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Analysis of Natural Radioactivity in Soil Samples by Gamma Spectrometry and Evaluation of Radiological Risk in Yaadga Region of Burkina Faso

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Abstract

The activity concentrations of primordial Radionuclides such as ^{238}U, ^{232}Th and ^{40}K in soil samples taken in the Yaadga Region of Burkina Faso around the gold mining site of Seguenega were measured by Gamma Spectrometry using High Purity Germanium detector. Radiological hazard assessment due to such natural radioactivity was also investigated. The average activity concentration of ^{238}U, ^{232}Th and ^{40}K were found to be 18.97 ± 1.43 $Bq.kg^{-1}$, 22.98 ± 0.96 $Bq.kg^{-1}$ and 212.72 ± 29.75 $Bq.kg^{-1}$ respectively. The average absorbed dose was 0.032 μGy/h whereas the Annual Committed Effective Dose was 0.040 ± 0.002 $mSv.y^{-1}$. The average radium equivalent activity concentration was 69.11 $Bq.kg^{-1}$. The external and internal Hazard indices were 0.18 and 0.24 respectively which are at least four times less than one. The mean effective dose rate, the mean values of Ra_{eq}, and H_{ex} and H_{in} for the studied area are below their respective permissible limits, thus indicating that radiation hazard is not significant in this area.

Keywords

Soil Sample, Activity Aoncentration, Uranium, Thorium, Potassium

1. Introduction

The main natural contributors to external exposure from gamma-radiation are the uranium and thorium series, also with potassium 40 (40 K) and may be present in small quantities on the surface of the earth [1] [2].

The Uranium-238 and its daughters rather than 226Ra and its daughter products are responsible for the major fraction of the internal dose received by humans from naturally occurring radionuclides. Even though the concentrations of these radionuclides are widely distributed in nature, they have been found to depend on the local geological conditions and as a result vary from place to place [3] [4]. This is because the specific levels are related to the type of rock from which the soil originates. Throughout the history of life on earth, organisms have been continuously exposed to radiation mainly from cosmic rays in the atmosphere, and from naturally occurring radionuclides which are ubiquitously distributed in all living and non-living components of the biosphere. A wide range of activity concentrations in a wide variety of materials is reported [5]. Mining has been identified as one of the potential sources of exposures to NORM [3]. Our country, Burkina Faso, is among the biggest gold producers in West Africa nowadays and many mining companies have been operating and some are even establishing. Burkina Faso is a country in West Africa with the capital city Ouagadougou. However, like in the other developing countries, there is a lack of control over mining activities mainly for radiological regulatory. Therefore, there is a general lack of awareness and knowledge of the radiological hazards and exposure levels by legislators, regulators and operators.

The objective of the study was to assess the level of NORM in the Yaadga Region of Burkina Faso surrounding the mining site of Seguenega. This consists of measuring the activity concentrations of 226 Ra, 232 Th and 40 K in soil samples from Seguenega area around the mining site, assessing the Radiological Hazard and risk associated with exposure to the members of the community living in this area.

2. Materials and Methods

2.1. Geological Characteristics of the Region

The studied area is the Yaagda region in the North of Burkina Faso surrounding the mining site of Seguenega, approximately 190 km from Ouagadougou, the Capital City of Burkina Faso.

- **Soils**

Soils in this region can be classified into four (04) groups:

Rough mineral soils, more or less hard and unsuitable for crops (10% of the area). The soils are not very evolved, having a humiferous horizon of 20 to 80 cm. More common in the region (57.6% of the area);

Soils of the type "ferruginous leached deep" (10% of the surface), they are located on medium glazes, and therefore fairly susceptible to erosion;

Brown and ferruginous soils, these soils are of satisfactory depth from 80 to120 cm and represent only 2.1% of the area;

Plains, lowland and depression soils; their silty-clay texture and their depth (over 120 cm) give them a good water retention capacity (20% of the area) [6].

➢ **Geology**

The crystalline rocks constitute almost the entire subsoil of the Yaadga Region except in the northwest where the base disappears under the sedimentary formations of the infra cambrian [6].

2.2. Sampling and Samples Preparation

Soil samples were collected randomly within selected areas around 1.7 km^2 surrounding the mining site of Seguenega in Burkina Faso. A plastic dust pan and brush are used to collect the soil and transferred into some clean polythene bags. The samples were properly labeled catalogued and brought to the radiation laboratory. The samples were analyzed using gamma spectrometry to determine the activity concentration of radionuclides. In the laboratory, the soil samples collected were air-dried in trays for 7 days and then oven dried at a temperature of 105˚C to remove all the moisture contents. The samples were then grinded into fine powder using a ball mill to increase the total emission area [7] and packed into 1 litre Marinelli beakers. The Marinelli beakers filled with the samples were then sealed and stored for four weeks in order to allow secular equilibrium between ^{226}Ra and ^{232}Th and their decay products before counting by gamma-ray

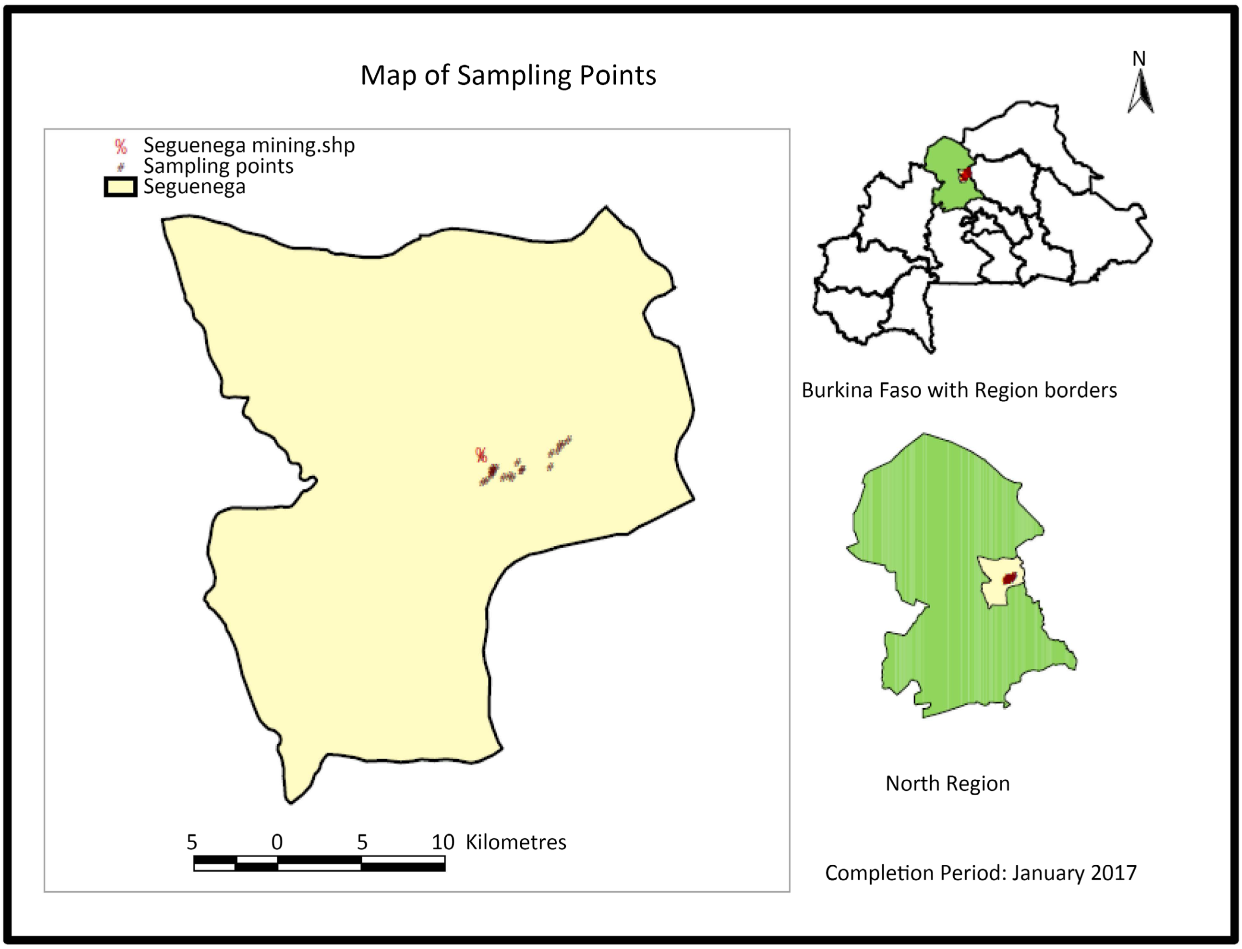

Figure 1. Sampling locations points.

spectrometry. Each sample was counted using a high purity germanium detector (HPGe).

Figure 1 shows the sampling locations obtained by using the GPS coordinates of sampling points.

2.3. Spectrometry System Calibration

The gamma spectrometry system used for this study consists of a High Purity Germanium (HPGe) detector with the following characteristics (Canberra detector model GX4020, cryostat model 7500SL and preamplifier model 2002CSL). It has a diameter of 60.5 mm, length of 61.5 mm. The resolution of the detector is 2.0 keV and relative efficiency of 40% for 1.33 MeV gamma energy of ^{60}Co. The output from the detector is connected to a desk top computer provided with "Genie 2000" configuration software for spectrum acquisition and evaluation. In order to do the measurement, energy and efficiency calibration were done previously.

A relationship between the channel numbers corresponding to specific gamma-ray energies was determined before sample counting. The establishment of this relationship is known as energy calibration and the idea is to identify the radionuclides in a sample. The linearity of energy response is an essential feature for any γ-ray detector and the direct proportionality between the quality of energy deposited in the detector by the incident radiation event and the height of the output pulse ensures that the system is working properly [8]. Accurate calibration involves a standard source with gamma ray energies that are not widely different from those to be measured in the unknown spectrum. The energy calibration was done by means of multi peaked and multi nuclides radioactive standard sources emitting gamma rays of precisely known energy and the peak position in channels with this energy is identified. In this study this was carried out by counting

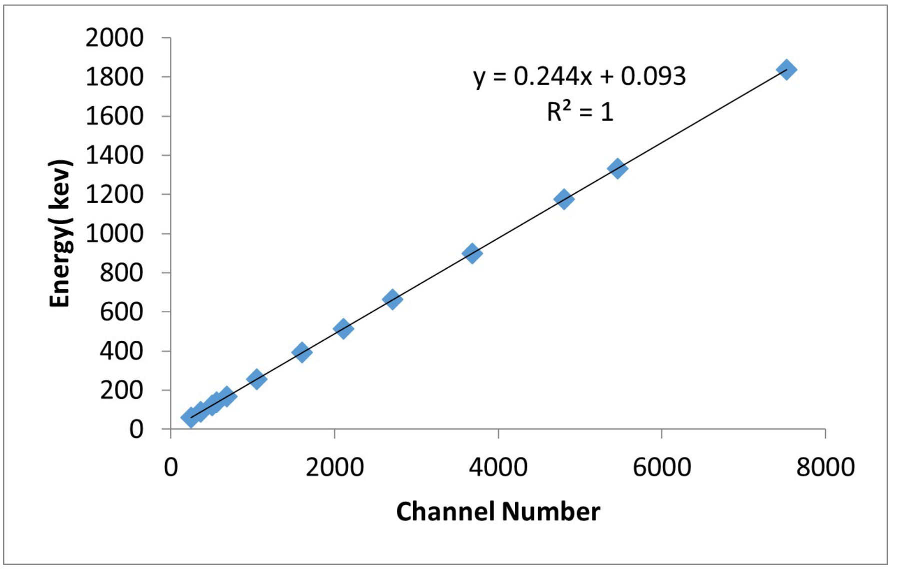

Figure 2. Energy calibration curve.

standard radionuclides (a mixture of ^{241}Am, ^{109}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{137}Cs, ^{113}Sn, ^{85}Sr and ^{88}Y) of known activities with well-defined energies in the energy range of 60 to ~2000 keV. The standard was counted on a detector for 10 hours or 36,000 s. The energy calibration curve is given in **Figure 2**.

2.4. Determination of Activity Concentration

From the spectrum analysis, count rates for each detected photo peak and activity per unit mass, the specific activity for each of the detected nuclides are calculated. The specific activity (in $Bq.kg^{-1}$), A_{Sk}, of a nuclide k, and for a peak at energy E, is given by Equation 1

$$A_{Sk} = \frac{(Net)_{Ek}}{\varepsilon_{Ek} \times p_{\gamma} \times T \times m}. \tag{1}$$

Where,

A_{Sk} is the activity concentration (Bq/kg) of the radionuclide of interest.

ϵ_{Ek} is the detection efficiency at energy E_k.

T is the counting live time.

$P\gamma$ is the number of gamma-rays per disintegration of this radionuclide for a transition at energy E of the measured sample of water [9]. If there is more than one peak in the energy analysis range for a nuclide, then an attempt is made to average the activities for the peak. The result is then the weighted radionuclide's average activity concentration. The activity concentrations of ^{238}U and ^{232}Th in samples collected were determined using the measured γ-ray photo peaks, emitted by specific radionuclides in their decay series whereas the activity concentrations of ^{40}K is calculated from the measured γ-ray photo peaks directly. In other words, the activity concentration of ^{238}U was calculated from the average of 609.31 keV of ^{214}Bi and 1764.5 keV of ^{214}Bi, in the decay series of ^{232}Th gamma photons are emitted at energies of 239 keV (^{212}Pb), 583 keV (^{208}Tl) and 911 keV (^{228}Ac) which are used to determine the activity concentrations of ^{232}Th by gamma spectrometry, and ^{40}K was determined from 1460.0 keV.

2.5. Calculation of Absorbed Dose Rate in air (D) and Annual Effective Dose Equivalent (AEDE) from Activity Concentration

A direct relationship between radioactivity concentrations of natural radionuclides and their exposure is referring to as absorbed dose rate in air at 1 m above the ground. This factor is important quantity to assess when considering radiation risk to a bio system. This is calculated from the activity concentrations by using Equation (2) [2] [9] [10].

$$D_{\gamma}\left(nGyh^{-1}\right) = DCF_K \times A_K + DCF_U \times A_U + DCF_{Th} \times A_{Th} \tag{2}$$

Where $DCF_K = 0.0417$, $DCF_U = 0.462$ and $DCF_{Th} = 0.604$ are the absorbed dose rate conversion factors for K-40, U-238 and Th-232 in nGy/h/Bq/kg and A_K, A_U and A_{Th} are the activity concentrations for K-40, U-238 and Th-232, respectively.

For the safe use of soil, D must be lower than the recommended value 55 nGy/h

[11] [12]. The Radium equivalent and hazard indices will be calculated for the studied soil.

In order to provide the radiological risk to which an individual is exposed, the absorbed dose is considered in terms of annual effective dose equivalent from terrestrial gamma radiation considering the conversion coefficients from absorbed dose in air to effective dose which is estimated to be 0.7 Sv/Gy and the outdoor occupation factor of 0.2 [3]. The outdoor annual effective dose equivalent was estimated by using the following Equation (3) [2] [13] [14].

$$E_{\gamma} = D_{\gamma} \times 0.2 \times 8760 \times 0.7 . \tag{3}$$

Where E_{γ} is the average annual effective dose and Dr is the absorbed dose rate in air.

2.6. Determination of Radium Equivalent Activity and Radiation Hazard Indices

The radiological hazard of the natural radioactivity was evaluated also by calculating the radium equivalent concentration (Ra_{eq}), the external and internal hazard indices. The radium equivalent concentration (Ra_{eq}) is used to compare the uniformity in radiation of material containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. It is based on the estimation that 350 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same γ-ray dose rate [15]. (Ra_{eq}) was calculated by using Equation (4) [16].

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_{K} . \tag{4}$$

Where C_{Ra}, C_{Th} and C_K are the activity concentration of 226 Ra, 232 Th and 40 K respectively. The external and internal hazard indices values must be less than one for the radiation hazard to be considered negligible *i.e.* the radiation exposure due to the radioactivity from the construction material is limited to 1.5 mSv/y [16]. In addition, Radon and its short-lived products are hazardous to the respiratory organs and as a result, the internal exposure to radon and its short-lived daughter products is quantified using the internal hazard index. Radiation exposure due to 226 Ra, 232 Th and 40 K may be external and defined in terms of external hazard index. To evaluate the external gamma (γ) radiation dose from soil, the following model was used as criterion. This model uses the external hazard index Hex defined Equation (5) [17].

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \le 1 \tag{5}$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations of 226 Ra, 232 Th and 40 K, respectively. This index must be less than unity so that the annual effective dose due to radioactivity in the soil will be less than or equal to 1.5 mSv yr^{-1}. Radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by the internal hazard index (Hin) which is given by the following Equation (6) [17].

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \le 1 \tag{6}$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations of 226 Ra, 232 Th and 40 K, respectively, in Bq kg^{-1} for the soil. For the safe use of a soil Hin should be less than unity.

3. Results and Dicussion

3.1. Activity Concentration

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil samples from Seguenega site in Yaadga Region of Burkina Faso around the mining site of Seguenega are shown in Table 1.

Table 1. Activity concentration in soil samples from Seguenega site.

Sample ID	Activity concentration (Bq/kg)		
	U	Th	K
SSSE-001	26.78 ± 3.03	25.89±2.03	266.36 ± 27.76
SSSE-002	20.43 ± 1.15	19.62±1.95	185.75 ± 19.36
SSSE-003	10.97 ± 0.44	12.52±0.14	412.89 ± 43.04
SSSE-004	19.20 ± 1.05	24.46±0.54	186.87 ± 19.48
SSSE-005	18.44 ± 2.02	21.95±1.89	136.25 ± 14.40
SSSE-006	17.90 ± 1.05	18.97±0.58	159.39 ± 16.84
SSSE-007	18.41 ± 1.58	22.22±1.91	204.90 ± 21.36
SSSE-008	18.27 ± 1.69	20.06±0.37	142.87 ± 15.10
SSSE-009	22.20 ± 1.53	29.00±1.41	301.92 ± 31.47
SSSE-010	22.62 ± 2.10	25.96±0.87	198.80 ± 20.72
SSSE-011	19.50 ± 1.33	21.80±0.32	144.89 ± 15.31
SSSE-012	20.56 ± 2.11	28.81±1.61	275.32 ± 28.70
SSSE-013	24.09 ± 1.80	28.97±0.47	297.97 ± 31.06
SSSE-014	15.76 ± 0.69	20.66±0.77	160.98 ± 16.78
SSSE-015	19.78 ± 1.26	21.65±0.72	197.48 ± 17.35
SSSE-016	17.56 ± 1.12	23.51±0.63	203.25 ± 19.21
SSSE-017	10.82 ± 0.61	22.83±0.44	165.72 ± 15.37
SSSE-018	18.14 ± 1.20	24.72±0.58	187.43 ± 17.11
Min	10.82 ± 0.61	12.52 ± 0.14	136.25 ±14.40
Max	26.78 ± 3.03	29.00 ± 1.41	412.89 ± 43.04
Mean	18.97 ± 1.43	22.98 ± 0.96	212.72 ± 29.75

The highest value of radioactivity of ^{238}U, ^{232}Th and ^{40}K are 18.97, 29.00 and 412.89 Bq.kg^{-1} respectively while the lowest values are 10.82, 12.52 and 136.25 Bq.kg^{-1}.

The mean values for ^{238}U, ^{232}Th and ^{40}K are 18.97 ± 1.43 Bq.kg^{-1}, 22.98 ± 0.96 Bq.kg^{-1} and 212.72 ± 29.75 Bq.kg^{-1} respectively.

The average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in this study are lower than the worldwide average values of 32, 45 and 420 Bq.kg^{-1} respectively [3]. The activity concentration varies from one location to another location. These differences could be explained by the mineral content difference of soil or the non-uniformity of sampling depth. We can also notice that the ^{238}U, ^{232}Th and ^{40}K activity concentration in all the samples are lower than the world average.

Figure 3. compares the average concentrations of radionuclides ^{238}U, ^{232}Th, and ^{40}K of this present work with our previous work concerning Kalsaka site [18].

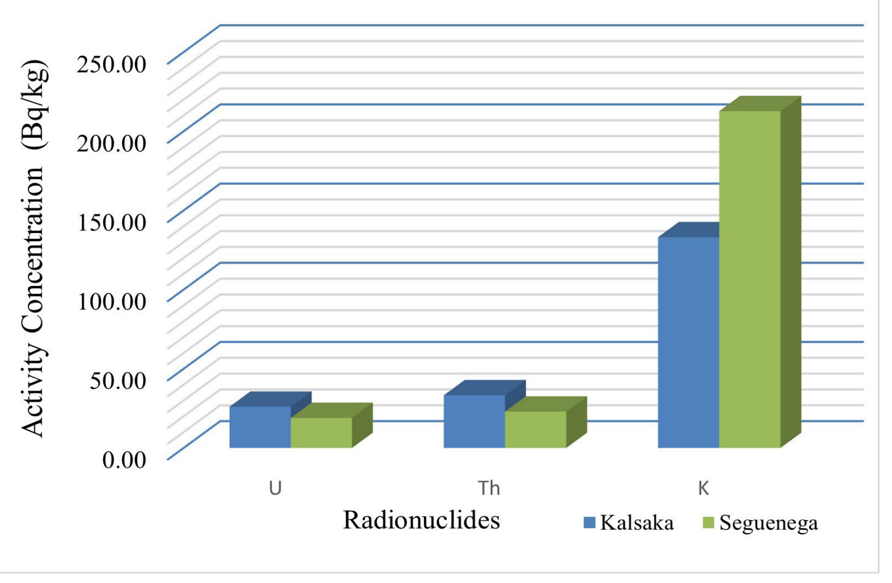

Figure 3. Comparison of activity concentration of ^{238}U, ^{232}Th and ^{40}K between Seguenega and Kalsaka sites.

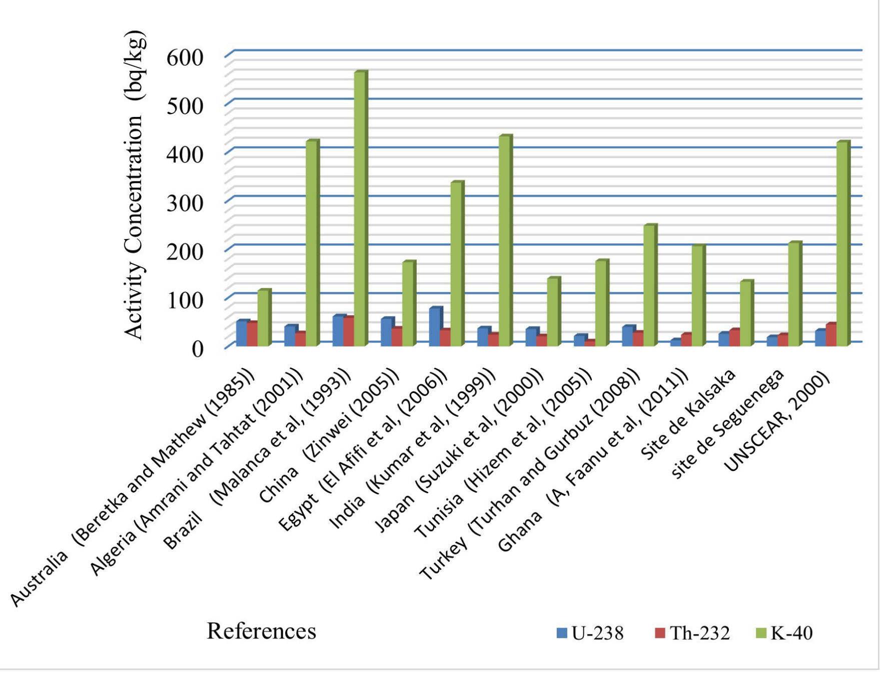

Figure 4. Comparison of activity concentrations of ^{238}U, ^{232}Th and ^{40}K of the present work and other works and UNSCEAR standards.

The average concentrations of ^{238}U and ^{232}Th at Kalsaka are higher than those at Seguenega wile, the average concentration of ^{40}K at Seguenega is almost twice more than Kalsaka site. This difference could be attributed to differences in geology and geochemical conditions.

Figure 4 shows a Comparison of the activity concentrations of ^{238}U, ^{232}Th and ^{40}K of the present work with our previous work concerning Kalsaka site, and other works [19]-[25] and UNSCEAR reference limits in soil sample. The results of the activity concentrations in this study are lower than the worldwide average values compared quite well with similar works which have been done in other countries as show in Figure 4.

3.2. Adsorption Dose Rate

The absorbed dose in air is the received dose in the open air from the radiation emitted from radionuclides activity concentrations in the environmental materials. This factor is important quantity to assess when considering radiation risk to a bio system. The absorbed dose rate obtained in this work varied in a range of 18.31 - 47.07 nGy/h with an average value of 31.97 nGy/h. The average value in this study is lower than the worldwide average value of 60 nGy/h estimated from soil concentrations.

3.3. Annual Effective Dose

The natural radioactivity in soil samples is usually determined from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K. The corresponding average annual effective dose for the present studies was 0.040 mSv/year

3.4. Radium Equivalent Activity

The radium equivalent activity (Raeq) is related to the external gamma dose from the terrestrial radionuclides and the internal dose due to radon and its decay products of ^{210}Pb and ^{201}Po. In this study, the average radium equivalent activity (Raeq) obtained in the samples was 69.11 Bq/kg in a range of 39.36 - 99.97 Bq/kg. The acceptable limit value of Raeq for building purposes is 370 Bq/kg for the material to be considered safe for use.

3.5. External and Internal Hazard Index

Radiation exposure due to ^{226}Ra, ^{232}Th and ^{40}K may be external and defined in terms of external hazard index. The average external is 0.19 which are less than the unity. Radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by the internal hazard index (Hin). The average internal is 0.24 which is less than the unity. Figure 5 shows a comparison between the external (Hex) and internal (Hin) risk indices of Kalsaka and Seguenega with the UNSCEAR reference limits

Table 2 shows the absorbed dose rate, the annual effective dose, the radium equivalent activity (Ra_{eq}), and the external (H_{ex}) and internal (H_{in}) hazard indices)

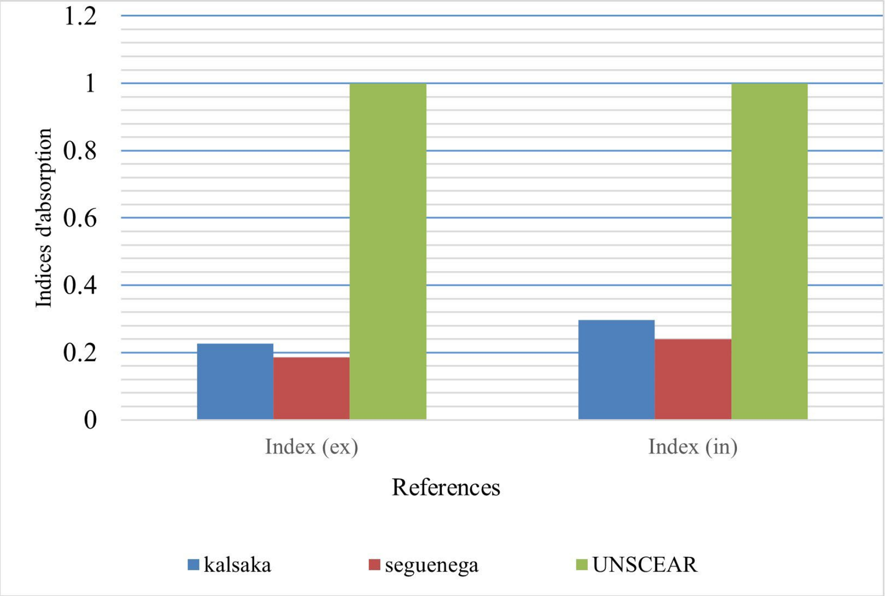

Figure 5. Comparison between external (Hex) and internal (Hin) risk indices of Kalsaka and Seguenega with the UNSCEAR reference limits.

in the soil samples activity from Yaadga Region of Burkina Faso surrounding the mining site of Seguenega.

The radium equivalent activity (Ra_{eq}), the external (H_{ex}) and internal (H_{in}) hazard are used in order to assess if the soil could be a source of public radiation exposure.

The values of Ra_{eq}, H_{ex} and H_{in} are below the acceptable values. This indicates that soil in the studied area that might be used for building purposes may not pose any significant radiological radiation hazard and, thus, regarded safe.

All the average values are below the references' limits.

Table 2. Doses and radium equivalent activity, and external (H_{ex}) and internal (H_{in}) hazard index.

SAMPLE ID	Absorbed Dose rate nGy/h	Annual Effective dose, mSv	Radium Equivalent (Bq/kg)	Hazard Index (ex)	hazard Index (in)
SSSE-001	39.12	0.05	84.31	0.23	0.30
SSSE-002	29.03	0.04	62.79	0.17	0.22
SSSE-003	29.81	0.04	60.60	0.16	0.19
SSSE-004	31.44	0.04	68.57	0.19	0.24
SSSE-005	27.44	0.03	60.28	0.16	0.21
SSSE-006	26.38	0.03	57.32	0.15	0.20
SSSE-007	30.47	0.04	65.96	0.18	0.23
SSSE-008	26.52	0.03	57.96	0.16	0.21
SSSE-009	40.36	0.05	86.92	0.23	0.29

Continued

SSSE-010	34.42	0.04	75.05	0.20	0.26
SSSE-011	28.22	0.03	61.83	0.17	0.22
SSSE-012	38.38	0.05	82.96	0.22	0.28
SSSE-013	41.05	0.05	88.46	0.24	0.30
SSSE-014	26.47	0.03	57.70	0.16	0.20
SSSE-015	30.45	0.04	65.95	0.18	0.23
SSSE-016	30.45	0.04	65.95	0.18	0.23
SSSE-017	30.45	0.04	65.95	0.18	0.23
SSSE-018	30.45	0.04	65.95	0.18	0.23
Mean	31.97	0.04	69.11	0.19	0.24
Min	18.31	0.03	39.36	0.11	0.14
Max	47.07	0.05	99.97	0.27	0.34

4. Conclusions

The activity concentrations of Natural Radionuclides ^{238}U, ^{232}Th and ^{40}K in soil samples were measured using Gamma Spectrometry with High Purity Germanium detector. The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were 18.97 ± 1.43 $Bq.kg^{-1}$, 22.98 ± 0.96 $Bq.kg^{-1}$ and 212.72 ± 29.75 $Bq.kg^{-1}$ respectively. The average absorbed dose was 0.032µGy/h whereas the Annual Committed Effective Dose was 0.040 ± 0.002 $mSv.y^{-1}$.

The average radium equivalent activity concentration was 69.11 $Bq.kg^{-1}$. The external and internal Hazard indices where 0.19 and 0.24 respectively which are around five times less than one. The mean effective dose rate of 0.04 ± 0.002 mSv y^{-1} and the mean values of Ra_{eq} and H_{ex} and H_{in} for the studied area are below their respective permissible limits. This indicates that soil in the studied area that might be used for building purposes may not pose any significant radiological radiation hazard and, thus, regarded safe. The results of this study indicate that radiation hazard for the moment is not significant in this area.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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