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Radioactivity measurements and radiation dose assessments due to natural radiation in Karabük (Turkey)

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Abstract In this work, the radionuclide activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in surface soils and radon levels in dwellings of Karabük, Turkey were determined in order to evaluate the environmental radioactivity. Concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides were determined using gamma spectrometry with using HPGe detector. The etch track detectors (CR-39) were used to determine the distribution of radon concentrations. The average activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K were found as 21.0, 23.5 and 363.5 Bq kg^{-1}, respectively. The calculated average annual effective dose equivalent from the outdoor terrestrial gamma radiation from ^{226}Ra, ^{232}Th and ^{40}K is 53.5 μSv y^{-1}. The average radon concentration and annual effective dose equivalent of ^{222}Rn in Karabük dwellings were obtained 131.6 Bqm^{-3} and 3.32 mSv y^{-1}, respectively. The evaluated data were compared with the data obtained from different countries.

Keywords Natural radionuclides · Gamma spectrometry · Etch track detectors · Annual effective dose

Introduction

Human population is exposed to ionizing gamma radiation emitted from naturally occurring radioactive ^{232}Th, ^{238}U series and radioactive ^{40}K in soil. These radionuclides are widely spread in the earth's environment and it is present at trace levels in all ground formations. Beck suggested that 50–80% of the total gamma flux at the earth's surface arises from ^{40}K and ^{232}Th, ^{238}U series [1]. Natural environmental radioactivity and associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soil of each region in the world [2–4]. Measurement of the concentrations of natural radionuclides in soil gives information on the natural sources. Knowledge of the distribution of these radionuclides in the environment is essential in the sense of controlling radiation levels.

Karabük province is in the northern part of Anatolia and about 230 km north of the capital city Ankara (Fig. 1). It has an area of approximately 4.145 km^2, and has a population of 227,610 (Central Karabük has a population of 119,303) on 31 December 2010. Karabük is one of the steel-iron production center of Turkey. The present shape of Karabük basin was formed at the end of Upper Lutetian geological time segment (it spans the time between 48.6 ± 0.2 and 40.4 ± 0.2 million years ago). Both northern and southern margins of the basin have tectonic characteristics [5]. Turkish seismic code defines Central Karabük as being in the first-degree earthquake zone [6]. These features make Karabük an interesting candidate for radiological studies. There has also not been any study on environmental doses from external exposures for Karabük city previously. Therefore, the main subject of present study is to determine the levels of ^{232}Th, ^{238}U and ^{40}K activity concentrations in soils, the associated external gamma dose rate estimations and indoor radon concentrations of Karabük, Turkey. The outcomes of this work will form a baseline data set, which will enable estimations of population exposure. The data will also contribute to the

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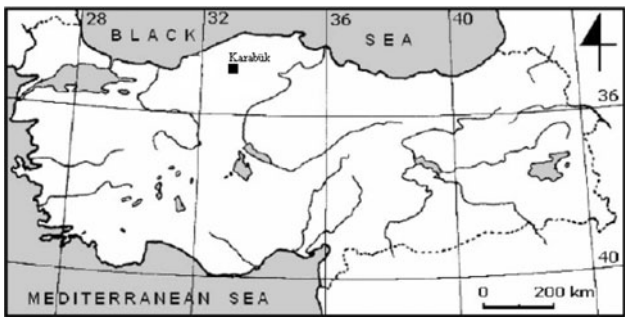

Fig. 1 Location map of Karabük city, Turkey

radioactivity mapping of Turkey surface soils and indoor radon levels.

Materials and methods

Measurement of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations

In order to measure the gamma radioactivity from surface soil samples in central Karabük city, 24 sampling stations were defined (Fig. 2). The stations were defined with squared method and each square has an area of 2 km^2. Soil samples were collected from uncultivated fields in summer 2008. Because of the precipitous land conditions no samples were collected from nineth station. A GPS system was used to obtain information about the geographical positions of the sampling locations. From each station, there sub samples were collected. These sub samples were combined and homogenized giving a soil sample representing this sample location. The soil samples were dried, pulverized, and sieved and a soil of less than 2 mm particle size was used. The samples were dried at 105 °C for 6 h. Dried samples were sieved, and put in polyethylene containers (9 cm diameter and 4 cm height). About 250–300 g of each samples were sealed for 25 days in order to attain radioactive equilibrium between ^{226}Ra and its daughters. The activities of ^{214}Pb and ^{214}Bi in equilibrium with their parents were assumed to represent the ^{226}Ra activity, while the activities of ^{228}Ac and ^{208}Tl were assumed to represent the ^{232}Th activity. Sample preparation and counting procedures were realized in Sarayköy Nuclear Research and Training Center.

Gamma spectrometry measurements were made with the high purity p-type coaxial Ge detectors with relative efficiencies of 150% (Ortec), 110% (Canberra) and 20% (Canberra) and resolution 1.9–2.2 keV at the 1332 keV gamma of ^{60}Co, and the high purity n-type coaxial Ge detectors with a relative efficiency of 70% (Ortec). The detectors were shielded in 10 cm thick lead well internally lined with 1 mm Cu and Cd foils. The detector outputs were connected to DSPEC Jr 2.0 MCAs (Ortec detectors) and DSA 1000 MCA (Canberra detectors). The energy and efficiency calibration of the spectrometer were carried out using calibration sources which contain ^{210}Pb, ^{241}Am, ^{57}Co, ^{137}Cs, ^{60}Co, ^{88}Y and ^{40}K peaks for energy range between 40 and 1850 keV. The activity concentrations of ^{226}Ra have been calculated by means of weighted mean of gamma-ray lines of ^{214}Pb ($E_\gamma = 295.2$, 351.9 keV) and ^{214}Bi ($E_\gamma = 609.3$, 1120.3 and 1764.5 keV). In the case of ^{232}Th series, the activities have been calculated by using the gamma-ray lines of ^{228}Ac ($E_\gamma = 911.1$, 968.9,

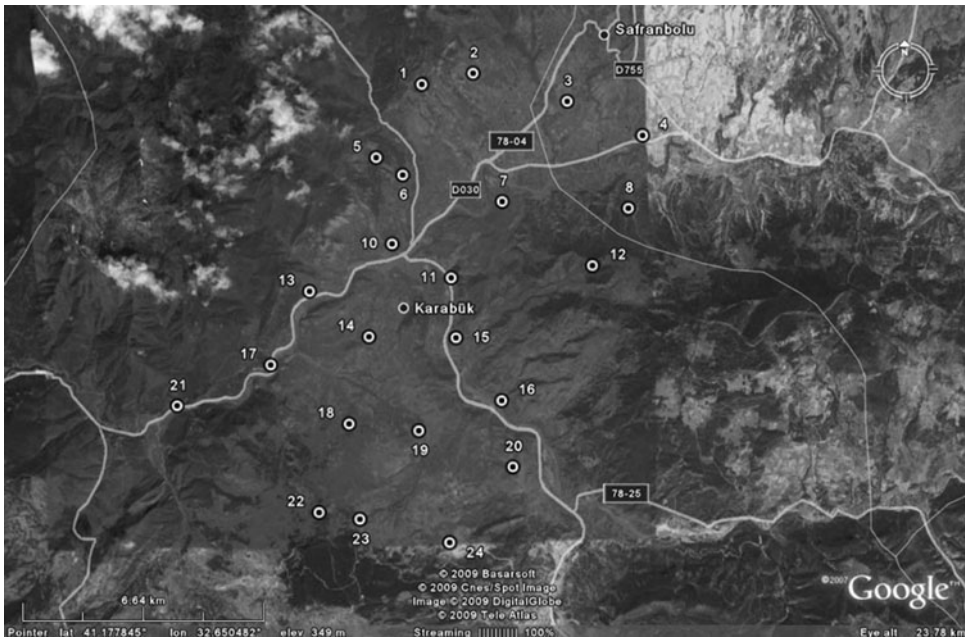

Fig. 2 Map of Karabük region and 24 sampling points. This map is provided by Google Earth

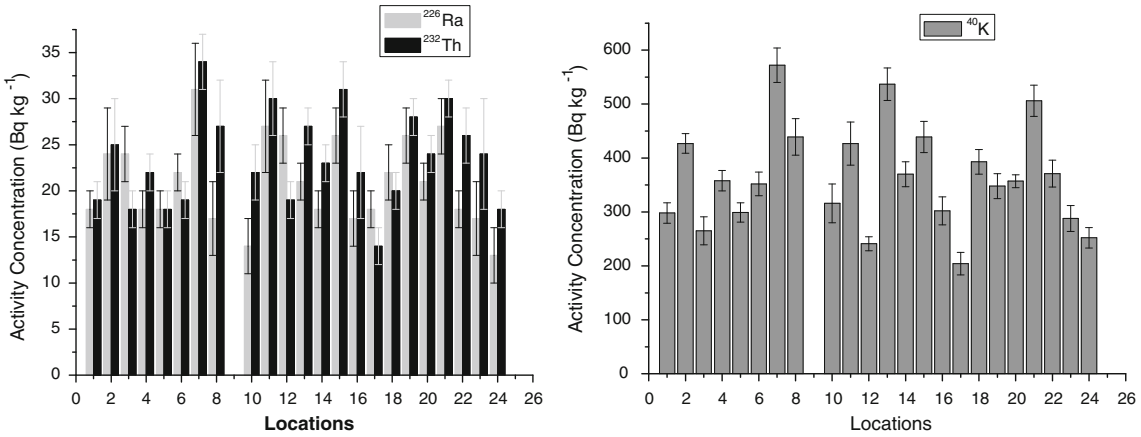

Fig. 3 ^{226}Ra, ^{232}Th and ^{40}K concentrations in soil samples collected in central Karabük, Turkey (Bq kg^{-1})

338.4 keV), ^{212}Pb ($E_\gamma = 238.6$ and 300 keV), ^{212}Bi ($E_\gamma = 727.2$ and 1620.7 keV) and ^{208}Tl ($E_\gamma = 583.1$ keV). The ^{40}K activity concentration was determined by measuring the ($E_\gamma = 1460.8$ keV) gamma-ray line. The counting time was on average 60,000 s for all samples. The background counting time was 250,000 s for each sample.

Radon measurements

For the measurement of indoor radon levels in Karabük CR-39 films (1 × 1 cm^2) were used. The films were fixed at the bottom of plastic cups measuring 70 mm in diameter and 45 mm height. The top of the cups was covered with a semi-permeable membrane. These films were placed 20 different dwellings in Karabük. The detectors were exposed at each measurement point in a period of 40 days for every visible etch pits. In this process, the detectors were etched in a solution of 30% NaOH at 60 °C for 4.5 h. The radon concentrations were estimated from the tracks left in the films by the alpha particles emitted from the ^{222}Rn and its progeny. Track-counting was performed by using an automatic counting device located at the Sarayköy Nuclear Research and Training Centre in Ankara (Turkey). This device includes an optical microscope reconnected to a CCD (Charge-Coupled Device) camera controlled by a personal computer and RADOSYS software. The track densities found on the films were automatically converted into radon concentrations (Bq m^{-3}) by this software.

Results and discussion

The measured activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, in surface soil samples collected from the 23 different areas of central Karabük were presented in Fig. 3. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the range of 13–31, 14–34, 204–572 Bq kg^{-1} and with the average values 21.0, 23.5 and 363.5 Bq kg^{-1}, respectively.

The average activity concentrations of terrestrial radionuclides ^{226}Ra, ^{232}Th and ^{40}K are lower than the worldwide average concentrations of these radionuclides reported by UNSCEAR (2000) as 35, 30 and 400 Bq kg^{-1}, respectively [7]. The comparison of average activity concentrations with the different parts of Turkey and the world is shown in Table 1.

The correlation analyses were made among the measured ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in the collected soil samples (Fig. 4). These analysis showed strongest correlation between ^{40}K and ^{232}Th activity concentrations with the significant correlation coefficient of $R = 0.847$. However, there were positive correlations of

Table 1 The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K in soil samples (in Bq kg^{-1}) compared with different parts of Turkey and the world

Location	^{226}Ra	^{232}Th	^{40}K	References
Average	21.0	23.5	363.5	Present study
Min	13.0	14.0	204.0	Present study
Max	31.0	34.0	572.0	Present study
Median	21.0	23.0	275.0	Present study
Egyptian	–	24.7	331.0	[8]
Sought India	35	29.8	117.5	[9]
Pakistan (Lahore)	25.8	49.2	561.6	[10]
Japan	–	54	794	[11]
Denmark	17	19	460	[7]
Saudi Arabia	23.8	18.6	162.8	[12]
Mexico	23	19	530	[13]
Vietnam(South-East)	19.6	31	34.6	[14]
İstanbul-Turkey	21	37	342	[15]
Manisa-Turkey	28.5	27.0	340	[16]
Kocaeli-Turkey	10–58	11–65	161–964	[17]

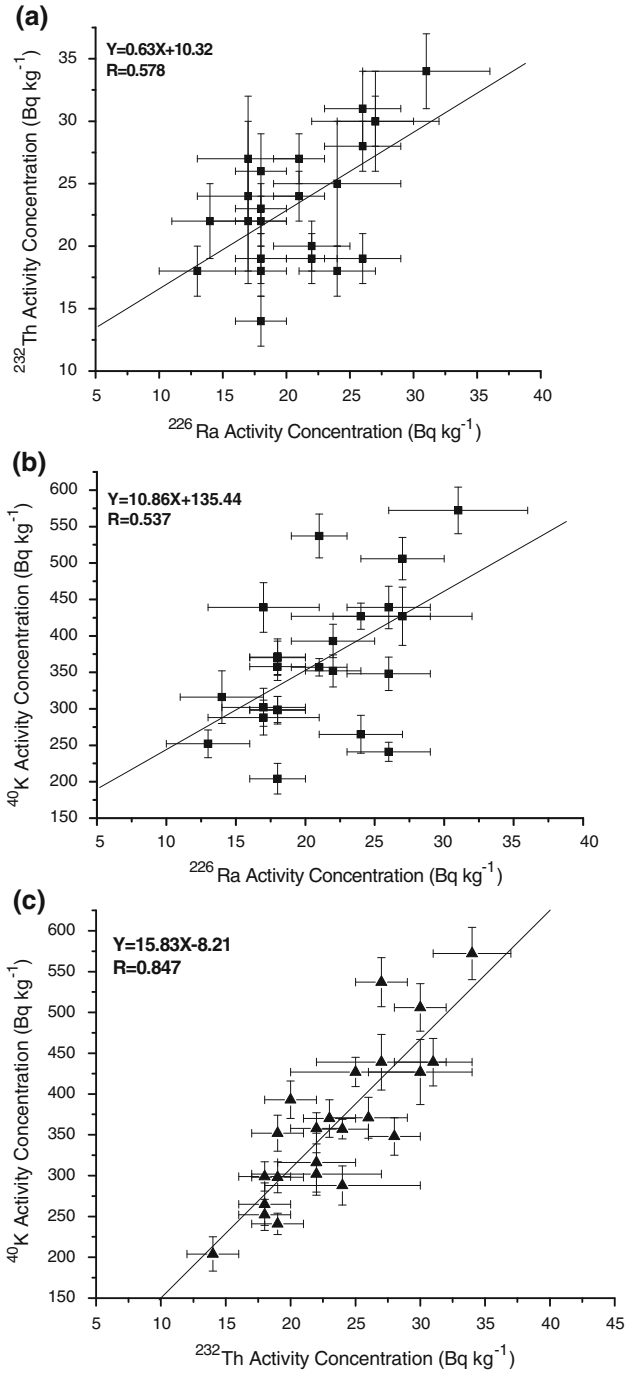

Fig. 4 Correlations of the radioactivity concentrations of **a** ^{232}Th versus ^{226}Ra, **b** ^{40}K versus ^{226}Ra and **c** ^{40}K versus ^{232}Th in the soils of Karabük

0.578 between ^{232}Th and ^{226}Ra concentrations and 0.537 between ^{40}K and ^{226}Ra concentrations.

The total air absorbed gamma dose rate in air 1 m above the ground (nGy h^{-1}) due to the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K can be calculated using the following Beck formula [18]:

Table 2 The calculated absorbed gamma dose rate and annual effective dose rates from soil samples and comparison with literature

	D (nGy h^{-1})	AED (μSv y^{-1})	References
Average	39.0	47.9	Present study
Min.	25.3	31.0	Present study
Max.	58.7	72.0	Present study
Median	37.6	46.2	Present study
Sought India	39.1	47.9	[9]
Pakistan (Lahor)	65.1	79.8	[10]
Denmark	38.5	47.2	[7]
Saudi Arabia	29.0	35.6	[12]
Mexico	44.2	54.2	[13]
Vietnam (South-East)	29.2	35.8	[14]
İstanbul-Turkey	46.3	56.8	[15]
Manisa-Turkey	43.7	53.5	[16]

$$D(\mathrm{nGh^{-1}}) = 0.0417C_K + 0.462C_{Ra} + 0.604C_{Th} \quad (1)$$

The dose rate of ^{226}Ra varies from 6 to 14.3 nGy h^{-1} with a mean value of 9.7 nGy h^{-1}. The ^{232}Th dose rate varies from 8.5 to 20.5 nGy h^{-1} with a mean value 13.9 nGy h^{-1}. That of ^{40}K varies from 8.5 to 23.9 nGy h^{-1} with a mean value of 15.2 nGy h^{-1}. Therefore the largest contribution from natural radionuclides in Karabük is due to ^{40}K. The average absorbed dose rate in air due to naturally occurring radionuclides is found to be 39 nGy h^{-1} while the average dose rate for the world is approximately 57 nGy h^{-1}.

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in air to effective dose rates (0.7 Sv Gy^{-1}) outdoor occupancy factor (0.2) proposed by UNSCEAR [7] were used. Thus, the annual effective dose (AED) can be given as

$$\mathrm{AED}\ (\mu\mathrm{Sv\ y^{-1}}) = D\,(\mathrm{nGy\ h^{-1}}) \times 8760\,\mathrm{h} \times 0.7\,\mu\mathrm{Sv\,Gy^{-1}} \times 0.2, \quad (2)$$

where D is absorbed dose rate in air. The world average annual effective dose equivalent from outdoor terrestrial gamma radiation is 70 μSv y^{-1} according to UNSCEAR [19], while that of Karabük has been determined to be 47.9 μSv y^{-1}. The calculated average absorbed gamma dose rate and average annual effective dose rate from soil samples are shown in Table 2.

Indoor ^{222}Rn measurements were in the range of 70.5–333.5 Bq m^{-3} with an average value of 131.6 Bq m^{-3}. The average indoor radon concentration has been determined to be 131.6 Bq m^{-3} (Table 3). As shown in Table 3, the average value is higher than the other studies made in Turkey. But, these values are below the action level 200–600 Bq m^{-3} recommended by International Commission on Radiological Protection [20]. The annual effective dose

Table 3 Indoor radon activity concentrations (20 samples) and compared with other studies

	Radon concentration (Bq m^{-3})	AED_{radon} (mSv y^{-1})	Reference
Average	131.6	3.32	Present study
Min	70.5	1.78	Present study
Max	333.5	8.41	Present study
Median	123.5	3.12	Present study
İstanbul-Turkey	10–260	0.5–13	[22]
İzmir-Turkey	53–86	2.65–4.3	[23]
Manisa-Turkey	97 (47–146)	4.86 (2.35–7.3)	[16]
Tekirdağ-Turkey	87	2.01	[24]
Kastamonu-Turkey	98.4 (29–177)	2.48 (0.73–4.46)	[25]

corresponding to the measured radon activity concentration is calculated by using the following formula [21]:

$$AED_{radon} = C_{Rn} F\ t\ d \quad (3)$$

where C_{Rn} represents the radon concentration (Bq m^{-3}). F is the equilibrium factor between radon and their decay products which is equal to 0.4 for indoor. The exposure time (t) is taken as 7008 h per year for indoor and d represent dose conversion factor equal to 9 nSv Bq^{-1} h^{-1} m^3. The conversion factor and equilibrium factor are given by UNSCEAR [7]. The average value of annual affective doses equivalent from ^{222}Rn were calculated as 3.32 mSv y^{-1} (Table 3). These dose values are the effective dose values between 3 and 10 mSv y^{-1} which are given as the range of action levels recommended by the ICRP [20].

Conclusion

The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K were measured of surface soils at 23 locations in central Karabük using a gamma spectrometry. A slight correlation has been found among ^{226}Ra, ^{232}Th and ^{40}K activity concentrations. The average concentrations of natural radionuclides ^{226}Ra ^{232}Th and ^{40}K are lower than the world average values. The calculated average absorbed gamma dose rate and annual effective dose rates due to natural radionuclides of soil samples lover than the global average value, but higher than that of some other results evaluated elsewhere in Turkey and in the other countries of the world.

Radon measurements were made at 20 buildings in Karabük dwellings by using solid state nuclear track detector. The evaluated average concentration 131.6 Bq m^{-3} is higher than the global average value 27.2 Bq m^{-3} given by UNSCEAR 1993, but lover than the action level 200–600 Bq m^{-3} recommended by International Commission on Radiological Protection [20].

The average annual effective dose equivalent from the calculated outdoor terrestrial gamma radiation for a person in Karabük is 47.9 mSv $y^{-1,}$ whilst the calculated annual effective dose equivalent from ^{222}Rn is 3.32 mSv y^{-1}.

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