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RESEARCH

Evaluation of natural radioactivity in soils of Konya (Turkey) and estimation of radiological health hazards

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Abstract Surface soil samples were collected from Konya, Turkey and natural activity concentrations were determined using the ɤ-ray spectroscopy system with HPGe detector. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were found to vary from 14.07 ± 0.71 Bq kg^{-1} dw to 67.27 ± 1.62 Bq kg^{-1} dw, 10.19 ± 2.60 Bq kg^{-1} dw to 46.09 ± 0.76 Bq kg^{-1} dw and 107.87 ± 13.32 Bq kg^{-1} dw to 605.95 ± 11.34 Bq kg^{-1} dry weight (dw), respectively. The radiological hazard parameters such as Ra_{eq}, D, AEDE, ELCR, AGDE, H_{ex}, H_{in}, and Iɤ evaluated the radiological risk for the public and environment. The mean values of D, AEDE and ELCR are lower than the world average value of 57 nGy h^{-1}, 70 μSv y^{-1}, 0.29 × 10^{-3} respectively. The activity concentration distribution maps of ^{226}Ra, ^{232}Th and ^{40}K and the radiological maps of the radiological hazard parameters were plotted using the Surfer programme. Cluster analysis was carried out to indicate the similarity between the variables.

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Introduction

People are unavoidably exposed to radiation throughout their lives. Naturally occurring radioactive materials (NORMs) contribute greatly to radiation. The radioactivity due to NORMs is detrimental to human health and causes environmental pollution. NORMs are present in soil, rock, water, air, sediment and sand. In soil, potassium (^{40}K), uranium (^{238}U), thorium (^{232}Th) and their decay products are known primary NORMs and cause an increase in radioactivity levels. Particularly, ^{226}Ra, ^{232}Th and ^{40}K induce the natural background radiation in soil and it's approximately 80% of the total radiation dose a person is exposed to in a year (Ibraheem et al., 2018). Knowing the radioactivity concentrations of NORMs in soil provides useful information in determining environmental radioactivity.

The level of human exposure depends on the geological morphology of the soil. Therefore, soil radioactivity concentration analysis plays a very significant role in determining the level of exposure of human beings (Tiomene et al., 2023). Exposure to NORMs causes many health problems such as lung diseases, leukemia and cancers (Uosif & El-Taher, 2008). Soils are evermore a source of radiation for all living beings because NORMs in soil transfer to plants, water, air, animals, humans, etc. (Murugesan et al., 2011; Özden & Aközcan, 2021).

The NORMs' distribution in the soil differs from area to area depending on the usage of phosphate fertilizer, mining activities, industrial activities, geological structure and geographical formation (Özden & Aközcan, 2021; Akkurt et al., 2022; Içhedef et al., 2015). Recycled by-products used in industry increase natural radioactivity levels (Żak et al., 2010). In the geological structure of the earth, there are rock beds just below the soil layer of a certain thickness. These rock beds are estimated to cause terrestrial radioactivity. It is known that most of the gamma radiations originate from the surface layer (0–25 cm) (Küçükönder et al., 2023; UNSCEAR, 1993). The safety of a population is directly related to the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K radionuclide concentrations in soil samples. Natural radionuclides in soils have attracted the attention of researchers because of the potential radiation exposure to humans and various studies have been carried out on this subject in different geological structures around the world (Al-Alawy et al., 2023; Alsaadi et al., 2023; Elsaman et al., 2022; Hafızoğlu, 2023; Özden, 2022; Özden & Aközcan, 2021; Pucha et al., 2023; Srinivasa et al., 2022).

The objective of this study is to indicate the natural radioactivity concentrations, the distribution of NORMs in soils in Konya, Turkey and also to evaluate the radiological parameters, namely, radium equivalent activity (Ra_{eq}), absorbed gamma dose rate (D), annual effective dose equivalent (AEDE), external hazard index (H_{ex}), internal hazard index (H_{in}), excess lifetime cancer risk (ELCR), annual gonadal dose equivalent (AGDE) and gamma representative level index (I_γ) due to soil samples. Cluster analyses were carried out to indicate the radionuclide distributions and to understand the relationships between parameters.

Materials and methods

Study area

Konya is the city with the largest surface area of Turkey. Konya is located on 37° 52′ 28.7148″ N and 32° 29′ 35.358″ E. It is estimated that Konya has a population of approximately 2.294.727 in 2022. The landform with the largest area in Konya is plains and plateaus. These plateaus, which are covered with rich steppes, are important for the province's livestock and agriculture. In Konya, alluvial, colluvial, red brown and brown large soil groups are the commonly seen soil types. Alluvial soils are found in most of the residential areas of the city (Polat & Önder, 2004). The southwest of Konya has a volcanic geographic structure and NORMs are present in volcanic soils (Ibraheem et al., 2018; Solgun et al., 2021).

Samples were gathered at a depth of approximately 5–7 cm from the soil surface and a total of 26 different points in Konya were sampled (Fig. 1).

Preparation of soil samples

After collected soil samples were brought to the laboratory in bags, unwanted materials such as gravel, stones, leaves, etc. were removed and soil samples were sieved through a 2-mm sieve. Before activity measurements, samples were dried in an oven at 105 °C for 24 h, were placed inside polyethylene containers and kept in them for 1 month to achieve radioactive secular equilibrium (Murthuza et al., 2022).

Activity measurements

Activity measurements of surface soil samples were performed using the ɣ-ray spectroscopy system with HPGe detector (ORTEC GEM70P4-95, USA) in Kırklareli University Central Research Laboratory. The HPGe detector has high resolution of 2.0 keV and 70% relative efficiency for 1.332 meV gamma energy of Co-60. The calibrations were made using a standard mixed source with an energy range of 80 to 2500 keV (Isotope Products Laboratories) including known activity levels of "^{210}Pb, ^{139}Ce, ^{109}Cd, ^{241}Am ^{57}Co, ^{113}Sn, ^{203}Hg, ^{85}Sr, ^{88}Y, ^{137}Cs, and ^{60}Co" peaks.

The ɣ-spectra of the soil samples were acquired by counting for 160,000 s (44 h) and the Gamma-Vision-32 software program was used to obtain activity concentrations. The activity concentration of ^{226}Ra was determined from ɣ-ray lines at, 351.9 keV for ^{214}Pb and 609.3 keV for ^{214}Bi, respectively. The content of ^{232}Th was obtained from photo peaks of ^{228}Ac at 911.2 keV and ^{208}Tl at 583.1 keV. The

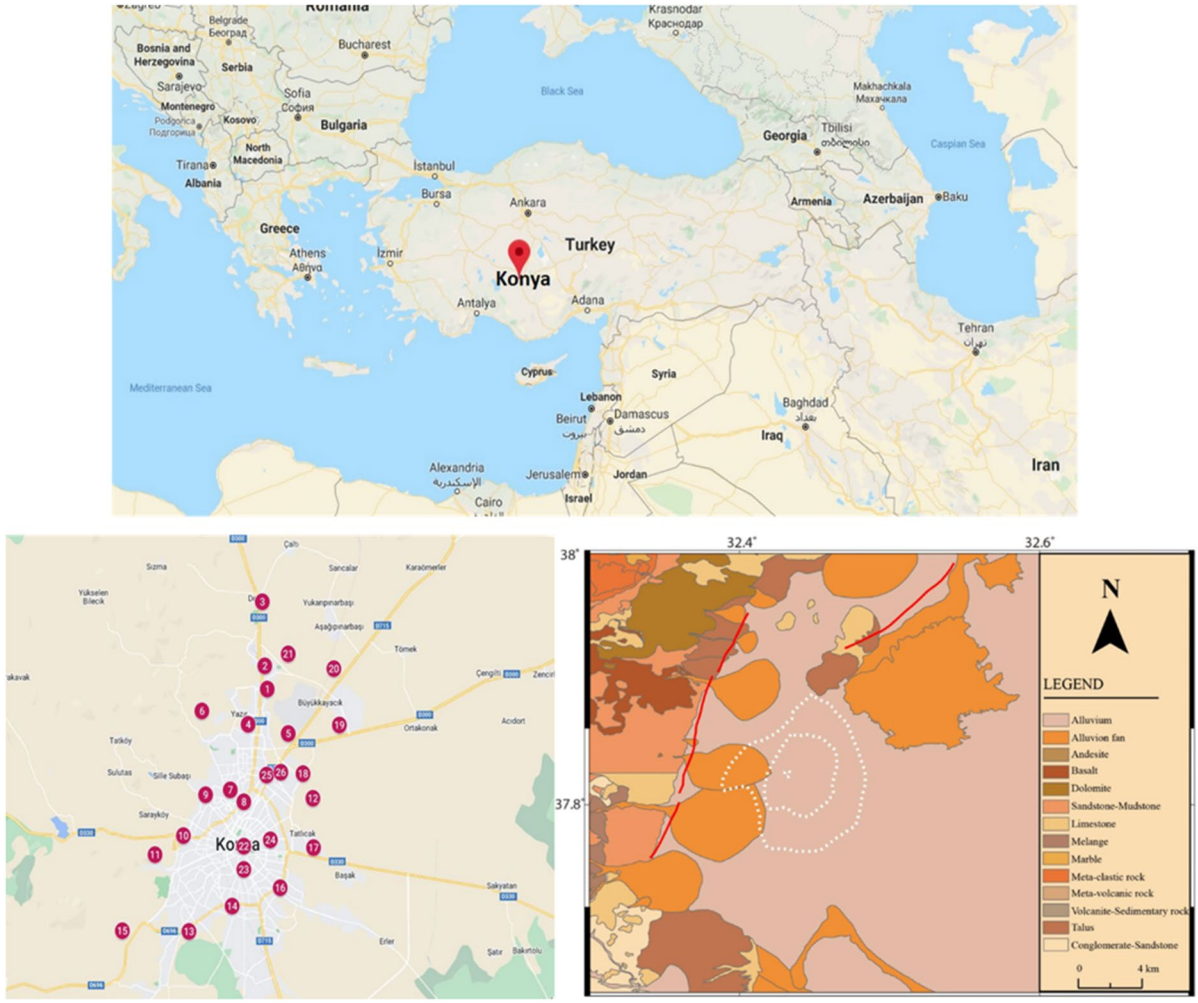

Fig. 1 Map of the study area, sampling points and geological map of Konya (Şireci et al., 2021)

activity concentration of ^{40}K was determined using an ɣ-ray line at 1460.8 keV (Aközcan et al., 2021; Özden & Aközcan, 2021).

The activity concentrations were calculated via the following equation (Hossain et al., 2010; Özden & Aközcan, 2021):

$$A(Bq\ kg^{-1}) = \frac{CPS}{\varepsilon x m x I_{\gamma}} \quad (1)$$

where $A\ (Bq\ kg^{-1})$ is the activity concentration of a radionuclide in the surface soil sample, CPS is the net ɣ counting rate, ε is the detection efficiency of a specific ɣ-ray, m is the mass of the measured sample and I_{γ} is the ɣ-ray emission probability.

Calculation of radiological hazard parameters

The radiological hazard parameters were calculated due to NORMs. In equations; the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K are defined by A_{Ra}, A_{Th} and A_K, respectively.

Radium equivalent activity (Ra_{eq})

NORMs are distributed nonuniformly in environmental media. Ra_{eq} is a proper parameter to compare activity concentrations in samples and has been determined to compare activity concentrations

of NORMs. Ra_{eq} was calculated in becquerels per kilogram using Eq. (2). (Beretka & Mathew, 1985).

$$Ra_{eq}\left(Bq\ kg^{-1}\right) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

In the equation, it is assumed that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th or 4810 Bq kg^{-1} of ^{40}K have the same gamma dose rate.

Absorbed gamma dose rate (D)

D (nGy h^{-1}) in air through terrestrial ɤ radiation at 1 m above the ground was found by the following equation (UNSCEAR, 2000):

$$D\left(nGyh^{-1}\right) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (3)$$

0.462 is the conversion factor for ^{226}Ra, 0.604 is the conversion factor for ^{232}Th and 0.0417 is the conversion factor for ^{40}K.

Annual effective dose equivalent (AEDE)

AEDE (μSv y^{-1}) caused by exposure to NORMs in surface soil samples was calculated using the following equation (Özden & Aközcan, 2021; Suresh et al., 2021):

$$AEDE\left(\mu Sv\ y^{-1}\right) = D\left(nGy\ h^{-1}\right) \times 8760\left(hy^{-1}\right) \times 0.2 \times 0.7\left(Sv\ Gy^{-1}\right) \times 10^{-3} \quad (4)$$

In the equation; *D*: the absorbed gamma dose rate (nGy h^{-1}), 8760: hours per a year, 0.2: the outdoor occupancy factor, and 0.7: is the dose convention factor (Sv Gy^{-1}). The equation was multiplied by 10^{-3} to convert to μSv.

Radiation hazard ındices

H_{ex} was calculated to estimate the level of radiological risk due to NORMs and external exposure to NORMs. H_{ex} was calculated for the surface soil samples by the Eq. (5) (Krieger, 1981).

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

H_{in} was calculated to estimate the level of radiological risk due to NORMs and internal exposure to NORMs. H_{in} was calculated for the surface soil samples by Eq. (6). (Awad et al., 2022).

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

H_{ex} and H_{in} values must be below unity to avoid radiation.

Excess lifetime cancer risk (ELCR)

ELCR gives the lifetime cancer risk probability from exposure to ionizing radiation in any population. ELCR was estimated using the following equation (Taqi & Namq, 2022):

$$ELCR = AEDE\left(\mu Sv\ y^{-1}\right) \times DL\ (y) \times RF\left(Sv^{-1}\right) \quad (7)$$

In the equation, AEDE: the annual effective dose equivalent, DL: the average duration (70 years), RF: fatal risk factor (0.057) (ICRP, 2007).

Annual gonadal dose equivalent (AGDE)

In UNSCEAR report (2010), especially the thyroid, bone marrow, skin and gonads are interested organs in radiation research. AGDE (μSv y^{-1}) is calculated to estimate the effect of ionizing radiation on these sensitive organs using the following relation (Hamideen, 2022; UNSCEAR, 2010):

$$AGDE\left(\mu Sv\ y^{-1}\right) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (8)$$

Gamma Representative Level Index ($I_ɤ$)

$I_ɤ$ was estimated to assess the ɤ radiation hazard due to NORMs in surface soil samples. $I_ɤ$ must be less than unity to avoid the radiation. $I_ɤ$ was calculated using the following relation (Boukhenfouf & Boucenna, 2011):

$$I_ɤ = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (9)$$

Results and discussions

Activity concentrations

The activity concentrations of NORMs in the surface soil of Konya City are plotted in Fig. 2. Geographic

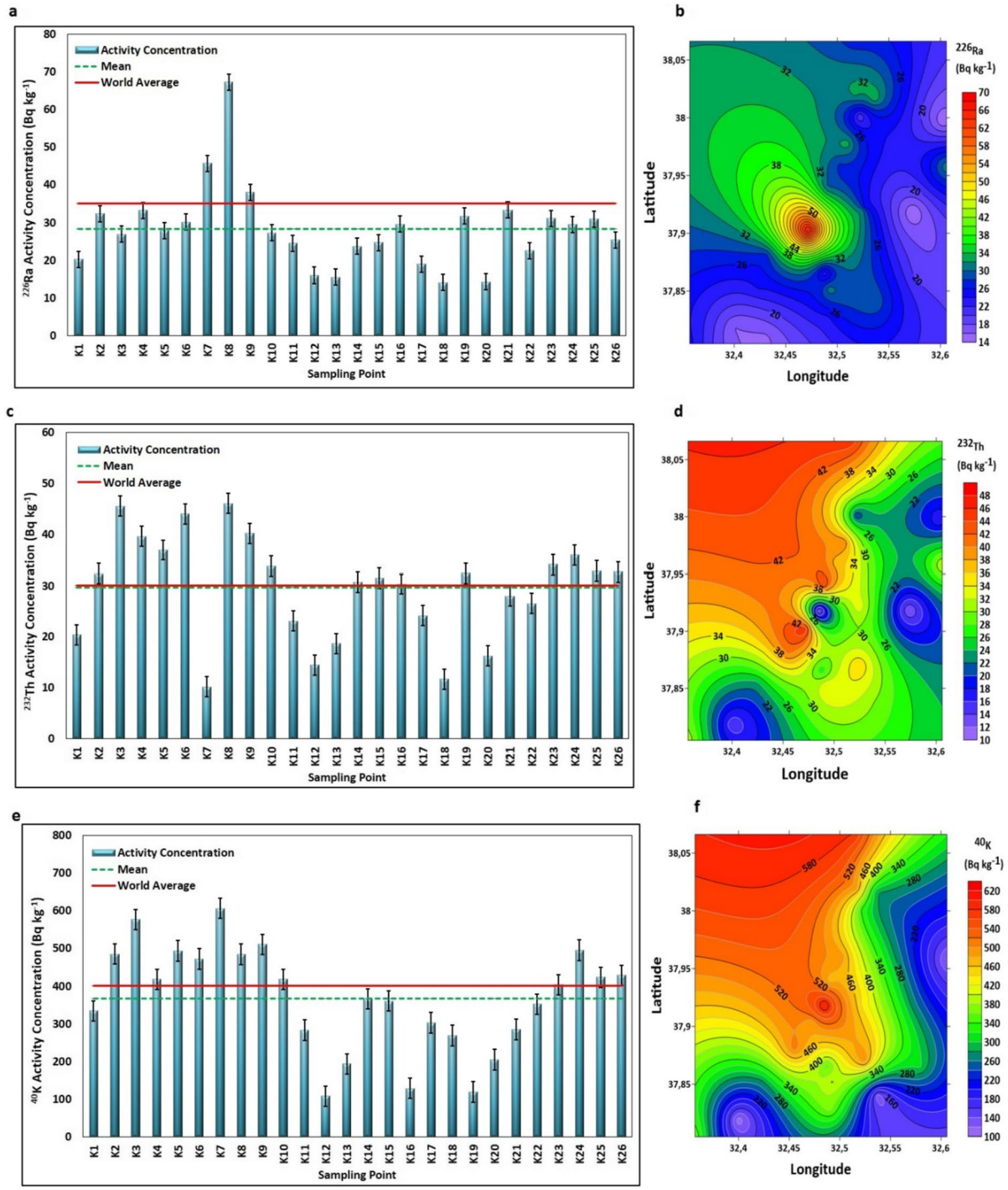

Fig. 2 Activity concentrations of (**a**) ^{226}Ra, (**c**) ^{232}Th, (**e**) ^{40}K and activity concentration distribution maps of (**b**) ^{226}Ra, (**d**) ^{232}Th, (**f**) ^{40}K

locations of collected soil samples and the obtained activity concentrations are listed in Table 1.

As can be seen in Table 1 and Fig. 2.a., the activity concentration of ^{226}Ra was ranged from 14.07 ± 0.71

Table 1 Geographic locations and the activity concentrations of NORMs in Bq kg^{-1}, dw

Sampling point	Geographic location		^{226}Ra	^{232}Th	^{40}K
	N	E			
K1	38° 00′ 04″	32° 31′ 19″	20.21 ± 0.47	20.37 ± 1.01	334.12 ± 5.59
K2	38° 01′ 10″	32° 31′ 01″	32.36 ± 1.30	32.37 ± 2.36	484.89 ± 11.66
K3	38° 03′ 58″	32° 30′ 55″	26.91 ± 0.98	45.53 ± 0.70	576.61 ± 10.18
K4	37° 58′ 39″	32° 30′ 35″	33.18 ± 0.74	39.58 ± 2.28	417.84 ± 9.98
K5	37° 57′ 36″	32° 30′ 05″	27.83 ± 1.18	36.93 ± 1.68	493.27 ± 11.02
K6	37° 56′ 24″	32° 29′ 24″	30.10 ± 1.08	43.99 ± 0.78	471.64 ± 11.93
K7	37° 55′ 04″	32° 29′ 06″	45.69 ± 2.57	10.19 ± 2.60	605.95 ± 11.34
K8	37° 54′ 10″	32° 28′ 18″	67.27 ± 1.62	46.09 ± 0.76	484.32 ± 11.36
K9	37° 52′ 50″	32° 27′ 18″	38.06 ± 1.27	40.18 ± 0.72	510.67 ± 12.31
K10	37° 52′ 51″	32° 25′ 51″	27.26 ± 1.30	33.81 ± 0.75	417.88 ± 11.66
K11	37° 51′ 14″	32° 25′ 25″	24.46 ± 3.59	23.12 ± 0.96	283.13 ± 13.01
K12	37° 49′ 07″	32° 23′ 60″	15.97 ± 3.04	14.43 ± 0.88	107.87 ± 13.32
K13	37° 48′ 33″	32° 25′ 49″	15.47 ± 1.56	18.69 ± 1.01	193.00 ± 13.97
K14	37° 49′ 39″	32° 29′ 25″	23.71 ± 1.24	30.66 ± 1.11	365.92 ± 17.18
K15	37° 48′ 16″	32° 21′ 25″	24.64 ± 1.21	31.48 ± 0.79	360.24 ± 12.63
K16	37° 50′ 25″	32° 32′ 15″	29.56 ± 1.79	30.32 ± 1.86	128.37 ± 10.02
K17	37° 51′ 54″	32° 34′ 45″	18.92 ± 0.92	24.16 ± 0.59	302.83 ± 8.80
K18	37° 55′ 07″	32° 34′ 24″	14.07 ± 0.71	11.66 ± 0.50	268.34 ± 7.82
K19	37° 57′ 28″	32° 36′ 21″	31.72 ± 1.92	32.38 ± 1.04	118.64 ± 4.82
K20	37° 59′ 48″	32° 36′ 09″	14.23 ± 0.55	16.24 ± 0.31	204.51 ± 5.07
K21	38° 00′ 59″	32° 32′ 11″	33.30 ± 1.04	28.01 ± 0.60	284.68 ± 8.81
K22	37°51′ 57″	32° 29′ 16″	22.51 ± 1.06	26.52 ± 0.64	351.56 ± 10.54
K23	37°51′ 06″	32° 29′ 33″	31.11 ± 2.32	34.09 ± 1.26	403.33 ± 9.66
K24	37°52′ 13″	32° 31′ 28″	29.52 ± 1.03	35.95 ± 0.62	495.23 ± 10.93
K25	37°55′ 12″	32° 31′ 29″	30.91 ± 1.26	32.87 ± 0.69	423.23 ± 12.77
K26	37°55′ 23″	32° 31′ 35″	25.38 ± 2.58	32.68 ± 4.78	428.63 ± 8.73
Minimum	-	-	14.07 ± 0.71	10.19 ± 2.60	107.87 ± 13.32
Maximum	-	-	67.27 ± 1.62	46.09 ± 0.76	605.95 ± 11.34
Average	-	-	28.24 ± 1.47	29.70 ± 1.20	366.03 ± 10.58
World Average	-	-	35	30	400

Bq kg^{-1} dw (sample K18) to 67.27 ± 1.62 Bq kg^{-1} dw (K8). The average of activity concentration of ^{226}Ra was found as 28.24 ± 1.47 Bq kg^{-1} dw. The average of activity concentration of ^{226}Ra is less than the world average. The ^{226}Ra activity concentrations for K7, K8 and K9 samples are higher than the world average. The activity concentration of ^{232}Th varied between 10.19 ± 2.60 Bq kg^{-1} dw (K7) and 46.09 ± 0.76 Bq kg^{-1} dw (K8) with an average value of 29.70 ± 1.20 Bq kg^{-1} dw. The ^{232}Th activity concentrations for K2, K3, K4, K5, K6, K8, K9, K10, K15, K19, K23, K24, K25, and K26 samples are found higher than the world average (Fig. 2.c.). The activity concentration of ^{40}K was ranged from 107.87 ± 13.32 Bq kg^{-1} dw (K12) to 605.95 ± 11.34 Bq kg^{-1} dw (K7). The average of the activity concentration of ^{40}K was calculated as 366.03 ± 10.58 Bq kg^{-1} dw. The average of the activity concentration of ^{40}K is lower than the world average (Fig. 2.e.). The ^{40}K activity concentrations for K2, K3, K4, K5, K6, K7, K8, K9, K10, K23, K24, K25, and K26 samples are found higher than the world average. The highest activity concentrations of NORMs in sampling points can be due to may be caused by the presence of industrial activities nearby and utilization of fertilizers in the soil (El Aouidi et al., 2021).

Activity concentration distribution maps are given in Fig. 2. Distribution maps of radionuclides were

Table 2 Comparison of obtained natural radioactivity concentrations with other studies

Region	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	References
North Cyprus	49.7–147.6	18.1–93.9	103.5–1468.6	(Abbasi et al., 2020)
Saudi Arabia	6–54	7–52	299–761	(Aydarous et al., 2022)
Seydisehir and Beysehir districts of Konya, Turkey	18–64	22–83	119–654	(Ozaydin Ozkara et al., 2021)
Istanbul, Turkey	19.97–50.80	21.38–52.61	464.06–711.27	(Günay, 2018)
Rize, Turkey	4.45–32.19	5.58–43.61	28.82–773.19	(Akçay, 2021)
İzmir, Turkey	23.5–59.5	37.5–64.4	354.7–978.4	(Özden & Aközcan, 2021)
Nevşehir, Turkey	7.40–193.90	<2.8–122.50	37.67–1370.20	(Bingöldağ & Otansev, 2020)
Egypt	6.6–37.1	2.9–55.7	37.0–873.5	(Salahel Din, 2022)
India	15.2–58	14–86.2	224.5–1650	(Srinivasa et al., 2022)
Namibia	7.74–20.04	8.59–31.74	108.8–484.9	(Hitila & Onjefu, 2022)
Laos	6.6–73.6	3.8–113.8	13.6–906.4	(Bui et al., 2020)
Iraq	4.4–34.7	1.5–13.3	42.1–583.9	(Smail et al., 2022)
Jordan	12.9–69.0	7.5–70.9	140.8–465.5	(Hamideen, 2022)
Yemen	22.73–39.95	50.4–94.95	924.57–1322.32	(El-Gamal et al., 2019)
Konya, Turkey	14.07–67.27	10.19–46.09	107.87–605.95	This study

plotted using the Surfer program (Golden Software Surfer 16). The highest activity concentrations can be seen as in red color in distribution maps and the lowest activity concentrations are in purple. The highest ^{226}Ra and ^{232}Th activity concentrations were observed at 37° 54′ 10″ N and 32° 28′ 18″ E. The highest ^{40}K activity concentration was observed at 37° 55′ 04″ N and 32° 29′ 06″ E.

Table 2 presents the comparison of the obtained natural radioactivity concentrations in this study with other studies in the world. Some activity concentration values of ^{226}Ra in the present study are lower than the studies in North Cyprus, Laos, Jordan, and Konya (Seydisehir-Beysehir districts, Turkey), while some values of ^{226}Ra are higher than that of Saudi Arabia, Konya (Seydisehir-Beysehir districts, Turkey), Istanbul (Turkey), Rize (Turkey), Izmir (Turkey), Egypt, India, Namibia, Iraq and Yemen. The highest value of ^{232}Th activity concentration is less than the highest value obtained in North Cyprus, Saudi Arabia, Konya (Seydisehir-Beysehir districts, Turkey), Istanbul (Turkey), Izmir (Turkey), Egypt, India, Laos, Jordan and Yemen. Similarly, the highest value of ^{40}K activity concentration is less than those of all compared studies except Namibia, Iraq and Jordan.

Radiological hazard parameters

The radiological hazard parameters were evaluated for prospective radiological hazards to human health (Table 3).

Ra_{eq} ranged from 44.91 to 170.47 Bq kg^{-1} with a mean value of 98.90 Bq kg^{-1}. All estimated Ra_{eq} values are lower than the recommended permissible limit (370 Bq kg^{-1}) (UNSCEAR, 2000). The minimum and the maximum values of D in the air due to the natural radionuclides were found as 20.59 and 79.11 nGy h^{-1} respectively. In addition, the mean value of D was calculated as 46.25 nGy h^{-1}. All calculated values of D except K3, K6, K8 and K9 sampling points are lower than the world average of 57 nGy h^{-1}. AEDE ranged from 25.25 to 97.02 μSvy^{-1}. The mean of AEDE was found as 56.73 μSvy^{-1}. The worldwide average of AEDE is 70 μSvy^{-1}. The mean of AEDE is lower than the world average, but AEDE values of some of the sampling points such as K3, K6, K8 and K9 are higher than the world average.

ELCR ranged from 0.10×10^{-3} to 0.39×10^{-3} with a mean of 0.23×10^{-3}. The mean of ELCR value was obtained to be lower than the world average value (0.29×10^{-3}). The highest and lowest values of all the calculated ELCR values appear at K8 and K12 sampling points, respectively. The ELCR values of K3, K6, K8 and K9

Table 3 The obtained radiological hazard parameters

Sampling point	Ra_{eq} (Bq kg^{-1})	D (nGy h^{-1})	AEDE (μSv y^{-1})	ELCR (10^{-3})	H_{ex}	H_{in}	AGDE (mSv y^{-1})	I_γ
K1	75.07	35.57	43.63	0.17	0.20	0.26	0.25	0.56
K2	115.99	54.72	67.11	0.27	0.31	0.40	0.39	0.86
K3	136.42	63.98	78.46	0.31	0.37	0.44	0.45	1.02
K4	121.95	56.66	69.49	0.28	0.33	0.42	0.40	0.90
K5	118.62	55.73	68.35	0.27	0.32	0.40	0.40	0.88
K6	129.32	60.14	73.76	0.29	0.35	0.43	0.42	0.95
K7	106.92	52.53	64.42	0.26	0.29	0.41	0.37	0.81
K8	170.47	79.11	97.02	0.39	0.46	0.64	0.55	1.23
K9	134.84	63.15	77.44	0.31	0.36	0.47	0.45	1.00
K10	107.79	50.44	61.86	0.25	0.29	0.36	0.36	0.80
K11	79.32	37.07	45.46	0.18	0.21	0.28	0.26	0.58
K12	44.91	20.59	25.25	0.10	0.12	0.16	0.14	0.32
K13	57.06	26.48	32.48	0.13	0.15	0.20	0.19	0.42
K14	95.73	44.73	54.86	0.22	0.26	0.32	0.32	0.71
K15	97.39	45.42	55.70	0.22	0.26	0.33	0.32	0.72
K16	82.80	37.32	45.77	0.18	0.22	0.30	0.26	0.59
K17	76.79	35.96	44.10	0.18	0.21	0.26	0.25	0.57
K18	51.41	24.73	30.33	0.12	0.14	0.18	0.18	0.39
K19	87.16	39.16	48.03	0.19	0.24	0.32	0.27	0.61
K20	53.20	24.91	30.55	0.12	0.14	0.18	0.18	0.39
K21	95.27	44.17	54.17	0.22	0.26	0.35	0.31	0.69
K22	87.50	41.08	50.38	0.20	0.24	0.30	0.29	0.65
K23	110.92	51.78	63.51	0.25	0.30	0.38	0.37	0.82
K24	119.06	56.00	68.68	0.27	0.32	0.40	0.40	0.89
K25	110.50	51.78	63.51	0.25	0.30	0.38	0.37	0.82
K26	105.12	49.34	60.51	0.24	0.28	0.35	0.35	0.78
Minimum	44.91	20.59	25.25	0.10	0.12	0.16	0.14	0.32
Maximum	170.47	79.11	97.02	0.39	0.46	0.64	0.55	1.23
Mean	98.90	46.25	56.73	0.23	0.27	0.34	0.33	0.73

sampling points were found to be higher than the world average. The highest and the lowest values of AGDE were determined as 0.55 (K8 sampling point) and 0.14 mSv y^{-1} (K12 sampling point) respectively. The mean AGDE value was found to be 0.33 mSv y^{-1} which is slightly higher than the global limit value of 0.3 mSv y^{-1}.

Radiological contour maps of Raeq (Bq kg^{-1}), D (nGyh^{-1}), AEDE (μSvy^{-1}), ELCR ($\times 10^{-3}$) and AGDE (mSv y^{-1}) are shown in Fig. 3. Contour shapes and colors are quite similar to each other as seen on the maps. The highest radiological hazard parameters were observed at 37° 54′ 10″ N and 32° 28′ 18″ E. Higher radiological hazard parameters may be due to industrial activities, geological structure and geographical formation in the area.

H_{ex}, H_{in} and I_γ values and means of them are compared with a recommended permissible limit in Fig. 4. H_{ex} ranged from 0.12 to 0.46 with a mean of 0.27. The highest and the lowest value of H_{in} was found as 0.64 and 0.16, respectively. The mean of H_{in} was calculated as 0.34. I_γ was found to vary from 0.32 to 1.23 with a mean value of 0.73. All calculated values of H_{in} and H_{ex} are found to be at a safe level, lower than the recommended permissible limit of 1. The mean values of H_{in}, H_{ex} and I_γ are below that of the unit limit. As seen in Fig. 4, the highest value of I_γ is above the recommended permissible limit of 1.

Cluster analysis (CA) was used to describe and classify variables with similar characters in the group. In cluster analysis, the similarity between

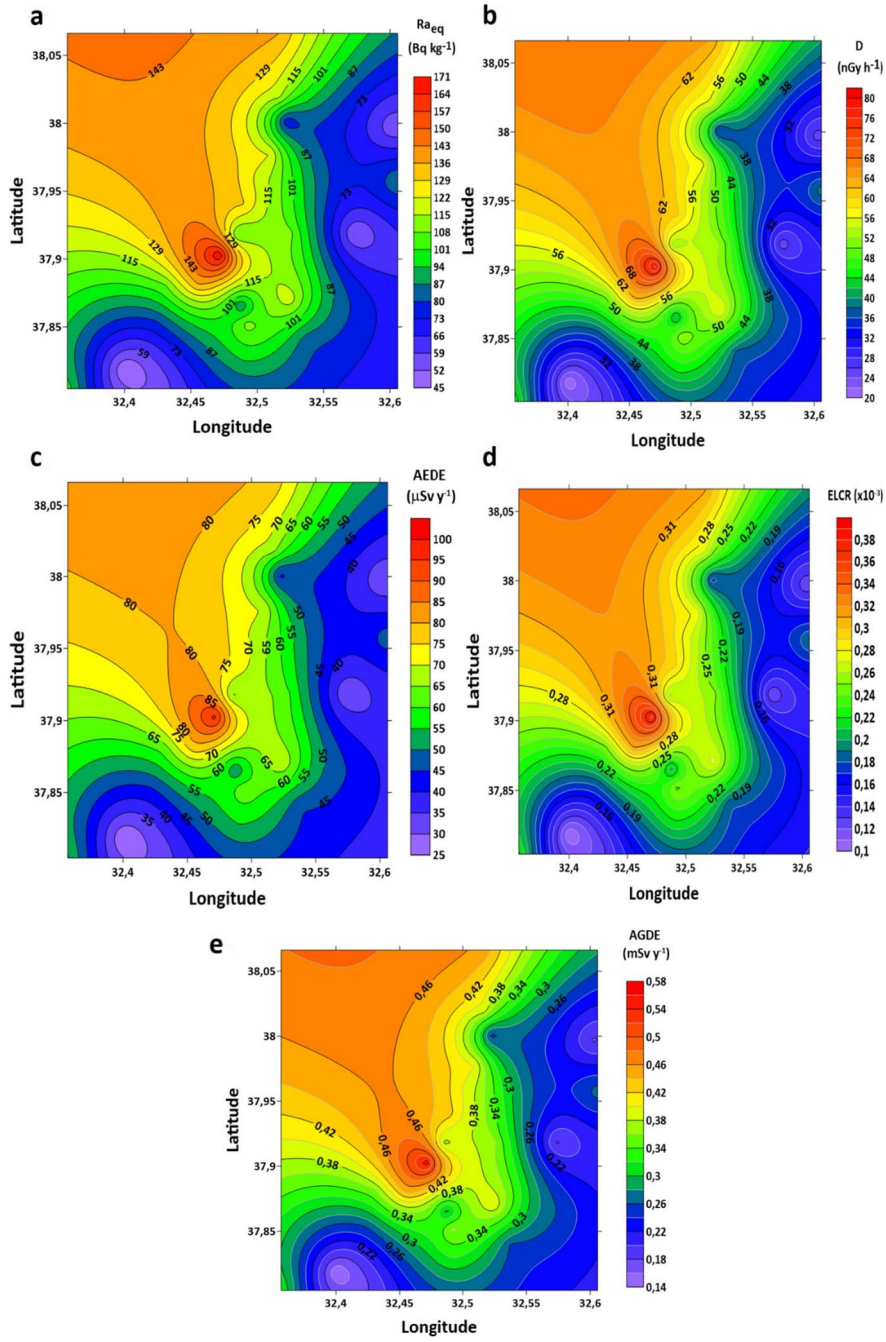

Fig. 3 Radiological maps of (**a**) Raeq (Bq kg^{-1}), (**b**) D (nGyh^{-1}), (**c**) AEDE (μSvy^{-1}), (**d**) ELCR (x10^{-3}) and **e**. AGDE (mSv y^{-1})

the variables is evaluated depending on the distance between the variables. While zero distance indicates 100% similarity between clusters, the similarity rate between clusters decreases as the distance increases. CA was performed using average linkage for activity concentrations of NORMs and radiological hazard parameters.

The dendrogram is shown in Fig. 5. In the dendrogram, activity concentrations and radiological hazard parameters were grouped into three clusters. Cluster-I includes ^{226}Ra, ^{232}Th and all radiological hazard parameters except Ra_{eq}. The reason why radiological hazard parameters are found in Cluster-1 is that radium and thorium have high activity in soil samples.

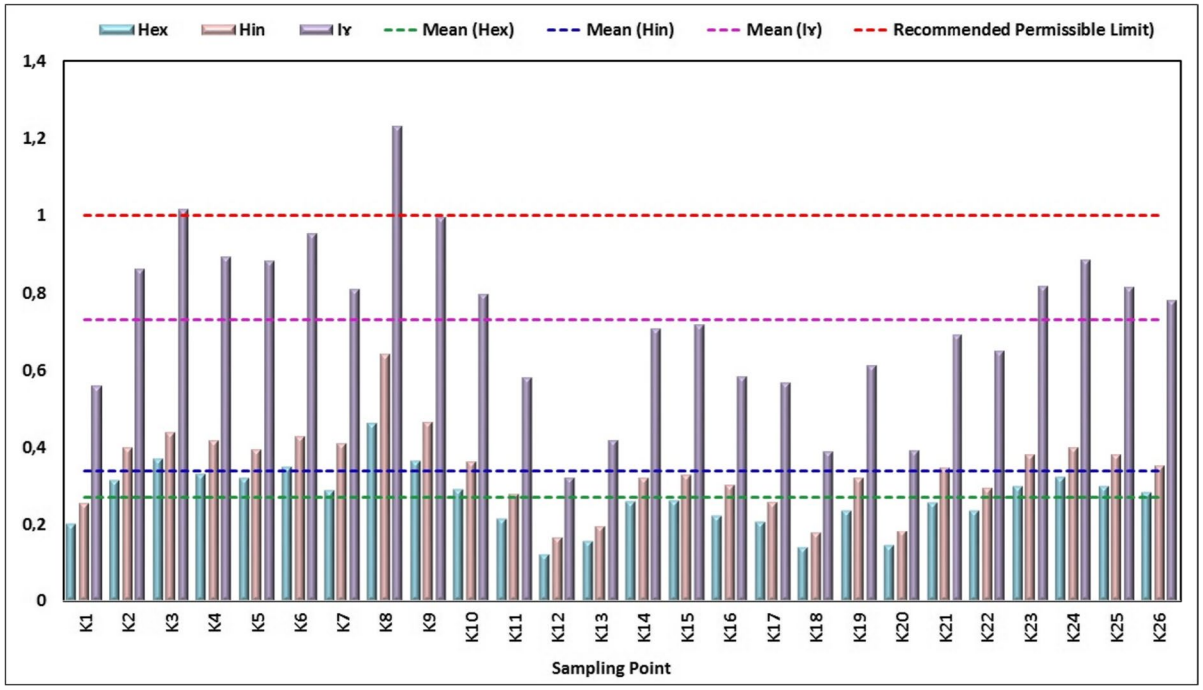

Fig. 4 H_{ex}, H_{in} and I_{γ} for surface soil samples

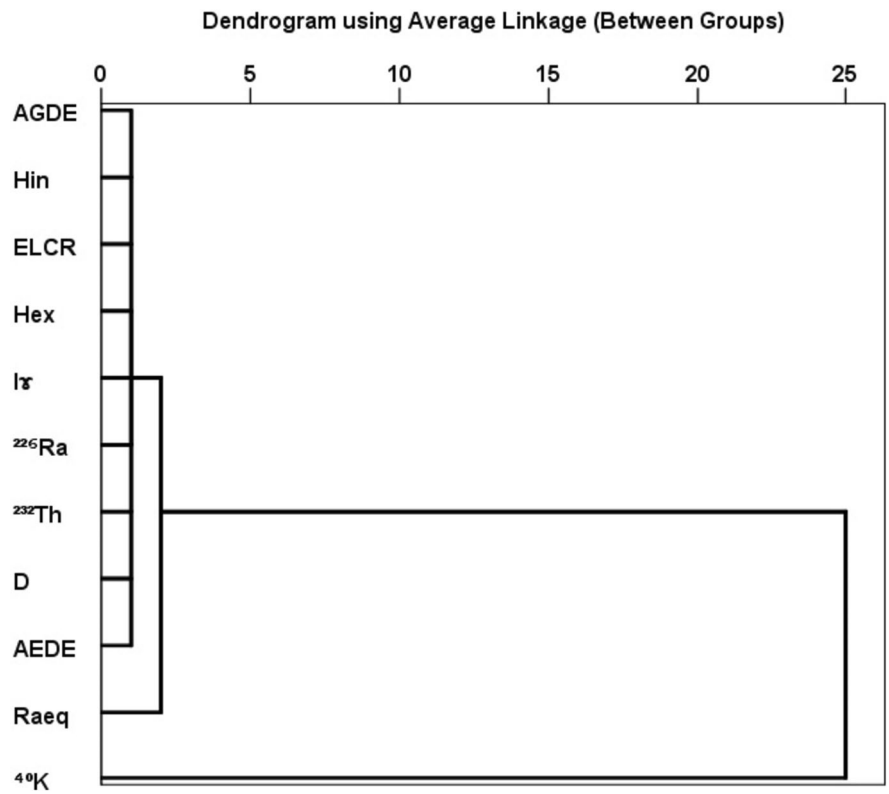

Fig. 5 Dendrogram using average linkage

Conclusion

The natural radioactivity concentrations in soil samples are determined for Konya city in Turkey. Using the coordinates in the studied area, mapping was made for activity concentrations and radiological hazard parameters. The average activity concentrations are lower than the world average value. In some regions of Konya, activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were higher than the world average. The reason for this may be industrialization, and the use of artificial fertilizers in those areas. The radiological hazard parameters were calculated, and compared with world average values and recommended permissible limits. The mean value of Ra_{eq} is lower than the recommended permissible limit. In addition, the mean values of D, AEDE and ELCR are lower than the world average value but the mean value of AGDE is slightly higher than the global limit value in this study. The mean values of H_{in}, H_{ex} and I_{γ} are below that of the unit limit. CA was used to classify variables. In CA analysis, radiological hazard parameters were found in Cluster-1. This is because radium and thorium have high activity in soil samples.

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Data availability All data were presented in the manuscript.

Declarations

Ethics approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Conflict of interest The authors declare no competing interests.

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