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Outdoor radioactivity and health risk assessment for capital city Ankara, Turkey

Enis Kapdan[1] · Nesrin Altinsoy[2] · Gürsel Karahan[1] · Ayhan Yuksel[1]

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Abstract
The aim of this study is to determine the soil radioactivity levels and assess the possible relevant health hazards for the inhabitants of Ankara province. Total of 341 samples were collected from predetermined locations and outdoor gamma dose rate measurements were carried out. The mean activity of ^{40}K, ^{226}Ra, ^{232}Th, and ^{137}Cs with the ranges were determined as 454 (23–1355), 27 (6–186), 33 (2–181) and 3.3 (0.5–20.9) Bq kg^{-1}, respectively. The average annual effective dose equivalent was found to be 71.8 μSv y^{-1} for public exposure and the average excess lifetime cancer risk value was calculated as 2.69E−04.

Keywords Cancer risk · Effective dose · Gamma dose rate · Soil radioactivity

Introduction

Radionuclides have been an essential part of the Earth since its formation. The Earth contains a lot of radioactive elements. The origin for part of them goes back to the creation of our world, while the others are continually produced through nuclear reactions in the universe [1]. Environmental radioactivity in soils originate from the radioactive decay series of ^{238}U and ^{232}Th, along with ^{40}K. Granite based geological background is relatively high in radioactivity due to abundant contents typical of ^{238}U and ^{232}Th in the soils [2]. Artificial radionuclides such as ^{137}Cs can also be result of fallout from testing of nuclear weapons and the nuclear reactor accidents [3]. Cs group nuclides are contained in high-level liquid waste in nuclear power plants, and ^{137}Cs, having a half-life of 30.1 years, exhibits particularly high radioactivity and heat generation [4].

The radionuclide distribution reflects migration of uranium and thorium under surface soil. Hydrogenous migration ability decreases in the order U > Ra > Th. Uranium can remain in soluble condition for a long time and gets migrated to a long distance by flow of river or streams. Uranium and thorium transfer is controlled by interchange of sorption and desorption. Rapid population growth and the use of fertilizers for agriculture increase the contamination of the soils [5].

Soil radioactivity evaluation is important in order to understand background radioactivity concentrations. The worldwide annual effective dose received by the population from all natural and artificial sources is 2.8 mSv, about which 85% of the dose (2.4 mSv) comes from only natural background radiations [6]. The radioactivity in environment can be transmitted into human body through two main pathways; external and internal exposure [7]. Irradiation of cells due to background radiation may create DNA damage. Radiation effects to DNA may result in a return to normal structure, or lead to changes in DNA that cause fatal or heritable changes (chromosomal aberrations and mutations) in surviving cells [8].

Due to the harmful effects of the background radiations, different studies have been performed to prevent potential human health hazards [9]. Therefore, in this study capital city Ankara in the Middle Anatolia region of Turkey was investigated in terms of activity concentration of radionuclides as well as outdoor gamma dose rates to reveal the radionuclide distribution around the region and asses the related potential health risks for inhabitants of the region.

✉ Nesrin Altinsoy
altinsoy@itu.edu.tr

1 Cekmece Nuclear Research and Training Centre, Altinsehir Yolu, 5 km, Halkali, 34303 Istanbul, Turkey

2 Institute of Energy, Istanbul Technical University (ITU), Ayazaga Kampusu, 34469 Istanbul, Turkey

Survey area

Located in the Middle Anatolia region of the country, capital city Ankara, is one of Turkey's most important city in terms of economic and agricultural activities, and it is shown with its neighbors together in Fig. 1. The city is the second most crowded city in Turkey and thirty-seventh in the world. The city center is located at the coordinates of 39°52′0″N, 32°52′0″E and at the altitude of 1050 m. The province has 25 districts with different geographic and geologic feature. Geographically, the province generally has flat and hilly areas, but there are mountainous parts (the highest one is 2015 m) in the north side especially in the district of the Çamlıdere, Kızılcahamam, Çubuk, and Kalecik [10]. The northern part of the region is volcanic area and there are anthracitic and andesitic rocks; granite type of rocks is on the northeast side; the limestone and sandstone are on the northwest. Southern and southeastern regions of the city are formed of mesozoic formations. There are quaternary formations around the Sakarya River, eocene formations around Polatlı, neogene formations around the Lake of Tuz [11].

Experimental

To determine the outdoor radioactivity in Ankara, 341 soil samples, average of 5 kg, were taken from depth of 10 cm and collected from predetermined locations and outdoor gamma dose rate measurements were carried out 1 m above the ground at the soil sampling stations in 2017. The number of stations with the altitude and catchment area of each district were given in Table 1. The geographic coordinates of the stations were determined by using GPS devices. To plot the spatial distribution maps, the inverse distance weighted (IDW) interpolation method was applied using ArcGIS (10.2 version) mapping software.

Open, flat, undisturbed and uncultivated locations close to settlements were selected as soil sampling stations. After removing the foreign bodies, the soil was placed in bags which were labeled and sealed at the sampling stations. After being dried at 105 °C 24 h, the samples were grained and then sieved using 2 mm sieves. Afterwards, to obtain the equilibrium of radionuclides in thorium and uranium series, samples were waited 28 days in the sealed, airproof marinelli beakers. Gamma spectrometry measurements were carried out using a coaxial HPGe detector (CanberraGMX-70) with 30% relative efficiency in multilayer shielding. The overall detector resolution (FWHM) of 1.9 keV was obtained for the 1332 keV gamma line of ^{60}Co. Energy calibration and relative efficiency calibration of the gamma spectrometer were carried out using ^{109}Cd, ^{57}Co, ^{113}Sn, ^{134}Cs, ^{137}Cs, ^{88}Y and ^{60}Co calibration sources in 1000 ml Marinelli beakers covering the energy range between 80 and 2500 keV. Each sample, as well as the background, was counted for 50,000 s at the accredited laboratories of the Radioactivity Analysis and Measurement Department in Çekmece Nuclear Research and Training Center (CNAEM) [12]. The specific activity ^{137}Cs and ^{40}K were measured directly by its own gamma-ray at 661.7 (85.2) keV and 1460.8 keV (10.7), respectively, while activities of ^{226}Ra and ^{232}Th were calculated based on the weighted mean value of their respective decay products in equilibrium. The specific activity of ^{226}Ra was

Fig. 1 Research region of Ankara

Table 1 Distribution of stations in the research region of Ankara

District	Population	Catchment area (km^2)	Altitude (m)	Number of stations
Akyurt	32,863	369	1050	6
Altındağ	371,366	123	1000	0
Ayaş	12,289	1041	900	14
Bala	21,682	1851	1320	32
Beypazarı	48,476	1697	700	23
Çamlıdere	7389	782	1250	5
Çankaya	921,999	483	1050	3
Çubuk	90,063	1198	940	19
Elmadağ	45,513	647	1150	8
Etimesgut	566,500	273	894	3
Evren	2753	222	922	12
Gölbaşı	130,363	1364	980	22
Güdül	8050	540	720	9
Haymana	27,277	2164	1230	41
Kazan	52,079	1110	880	13
Kalecik	12,897	547	750	6
Keçiören	917,759	159	950	0
Kızılcahamam	24,947	1623	980	15
Mamak	637,935	321	950	4
Nallıhan	28,621	2079	630	18
Polatlı	124,464	3618	870	49
Pursaklar	142,317	169	1030	4
Şereflikoçhisar	33,599	2155	975	32
Sincan	524,222	880	790	17
Yenimahalle	659,603	219	875	6
Ankara	5,445,026	25,634	1050	361

measured using the 295.2 (18.2), 351.9 (35.1) keV gamma rays from ^{214}Pb and the 609.3 (44.6), 1764.5 (15.1) keV from ^{214}Bi. The specific activity of ^{232}Th was measured using the 338.4 (11.3), the 911.2 (26.6) keV from ^{228}Ac and 583.2 (30.6) keV from ^{208}Tl [13]. To minimize the effect of the background radiations, the detection system and laboratory were shielded very well. The MDA was determined for ^{137}Cs (range from 0.4 to 0.9 Bq kg^{-1} with a mean of 0.5 Bq kg^{-1}), ^{40}K (from 7.2 to 15.5 Bq kg^{-1} with a mean of 9.8 Bq kg^{-1}), ^{226}Ra (from 1.1 to 2.4 Bq kg^{-1} with a mean of 1.5 Bq kg^{-1}) and ^{232}Th (from 0.9 to 1.8 Bq kg^{-1} with a mean of 1.2 Bq kg^{-1}). Any radionuclide with activity level below the MDA was excluded from the average activity calculations [14].

Gamma absorbed dose rate in air (ADRA) at 1 m above the ground due to ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in nGy h^{-1} was calculated using the following equation [15].

$$\mathrm{ADRA} = aC_{Ra} + bC_{Th} + cC_K + dC_{Cs} \quad (1)$$

Here C_{Th}, C_{Ra}, C_K and C_{Cs} are ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs activity in Bq kg^{-1} in soil, respectively. The values of a, b, c, and d are coefficients of 0.461, 0.623, 0.0417 and 0.1243 nGy h^{-1} (Bq $kg^{-1})^{-1}$, respectively. The methodology used for the derivation of the gamma dose rates was introduced by Beck and De Planque. They used the polynomial expansion matrix equation method for solving the soil/air transport problem in order to calculate the exposure rates 1 m above ground level for distributed sources of gamma emitters in soil [15–19].

The gamma ray radiation hazard due to the defined radioisotopes was assessed by radium equivalent activity (Ra_{eq}). Ra_{eq} was calculated according to Eq. (2) [14].

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2)$$

The outdoor gamma dose rate measurements in the research region were performed in summer season by the portable device (Thermo Scientific) connected with high sensitivity NaI scintillation detector (NBR model of Thermo Scientific) calibrated at the beginning and at the end of the study by accredited Secondary Standard Dosimetry Laboratory (SSDL) of Turkish Atomic Energy Authority (TAEA). Absorbed gamma dose rate values measured about 1 m above the ground for 2 min were taken at three different points in a circle with 5 m radius at each station. After getting the average of three different measurements, results were recorded in μR h^{-1} and then the conversion factor of 8.7 nGy μR^{-1} was used to change the unit of μR h^{-1} to the nGy h^{-1}. To obtain the annual effective dose equivalent (AEDE), the following equation was used [15]:

$$AEDE = ADRA \times DCF \times OF \times T \quad (3)$$

Here ADRA is the absorbed dose rate in air in nGy h^{-1}, DCF is the dose conversion factor in Sv Gy^{-1} which is assigned as 0.7 for adults, OF is the occupancy factor of 0.2 and T is the time in 8760 h y^{-1}. In addition, to obtain the excess lifetime cancer risk (ELCR) value for inhabitants of the region, the following equation was used [16].

$$ELCR = AEDE \times DL \times RF \quad (4)$$

Here DL is the average duration of life which is considered as 70 years, RF is the fatal cancer risk factor in Sv^{-1}, and in this study, the RF value suggested by ICRP 103 was used as 0.055 for stochastic effects to public [20].

Results and discussion

As a result of analyzing 341 soil samples by means of gamma spectrometry technique, mean radioactivity concentration values (± standard deviations) of ^{40}K, ^{226}Ra, ^{232}Th, and ^{137}Cs were determined as 454 ± 197, 27.0 ± 16.3, 33.1 ± 19.7 and 3.3 ± 2.9 Bq kg^{-1}, respectively for the region. The mean radionuclide activities of each district were presented in Table 2. It was seen that the variations in natural radionuclide activities observed in the Table 2 were caused by the radiochemical structure of the soil directly. Also, the highest ^{40}K, ^{226}Ra, and ^{232}Th, activities were observed at the stations in Nallıhan, Polatlı, and Evren district as 1354.9, 185.8, and 181.2 Bq kg^{-1} respectively in the region. Furthermore, the distribution of activities in district is also demonstrated by boxplot in Fig. 2, here, the ends of vertical red lines indicate the minimum and maximum activity values determined in district and the box width shows the variation of mean value depending on standard deviation and in the figure, the longest boxes belong to district of Kazan and Nallıhan

Table 2 Radiologic parameters determined in the research region of Ankara

District	Activity concentration				ADRA (measured) nGy h^{-1}	AEDE μSv h^{-1}	ELCR
	^{40}K	^{226}Ra	^{232}Th	^{137}Cs			
Akyurt	544	23.9	40.6	4.8	65.3	80.08	3.00E−04
Ayaş	412	21.3	30.8	3.3	53.1	65.13	2.44E−04
Bala	468	26.0	33.1	3.8	60.0	73.67	2.76E−04
Beypazarı	547	28.4	34.9	4.4	63.7	78.18	2.93E−04
Çamlıdere	496	39.4	39.3	1.4	75.7	92.89	3.48E−04
Çankaya	329	16.2	26.3	2.8	44.4	54.45	2.04E−04
Çubuk	497	29.6	41.2	3.1	70.7	86.72	3.25E−04
Elmadağ	395	21.5	30.3	3.3	51.3	62.99	2.36E−04
Etimesgut	198	18.6	22.3	1.6	39.2	48.05	1.80E−04
Evren	916	35.5	80.8	4.6	114.1	139.97	5.25E−04
Gölbaşı	339	20.2	26.8	2.9	46.1	56.59	2.12E−04
Güdül	564	34.1	47.3	2.6	74.5	91.43	3.43E−04
Haymana	362	22.4	24.9	4.0	46.1	56.59	2.12E−04
Kalecik	433	19.1	26.1	5.6	49.3	60.55	2.27E−04
Kazan	520	23.9	37.3	3.6	68.7	84.35	3.16E−04
Kızılcahamam	573	50.7	72.1	3.6	104.5	128.25	4.81E−04
Mamak	474	19.8	32.3	2.6	57.9	71.01	2.66E−04
Nallıhan	452	29.7	25.4	2.9	53.1	65.13	2.44E−04
Polatlı	341	33.2	24.1	3.0	52.4	64.25	2.41E−04
Pursaklar	465	20.9	33.2	0.9	60.1	73.79	2.77E−04
Sincan	503	28.1	31.9	2.5	62.7	76.96	2.89E−04
Şereflikoçhisar	483	22.4	30.6	3.1	56.5	69.36	2.60E−04
Yenimalle	428	18.9	23.7	1.4	47.0	57.66	2.16E−04
Ankara	454	27.0	33.1	3.3	58.5	71.83	2.69E−04
Worldwide	400	35	30	–	54.0	–	–

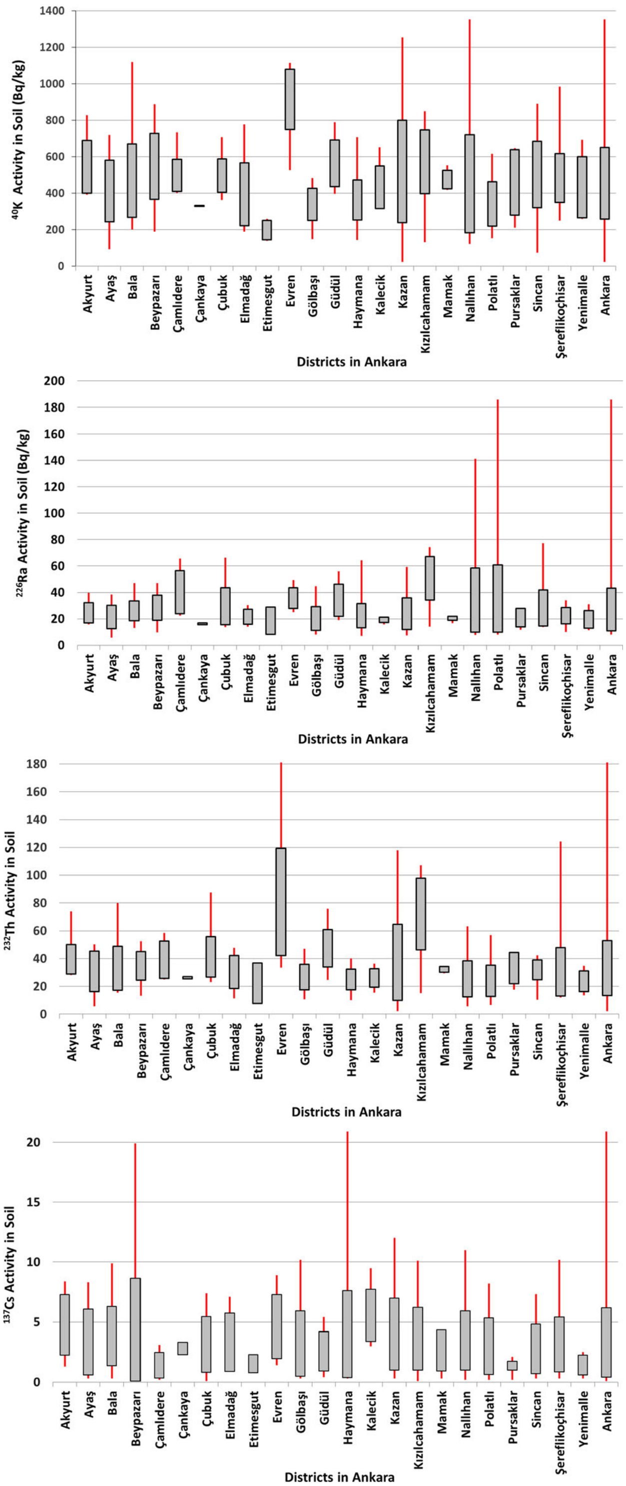

Fig. 2 Radionuclide concentration in soil (Bq kg^{-1})

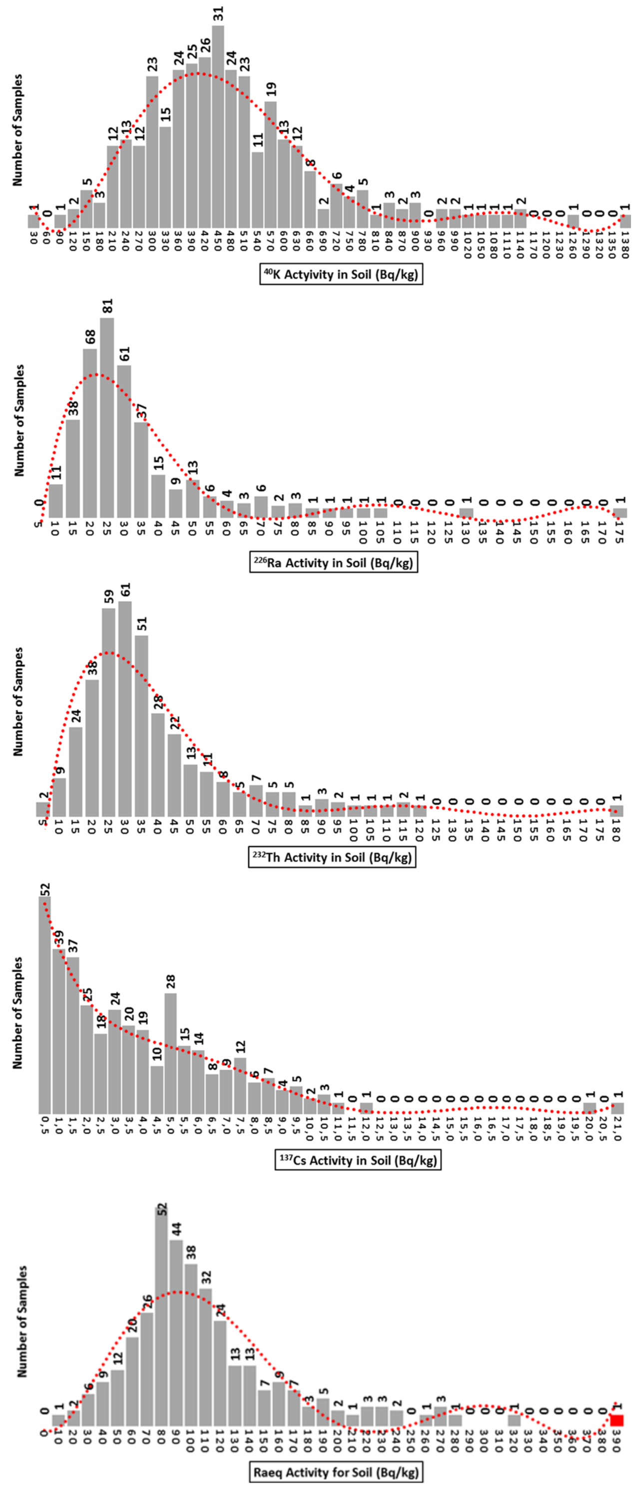

Fig. 3 Distribution of radionuclide concentration

for ^{40}K, Polatlı and Nallıhan for ^{226}Ra, Evren and Kazan for ^{232}Th, this is caused by the variation in activities depending on the wide catchment area of those district.

^{137}Cs is spread to the atmosphere because of nuclear activities and most of the fallout radiation accumulates in the soil [21]. Chernobyl nuclear reactor accident in 1986 has affected Turkey like other close countries. Studies carried after the accident pointed out to ^{137}Cs accumulation especially at the north coast of Turkey and Thrace [22]. ^{137}Cs from the fallout plays a less role in external radiation

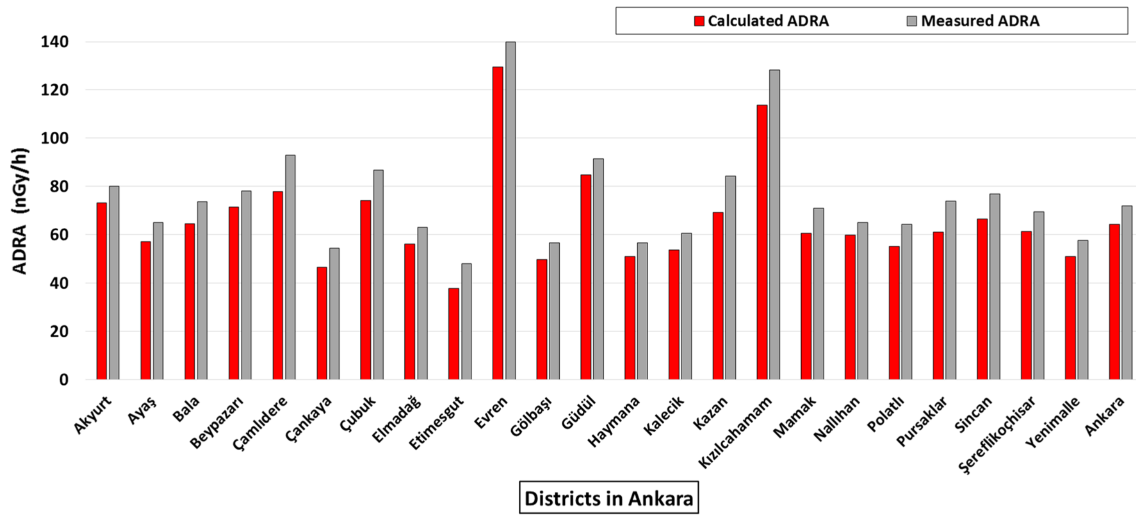

Fig. 4 Distribution of absorbed dose rate (nGy h^{-1}) in air

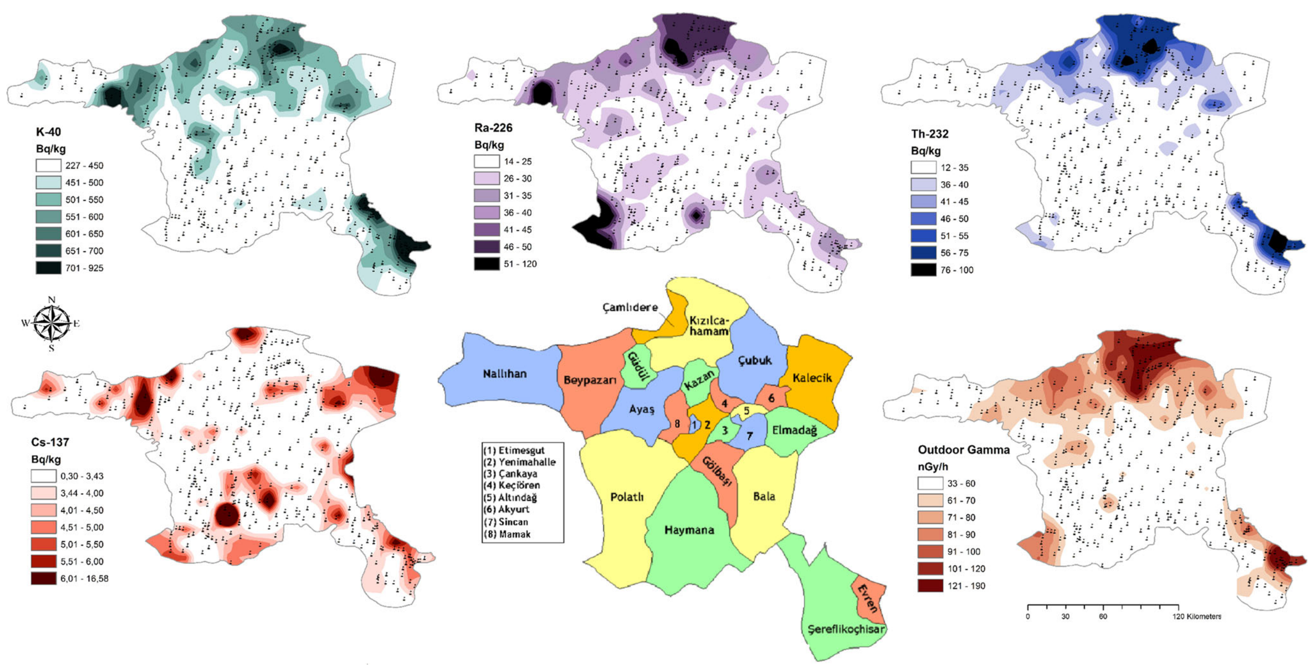

Fig. 5 Spatial distribution of radionuclide concentration and ADRA in Ankara

exposures than in potential exposures from naturally occurring radionuclides, especially in forest soils. ^{137}Cs activity was determined at different levels in all over the region in this study and the highest activity seen in Haymana district with 20.9 Bq kg^{-1}. Moreover, the distribution of radionuclide activities in the region is also demonstrated by histograms in Fig. 3 and in the histogram of Ra_{eq} calculated using Eq. (2), red bars refer the number samples of activity values exceeding the limit value of 370 Bq kg^{-1} [23]. Looking to the histograms, the shape of ^{137}Cs distribution, which differs from the others, is in the form of a right triangle because of the random distribution of artificial nuclides in fallout.

The absorbed dose rate in air (ADRA) 1 m above the ground consisting of the terrestrial and the cosmic gamma components was determined as 58.5 ± 27.1 nGy h^{-1} for the entire region. The mean outdoor gamma dose rates measured by readings at 341 stations were given for each district in Table 2 and the measured and calculated (terrestrial) absorbed dose rates for each district were illustrated together in Fig. 4. Analyzing the results in the figure, it was seen that the district of Evren, where radionuclide concentrations were determined at the highest values, has

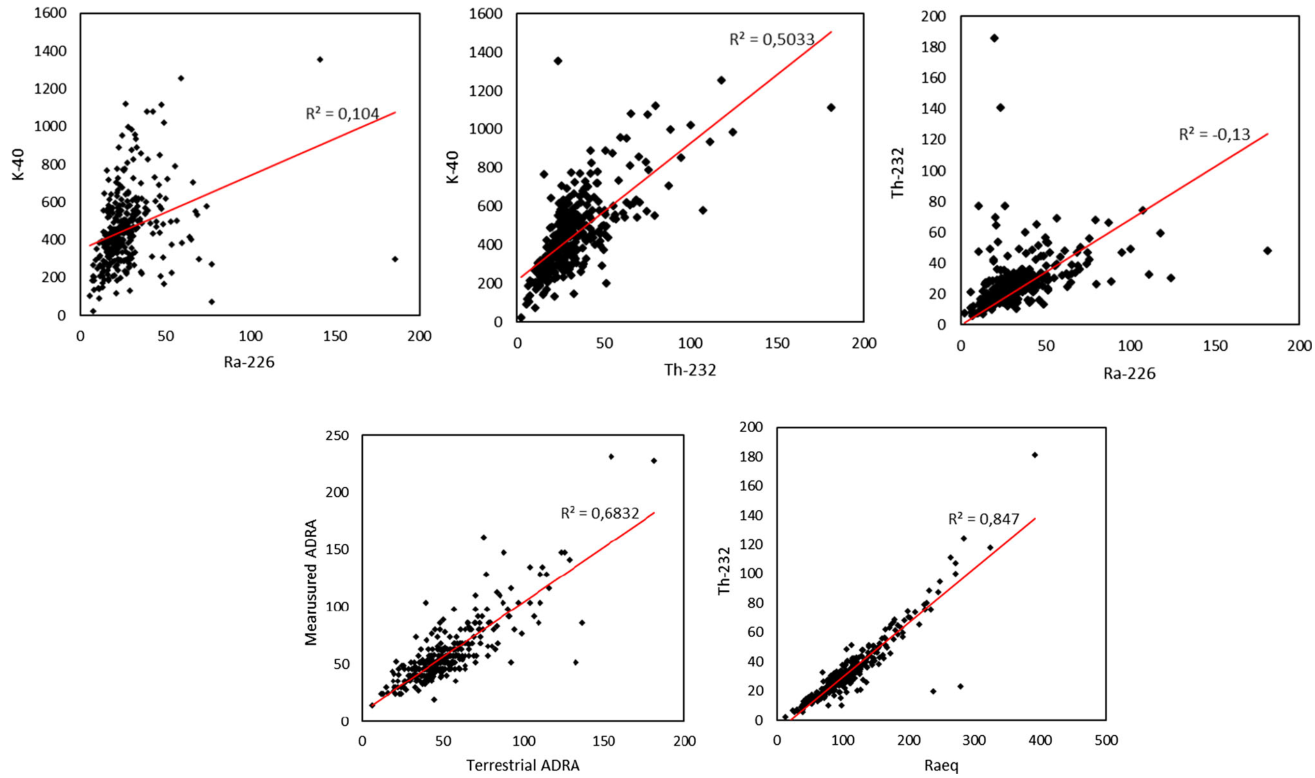

Fig. 6 Variation of radionuclide activity concentration

the highest mean value with 114.1 ± 72.1 nGy h^{-1}. However, the highest dose rate observed in the region is at the station in Kazan district as 257 ± 35 nGy h^{-1}. Furthermore, the average terrestrial ADRA value for the region, which was calculated by placing the soil radionuclide concentration values to the Eq. (1), was found to be 52.4 ± 24.3 nGy h^{-1} and it was observed that the terrestrial gamma dose rates varied considerably between different locations in the region. This variation is mainly caused by varying concentration of the radionuclides depending on the geochemical structure of soil in the region and weakly caused by fallout of artificial nuclides. Moreover, the mean ADRA value due to cosmic gamma radiations for the region was calculated as 6.1 ± 3.1 nGy h^{-1} subtracting the calculated terrestrial gamma dose rate from the measured one. Cosmic gamma dose rates mainly depend on the altitude and weakly geomagnetic latitude of the regions investigated [15]. Therefore, the changes in cosmic radiation levels in the region could be explained by the changes in altitudes entire region as explained at the previous section.

The spatial distribution of the radionuclide activities and ADRA for the region were presented in Fig. 5 and location of sampling stations were also indicated in these maps. Analyzing the maps together, the impact of denser regions in all radionuclide maps to those regions in ADRA distribution map is seen clearly, but the general shape of ADRA map more resembles the shape of ^{232}Th activity map due to high activity concentration of ^{232}Th around the region.

Biological annual effective radiation doses (AEDE) and the related cancer risks were calculated to reveal the health effects of ionizing background radiations. Therefore, the mean AEDE values due to cosmic and terrestrial gamma radiations were found to be 8 ± 3 and 64 ± 32 µSv y^{-1}, respectively using Eq. (3). Biological effective radiation doses due to terrestrial gamma radiation could change depending on weather conditions, duration of exposure, humidity, the rate of fertilizer usage and the asphalt thickness above the soil. Biological effective dose values due to cosmic radiation exposure mainly depend on the altitude of the location. Therefore, traveling between different locations in the region and living in different parts of the region would affect the cosmic radiation exposure to the inhabitants. Moreover, the average estimated excess cancer risk values (ELCR) for inhabitants of the region were calculated as (0.28 ± 0.15) E−04 and (2.41 ± 1.23) E−04 due to cosmic and terrestrial ionizing radiation exposures respectively using Eq. (4) with the risk factor suggested by ICRP [20]. The determined cancer risk values directly depend on methods and risk factors chosen. For this reason, different models can give different outputs. Furthermore, the calculated AEDE and ELCR values are given in Table 2 for inhabitants of each district.

Table 3 Background radioactivity studies

City	Country	Date of study	References	Number of sample	Radionuclide activity (Bq kg^{-1})				ADRA nGy h^{-1}
					^{40}K	^{226}Ra	^{232}Th	^{137}Cs	
Adana	Turkey	2008	[24]	38	298	21	21	–	67
Ardahan	Turkey	2011	[25]	33	341	36	31	14	50
Artvin	Turkey	2011	[25]	57	358	22	19	54	38
Balikesir	Turkey	2011	[9]	70	675	–	55	4	127
Batman	Turkey	2010	[26]	72	274	35	25	12	–
Bayburt	Turkey	2009	[27]	41	522	40	35	9	–
Bursa	Turkey	2010	[28]	50	430	56	32	5	90
Cankırı	Turkey	2012	[29]	48	357	–	22	4	70
Çanakkale	Turkey	2010	[30]	12	1200	115	110	20	66
Gaziantep	Turkey	2006	[31]	39	289	33	24	8	50
Giresun	Turkey	2008	[32]	16	733	33	43	318	–
Istanbul	Turkey	2000	[33]	105	342	27	37	–	60
Kastamonu	Turkey	2007	[34]	10	431	37	27	8	–
Kayseri	Turkey	2012	[35]	81	429	–	37	17	59
Kirklareli	Turkey	2009	[36]	177	667	37	40	8	118
Manisa	Turkey	2006	[37]	64	340	–	27	–	78
Samsun	Turkey	2012	[38]	75	341	31	22	16	–
Sanliurfa	Turkey	2007	[39]	45	299	31	25	9	89
Trabzon	Turkey	2011	[3]	222	443	41	38	25	59
Yalova	Turkey	2011	[40]	40	419	27	22	3	49
Average	Turkey			65	459	39	35	31	71
Riyadh	S. Arabia	2008	[41]	100	63	4	4	–	–
Canary Islands	Spain	2017	[42]	350	384	25	29	–	–
Rajasthan	India	2015	[43]		549	55	24	–	68
West Bank	Palestine	2008	[44]	38	630	–	48	–	121
Fars	Iran	2011	[45]	126	271	–	15	6	–
Punjab	India	2017	[46]	46	443	134	56	–	–
Slovenia	Slovenia	2013	[47]	70	800	63	77	–	–
Rio de Janeiro	Brazil	2018	[48]	259	114	32	–	–	–
Kuala Lumpur	Malaysia	2017	[49]	16	727	–	191	–	251
Tripoli	Lybia	1997	[50]	60	270	–	10	–	–
Worldwide		2000	[15]	–	400	35	30	–	54
Ankara	Turkey	2018		341	454	27	33	3	59

To reveal the correlation relation between activity concentration of naturally occurring radionuclides and dose rates, Pearson correlation coefficients were determined and the plotted correlation charts were given in Fig. 6. Analyzing the charts, it was seen that there were good correlations between activity concentrations of ^{40}K and ^{232}Th ($R^2 = 0.503$, S = 7.090), between ^{232}Th and $^{226}Ra_{eq}$ ($R^2 = 0.847$, S = 0.370) and between calculated terrestrial and measured gamma dose rates ($R^2 = 0.683$, S = 0.954), poor correlations between ^{40}K and ^{226}Ra ($R^2 = 0.104$, S = 3.903) and between ^{232}Th and ^{226}Ra ($R^2 = 0.130$, S = 0.685) Here, S refers the slope value of the slope line.

Finally, the average activity values of radionuclides and outdoor gamma dose rate values determined for other cities with worldwide averages were listed in Table 3. It was seen that mean activity of radionuclides ^{40}K, ^{137}Cs, ^{226}Ra, ^{232}Th, and absorbed dose rate in air (ADRA) for research region of Ankara was in the range of the values determined in other cities. Besides, the results of the study were quite comparable with the cities of Çankırı and Kastamonu located in the same geographical region of Middle Anatolia, as can be seen in Fig. 1. Moreover, mean values of the radionuclide concentrations for the region were also comparable with the worldwide averages. However, if the average absorbed gamma dose rates due to cosmic and terrestrial radiations were calculated using Eq. (1) with the average worldwide radionuclide concentrations, these values would be 2.4 and 51.6 nGy h^{-1} as worldwide averages. Comparing these values with those of the region, it is seen that there is a deviation in cosmic radiation values and this should be caused by mainly high altitude of the region.

Conclusions

This study evaluated activity concentration of radionuclides in soil and outdoor ADRA values as well as the related health risks in Ankara the capital city of Turkey. In this study, it was seen that the drastic changes in outdoor gamma dose rates were caused by mainly variety of the geological structure of the region and weakly change of altitude in the region. Furthermore, it was observed that the average radionuclide concentration in soil of the Ankara was close to the Turkey and worldwide averages. Also, ^{137}Cs activity was still observed at different levels in the research region of Ankara 32 years after the Chernobyl accident. Another important result of the study was that although the average ^{232}Th activity determined for the region was seen to be very close to the average values, it was observed to be at high levels in some parts of the region particularly around the Evren and Kızılcahamam district. Therefore, these regions should be investigated more detailed in terms of public health.

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