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ORIGINAL PAPER

Natural radioactivity and radiological damage parameters for soil samples from Cekmekoy-İstanbul

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Abstract

Since the existence of the world, human beings have been exposed to natural radiation. Determining the natural radiation level and the radiological parameters is very important in terms of determining the amount of radiation people will be exposed to. Since the population of Istanbul is very high, the number of people that will be affected by the radiation level there is high. In this study, it was aimed to determine the natural radiation level and radiological parameters in Cekmeköy district of Istanbul. For this, natural radionuclides were measured with gamma spectroscopy system based on NaI(Tl) detector for 17 soil samples collected from Cekmeköy-Istanbul. As a result of this study, the mean activity concentrations of ^{40} K, ^{226}Ra, and ^{232}Th obtained as a result of the measurements were found to be 449 ± 9, 29 ± 1, and 28 ± 1 Bqkg^{-1}, respectively. Mean absorbed dose rate (D_R) and excess lifetime cancer risk (ELCR) were calculated as 49 nGyh^{-1} and 0.21×10^{-3}, respectively. Basic statistics were performed to determine the relationship between the activity concentrations of radionuclides and radiological parameters. In conclusion, mean natural radioactivity and radiological parameter levels are calculated lower than the world average.

Keywords Natural radioactivity · Soil · Cekmeköy · Radiological damage indices

Introduction

Human are exposed to two kinds of radiation, natural and artificial, in their daily lives (Gunay et al. 2018; Çelen et al. 2019). A large part of the total radiation exposure of living beings is due to natural source radiation. Natural background radiation in the soil comes from ^{40} K, ^{226}Ra, and ^{232}Th is the source of about 80% of the total radiation dose a person experiences in a year. Because each region in the world has a unique geological and geographical structure (Külahçı et al. 2020; Kulalı 2020), the activity concentrations of natural radionuclides in the soil may vary from region to region (Turgay 2019, Akkurt etal. 2015).

The concentration and distribution of radionuclides are the main subject of many scientific studies in the evaluation and monitoring of environmental radioactivity. The concentration of radionuclides in the soil is important for finding the source of natural radioactivity, determining environmental effects and assessing radiation risks (Tekin et al. 2020; Çelen & Evcin 2020; El-Agawany F.I et al. 2021, Çelen 2021). For this reason, many researchers in different parts of the world have studied natural radiation activity concentrations of different types of materials, especially terrestrial origin (Malidarre et al. 2020, Kayıran. 2021, Malidarre and Akkurt, 2021, Baykal et al 2021). In these studies, various radiation hazard indexes were calculated using the conversion factors given in UNSCEAR reports and natural radionuclide concentrations to determine health risks (Akkurt & Tekin 2020; Rammah et al. 2020; Tekin et al. 2018).

The main purpose of this study is to determine the natural radioactivity concentrations in some soil samples in Çekmeköy-İstanbul. In addition, various radiological

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parameters were calculated using natural radioactivity results. These radiological parameters are radium equivalent activity (Ra_{eq}), absorbed dose rate (D), annual effective dose (AED), annual gonadal dose equivalent (AGDE), excess lifetime cancer (ELCR), danger indices (H_{ex} and H_{in}), and gamma representative level index (Iγ). In addition, statistical analyses (basic statistics, histograms, and Pearson correlation analyses) were performed to determine the relationships between the activity concentrations of radionuclides and radiological parameters. As a result of these calculations, the radiation dose level to which the people in the study area will be exposed, and the risk of potential cancer was determined.

Material and method

Soil sample collection and preparation

Istanbul is one of the most populous cities of both Europe and Turkey with a population of approximately 16 million. It is also the center of both tourism and trade in Turkey. People in Istanbul are more likely to be affected by radiation because of the high population. Therefore, Istanbul has been determined as the study area. Natural radiation measurements were made in some districts of Istanbul. A comprehensive natural radiation study has not been carried out in the Cekmeköy district of Istanbul. Determining the natural radiation level and radiological parameters in this district is very important in terms of determining the level of radiation that people living in this district will be exposed to. For these reasons, it has been chosen as the Cekmeköy district of Istanbul as the study area.

Within the scope of this study, soil samples were collected from 17 different locations in Istanbul-Cekmeköy region (Fig. 1 and Fig. 2). Each of the soil samples collected weighs approximately 500 g. Soil samples were collected with a core tool up to 10 cm deep. All soil samples were dried in an oven at about 110 °C for 24 h to ensure complete removal of moisture. Soil samples were sieved with a 1-mm mesh sieve to homogenize the stones, pebbles, and other macro impurities after grinding. Homogenized soil samples were placed in a standard 500 ml airtight PVC plastic container. After the lids were tightly closed, the lids were tightly sealed with vinyl tape to prevent possible escape of the radon gases. Finally, prior to measurement, soil samples were stored for a period of 4 weeks to ensure radioactive secular equilibrium between ^{238}U (^{226}Ra) and ^{232}Th (^{228}Ra) and their progeny.

Gamma spectrometric analysis

The activity concentrations of natural radionuclides in soil samples prepared for measurement were determined using gamma ray spectrometry. This spectrometer system contains thallium-activated sodium iodide (NaI(Tl)) scintillation crystal connected to photomultiplier tubes. When designing the geometry of the measuring system, the detector is placed in the lead block to reduce the effects of background radiation on the measurements.

Energy calibration and detection efficiency of the system are required before the measurements of natural radioactivity. Energy calibration was done using radioactive sources of ^{137}Cs (662 keV) and ^{60}Co (1173 and 1332 keV), whose γ-energies are known. By recording counts from different sources, the energy of incoming radiation over a

Fig. 1 Çekmeköy-Istanbul

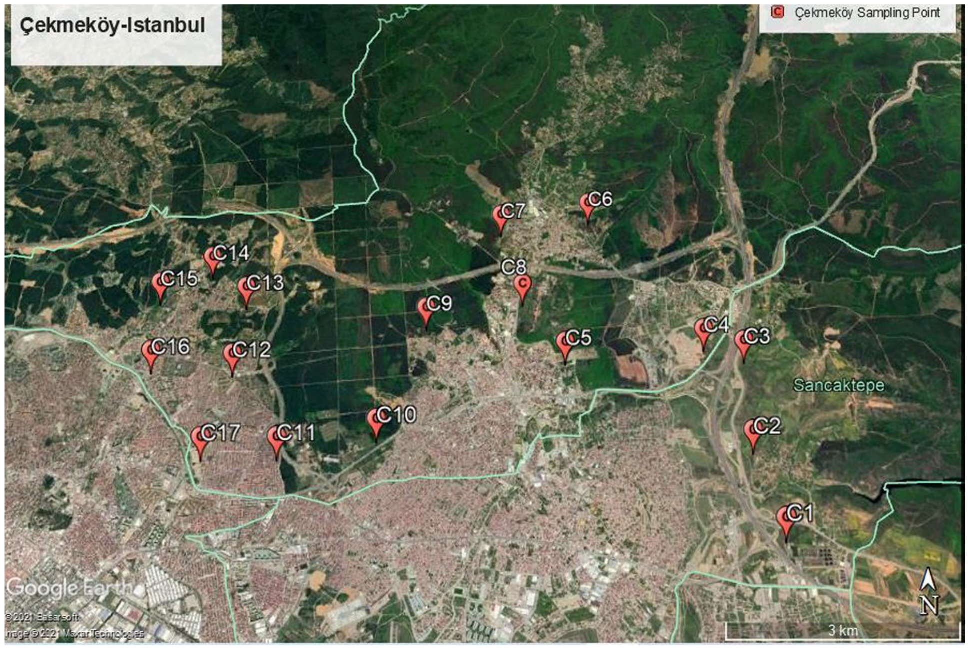

Fig. 2 Sampling points in Cekmekoy district

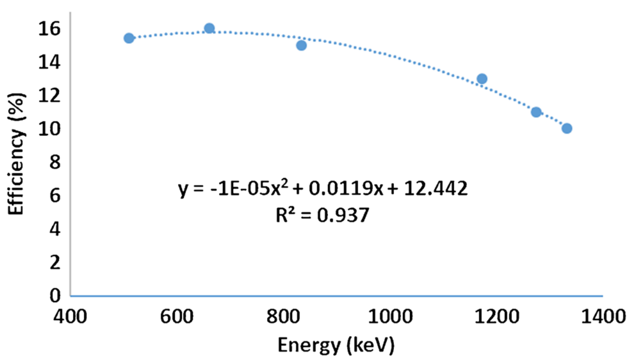

Fig. 3 Detection efficiency depending on gamma ray energies

wide energy range was distinguished. The equation of the curve passing through the points determined by using the energy of the incident peak and the channel number where that peak is detected was obtained by the least squares method.

The detector efficiency calibrations were performed with a certified standard gel source with a similar density to the measured samples (Kuluozturk et al. 2020). The obtained efficiency calibration curve is displayed in Fig. 3.

As can be seen from Fig. 3, the efficiency values are consistent since the R^2 value is 0.937.

In the analysis of the spectra obtained as a result of the measurements, the areas of the spectra were calculated using the computer software MAESTRO32. The amount of natural radioactivity of ^{40}K, ^{226}Ra, and ^{232}Th natural elements was calculated using photopics in 1461, 1760, and 2610 keV gamma ray energies, respectively, in the natural gamma ray spectrum (Akkurt et al. 2014).

The activities of ^{40}K, ^{226}Ra, and ^{232}Th natural radionuclides were calculated using the following equation with the help of spectrum fields (Beretka and Mathew 1985).

$$C(Bq/kg) = \frac{N_S - N_B}{E_\gamma . P_\gamma . t . M_S} \tag{1}$$

where N_S is the net photopic area for the sample, N_B is the background photopic area, E_γ is the gamma ray detection efficiency, P_γ is the gamma ray emission probability, t is the measurement time, and M_S (kg) is the dry mass of the soil samples.

Results and discussion

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

The results of this study are shown in Table 1. The range and average values (in brackets) of the activities for ^{40}K, ^{226}Ra, and ^{232}Th are 294–612 (449 ± 9), 19–41 (29 ± 1), and 18–39 (28 ± 1) Bqkg^{-1}, respectively. In the results obtained, ^{40}K activity always contributes greatly to the specific activity compared to ^{232}Th and ^{226}Ra in all soil samples studied.

In UNSCEAR 2000 reports, the world's mean values of activity concentrations of primordial radionuclides ^{40}K, ^{226}Ra, and ^{232}Th are 400, 35, and 30 Bqkg^{-1}, respectively (UNSCEAR, 2000). The mean concentrations of ^{226}Ra and ^{232}Th were lower than the world's average values in all soil samples, while the mean values of ^{40}K were higher than the world's average values. The measured activity concentrations for ^{40}K, ^{226}Ra, and ^{232}Th are illustrated in Fig. 4.

Table 1 The activity concentrations of radionuclides for soil samples

Samples code	Activity concentrations ($Bqkg^{-1}$)		
	^{40}K	^{226}Ra	^{232}Th
C-1	382 ± 8	38 ± 1	33 ± 1
C-2	294 ± 6	41 ± 1	39 ± 1
C-3	397 ± 8	38 ± 1	34 ± 1
C-4	458 ± 9	29 ± 1	29 ± 1
C-5	424 ± 8	20 ± 1	24 ± 1
C-6	342 ± 7	26 ± 1	38 ± 1
C-7	543 ± 11	29 ± 1	25 ± 1
C-8	494 ± 10	33 ± 1	29 ± 1
C-9	388 ± 8	28 ± 1	26 ± 1
C-10	582 ± 12	31 ± 1	28 ± 1
C-11	485 ± 10	24 ± 1	20 ± 1
C-12	612 ± 12	35 ± 1	32 ± 1
C-13	498 ± 10	27 ± 1	18 ± 1
C-14	553 ± 11	32 ± 1	23 ± 1
C-15	372 ± 8	19 ± 1	22 ± 1
C-16	396 ± 8	23 ± 1	25 ± 1
C-17	416 ± 8	25 ± 1	29 ± 1
Mean	449 ± 9	29 ± 1	28 ± 1

In many countries, studies have been carried out to measure the level of natural radioactivity in the soil. In Table 2, the activity concentrations of the ^{40}K, ^{226}Ra, and ^{232}Th radionuclides in soil samples obtained in this study are compared with studies carried out in other countries and world mean.

Absorbed gamma dose rate (DR)

Dose rates absorbed in the air 1 m above the location caused by external terrestrial gamma radiation due to the distribution of ^{40}K, ^{226}Ra, and ^{232}Th natural radioactive elements were calculated. To calculate the absorbed gamma dose rate (D_R), dose conversion factors in $nGyh^{-1}$, which are specified in UNSCEAR2000 reports, are used. These dose conversion factors are 0.0417, 0.462, and 0.604 $nGyh^{-1}$ for ^{40}K, ^{226}Ra, and ^{232}Th natural radioactive elements, respectively (UNSCEAR 2000).

$$D_R(nGyh^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (2)$$

where C_K, C_{Th}, and C_{Ra} are the activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th, respectively. The calculated D_R results for soil samples have been displayed in Fig. 5. It was observed that D_R in soil samples with natural radionuclide measurements ranged from 37 (C-15) to 62 (C-12) $nGyh^{-1}$ with an average value of 49 $nGyh^{-1}$. The world mean value for D_R is 59 $nGyh^{-1}$ (UNSCEAR 2000). It can be seen from Fig. 5 that the calculated average D_R value in this study area is lower than the world mean.

Annual effective dose (AED)

It is possible to estimate the annual effective dose (AED) using D_R calculated above and the outer occupancy factor. The conversion coefficient for D_R in the UNSCEAR2000 reports is given as 0.7 $SvGy^{-1}$. In addition, the external occupancy factor was taken as 0.2, assuming that adults spend approximately 20% of their time outside. Therefore,

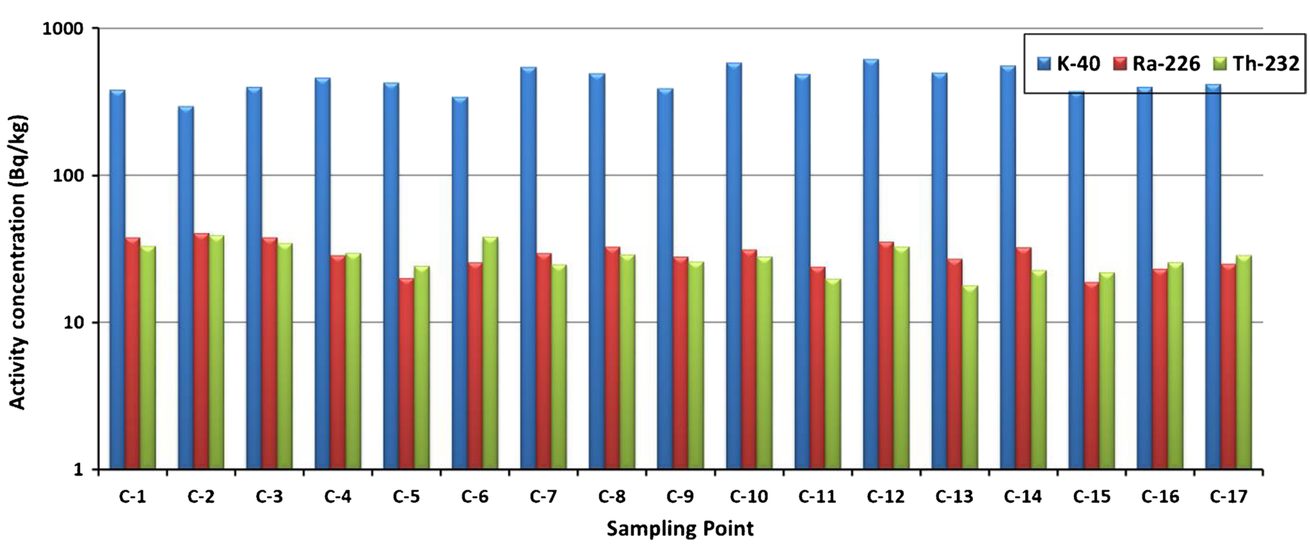

Fig. 4 ^{40}K, ^{226}Ra, and ^{232}Th radionuclide activity concentration in soil samples in Cekmekoy

Table 2 Activity concentrations measured in different countries

Locations	^{40}K (Bqkg^{-1})	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	References
Vietnam	412	43	60	(Huy et al. 2012)
Yemen	939	48	42	(Harb et al. 2012)
Kuwait	368	17	14	(Bajoga et al. 2017)
India	818	27	63	(Reddy et al. 2017)
Turkey	268	25	36	(Celik and Kosal, 2019)
Iraq	452	14	7	(Ahmed and Akrawy 2005a, b)
Syria	116	15	24	(Al-Masri et al., 2006)
Iran	555	39	43	(Asgharizadeh et al. 2013)
Pakistan	562	26	49	(Akhtar et al. 2005)
World (Average)	400	35	30	(UNSCEAR 2000)
Present study	449	29	28	

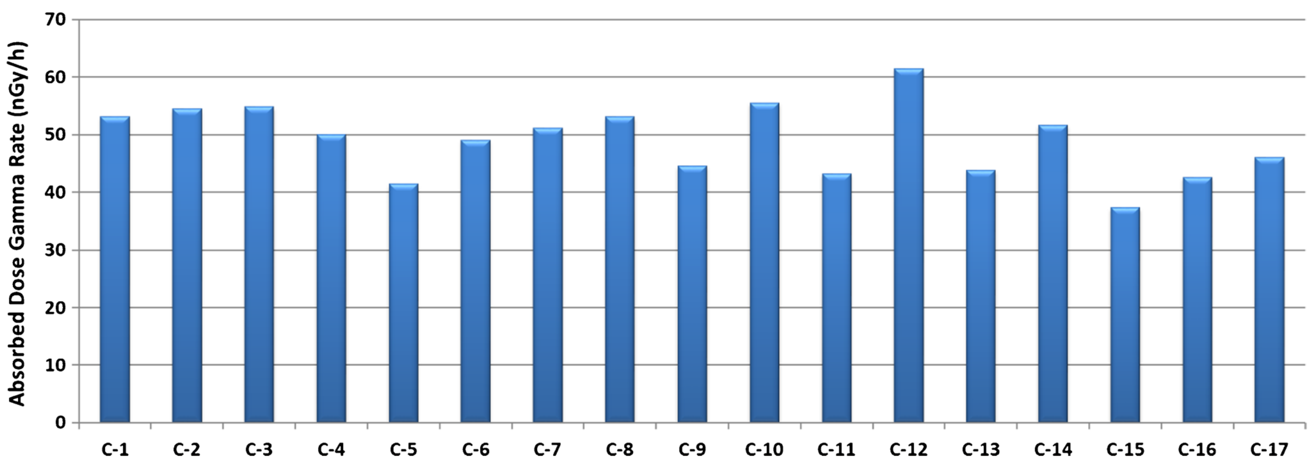

Fig. 5 The absorbed gamma dose rate results for soil samples in Cekmekoy

AED (mSvy^{-1}) was computed by the formula (UNSCEAR 2000).

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

AED results for soil samples have been displayed in Fig. 6. The range of AED in the studied area is 0.046 (C-15)–0.075 (C-12) mSvy^{-1}, respectively, with the mean of 0.060 mSvy^{-1}. From Fig. 6, it is clear that the mean value of AED is lower than the recommended safety limit of 0.46 mSvy^{-1}(UNSCEAR 2000).

Annual gonadal dose equivalent (AGDE)

Annual gonadal dose equivalent (AGDE) is used to determine the genetic effect of gamma radiation from ^{40}K, ^{226}Ra, and ^{232}Th natural radionuclides on sensitive organs such as gonads, bone marrow, and bone surface cells. AGDE was calculated using the following equation according to the activity concentration values of the mentioned natural radionuclides (Mamont-Ciesla et al., 1982).

$$AGDE(mSvy^{-1}) = 3.09C_{Ra} + 4.18C_{Th} + 0.314C_K \quad (4)$$

AGDE results in soil samples have been displayed in Fig. 7. The lowest calculated AGDE value is 0.266 mSvh^{-1} in the sample of C-15 and the highest AGDE value is 0.437 mSvh^{-1} in the sample of C-12 with the average value of 0.348 mSvy^{-1}.

Excess lifetime cancer risk (ELCR)

In case of exposure to radiation dose for a long time, stochastic effects such as cancer occur. Therefore, a person's risk of developing cancer is assessed by calculating the risk of over life cancer (ELCR), which varies in direct proportion to the radiation dose. ELCR risk factor can be calculated using the equation below (Günay 2018).

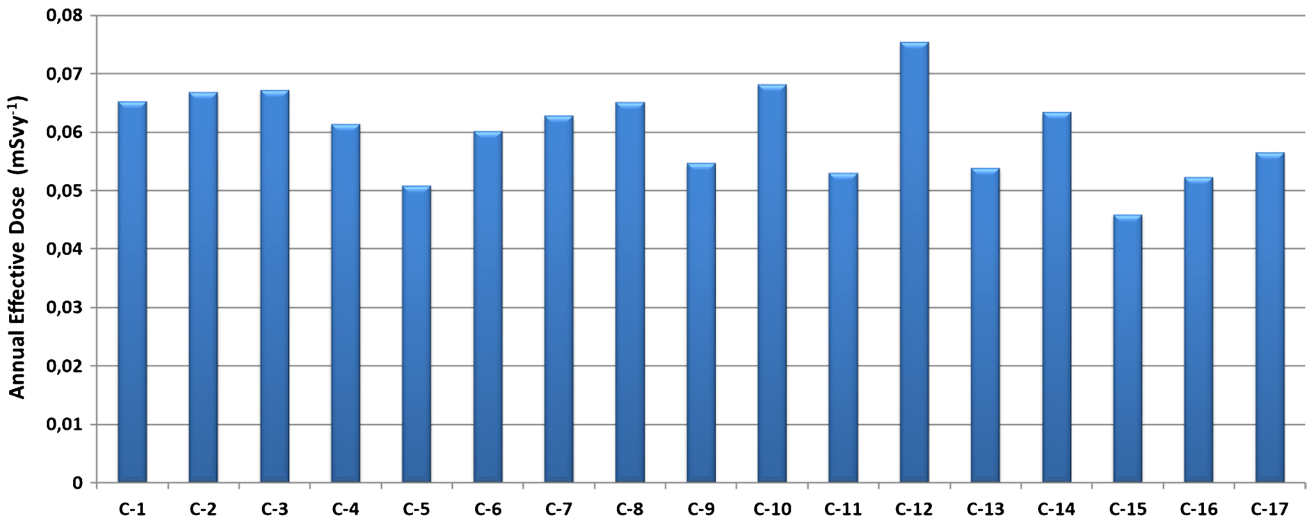

Fig. 6 The annual effective dose results for soil samples in Cekmekoy

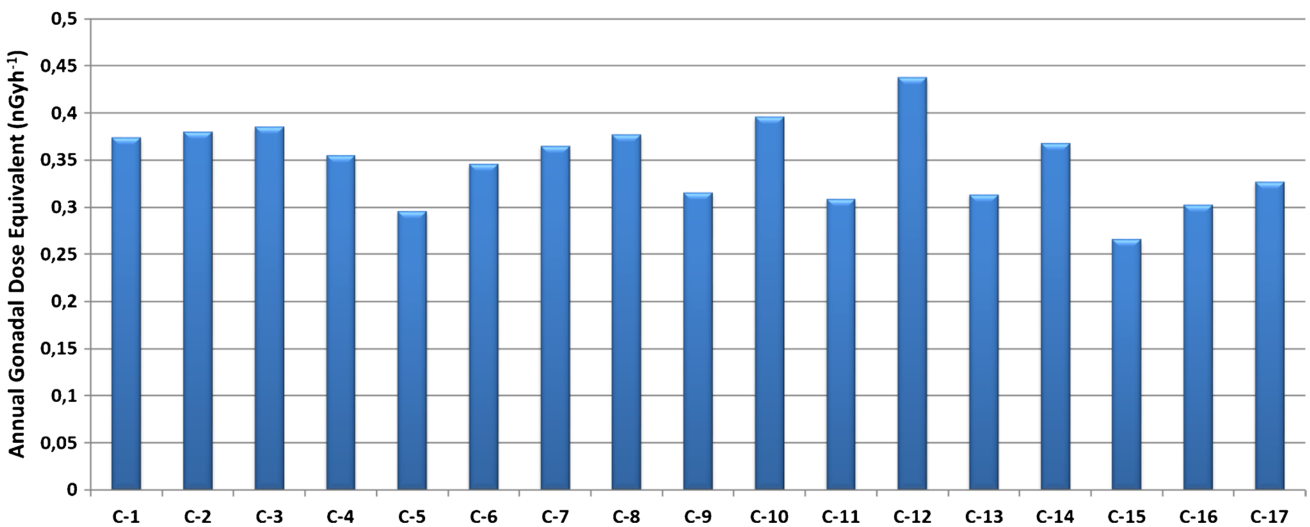

Fig. 7 The annual gonadal dose equivalent results for soil samples in Cekmekoy

$$ELCR = AED\left(mSvy^{-1}\right) * DL(y) * RF\left(Sv^{-1}\right) \quad (5)$$

where *AED* is an annual effective dose equivalent, *DL* is the average lifetime assumed to be 70 years for an adult person, and *RF* is a fatal cancer risk factor of 0.05 per Sievert for publicly available stochastic effects in ICRP (1990) reports (ICRP 1990, 1992). From Fig. 8, the lowest calculated ELCR value is 0.160×10^{-3} in the sample of C-15, and the highest ELCR value is 0.264×10^{-3} in the sample of C-12 with an average of 0.210×10^{-3}. The average value of ELCR is lower than the world mean value of 0.29×10^{-3} (UNSCEAR 2000).

Radium equivalent activity (Ra_{eq})

Radium equivalent activity (Ra_{eq}) index has been defined for the evaluation of radiation hazards associated with these elements of substances containing ^{40}K, ^{226}Ra, and ^{232}Th natural radioactive elements. This index can be calculated using the relation below (UNSCEAR 2000; Aközcan et al. 2021)

$$Ra_{eq} = 0.077C_K + C_{Ra} + 1.43C_{Th} \quad (6)$$

Ra_{eq} results for soil samples have been displayed in Fig. 9. Ra_{eq} in soil samples ranges from 78.49 (C-15) to 129.01

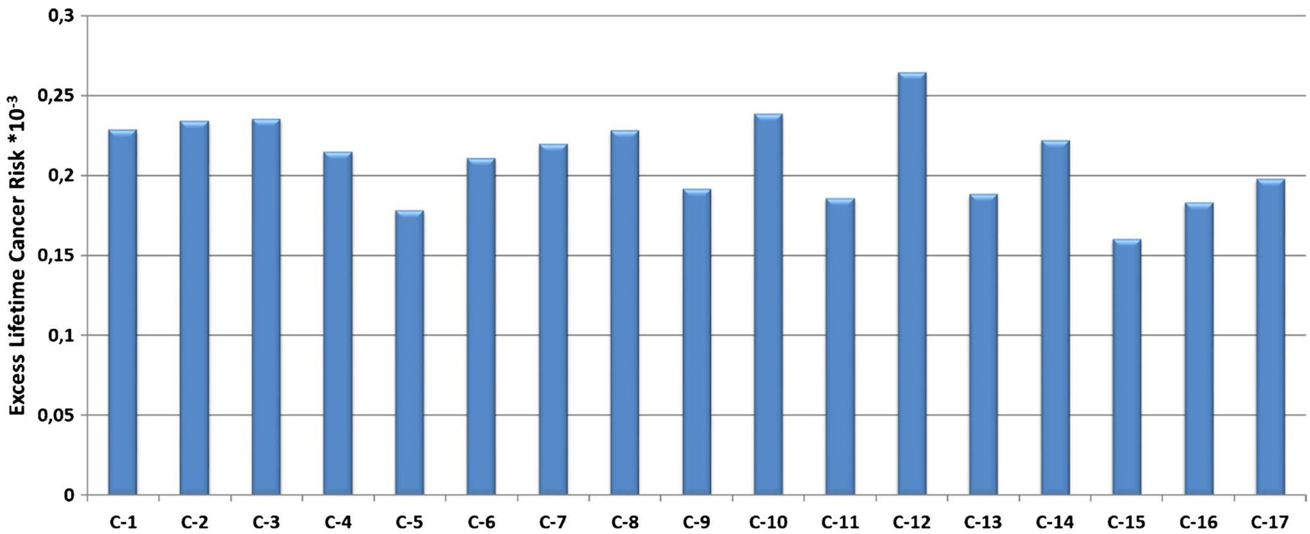

Fig. 8 Excess lifetime cancer risk results for soil samples in Cekmekoy

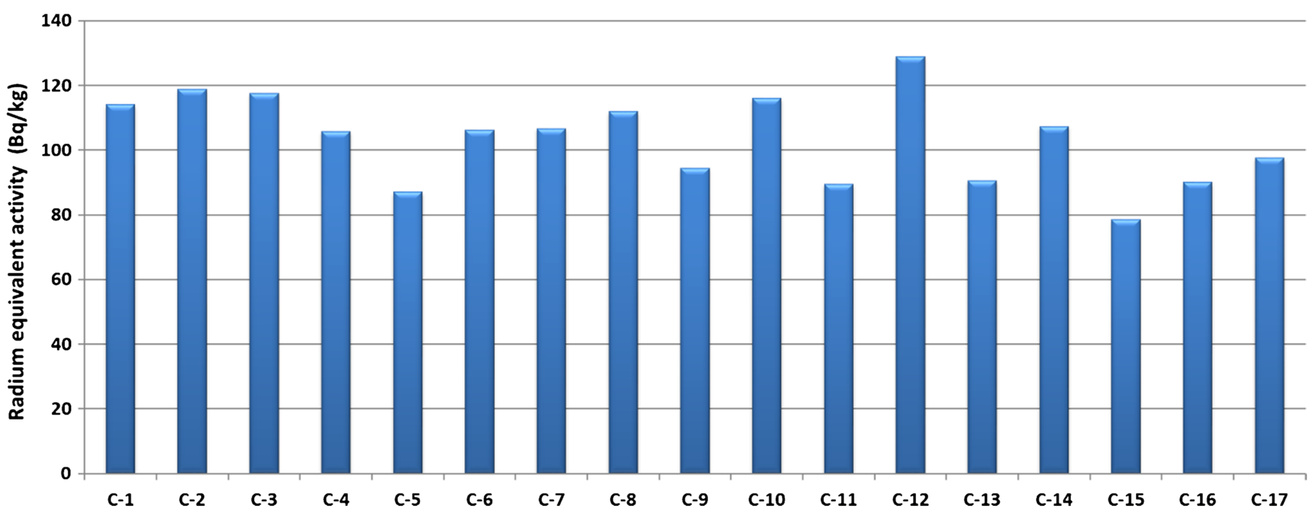

Fig. 9 Radium equivalent activity for soil samples in Cekmekoy

$Bqkg^{-1}$ (C-12) with a mean value of 103.59 $Bqkg^{-1}$ which is less than the recommended maximum value of 370 $Bqkg^{-1}$.

External and internal hazard index (H_{ex}, H_{in})

Health effects of environmental materials such as stone, soil containing ^{40}K, ^{226}Ra, and ^{232}Th natural radionuclides on health are evaluated with a parameter called external hazard index (H_{ex}). In addition to the external hazard index, radon and short-lived products of environmental materials, which arise due to the indoor use, are also dangerous for health. Internal exposure to radon and its progeny are assessed by the internal hazard index (H_{in}). These two parameters should not exceed the unit limit in terms of radiation hazard. The external hazard index (H_{ex}) and the internal hazard index (H_{in}) were quantified from the equations (Günay & Eke 2019).

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810}, H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (7)$$

The H_{ex} and H_{in} hazard indices results for soil samples have been displayed in Fig. 10. The H_{ex} values ranged from 0.212 (C-15) to 0.348 (C-15) with an average value of 0.280. The H_{in} values ranged from 0.2563 (C-15) to 0.444 (C-15) with an average value of 0.359. Also it was found that all the values of H_{ex} and H_{in} are well below the recommended safety limit of ≤ 1 (UNSCEAR 2000).

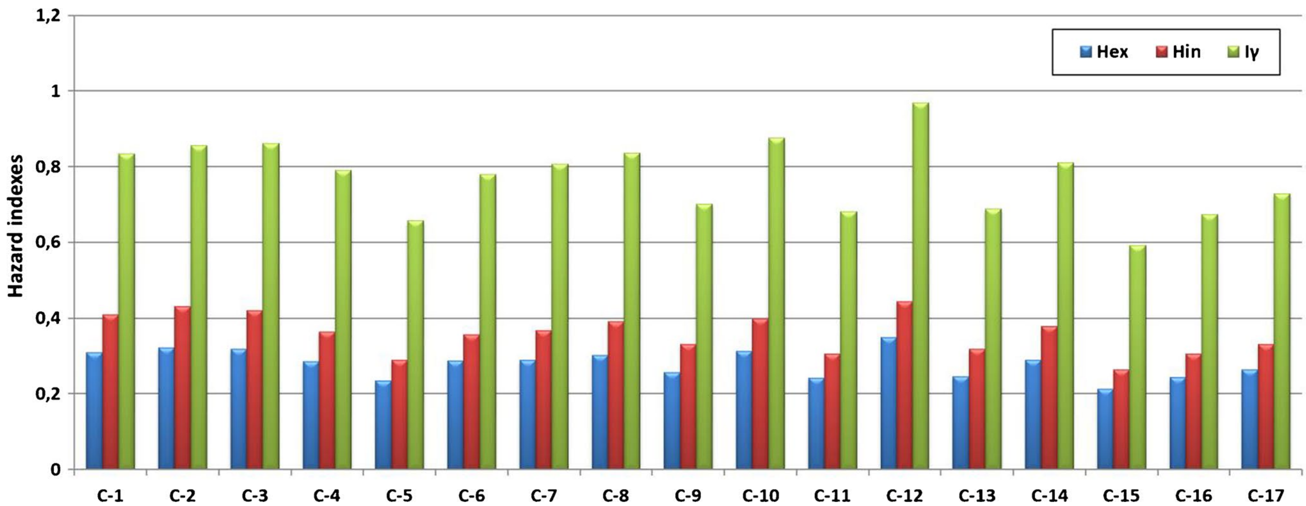

Fig. 10 External, internal, and gamma representative level index for soil samples in Cekmekoy

Gamma representative level index (I_γ)

A representative level index (Iγ) has been defined to determine the level of danger associated with the annual dose rate of excessive external gamma radiation from natural gamma emitters in environmental materials. Depending on the activity concentrations of natural radionuclides, the level of gamma radiation hazard of soil samples was evaluated with the radiation hazard index Iγ and calculated using the following equation (Alam et al. 1999).

$$I\gamma = \frac{1}{150C_{Ra}} + \frac{1}{100C_{Th}} + \frac{1}{1500C_K} \quad (8)$$

I_γ results for soil samples have been displayed in Fig. 10. The calculated values of $I\gamma$ vary from 0.591 (C-15) to 0.969 (C-12) with mean value of 0.772. To keep the radiation hazard at harmless values, $I\gamma$ must be less than unity. The mean ($I\gamma$) value in the study area is below than the world mean value < 1 (UNSCEAR 2000).

Statistical analysis

In data sets with more than one random variable obtained as a result of measurements or calculations, basic statistical methods are used to analyze the relationship and behavior between variables. In addition, basic statistical analysis helps in organizing and simplifying the data used to evaluate relationships between samples and variables. In this study, SPSS.22.0 was used for basic statistical analysis of the behavior of samples and variables. Basic statistics, histograms and Pearson correlation analyses were performed for the statistical analysis of the results obtained in the study.

Table 3 shows the basic statistics of natural radionuclides in Cekmeköy soil samples such as minimum, maximum, average, standard deviation, variance, skewness, and kurtosis. In this study, the standard deviations of activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th natural radionuclides measured in soil samples are smaller than the average values. This indicates that the activity concentration of potassium, uranium, and thorium samples is high homogeneity (Chandrasekaran et al., 2014).

Skewness is defined as the degree of distortion of the symmetricity of the normal distribution curve. The distribution curve is called positive skewed or right skewed if tailed to the right, negative skewed or skewed to the left. In this study, the skewness values of natural radionuclide activity concentrations define the degree of asymmetry around the mean of a distribution. The activity concentrations of the ^{40}K, ^{226}Ra, and ^{232}Th radionuclides have a positive skewness, indicating that their distribution is asymmetric (Ravisankar et al., 2015). The frequency distribution of ^{40}K, ^{226}Ra, and ^{232}Th is shown in Fig. 11. Kurtosis is defined as

Table 3 Basic statistics values ^{40}K, ^{226}Ra, and ^{232}Th natural radionuclide activity concentration in soil samples

Variables	^{40}K	^{226}Ra	^{232}Th
Mean	449.12	29.21	27.83
Std. deviation	88.97	6.34	6.05
Variance	7915.36	40.03	36.60
Skewness	0.26	0.16	0.28
Kurtosis	-0.71	-0.75	-0.54
Range	318.48	21.79	21.24
Minimum	293.86	18.76	17.67
Maximum	612.34	40.55	38.91

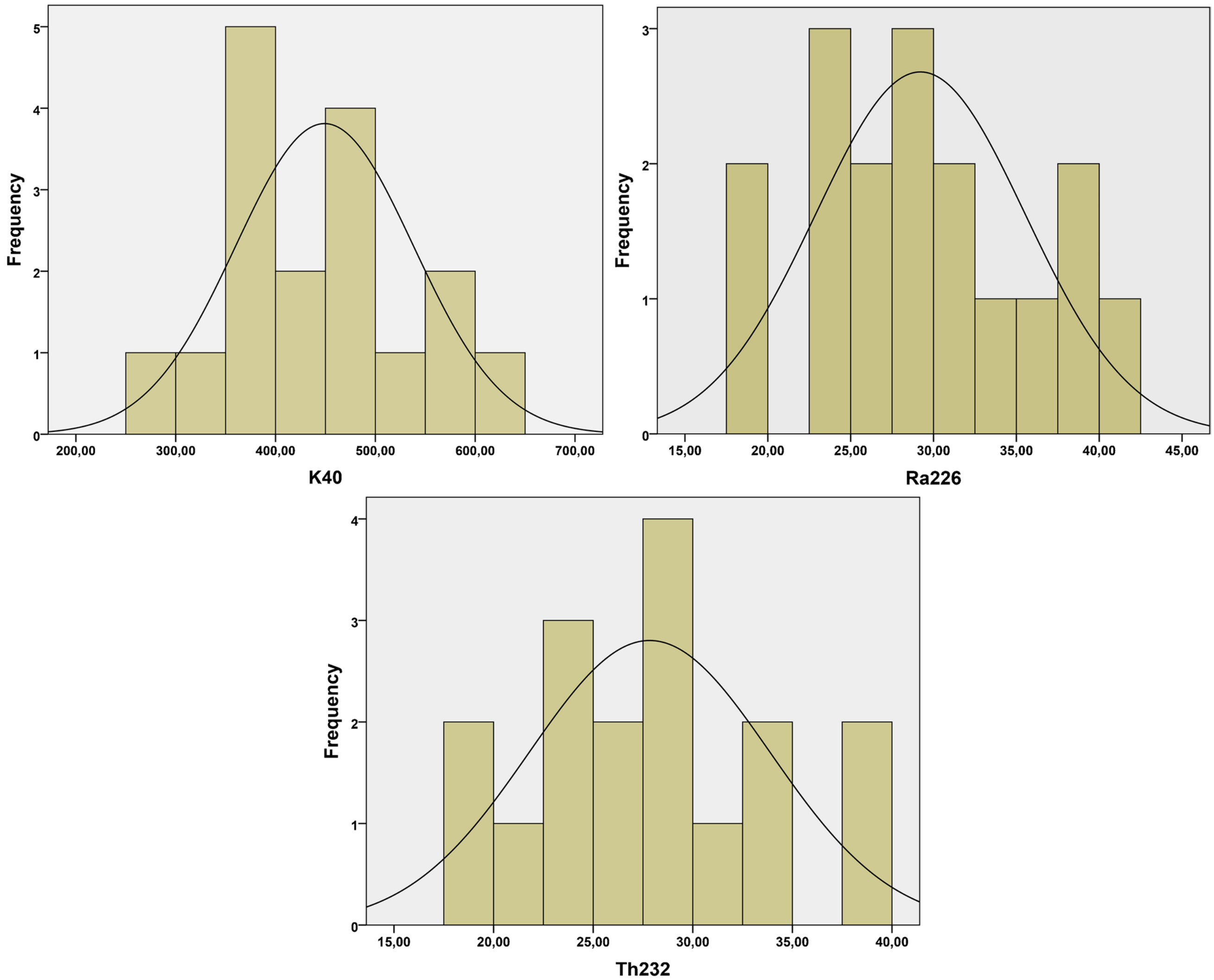

Fig. 11 Frequency distribution of ^{40} K, ^{226}Ra, and ^{232}Th activity concentrations

the degree of sharpness or kurtosis (extent) of the normal distribution curve. If the top of the curve is pointed, the distribution is leptokurtic, and it has a high kurtosis coefficient. If the top of the distribution curve is flat, the distribution is plastic, and the flatness coefficient is low (Gupta 2001). The kurtosis value of ^{40} K, ^{226}Ra, and ^{232}Th activity concentrations is negative, indicating that the curve peaked less than the normal curve.

The strength of the linear relationship between the two variables is defined by the Pearson correlation coefficient. Pearson correlation analysis was applied to determine the relationship between the activity concentrations of ^{40} K, ^{226}Ra, and ^{232}Th natural radionuclides and their radiological parameters. Correlation coefficients obtained as a result of the analyses are presented in Table 4. The relationship between the activity concentrations of ^{226}Ra and ^{232}Th natural radionuclides and all radiological parameters showed a very high correlation coefficient, but showed that the correlation coefficient between ^{40} K activity concentration and radiological parameters were low. This analysis showed that the radiological parameters varied depending on the activity concentrations of ^{226}Ra and ^{232}Th natural radionuclides. ^{40} K activity concentration showed that it is not responsible for radiological parameters.

Table 4 Pearson correlation coefficients among the radionuclides and radiological parameters for soil samples

	^{40}K	^{226}Ra	^{232}Th	D	AEDE	AGDE	ELCR	Ra_{eq}	H_{ex}	H_{in}	I_{γ}
^{40}K	1										
^{226}Ra	0.075	1									
^{232}Th	-0.404	0.623	1								
D	0.390	0.870	0.631	1							
AEDE	0.385	0.873	0.633	1	1						
AGDE	0.438	0.851	0.595	0.999	0.998	1					
ELCR	0.390	0.870	0.631	1	1	0.999	1				
RA_{eq}	0.279	0.890	0.715	0.993	0.993	0.985	0.993	1			
H_{ex}	0.277	0.891	0.716	0.993	0.993	0.985	0.993	1	1		
H_{in}	0.220	0.948	0.703	0.978	0.978	0.966	0.978	0.989	0.989	1	
I_{γ}	0.388	0.860	0.641	1	0.999	0.998	1	0.993	0.993	0.975	1

Conclusion

Activity concentrations of natural radionuclides ^{40}K, ^{226}Ra, and ^{232}Th were measured in soil samples collected from Çekmeköy-Istanbul using gamma ray spectroscopy technique with NaI (Tl) detector. As a result of this study, the mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th were found to be 449.12 ± 8.98 Bqkg^{-1}, 29.21 ± 0.58, and 27.83 ± 0.55 Bqkg^{-1}, respectively. Mean absorbed dose rate (D_R), annual effective dose (AED), annual gonadal dose equivalent (AGDE), excess lifetime cancer risk (ELCR), and radium equivalent activity (Ra_{eq}) were calculated as 49.03 nGyh^{-1}, 0.060 mSvy^{-1}, 0.348 mSvy^{-1}, 0.21×10^{-3}, and 103.59 Bqkg^{-1}, respectively**.** It was concluded that experimentally found average activity concentrations results and theoretically calculated radiological damage parameters were below the recommended safety limit values. Basic statistical analysis showed that the natural radioactivity variation in soil samples in the study area was dependent on thorium and uranium concentration. The data produced in this study will provide basic data for natural radioactivity radiological parameters in the studied area and will be useful for the application of radiation protection standards for people, animals, and the environment living in the region.

Declarations

Conflict of interest The authors declare no competing interests.

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