

Natural Radioactivity Measurement and Dose Assessment in Soil Samples from Some Selected Areas of Mali

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Abstract

This is the first time that a study applies the gamma ray spectroscopy using a high purity germanium to evaluate the terrestrial gamma radiation level by detector in selected regions of Mali. The results reveal that the activity concentrations of naturally occurring ²²⁶Ra, ²³²Th and ⁴⁰K radionuclides ranges between respectively 17.26 ± 1.81 and 105.43 ± 10.36 ; 20.41 ± 2.52 and 180.85 ± 19.69 ; 41.33 ± 8.26 and 627.63 ± 85.62 Bq·kg⁻¹. The measures of radium equivalent activity (Ra_{eq}), absorbed dose rates (ADR), annual effective dose rate (AEDR), external hazard index (H_{ex}), internal hazard index (H_{in}) and excess lifetime cancer risk (ELCR) were evaluated. Some of the obtained values exceed the recommended safe levels. Further studies are necessary to constitute a baseline reference data about the terrestrial radiation in Mali.

Keywords

Soil Radioactivity, Radiological Hazard, Population Exposure, Gamma Spectrometry, Mali

1. Introduction

Natural radionuclides of terrestrial origin, known as primordial radionuclides, are widespread in the earth's environment and exist in varying proportion in the entire natural environment, including the human body.

Only those radionuclides with half-lives comparable to the age of the earth such as ²²⁶Ra, ²³²Th, ⁴⁰K, and their decay products, exist in sufficient quantity to contribute significantly to population exposure [1].

To assess the health risk, it is important to estimate the radiation dose distri-

bution due to natural radionuclides that depend mainly on the local geological and geographical conditions.

In Mali, our previous study investigated on the natural radiological exposure for human being, focusing on the radon that is formed along with the ^{228}U decay disintegration chain [2].

In the same vein, our research team has collected some soil samples from four regions in Mali for gamma ray analysis.

The purpose of this study is to determine the concentration of soil radionuclides' activity and to evaluate the health risks via the gamma radiation parameters such as Radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), absorbed dose rate (ADR), annual effective dose rate (AEDR) and excess lifetime cancer risk (ELCR). According to UNSCEAR (2000), only two African countries (Algeria and Egypt) were contributed to the 2000 report on the formulation of the world average radionuclide concentrations and the associated external exposure rates. This is the first time that such study is conducted to analyze the concentration of soils radionuclides in Mali. The results will help enrich the various studies reported in Africa since 2000 [3]-[8].

2. Materials and Methods

2.1. Geographical Description of the Study Area

Mali is a landlocked country in West Africa. It is the eighth largest country in Africa with an area of just over 1,240,000 square kilometres. This country is divided into eight regions and one capital district (see **Figure 1**). Each of the regions bears the name of its principal city. The regions are divided into 49 cercles. The cercles and the capital district are divided into 703 communes. The capital Bamako is administered separately and is in its own district.

Soil samples were collected from Bamako district ($12^{\circ}38'21''\text{N } 8^{\circ}0'10''\text{W}$), third region Sikasso ($11^{\circ}19'\text{N } 5^{\circ}40'\text{W}$), fourth region Ségou ($13^{\circ}27'\text{N } 6^{\circ}16'\text{W}$)

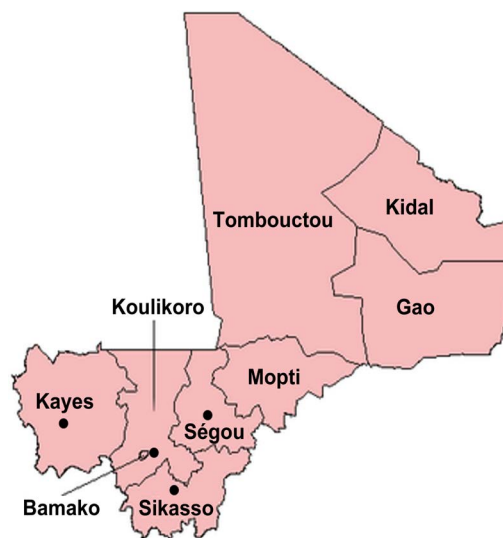


Figure 1. The sample collection areas on the Malian map.

and Faléa (12° 15' 53" N 11° 16' 30" W) a village located in the rural commune of the cercle of Kéniéba in the first region Kayes (**Figure 1**).

2.2. Sample Collection and Preparation

Soil samples were randomly collected by digging a half meter deep hole in different locations of the investigated areas: two samples from Bamako, Sikasso, and Segou, three samples from Falea (Kayes region). The distance between each site of collected sample was about 5 - 15 km. All the samples were dried, crushed, homogenised and passed through a 2 mm sieve and then oven-dried at 40 °C for 24 h. Before measuring the radioactivity, the conditioned samples were stored in cylindrical SG50 containers for one month to allow the short-lived daughters of ^{238}U and ^{232}Th decay series to reach a secular equilibrium.

2.3. Gamma Ray Detection System

The gamma-ray activities were measured by using a shielded planar Hyper-Pure Germanium (HPGe) detector and associated electronics. The detector, a BE 3830 model coupled to an 8192 channel analyser piloted by Genie 2000 software were supplied by Canberra [9]. The experimental detector resolution is 1.97 keV at 1332 keV and 0.65 keV at 122 keV. Each sample was counted for 200,000 s.

2.4. Calculation Formulae for Radiation Exposure Parameters

2.4.1. Radium Equivalent Activity (Ra_{eq})

Radium equivalent Ra_{eq} represents the sum of the specific activities of ^{226}Ra , ^{232}Th , and ^{40}K based on the assumption that 370 Bq·kg⁻¹ of ^{226}Ra , 259 Bq·kg⁻¹ of ^{232}Th , and 4810 Bq·kg⁻¹ of ^{40}K would produce the same dose rate of gamma radiation.

Radium equivalent activity is calculated through the following relation [10]:

$$Ra_{eq} = A_{Ra} + 1.43 \times A_{Th} + 0.077 \times A_K \quad (1)$$

where A_{Ra} , A_{Th} and A_K are the activity concentrations respectively of ^{226}Ra , ^{232}Th and ^{40}K expressed in Bq·kg⁻¹.

2.4.2. Absorbed Dose Rate (ADR)

The absorbed gamma dose rate ADR (nGy·h⁻¹) due to the activity of ^{226}Ra , ^{232}Th and ^{40}K in the air at 1 m above the ground is defined by the following expression:

$$\text{ADR} \left(\text{nGy} \cdot \text{h}^{-1} \right) = 0.462 A_{Ra} + 0.604 A_{Th} + 0.042 A_K \quad (2)$$

where A_{Ra} , A_{Th} and A_K are defined in the above equation.

2.4.3. Annual Effective Dose Rate (AEDR)

The annual effective dose rate received by the population is calculated using the following equation according to UNSCEAR [1]:

$$\text{AEDR} \left(\text{mSv} \cdot \text{y}^{-1} \right) = \text{ADR} \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (3)$$

where ADR is the estimated absorbed dose rate (nGy·h⁻¹) given in Equation (2), 0.7 Sv·Gy⁻¹ the conversion coefficient from absorbed dose in the air to effective

dose received by adults, 0.2 is the fraction of time spent indoors and 8760 is the time in hours in 1 year.

2.4.4. External Hazard Index (H_{ex}) and Internal Hazard Index (H_{in})

The external hazard index is a criterion used to assess soil radiation exposure rate on a human body. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} ($370 \text{ Bq}\cdot\text{kg}^{-1}$) and the maximum of the annual radiation dose ($1.5 \text{ mSv}\cdot\text{y}^{-1}$). The external hazard index H_{ex} is calculated by the following formula:

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

The internal exposure to radon and its daughter progenies is quantified by the internal hazard index H_{in} , which is given by the equation:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

2.4.5. Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk (ELCR) gives the probability of developing cancer during the life of a human being at a given exposure level. The ELCR is calculated using the following equation [7] [11] [12] [13]:

$$\text{ELCR} = \text{AEDR} \times \text{RF} \times \text{DL} \quad (6)$$

where AEDR is the annual effective dose rate, DL the average duration of life for human being (70 years) and RF is the mortal cancer risk factor (Sv^{-1}). For stochastic effects, ICRP 60 uses RF values of 0.05 for the public [14].

3. Results and Discussion

Table 1 summarizes the measured concentrations of the specific activity of ^{226}Ra ,

Table 1. Measured activity levels ($\text{Bq}\cdot\text{kg}^{-1}$) of specific radionuclides for soil samples at various locations of Mali.

Sample No.	Sector	^{226}Ra	^{232}Th	^{40}K
S1	Bamako 1	22.67 ± 2.95	37.78 ± 5.02	622.28 ± 85.36
S2	Bamako 2	22.67 ± 2.48	35.56 ± 4.10	627.63 ± 85.62
S3	Ségou 1	17.26 ± 1.81	20.41 ± 2.52	52.06 ± 15.49
S4	Ségou 2	22.66 ± 2.35	26.02 ± 2.97	41.33 ± 8.26
S5	Sikasso 1	28.20 ± 2.63	36.81 ± 3.92	245.34 ± 27.37
S6	Sikasso 2	25.95 ± 2.82	34.03 ± 4.10	210.93 ± 30.62
S7	Kayes 1	105.43 ± 10.36	180.85 ± 19.69	76.71 ± 14.96
S8	Kayes 2	77.01 ± 7.91	68.41 ± 8.20	185.16 ± 28.88
S9	Kayes 3	85.93 ± 8.35	85.65 ± 9.41	143.46 ± 21.38
Range		17.26 - 105.43	20.41 - 180.85	41.33 - 627.63
Average		45.31 ± 4.63	58.39 ± 6.66	244.99 ± 35.33

^{232}Th , ^{40}K , which ranges respectively, from 17.26 ± 1.81 to 105.43 ± 10.36 $\text{Bq}\cdot\text{kg}^{-1}$, 20.41 ± 2.52 to 180.85 ± 19.69 $\text{Bq}\cdot\text{kg}^{-1}$, 41.33 ± 8.26 to 627.63 ± 85.62 $\text{Bq}\cdot\text{kg}^{-1}$ in the selected soil samples. The mean activity of ^{40}K observed (244.99 ± 35.33 $\text{Bq}\cdot\text{kg}^{-1}$) in the present study is below the recommended limit (400 $\text{Bq}\cdot\text{kg}^{-1}$) [1]. Meanwhile, the mean activity concentration levels of ^{226}Ra (45.31 ± 4.63 $\text{Bq}\cdot\text{kg}^{-1}$) and ^{232}Th (58.39 ± 6.66 $\text{Bq}\cdot\text{kg}^{-1}$) are higher than the worldwide mean reported values (35 and 30 respectively).

The radium equivalent activity, the gamma absorbed dose rate, the annual effective dose rate, the external, and internal hazard index, the excess lifetime cancer risk due to ^{226}Ra , ^{232}Th and ^{40}K in the soil samples was calculated from respectively Equations (1)-(6) and are presented in column 3, 4, 5, 6, 7, 8 of **Table 2**.

As can be seen from **Table 2** the calculated radium equivalent (Ra_{eq}) is between 50.45 ± 6.61 and 369.95 ± 39.67 with the average of 266 Bq/kg . None of those values exceeded the suggested maximal admissible value of 370 Bq/kg that is acceptable as safe limit.

The absorbed dose rate (ADR) obtained by equation (2) indicated that the lowest dose rate was 22.49 ± 3.01 nGy/h for the soil sample S4, while the highest dose rate was 161.16 ± 17.31 nGy/h for the soil represented by sample S7. Except the dose rates of samples S7, S8, S9, all the calculated dose rates were lesser than the global average value 57 nGy/h according to UNSCEAR,2000 report.

The annual effective dose rates (AEDR) in the air varied from 0.028 ± 0.004 to 0.198 ± 0.021 mSv/year with an average value of 0.082 ± 0.001 mSv/year which is higher than the world's mean (0.07 mSv/year).

For the external hazard index results showed that no soil sample exceed unity. It is noteworthy that only the internal hazard index value of soil represented by sample S7 is higher than the permissible value (unity).

Table 2. Radium equivalent activity (Ra_{eq}), absorbed dose rate (ADR), annual effective dose rate (AEDR), external hazard index (H_{ex}), internal hazard index (H_{in}) and excess lifetime cancer risk (ELCR) of selected soil samples in Mali.

Sample No.	Sector	Ra_{eq} ($\text{Bq}\cdot\text{Kg}^{-1}$)	ADR ($\text{nGy}\cdot\text{h}^{-1}$)	AEDR ($\text{mSv}\cdot\text{y}^{-1}$)	H_{ex}	H_{in}	ELCR ($\times 10^{-3}$)
S1	Bamako 1	124.61 ± 16.70	59.43 ± 7.98	0.073 ± 0.009	0.34 ± 0.05	0.40 ± 0.05	0.26 ± 0.03
S2	Bamako 2	121.85 ± 14.94	58.31 ± 7.22	0.072 ± 0.009	0.33 ± 0.04	0.40 ± 0.05	0.25 ± 0.03
S3	Ségou 1	50.45 ± 6.61	22.49 ± 3.01	0.028 ± 0.004	0.14 ± 0.02	0.18 ± 0.02	0.10 ± 0.01
S4	Ségou 2	63.05 ± 7.23	27.92 ± 3.23	0.034 ± 0.004	0.17 ± 0.02	0.23 ± 0.03	0.11 ± 0.01
S5	Sikasso 1	99.73 ± 10.34	45.57 ± 4.73	0.056 ± 0.006	0.27 ± 0.03	0.35 ± 0.04	0.20 ± 0.02
S6	Sikasso 2	90.85 ± 11.04	41.40 ± 5.06	0.051 ± 0.006	0.25 ± 0.03	0.32 ± 0.04	0.18 ± 0.02
S7	Kayes 1	369.95 ± 39.67	161.16 ± 17.31	0.198 ± 0.021	0.99 ± 0.11	1.28 ± 0.14	0.69 ± 0.07
S8	Kayes 2	189.09 ± 21.86	84.67 ± 9.82	0.104 ± 0.012	0.51 ± 0.06	0.72 ± 0.08	0.36 ± 0.04
S9	Kayes 3	219.46 ± 23.45	97.46 ± 10.44	0.120 ± 0.013	0.60 ± 0.06	0.83 ± 0.09	0.42 ± 0.04
Range		50.45 - 369.95	22.49 - 161.16	0.028 - 0.198	0.14 - 0.99	0.18 - 1.28	0.10 - 0.69
Average		147.676 ± 16.87	66.49 ± 7.64	0.082 ± 0.001	0.40 ± 0.05	0.52 ± 0.06	0.29 ± 0.032
Safe level		370	57	0.07	1	1	0.29

Except samples S7, S8, and S9, it was found that the life cancer risk value is lesser than the world average of 0.29×10^{-3} . In the first region Kayes there is a possibility of developing cancer cases among people.

A more detailed analysis of the overall results from calculated radiological parameters shows that soil samples collected in the fourth region Ségou presented the lowest value and those in Kayes region the highest value. More investigations were undertaken to understand the exceeded value obtained in the cercle of Falea located in western Mali approximately 350 km west of the capital, Bamako. The information collected showed that the cercle of Falea is a uranium, silver and copper deposit. The current resource estimate is approximately 45 million pounds of U_3O_8 [$\sim 17,300$ t U] at an average grade of $\sim 0.07\%$ U_3O_8 [$\sim 0.06\%$ U]. The deposit also contains ~ 37 million Oz Ag and $\sim 70,000$ t Cu. The dominant uranium mineral is uraninite; copper is present mainly as chalcopyrite and silver mainly as argentite, and in its native form. Only 5% of the property has been explored to date, and all zones remain open [15] [16].

In sum, the nature of the Falea deposit (an unconformity-associated uranium deposit) may explain the high values of the radium and thorium concentrations, impacting those of the radiological parameters.

4. Conclusions

In the present work, we used gamma spectrometry to determine natural radioactivity in 9 soil samples in Mali. The specific activities of the ^{226}Ra , ^{232}Th and ^{40}K radionuclides measured in these samples vary respectively from 17.26 ± 1.81 to 105.43 ± 10.36 Bq·kg⁻¹, 20.41 ± 2.52 to 180.85 ± 19.69 Bq·kg⁻¹, 41.33 ± 8.26 to 627.63 ± 85.62 Bq·kg⁻¹.

The level of the natural radiation in the studied areas does not exceed the norm, except in Falea location where samples S7, S8 and S9 were collected.

Although the study did not cover the entire country of Mali, however, the findings reported in this workpaper provide relevant information and data which would document and enrich the world database on natural radioactivity emitted from soil and their effects on human bodies.

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Conflicts of Interest

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

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