Research Article

Natural Radioactivity Measurements and Radiation Dose Estimation in Some Sedimentary Rock Samples in Turkey

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The natural radioactivity existed since creation of the universe due to the long life time of some radionuclides. This natural radioactivity is caused by γ -radiation originating from the uranium and thorium series and ^{40}K . In this study, the gamma radiation has been measured to determine natural radioactivity of ^{238}U , ^{232}Th , and ^{40}K in collected sedimentary rock samples in different places of Turkey. The measurements have been performed using γ -ray spectrometer containing NaI(Tl) detector and multichannel analyser (MCA). Absorbed dose rate (D), annual effective dose (AED), radium equivalent activities (Ra_{eq}), external hazard index (H_{ex}), and internal hazard index (H_{in}) associated with the natural radionuclide were calculated to assess the radiation hazard of the natural radioactivity in the sedimentary rock samples. The average values of absorbed dose rate in air (D), annual effective dose (AED), radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), and internal hazard index (H_{in}) were calculated and these were 45.425 nGy/h, 0.056 mSv/y, 99.014 Bq/kg, 0.267, and 0.361, respectively.

1. Introduction

The natural radioactivity existed since creation of the universe due to the long life time of radionuclide. This natural radioactivity is caused by γ -radiation originating from the uranium and thorium series and ^{40}K . Natural radioactivity arising from natural sources is the main contribution to the annual dose received by the world's population, exposure resulting from radionuclides inherent in the earth's crust and from cosmic rays. The terrestrial radionuclides are ubiquitous, belonging to the ^{238}U and ^{232}Th series and their decay products as well as single decay radionuclides, particularly ^{40}K . Gamma radiation emitted from such naturally occurring radionuclides in all ground formations represents the main external exposure to human body [1]. The knowledge of concentrations and distributions of the radionuclides are of interest since it provides useful information in the monitoring of environmental radioactivity. Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and

geographical conditions and appear at different levels in the soils and rocks of each region in the world [2–4].

In this study, the natural radioactivity concentrations of ^{40}K , ^{238}U (^{226}Ra), and ^{232}Th in some sedimentary rock samples collected in different regions of Turkey have been investigated. The results were used to assess the radiological hazard associated with the absorbed gamma dose rate in air (D), the annual effective dose rate, radium equivalent activities (Ra_{eq}), external hazard index (H_{ex}), and internal hazard index (H_{in}) from gamma radiation.

2. Material and Methods

In this study 19 different types of sedimentary rocks have been collected in different regions of Turkey. In Figure 1 the locations of Turkey in which samples were collected have been shown. After collection of samples, they were crushed and grinded to get proper grain size 100 mesh sieve. Then, samples were dried until 100°C in an oven for about 24 h. The dried samples have been filled in a cup which is sealed tightly

FIGURE 1: The location of the sampling sites of the sedimentary rocks in Turkey.

with a thick tape around its neck to limit any gas escape from it, and it was stored for four weeks to get secular equilibrium to be achieved between ^{238}U and its progeny [5].

The radioactivity of ^{226}Ra , ^{232}Th , and ^{40}K in the sedimentary rock samples was determined using a gamma-ray spectrometry [6] consisting of a $3'' \times 3''$ NaI(Tl) detector connected to a 16384-channel multichannel analyser (MCA). Before measurement the system should be calibrated. This is done using ^{137}Cs and ^{60}Co radioactive sources, which produce γ -ray energy of 662, 1173, and 1332 keV, respectively. The γ -ray spectrum obtained from the mentioned source and related fit has been displayed in Figure 2.

The spectrum is analyzed using the MAESTRO32 obtained from ORTEC. The measurement was based on recording natural radioactivity quantities of three natural long-live elements: ^{226}Ra , ^{232}Th , and ^{40}K which are considered the photopeaks at 1760, 2610, and 1461 keV, respectively, in the natural γ -ray spectrum [5]. The efficiency calibration of the detector system was measured [7] and the results have been used in this work.

The activities for the natural radionuclides were calculated using the following relation [8]:

$$A (\text{Bq/kg}) = \frac{N}{\varepsilon \cdot \gamma \cdot t \cdot m}, \quad (1)$$

where A is the activity of the radionuclide in Bq/kg and N is the net peak area under the most prominent photo peaks calculated by subtracting the respective count rate from the background spectrum obtained for the same counting time. The net count rate in the measurement is calculated from the background subtracted area of prominent gamma-ray peaks. ε is the detector efficiency of the specific gamma-ray, γ the absolute transition probability of gamma decay, t the counting time (s) which is 72000 s, and m the mass of the sample (kg).

3. Results and Discussion

The activity concentrations of natural radionuclides (^{40}K , ^{238}U (^{226}Ra), and ^{232}Th) in the sedimentary rocks collected

FIGURE 2: Calibration spectrum obtained for ^{137}Cs and ^{60}Co source (a) and related fit (b).

in Turkey are presented in Table 1. As shown in Table 1, the activity concentrations of sedimentary rock samples have ranged from 143.97 to 452.34 Bq/kg for ^{40}K , from 12.01 to 48.95 Bq/kg for ^{226}Ra , and from 8.2 to 53.27 Bq/kg for ^{232}Th . The obtained results have been displayed in Figure 3.

The highest concentrations for all natural radionuclides were detected in the sample 13 (S13) which was collected from

TABLE 1: The activity concentration of ^{40}K , ^{226}Ra , and ^{232}Th (in Bq/kg) of sedimentary rock samples.

Sample	Region	Activity concentration (Bq/kg)		
		^{40}K	^{226}Ra	^{232}Th
S1	Bursa	253.85 ± 12.69	36.23 ± 1.81	25.05 ± 1.25
S2	Bilecik	189.52 ± 9.48	25.34 ± 1.27	18.77 ± 0.94
S3	Balıkesir	197.17 ± 9.86	34.04 ± 1.70	27.02 ± 1.35
S4	Karaman	143.97 ± 7.20	48.00 ± 2.40	39.18 ± 1.96
S5	Eskişehir	284.26 ± 14.21	28.83 ± 1.44	8.20 ± 0.41
S6	Kayseri	247.30 ± 12.36	17.55 ± 0.88	33.49 ± 1.67
S7	Diyarbakır	179.65 ± 8.98	27.83 ± 1.39	18.55 ± 0.93
S8	Malatya	158.74 ± 7.94	44.48 ± 2.22	34.46 ± 1.72
S9	Elazığ	264.01 ± 13.20	12.01 ± 0.60	45.93 ± 2.30
S10	Isparta	183.55 ± 9.18	35.67 ± 1.78	22.77 ± 1.14
S11	Burdur	346.12 ± 17.31	32.83 ± 1.64	37.52 ± 1.88
S12	Hatay	180.19 ± 9.01	37.43 ± 1.87	31.86 ± 1.59
S13	Afyon	452.34 ± 22.62	48.95 ± 2.45	53.27 ± 2.66
S14	İzmir	168.57 ± 8.43	22.57 ± 1.13	24.39 ± 1.22
S15	Manisa	180.19 ± 9.01	37.43 ± 1.87	31.86 ± 1.59
S16	Denizli	260.41 ± 13.02	41.86 ± 2.09	36.73 ± 1.84
S17	Kastamonu	376.39 ± 18.82	48.62 ± 2.43	42.18 ± 2.11
S18	Karabük	156.98 ± 7.85	30.90 ± 1.55	27.86 ± 1.39
S19	Amasya	395.28 ± 19.76	47.94 ± 2.40	47.29 ± 2.36
UNSCEAR 2000		500.00	50.00	50.00

FIGURE 3: The activity concentration of ^{40}K , ^{226}Ra , and ^{232}Th for all samples.

Afyon region. The worldwide average concentrations have been reported as 50 Bq/kg for ^{226}Ra and ^{232}Th concentrations and 500 Bq/kg for ^{40}K in the UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation [9–12]. It was found that obtained results for ^{40}K and ^{226}Ra concentrations are lower than the worldwide average values. For ^{232}Th concentration, S13 is higher than the worldwide average values.

The ^{40}K , ^{226}Ra , and ^{232}Th activity concentrations are used for estimation of the absorbed dose rate (D), the annual effective dose rates (AED), the radium equivalent activity (Ra_{eq}), and the index of external and internal radiation hazard (H_{ex} and H_{in}).

FIGURE 4: Gamma absorbed dose rate at 1 m above ground for all samples.

The absorbed dose rate (D) in air at 1 m above the ground is calculated to provide a characteristic of the external terrestrial γ -ray [5, 11, 13]:

$$D \text{ (nGy} \cdot \text{h}^{-1}) = 0.462A_{\text{Ra}} + 0.604A_{\text{Th}} + 0.0417A_{\text{K}}, \quad (2)$$

where A_{Ra} , A_{Th} , and A_{K} are activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K in Bq/kg, respectively. The absorbed dose rate ranged from 30.13 to 73.65 nGy $\cdot$ h $^{-1}$. The absorbed dose rate is displayed in Figure 4. The global average value of absorbed dose rate is 55 nGy $\cdot$ h $^{-1}$ [11].

The annual effective dose rates (AED) should be obtained to test the health effect of those absorbed dose rates. In order to estimate the annual effective doses, one has to take into account to conversion coefficient from absorbed dose in air to effective and the outdoor occupancy factor. In the

UNSCEAR [11] reports, a value of 0.7 Sv/Gy was used for the conversion coefficient from absorbed dose in air to effective dose received by adults and 0.2 for the outdoor occupancy factor. The annual effective dose equivalent was calculated from the following equation:

$$\text{AED} (\text{mSv} \cdot \text{y}^{-1}) = D (\text{nGy} \cdot \text{h}^{-1}) \times 8760 (\text{h}) \times 0.2 \times 0.7 (\text{Sv/Gy}) \times 10^{-6}. \quad (3)$$

The annual effective dose rate values varied from 0.037 to 0.09 mSv·y⁻¹. The AED results have been displayed in Figure 5. The average AED from the terrestrial radionuclides is 0.46 mSv·y⁻¹ in areas with the normal background radiation [11].

Distribution of ⁴⁰K, ²²⁶Ra, and ²³²Th was not uniform in sedimentary rock samples. Uniformity with respect to exposure to radiation was defined in terms of radium equivalent activity (Ra_{eq}) in Bq/kg to compare the specific activity of materials containing different amounts of ⁴⁰K, ²²⁶Ra, and ²³²Th. The radium equivalent activity was calculated as follows [14]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K, \quad (4)$$

where A_{Ra} , A_{Th} , and A_K are the activity concentration of ²²⁶Ra, ²³²Th, and ⁴⁰K in Bq/kg, respectively. Ra_{eq} is estimated for the collected samples and is displayed in Figure 6. The values of Ra_{eq} varied from 62.44 to 159.15 Bq/kg. The recommended maximum value for Ra_{eq} is 370 Bq/kg [14].

The external hazard index (H_{ex}) and internal hazard index (H_{in}) are calculated from the equations [14]

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1, \quad (5)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1,$$

where A_{Ra} , A_{Th} , and A_K are activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K in Bq/kg, respectively. The values of internal and external radiation hazard index must be less than unity for radiation hazard to be negligible.

The value of H_{ex} must be less than unity, which corresponds to the upper limit of Ra_{eq} (370 Bq/kg), in order to keep the radiation hazard under limit. The results have been displayed in Figure 7.

Also, all index results have been displayed in Table 2. It can be seen that the obtained values of absorbed dose rate for sedimentary rock samples except those collected from Afyon (S13), Kastamonu (S17), and Amasya (S19) are lower than the global average value of absorbed dose rate, which is 55 nGy·h⁻¹. For the annual effective dose, it is clear that none of the results are higher than the UNSCEAR limit, where the average AED from the terrestrial radionuclides is 0.46 mSv·y⁻¹ in areas with the normal background radiation. The estimated values of Ra_{eq} in the present work are lower than the recommended maximum value of 370 Bq/kg. For internal and external radiation hazard index, it can be seen that all measured results are lower than the upper limit of unity.

FIGURE 5: Effective dose rate for all samples.

FIGURE 6: Radium equivalent activity for all samples.

FIGURE 7: External and internal hazard index for all samples.

4. Conclusion

The level of natural radioactivity in sedimentary rock samples collected from different regions of Turkey was evaluated using gamma-ray spectrometry. The mean activity concentrations of ⁴⁰K, ²²⁶Ra, and ²³²Th were 243.08, 34.66,

TABLE 2: Results of the absorbed dose rate (D), the annual effective dose rates (AED), the radium equivalent activity (Ra_{eq}), and the index of external and internal radiation hazard (H_{ex} , H_{in}).

Sample	Region	D (nGy/h)	AED (mSv/y)	Index			
				Ra_{eq} (Bq/kg)	H_{ex}	H_{in}	I_γ
S1	Bursa	42.45 ± 2.12	0.05	91.60 ± 4.58	0.25	0.35	0.33
S2	Bilecik	30.95 ± 1.55	0.04	66.78 ± 3.34	0.18	0.25	0.24
S3	Balıkesir	40.27 ± 2.01	0.05	87.86 ± 4.39	0.24	0.33	0.31
S4	Karaman	51.84 ± 2.59	0.06	115.11 ± 5.76	0.31	0.44	0.40
S5	Eskişehir	30.13 ± 1.51	0.04	62.44 ± 3.12	0.17	0.25	0.23
S6	Kayseri	38.65 ± 1.93	0.05	84.48 ± 4.22	0.23	0.28	0.31
S7	Diyarbakır	31.55 ± 1.58	0.04	68.19 ± 3.41	0.18	0.26	0.25
S8	Malatya	47.98 ± 2.40	0.06	105.97 ± 5.30	0.29	0.41	0.37
S9	Elazığ	44.30 ± 2.22	0.05	98.02 ± 4.90	0.26	0.30	0.36
S10	Isparta	37.88 ± 1.89	0.05	82.36 ± 4.12	0.22	0.32	0.29
S11	Burdur	52.26 ± 2.61	0.06	113.14 ± 5.66	0.31	0.39	0.41
S12	Hatay	44.05 ± 2.20	0.05	96.87 ± 4.84	0.26	0.36	0.34
S13	Afyon	73.65 ± 3.68	0.09	159.95 ± 8.00	0.43	0.56	0.58
S14	İzmir	32.19 ± 1.61	0.04	70.42 ± 3.52	0.19	0.25	0.25
S15	Manisa	44.05 ± 2.20	0.05	96.87 ± 4.84	0.26	0.36	0.34
S16	Denizli	52.38 ± 2.62	0.06	114.43 ± 5.72	0.31	0.42	0.41
S17	Kastamonu	63.64 ± 3.18	0.08	137.92 ± 6.90	0.37	0.50	0.50
S18	Karabük	37.65 ± 1.88	0.05	82.83 ± 4.14	0.22	0.31	0.29
S19	Amasya	67.20 ± 3.36	0.08	146.01 ± 7.30	0.39	0.52	0.53

and 31.92 Bq/kg, respectively. The mean activity concentrations are lower than the world mean values identified by UNSCEAR [11]. From the measured values, the average values of absorbed dose rate in air (D), annual effective dose (AED), radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), and internal hazard index (H_{in}) were calculated and these were 45.43 nGy/h, 0.056 mSv/y, 99.0 Bq/kg, 0.27, and 0.36, respectively. All the calculated values are lower than the recommended maximum values in the UNSCEAR [11] reports. As a result of these, it can be concluded that for people who are using and mining sedimentary rock in these regions of Turkey are safe in terms of radiation hazards.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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