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ORIGINAL ARTICLE

Natural and artificial radioactivity levels and hazards of soils in the Kücük Menderes Basin, Turkey

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Abstract In this study, natural and artificial radionuclide activity concentrations in surface soils of Kücük Menderes Basin have been measured using gamma spectroscopy. The soil samples were collected from agricultural lands in the Kücük Menderes Basin in Turkey. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the soils were found to be range of 12.63 ± 2.28–72.51 ± 11.23, 11.45 ± 2.4–58.12 ± 4.76, 234.8 ± 14.85–1058.52 ± 24 Bq kg^{-1} dw and 2.31 ± 0.18–7.75 ± 1.14 Bq kg^{-1}, respectively. The natural gamma radioactivity of the terrestrial radionuclides in soil samples and the gamma absorbed dose rate, the annual effective dose equivalent, the radium equivalent activity, the external hazard index, were calculated and compared with the international recommended values.

Keywords Radionuclide · Soil · Kucuk Menderes Basin · Dose rate

Introduction

Humans are exposed to background radiation that stems both from natural and artificial sources (Taskin et al. 2009). The two significant natural sources of external radiation to which human are exposed are cosmic rays and terrestrial gamma rays. Terrestrial gamma rays are essentially due to radionuclides belonging to uranium-238 (^{238}U) and thorium-232 (^{232}Th) series and singly occurring potassium-40 (^{40}K) that are present in the earth's crust (Murty and Karunakara 2008). Artificial radionuclides can also be present like Caesium-137 (^{137}Cs) is a fission product which is formed through nuclear weapon tests and nuclear power plant accidents (Kurnaz et al. 2011).

Distributions of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in soils depend on the radionuclide distribution in rocks from which they originate and on the processes through which the soils are concentrated (Song et al. 2012). Soil is the most important source of terrestrial gamma radiation levels, containing trace quantities of terrestrial radionuclides, whose concentrations depend on the local geology of each region in the world (UNSCEAR 2000; Montes et al. 2012; Turhan et al. 2012).

The main objective of this study is to: (i) determine the concentration of natural and artificial radionuclides (^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs) in the soil of Kucuk Menderes River Basin, Aegean Region, Turkey; (ii) calculate the important radiological parameters to assess the complete radiological hazardous nature of the soils.

Materials and methods

Study area

Kucuk Menderes River Basin, covering about 3,500 km^2 area, extends westwards towards Aegean Region (Fig. 1). The region is located at western part of Turkey. Kucuk Menderes basin is a very productive agricultural area, with industrial sites concentrated in the west. Almost all irrigation and industrial water needs in the basin have been supplied using groundwater resources (Pusatli et al. 2009).

Sample collection and preparation for gamma ray spectrometry

Surface soil samples at 0–5 cm depth level weighing from to 1.5 to 2 kg were collected from 40 sites on the Kücük

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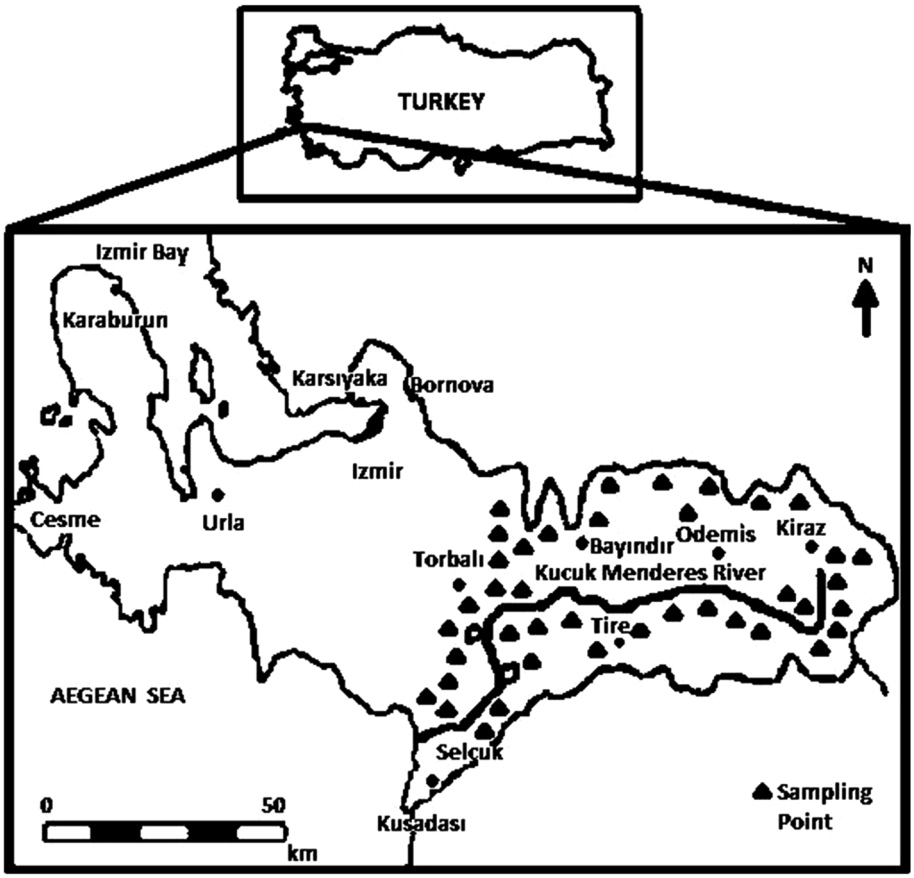

Fig. 1 Map of the study area

Menderes River, in August 2010. Samples were dried in an oven at about 105 °C for 24 h, pulverized, homogenized and sieved through 2 mm mesh. All samples were transferred to containers, weighed, hermetically sealed and stored for 4 weeks to ensure that ^{238}U and ^{232}Th attained the secular equilibrium with their short-lived decay products (Turhan et al. 2012).

Gamma ray spectrometry system

Measurement of the natural radioactivity (^{226}Ra, ^{232}Th and ^{40}K) and ^{137}Cs in the soil samples was conducted with the high-resolution gamma ray spectrometers with p-type coaxial HPGe detector. A solid nuclide mixture of gamma reference calibration source from Isotope Product Laboratories (containing the radionuclides ^{241}Am, ^{109}Cd, ^{57}Co, ^{123m}Te, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y, ^{60}Co peaks for energy range between 80 and 2,500 keV) was used for the full-energy peak (FEP) efficiency calibration. Each sample was measured for an accumulating time between 12 and 24 h. Background measurements were taken under the same conditions of sample measurements and subtracted in order to get net counts for the sample. The activity concentrations of ^{232}Th and ^{238}U were calculated assuming secular equilibrium being established with their decay products. The gamma-ray line of the 351.9 keV from ^{214}Pb and the 609.3 keV from ^{214}Bi were used to determine the activity concentration of ^{226}Ra. The gamma-ray line of the 911.1 keV from ^{228}Ac and the 583.1 keV from ^{208}Tl were used to determine the activity concentration of ^{232}Th. The activity of ^{40}K and ^{137}Cs were evaluated using its 1,460 and 662 keV peaks.

The detection limits were estimated to be 3.4 Bq kg^{-1} for ^{226}Ra, 5.2 Bq kg^{-1} for ^{232}Th, 10.1 Bq kg^{-1} for ^{40}K and 1.0 Bq kg^{-1} for ^{137}Cs.

Results and discussions

The results of activity concentrations in soil samples collected from the studied site (Kucuk Menderes River Basin) varied from 13 to 73 Bq kg^{-1} for ^{226}Ra, 11 to 58 Bq kg^{-1} for ^{232}Th, 235 to 1,059 Bq kg^{-1} for ^{40}K and 2 to 8 Bq kg^{-1} for ^{137}Cs.

The average concentrations found in this study are 48.35, 20.48, 744.76 and 3.31 Bq kg^{-1}, respectively, although the average concentrations obtained in surface soil samples in this study are comparable to those from some cities in Turkey and world (Table 1). The concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the

Table 1 Comparison of the activity concentrations of the ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs (dw) in soil samples with values reported for different regions of Turkey and different countries

Region	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	^{137}Cs (Bq kg^{-1})	References
Tripoli/Libya	10.5	9.5	270		Shenber (1997)
Jordan	52.9	24.0	442.6	–	Ahmad and Hussein (1998)
Istanbul/Turkey	–	37	342	18	Karahan and Bayulken (2000)
India	–	119	406	–	Kannan et al. (2002)
Tekirdağ/Turkey	–	39	579	5	Yarar and Kam (2005)
Manisa/Turkey	–	27	340	–	Erees et al. (2006)
Kastamonu/Turkey	37.4	27.2	431.4	8.0	Kam and Bozkurt (2007)
Rize/Turkey	–	42	653	85	Kurnaz et al. (2007)
Sanlıurfa/Turkey	–	25.0	298.6	9.1	Bozkurt et al. (2007)
Kirklareli/Turkey	37	40	667	8	Taskin et al. (2009)
Bakırçay River/Turkey	74.4	30.7	288	–	Saç et al. (2012)
Kucuk Menderes River/Turkey	48.4	20.5	744.8	3.3	Present study

world have averages in soil of 35, 30 and 400 Bq kg^{-1}, respectively (UNSCEAR 2000). The mean activity concentration of ^{226}Ra and ^{40}K is higher than the reported International Limits. The artificial radioactive compound, ^{137}Cs isotope does not exist in soil naturally and it is a product of fallout radioactivity (Karahan and Bayulken 2000). In the present study the highest recorded value of ^{137}Cs equals 8 Bq kg^{-1}.

The external terrestrial gamma radiation absorbed dose in air at 1 m above the ground level is calculated by using the following equation (UNSCEAR 2000; Kurnaz et al. 2007):

$$\mathrm{D}\left(\mathrm{nGyh}^{-1}\right) = 0.462\mathrm{C}_{\mathrm{Ra}} + 0.604\mathrm{C}_{\mathrm{Th}} + 0.0417\mathrm{C}_{\mathrm{K}} + 0.03\mathrm{C}_{\mathrm{Cs}} \quad (1)$$

where D is the total absorbed dose rate (D) in air at 1 m above ground level; C_{Ra}, C_{Th}, C_K and C_{Cs} are the activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, respectively.

The absorbed gamma D's in air at Kucuk Menderes Basin for soil samples are found between 22.62 and 112.97 nGyh^{-1}. The mean absorbed gamma D in air was calculated as 66.77 nGyh^{-1}and found to be comparable to the world average of 59 nGyh^{-1} (UNSCEAR 2000).

The average D value was calculated as 65, 60.9, 59, 56.8 nGy/h, in Istanbul (Karahan and Bayulken 2000), in Sanlıurfa (Bozkurt et al. 2007), in Trabzon (Kurnaz et al. 2011), in Bakırcay (western Turkey) (Saç et al. 2012), respectively. These average values in general are similar to our result.

To estimate the annual effective D's, the conversion coefficient of 0.7 Sv Gy^{-1} from absorbed dose in air to effective dose received by adults, and 0.2 for the outdoor occupancy factor were used according to UNSCEAR (2000).

The annual effective dose equivalent (AEDE) given by UNSCEAR (2000) was calculated from the equation:

$$(\mathrm{AEDE})\left(\mathrm{mSv\ y}^{-1}\right) = \mathrm{D}\left(\mathrm{nGy\ h}^{-1}\right) \times 8{,}760\left(\mathrm{h\ y}^{-1}\right) \times 0.2 \times 0.7\left(\mathrm{Sv\ Gy}^{-1}\right) \times 10^{-6}. \quad (2)$$

The calculated values of annual effective dose due to gamma radiation range from 0.03 to 0.14 mSv y^{-1} with a mean value of 0.08 mSv y^{-1} which is higher than the world average of 0.07 mSv y^{-1} (UNSCEAR 2000).

The distribution of ^{226}Ra, ^{232}Th and ^{40}K in soil is not uniform. Uniformity with respect to radiation exposure has been defined in terms of radium equivalent activity (Ra_{eq}) in Bq kg^{-1}. Radium equivalent activity is a widely used hazard index, with a formula for comparing the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K (Abdi et al. 2009). The Ra_{eq} calculated by (Beretka and Mathew 1985):

$$\mathrm{Ra}_{\mathrm{eq}}\left(\mathrm{Bq\ kg}^{-1}\right) = \mathrm{C}_{\mathrm{Ra}} + 1.43\mathrm{C}_{\mathrm{Th}} + 0.07\mathrm{C}_{\mathrm{K}}.$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The average Ra_{eq} was calculated as 129.8 Bq kg^{-1}, which is within the range of 45.44–229.7 Bq kg^{-1}. The estimated values of Ra_{eq} in the present study are lower than the recommended maximum value of 370 Bq kg^{-1} (Kurnaz et al. 2007; Baykara et al. 2011).

The external hazard index (H_{ex}) is defined as follows (Sroor et al. 2002):

$$\mathrm{H}_{\mathrm{ex}} = \mathrm{C}_{\mathrm{Ra}}/370 + \mathrm{C}_{\mathrm{Th}}/259 + \mathrm{C}_{\mathrm{K}}/4{,}810.$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K Bq kg^{-1}, respectively. The results range from 0.13 to 0.64 and average value was found to be 0.37. The average values of H_{ex} were found to be 0.99 for

Eskisehir/Turkey (Orgun et al. 2005), 0.45 for Rize/Turkey (Kurnaz et al. 2007), and 1.2 for China (Song et al. 2012).

Conclusion

In this study, the distributions of terrestrial and artificial radionuclides in the soil samples from 40 areas of Kucuk Menderes River Basin, Western Turkey (Aegean Region) were determined using gamma ray spectrometry with HPGe detector. The results showed that the mean concentrations of the ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in soil samples are comparable to the reported literature values. From the measured values, the average values of absorbed gamma dose rate in air (D), AEDE, the Ra_{eq}, the H_{ex} were calculated. The estimated average air-absorbed D and annual effective dose for all samples are 67 nGy h^{-1} and 0.08 mSv, respectively. All the calculated external hazard indices were found to be <1, indicating a low dose.

This study may be used as a baseline for future investigations.

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