Bq/L}) = \frac{KC}{t \times v \times \varepsilon \times P_\gamma} \quad (7)$$

where A is the activity concentration of the radionuclide in Bq/kg, and for liquids in Bq/L, KC is the net count for each radionuclide which is the count minus the background (count per second), t is the counting lifetime in seconds, v is the volume of water in liter, m is the mass in kg, ε is the detector energy dependent efficiency for each radionuclide, and P_γ is gamma ray yield per disintegration of the nuclide (emission probability) [28, 21].

RESULTS AND DISCUSSIONS

The tables of the specific activity of ^{238}U, ^{232}Th, and ^{40}K in the samples are shown below the distances of sample collections from the mining point up to about 1.6 km away. In Table 1 the specific activities of ^{238}U, ^{232}Th, and ^{40}K from the soil samples are given. The highest concentration of ^{238}U in the soil samples is 36.99 Bq kg^{-1} at about 650 m away, while for ^{232}Th it is 31.90 Bq kg^{-1} at about 550 m, while the highest activity of ^{40}K is 59.14 Bq kg^{-1} at a distance of 450 m.

Table 1

The specific activity, annual effective dose, and excess lifetime risk due to ^{238}U, ^{232}Th, and ^{40}K in soil samples

Distance (m)	Specific activity (Bq kg^{-1}) in soil			Annual effective dose (mSv/y)	Excess lifetime cancer risk (× 10^{-3})
	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)		
150	18.16±7.54	12.59±6.01	BDL	1.99E–02	6.96E–02
250	24.61±3.87	14.22±3.97	6.79±2.07	2.51E–02	8.79E-02
350	30.85±10.54	16.36±5.72	23.88±5.09	3.12E-02	1.09E-01
450	31.62±9.05	27.51±8.45	59.14±7.98	4.19E-02	1.47E-01
550	30.46±9.87	31.90±6.56	8.72±3.07	4.20E-02	1.47E-01

650	36.99±10.14	30.09±7.17	22.42±2.54	4.50E-02	1.58E-01
750	31.36±7.09	30.12±8.32	19.63±7.09	4.17E-02	1.46E-01
850	27.97±4.72	22.99±7.35	19.67±3.09	3.44E-02	1.20E-01
950	17.08±8.14	24.43±8.32	20.22±7.31	2.93E-02	1.03E-01
1050	18.44±1.09	17.85±3.42	17.72±6.03	2.49E-02	8.73E-02
1150	16.37±5.28	19.05±5.61	9.79±2.54	2.43E-02	8.50E-02
1250	21.80±6.04	16.03±4.87	14.34±5.81	2.53E-02	8.85E-02
1350	19.05±6.03	14.89±5.81	13.29±4.15	2.28E-02	7.99E-02
1450	15.09±7.04	12.34±6.98	12.17±2.29	1.86E-02	6.50E-02
1550	12.37±4.81	17.99±1.42	8.16±1.79	2.11E-02	7.40E-02
MEAN	**23.48**	**20.56**	**17.06**	**2.98E-02**	**1.04E-01**

BDL – below detectable level

The mean specific activity of ^{238}U, ^{232}Th, and ^{40}K for the soil samples are 23.48 Bq kg^{-1}, 20.56 Bq kg^{-1}, and 17.06 Bq kg^{-1} respectively for the soil samples whereas the highest and the lowest activities of ^{238}U occurs at about 650 m and 1,550 m away from the mining center. The highest and the lowest activities of ^{232}Th occur at the distance of 750 m and 1,450 m, respectively. In addition, the specific activity of ^{40}K has its highest value at 450 m away while its lowest value obtained at about 150 m away from the point of interest.

In the Table 2, it is shown the specific activity of ^{238}U, ^{232}Th, and ^{40}K from the water samples collected with the mean specific activity of 1.46 Bq L^{-1}, 1.42 Bq L^{-1}, and 7.27 Bq L^{-1} for ^{238}U, ^{232}Th, and ^{40}K, respectively.

^{238}U highest activity of 7.24 Bq L^{-1} at about 750 m; and that of ^{232}Th is 1.97 Bq L^{-1} at about 1,250 m away, while the ^{40}K highest activity of 13.19 BqL^{-1} occurs at a distance of 550 m from the point of study. In addition, the lowest activity concentrations from water samples are 0.07 Bq L^{-1}, 0.46 BqL^{-1}, and 3.87 Bq L^{-1} for ^{238}U, ^{232}Th, and ^{40}K at the distances 1,250 m, 1,550 m, and 1,450 m, respectively. At some distances for some samples, the radioactive substances are below detectable level (BDL) as indicated on the Tables 1, 2, and 3 for the collected samples of soils, water, and vegetation.

Table 2

The specific activity, annual effective dose and excess lifetime risk due to ^{238}U, ^{232}Th, and ^{40}K in water samples

Distance (m)	Specific activity (Bq L^{-1}) in water			Annual effective dose (mSv/y)	Excess lifetime cancer risk ($\times10^{-3}$)
	^{238}U (Bq L^{-1})	^{232}Th (Bq L^{-1})	^{40}K (Bq L^{-1})		
150	0.65±0.10	1.26±0.17	5.69±1.40	1.62E-03	5.67E-03
250	0.67±0.14	1.82±0.90	BDL	1.77E-03	6.18E-03
350	0.25±0.08	1.61±0.26	10.45±2.26	1.89E-03	6.63E-03
450	1.45±0.60	1.49±0.09	10.41±1.76	2.49E-03	8.71E-03
550	0.99±0.06	1.78±0.45	13.19±2.17	2.59E-03	9.07E-03
650	3.11±1.10	1.61±1.02	9.48±3.12	3.47E-03	1.21E-02
750	7.24±1.31	1.25±0.69	7.02±2.21	5.41E-03	1.89E-02
850	2.65±1.09	1.68±1.30	10.49±3.32	3.32E-03	1.16E-02
950	0.65±0.14	1.84±1.13	12.38±4.16	2.37E-03	8.30E-03
1050	2.58±0.60	1.3±1.02	BDL	2.47E-03	8.63E-03
1150	0.62±0.15	1.63±0.26	11.9±3.52	2.20E-03	7.70E-03
1250	0.07±0.60	1.97±0.17	8.87±2.63	1.99E-03	6.98E-03
1350	0.56±0.13	0.64±0.08	5.28±0.57	1.07E-03	3.76E-03
1450	BDL	1.04±0.15	3.87±0.52	9.90E-04	3.46E-03
1550	0.44±0.21	0.46±0.09	BDL	6.00E-04	2.10E-03
MEAN	**1.46**	**1.42**	**7.27**	**2.28E-03**	**7.99E-03**

Table 3

The specific activity, annual effective dose and excess lifetime risk due to ^{238}U, ^{232}Th and ^{40}K in vegetation samples

Distance (m)	Specific activity (Bq kg^{-1}) in vegetation			Annual effective dose (mSv/y)	Excess lifetime cancer risk ($\times10^{-3}$)
	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})		
150	3.63±1.60	4.02±1.91	354.00±25.94	2.32E-02	0.081
250	BDL	BDL	931.01±25.02	4.76E-02	0.167
350	4.01±1.63	5.44±1.65	415.09±28.68	2.76E-02	0.097
450	ND	1.54±1.11	1,033.02±76.62	5.40E-02	0.189
550	5.33±1.69	2.95±0.86	496.10±32.96	3.06E-02	0.107

650	3.46±0.65	5.43±1.53	280.03±21.10	2.04E-02	0.071
750	BDL	8.29±1.90	337.11±71.68	2.36E-02	0.082
850	8.40±1.68	6.26±1.26	409.64±51.10	3.05E-02	0.107
950	4.49±1.43	7.57±1.87	645.97±41.74	4.13E-02	0.145
1050	8.26±1.67	7.46±1.23	377.80±91.25	2.97E-02	0.104
1150	5.25±1.10	6.19±1.87	245.09±65.15	2.02E-02	0.071
1250	8.17±1.86	5.98±1.69	335.09±23.93	2.63E-02	0.092
1350	6.19±0.67	4.87±1.47	239.18±21.50	1.94E-02	0.068
1450	5.28±1.71	7.09±1.87	823.76±45.46	5.05E-02	0.177
1550	3.28±1.50	5.87±1.49	734.56±32.16	4.39E-02	0.154
MEAN	**4.38**	**5.26**	**510.47**	**3.26E-02**	**1.14E-01**

BDL = below detectable level
ND = non determined

In the Table 3, the specific activity of ^{238}U, ^{232}Th, and ^{40}K from the vegetation samples are illustrated. The highest specific activities for ^{238}U is 8.40 Bq kg^{-1} at the distance of about 850 m away, while ^{232}Th has an activity of 7.57 Bq kg^{-1} at about 950 m, and ^{40}K highest specific activity is 1,033.02 Bq kg^{-1} at a distance of 450 m away. In addition, the mean activities were found to be 4.38 Bq kg^{-1}, 5.26 Bq kg^{-1}, and 510.50 Bq kg^{-1} for ^{238}U, ^{232}Th, and ^{40}K, respectively.

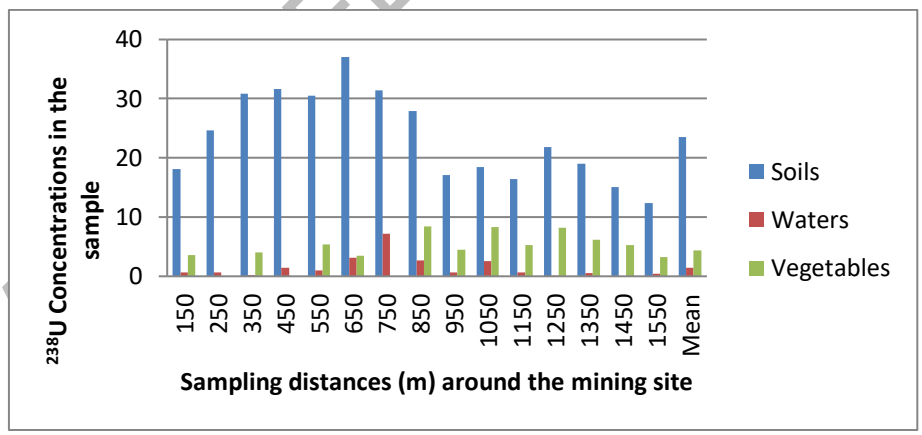

Fig. 2. Comparison of concentration (Bq kg^{-1}) of ^{238}U in the natural samples of soil, water and vegetables.

Due to the high human activities within the vicinity of the mining area, the comparison of the concentration of each radioactive material in each of the sample was performed, and the results for ^{238}U are shown in Figure 2. From the samples of soils, water, and vegetation the concentration of ^{238}U is generally highest in soil than in water and vegetation. Thus, vegetation has higher ^{238}U concentration than water samples. The mean values obtained were 23.48 Bq kg^{-1} of ^{238}U for soils, 4.38 Bq kg^{-1} for vegetation, and 1.46 Bq L^{-1} for water samples. The comparison of the ^{232}Th concentration in each sample has been done and the results are shown in Figure 3. Soils have the highest concentration of ^{232}Th followed by vegetation samples and the water samples.

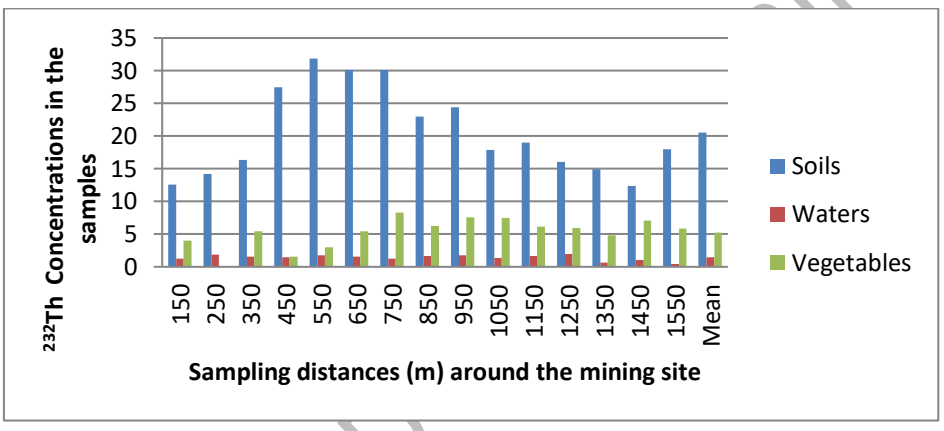

Fig. 3. Comparison of concentration (Bq kg^{-1}) of ^{232}Th in the natural samples of soil, water and vegetables.

The highest value of ^{238}Th concentration is 31.90 Bq kg^{-1} in soil samples at about 550 m away from the mining point, while that of the vegetation samples is 8.29 Bq kg^{-1} at about 750 m from the mining point, and also, that of the water samples is 1.97 Bq L^{-1}. The mean values of ^{238}Th in the three samples are 20.56 Bq kg^{-1}, 5.26 Bq kg^{-1}, and 0.46 Bq L^{-1} for soils, vegetation, and water samples, respectively. ^{40}K concentrations were also compared for the three samples collected at different distances from the mining site (Figure 4). The highest concentration of ^{40}K considering all the samples (soil, vegetation, and water) was obtained from the vegetation samples this value being 1,033.02 Bq kg^{-1} at a distance of 450 m away from the mining site.

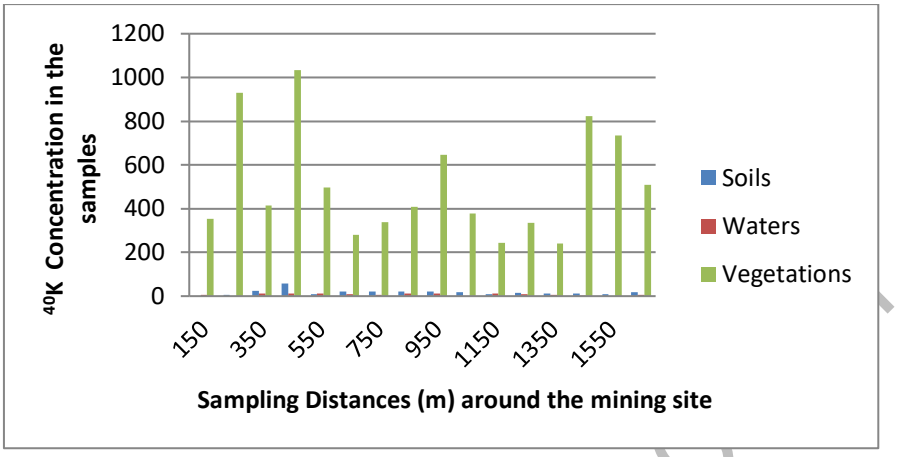

Fig. 4. Comparison of concentration (Bq kg^{-1}) of ^{40}K in the natural samples of soil, water, and vegetables.

The highest concentrations of ^{40}K in the soils sample are 59.14 Bq kg^{-1}, at a distance of 450 m from the mining. In water samples at a distance of 550 m away, a value of 13.19 Bq L^{-1} was obtained. The mean concentration of ^{40}K was obtained for all the samples, 17.06 Bq kg^{-1} for the soil samples, 510.50 Bq kg^{-1}, for the vegetation samples, and 7.27 Bq L^{-1} for the water samples. These values were compared with those from similar researches carried out in various region of the world (Table 4). Our results are comparable with the data from other parts of the world and the mean values for ^{232}Th and ^{40}K are very low when compared with the literature results.

Table 4

Comparison of natural radioactivity levels in the soil samples of Sagamu, Nigeria, with those in other countries

Country	Specific activity in soil (Bq kg^{-1})			
	^{232}Th		^{40}K	
	Range	Mean	Range	Mean
Denmark [16]	[8,30]	19	[24,610]	460
India [20]	[5,42]	22	[250,980]	640
Japan [15]	[2,88]	28	[15,990]	310
Ireland [11]	[3,60]	26	[40,800]	350
USA [10]	[4,13]	35	[100,700]	370
China [23]	[1,36]	41	[91,800]	440

Poland [31]	[4,77]	21	[110,970]	410
Iraq [14]	[8,28]	19	[204,568]	289
Sagamu, Nigeria, (our study)	[12,31]	20	[8,590]	17
Worldwide, average [20]	[11,64]	30	[140,850]	400

The annual effective dose has been evaluated in the samples of the soils, water, and vegetation collected from different points away from the mining site to about 1.5 km because many commercial activities are ongoing within this range. The annual effective dose (*AED*) evaluated are then compared, samples by samples, from each distances away from the mining site as shown in Figure 5. In soil sample we obtained the annual effective dose within the distance 150 – 1,550 m in range of 4.50E-02 mSv y^{-1} – 1.86E-02 mSv y^{-1}; while the mean is 2.98E-02 mSv y^{-1}. In the water samples, collected within the same distance, the annual effective dose is within the range of 5.41E-03 mSv y^{-1} – 6.00E-04 mSv y^{-1} and the mean value is 2.28E-03 mSv y^{-1}, while that of vegetation within the same distances is 5.40E-02 mSv y^{-1}– 1.94E-02 mSv y^{-1} with the mean of 3.26E-02 mSv y^{-1}.

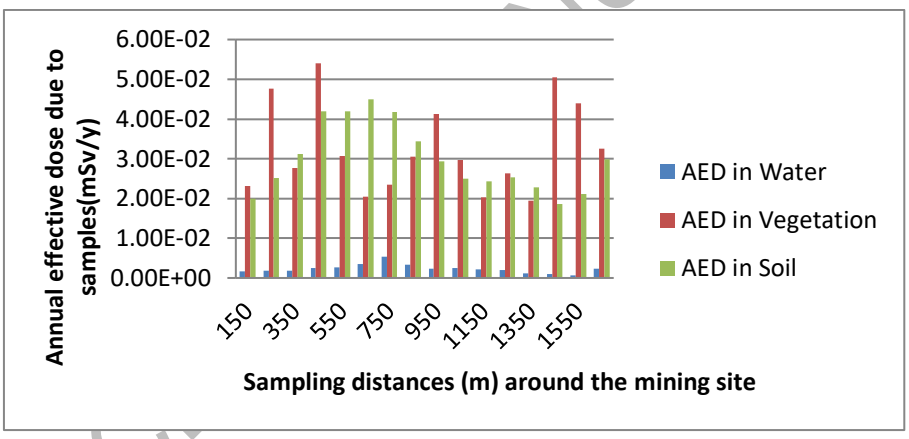

Fig. 5. Comparison of the annual effective dose of radiation from all the samples.

For the samples of soils, water, and vegetation, as shown in Figure 5, the values of the annual effective dose increases from 450 m away to about 1.0 km from the mining site. The obtained *AED* value is generally higher in the vegetation around the mining site as compared to the *AED* due in the soils and that in the water around, at the same distances. It is worth noting that most of the recoded high values of *AED* in all the samples were obtained between 450 m to 850 m away from the mining site. Afterwards there were sporadic spikes in the values of *AED* as the distances increases from the mining site. In addition to this, the average of the *AED* is reasonably high in soils and vegetation samples. The mean annual effective dose at the different

locations in all samples were lower in some cases than the worldwide effective dose of 1 mSv y^{-1} as recommended for the general public [23].

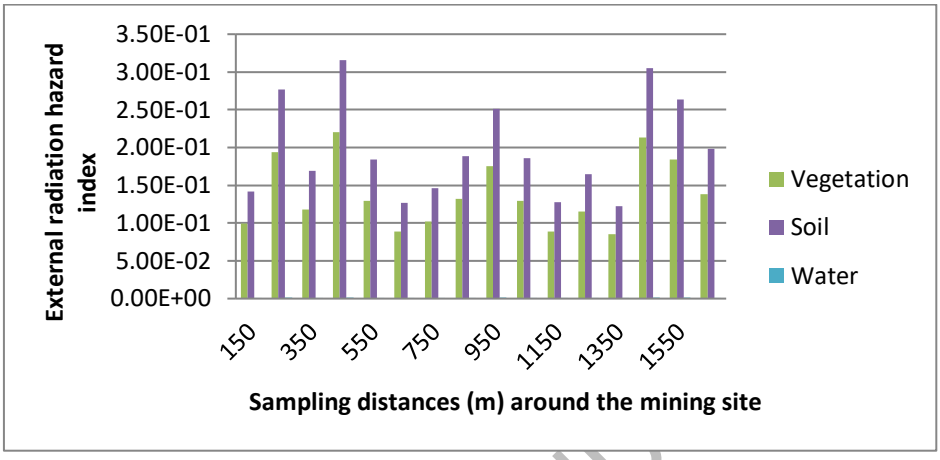

Fig. 6. Comparison of external radiation hazard index due to all the samples.

Figure 6 illustrates the comparison between the external radiation hazard index H_{ex} from water, soils, and vegetation samples. In the case of soil samples, the value of the H_{ex} is generally higher than those obtained for both water and vegetation samples. The highest values of H_{ex} are recorded at 450 m and 1,450 m distances away from the mining site. The H_{ex} values in vegetation are higher than that of the water.

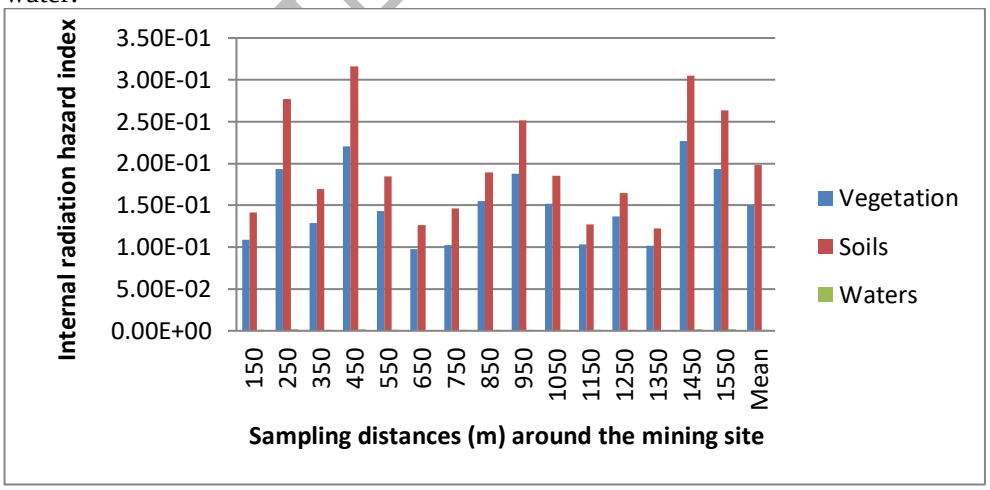

Fig. 7. Comparison of internal radiation hazard index due to all the samples.

This study also evaluated H_{in} sample by sample, at various distances from the mining point and then a comparison was made between the three samples as shown in Figure 7. The H_{in} in the soil samples were of higher values when compared from one point to the other and these values are in the range of 1.22E-01 – 3.16E-01 with mean value of 1.98E-01. The H_{in} obtained from the vegetation is in the range 9.79E-02 and 2.27E-01 with the mean of 1.50E-01, while that of the water is between 8.05E-04 and 1.92E-03 with the mean of 1.25E-03. The probability of cancer risk in a lifetime of the people living around the mining site up a distance of 1.5 km away has been estimated. The excess lifetime cancer risk was evaluated for each of the samples and the obtained results were compared as shown in Figure 8. It is likelihood that a healthy person will develop or die from cancer during his/her lifetime around the mining site.

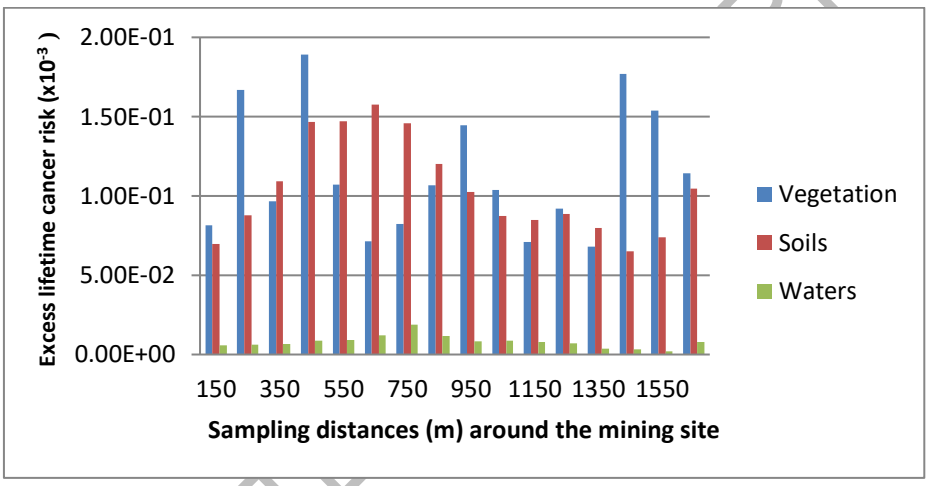

Fig. 8. Comparison of excess lifetime cancer risk due to samples.

Excess lifetime cancer risks (*ELCR*) due to vegetation samples have been estimated and its values were found to be higher than those of soils and water samples. Figure 8 shows the comparison between the *ELCR* values as a function of mining site distances. For the vegetation samples, the *ELCR* were in the range of 6.81E-05 and 1.89E-04 with the mean value of 1.14E-04. The *ELCR* due to soil samples were in the range of 6.50E-05 and 1.58E-04 with the mean value of 1.04E-04, whereas the *ELCR* values for water samples were between 2.10E-05 – 1.89E-05 with the mean value of 7.99E-05. When compared the *ELCR* dependence of distance, its values from the vegetation was higher than those obtained for the soils and water samples. This is an indication that the probability of lifetime excess cancer risk in vegetation is higher than in other samples studied. However, the lifetime cumulative effects on persons living in the close proximity to the mining site may create health issues in lifetime.

CONCLUSION

The concentrations of ^{238}U, ^{232}Th, and ^{40}K were quantified and analyzed in various samples collected from soil, water, and vegetation.

The results of our study on quantification of primordial radionuclides with radiobiological health impact of the natural samples of soil, water, and vegetation around a mining site in Sagamu, southwest Nigeria demonstrated that the radioactivity levels obtained from all the samples were comparable with the results of similar studies from other regions of the world.

The excess lifetime cancer risk was estimated from each of the sample at about the same distances from the mining site and the evaluated values were below the world average recommended by UNSCEAR.

The values of hazard index show that in a long time the cumulative effects of *AED* may be a health issue for people that live within these considered areas.

Acknowledgment: We wish to acknowledge Miss S. Adekanle for the role she played in assisting during the sample collections at various levels of the field work.

Data availability statement: All the data that supports the findings of this study are available within the article.

Funding statement: There is no funding from any organization of society for this research work. The research financial cost has been a personal contribution.

Conflicts of interest: There is no known conflict of interest in this research work. The research work is purely academic for better scientific information within the scientific community and the society at large.

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