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Assessment of natural radioactivity in Elazığ region, eastern Turkey

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Abstract In this study, the background radiation level of Elazığ region was determined. Indoor radon measurements were made with CR-39 track detectors and a total of 208 houses were screened. Average radon concentration was 98 Bq/m^3 and effective dose value was 2.48 mSv/year. Gamma radiation in air was measured with a plastic scintillator at 214 points. Average indoor and outdoor absorbed dose values were 105.8 and 85.4 nGy/h, respectively. Radioactivity levels of water and soil samples were calculated with gross alpha and gross beta methods. Average gross alpha and gross beta radioactivity concentrations were calculated, respectively, as 0.091 and 0.037 Bq/L for drinking waters and as 289.7 and 143.2 Bq/kg for surface soil.

Keywords Radioactivity · Gamma dose · Water · Soil · Elazığ · Turkey

Introduction

Humans are always exposed to environmental radiation of terrestrial and cosmic origin. The biggest contribution to environmental radiation comes from radon gases and its decay products. Terrestrial radiation mainly originates from radioactive nuclides existing in the first phase of the formation of the solar system. These radioactive nuclides exist in air, water, soil, rocks and building construction materials, depending on the geological and geographical features of the region. Cosmic radiation originates from outer space and contributes to background radiation depending on variations with elevation and latitude [1]. Natural radioactivity measurements in air, soil and water are necessary to determine the effects of exposure to environmental radiation [2–9]. Therefore, the present study examined the natural background radiation level of Elazığ district, in Turkey. Indoor radon and absorbed dose in air and gross alpha and gross beta levels of surface soil and water were measured.

The province of Elazığ, located in the southeastern part of the Eastern Anatolian Region, between longitude 40°21′–38°30′ E and latitude 38°17′–39°11′ N. Its surface area is 9,151 km^2, which is 0.12% of Turkey's territory. The average altitude of the study area is 1,067 m. The province has a population of 540,000 and is divided into 11 administrative regions, consisting of a center and districts (Fig. 1). Elazığ region has various metamorphic, magmatic and sedimentary rock units of differing ages, spanning Paleozoic to quaternary. The province extends for approximately 150 km in an E-W direction and approximately 65 km in a N–S direction. Approximately 50% of the province consists of grasslands, 28% is agricultural land, 12% forest, and 10% is water (dams and lakes). The province is rich in mineral resources and mining activities include copper, florid, chalcopyrite, zinc, lead, chrome, manganese, molybdenum, iron and wolfram. A continental climate prevails in the province; winters are cold and rainy, and summers are hot and arid. Average annual precipitation between the years 2000 and 2009 was 375 mm. However, dam lakes near the province partially

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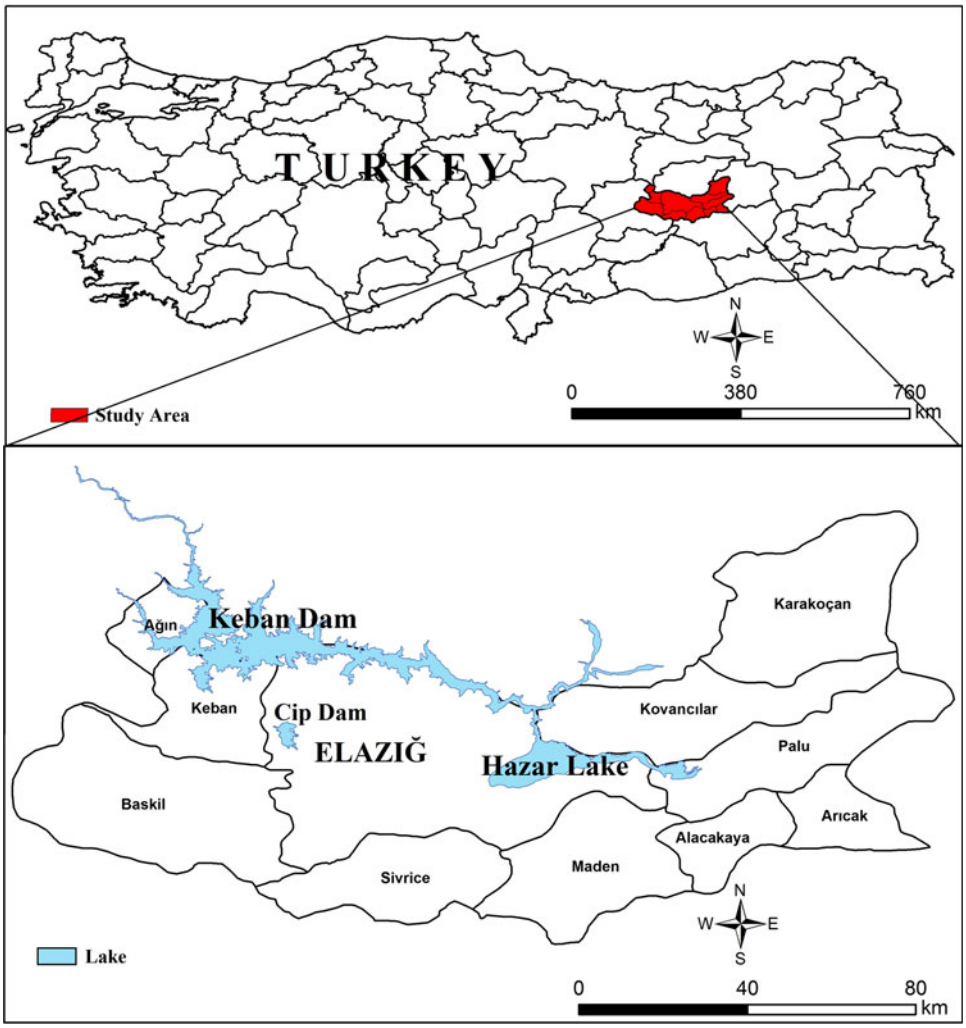

Fig. 1 Map of Turkey showing the study area

affect the climate. The province includes Keban Dam Lake, Cip Dam Lake and Hazar Lake, located in the southeast of the province, which is a tectonic lake with tourism and economic importance. Keban Dam Lake, which covers 675 km^2, is the largest artificial lake in Turkey, and is used for power generation, fishing and aquaculture. The Keban hydro-power installation produces an annual power output of 75 billion kW/h and it meets 8% of Turkey's power requirement. Cip Dam Lake, locating in the western part of the province, is used to irrigate 88 hectares of agricultural land [10].

Materials and methods

Indoor ^{222}Rn concentrations

Indoor radon levels were measured using CR-39 nuclear track detectors. CR-39 plates were cut in dimension of 20 × 20 × 20 mm and placed vertically in a 100 mL radon diffusion tank. The intake of the diffusion tank was covered to protect the detector from dust particles and aerosols (except radon gas). The diffusion tanks were then packaged and foiled. The CR-39 radon detectors were calibrated using a 225-L radon calibration chamber with an equilibrium concentration of 3.2 kBq/m^3. A total of 208 detectors were placed in apartments and houses for 3 months. At the end of this period, the detectors were analyzed at the Radon Laboratories of the Turkish Atomic Energy Agency Çekmece Nuclear Research and Training Center Health Physics Unit. The CR-39 films were chemically etched in 30% NaOH solution at 62 °C for 15 h, then washed twice with distilled water and dried. Then, etches of alpha particles on each film were counted with an optical microscope. The ^{222}Rn concentrations were obtained in units of Bq/m^3.

Gamma absorbed dose in air

Indoor and outdoor gamma radiation levels were measured using a dose rate meter (Eberline smart portable device,

Table 1 Indoor ^{222}Rn activity concentrations and comparison with literature

District	Number of houses	^{222}Rn activity concentrations (Bq/m^3)	Effective dose (mSv/year)	References
City center	23	87 ± 6	2.20 ± 0.15	Present study
Sivrice	21	114 ± 14	2.88 ± 0.35	Present study
Maden	14	154 ± 21	3.89 ± 0.53	Present study
Baskil	22	98 ± 12	2.47 ± 0.30	Present study
Keban	20	127 ± 21	3.20 ± 0.53	Present study
Ağın	22	112 ± 17	2.83 ± 0.43	Present study
Alacakaya	20	89 ± 12	2.25 ± 0.30	Present study
Kovancılar	19	71 ± 12	1.79 ± 0.30	Present study
Arıcak	20	72 ± 5	1.82 ± 0.13	Present study
Karakoçan	13	79 ± 13	1.99 ± 0.33	Present study
Palu	14	80 ± 8	2.02 ± 0.20	Present study
Elazığ (average)		98 ± 13	2.48 ± 0.32	Present study
Manisa-Turkey		97 (47–146)	4.83 (2.35–7.3)	[13]
Kastamonu-Turkey		98.4 (29–177)	2.48 (0.73–4.46)	[14]
İzmir-Turkey		53–86	(2.69–4.3)	[13]
İstanbul-Turkey		10–260	0.5–13	[15]
Tekirdağ-Turkey		87	2.01	[16]
Karabük-Turkey		131.6	3.32	[17]
Giresun-Turkey		130 (52–360)	3	[18]
Batman-Turkey		84 (23–145)		[19]

Note The ranges corresponding to data are given in parentheses

ASP2e, connected to a SPA-8 model plastic scintillation detector). The measurements were conducted at 214 points that were selected to characterize indoor and outdoor districts at 1 m above ground level. For each point, measurements were taken in air ten times for a preset time of 100 s and the results were recorded in units of nGy/h.

Radioactivity in drinking water

A total of 18 water samples were collected from selected locations and transferred to the laboratory in 1 L polythene bottles. By adding nitric acid to the water samples (approximately 15 mL from 1 N HNO_3), the pH levels were adjusted to a value smaller than 2 in a controlled manner. After shaking the samples in the collection bottles, they were transferred into three different beakers of 100 mL in an amount that would not cause self-absorption. The water samples were then evaporated from the beakers at 60 °C with an electric stove until a volume of 5–10 m^3 remained, which was then transferred into 11.34 cm^2 aluminum planchettes whose counterweights were determined. The planchettes were oven dried at 105 °C for 2 h. After completion of drying, the planchettes were directly exposed to dim red light and kept in desiccators until counting. The gross alpha radioactivity was counted by a ZnS(Ag) scintillator supported by a photomultiplier tube with a 7286 low-level alpha-counter (NE Technology Inc.). The ZnS(Ag) scintillator had a radius of 44 mm. Gross beta counting was performed by a low background plastic beta-scintillator (2059) and a photomultiplier tube through an SR8 dual radiation counter (NE Technology Inc.). Lead shielding was used for both systems to eliminate external radiation. The gross alpha and gross beta radioactivity concentrations of each sample were acquired in units of Bq/L.

Radioactivity in surface soil

A total of 19 soil samples were taken from uncultivated land (from the first 10 cm of topsoil) and labeled in polythene bags. Samples were transferred to the laboratory without delay and foreign materials such as grass, stone or pebbles were meticulously removed. The soil samples were laid on foils dried for 10 days at room temperature to minimize the moisture content. Then, soil samples were covered with aluminum foil and oven dried at 105 °C. At the end of this process, the soil samples were completely dry and were sieved through a 200 mesh (74 μm) and labeled in clean plastic bags. Each soil sample was transferred homogeneously into three different aluminum planchettes whose tares were taken in an amount that would not cause self-absorption, distilled water was added

and they were dried on an electric stove. Samples on the planchette were then oven dried at 105 °C for 2 h and kept in desiccators until counting. The radioactivity level of samples (gross alpha and gross beta) was measured with the counting system used for water measurements. The results were obtained in units of Bq/kg.

Results and discussion

Radon radioactivity concentrations are shown in Table 1. Average radon activity concentration is 98 Bq/m^3 (standard deviation: 13) and ranges from 71 to 154 Bq/m^3. All values exceed the global average of 40.3 Bq/m^3 [11]. Average annual effective dose is 2.48 mSv/year (standard deviation: 0.32) and the values range from 1.79 to 3.89 mSv/year. When determining the annual effective dose, a dose conversion factor of 9 (nSv h^{-1})/(Bq/m^3) was used, occupancy factor was 0.8 and equilibrium factor for indoor radioactives was 0.4. All values exceeded the global average of 1.094 mSv/year [12]. Radon concentrations observed in this study are comparable to those in other Turkish provinces [13–19].

Absorbed dose and annual effective dose values are given in Table 2. Average absorbed dose values are 105.8 nGy/h (standard deviation: 23.1) and 85.4 nGy/h (standard deviation: 23.1), respectively for indoor and outdoor environments. Indoor and outdoor absorbed dose values range from 58.4 to 216.7 and 51 to 158.1 nGy/h, respectively. Indoor gamma dose values are generally higher than outdoor gamma dose values. Absorbed dose values are converted to annual dose value by using a dose conversion factor of 0.7 Sv/Gy and occupancy factors of 0.8 and 0.2, respectively, for indoor and outdoor environments [20]. Average annual effective dose values were 523 μSv (standard deviation: 114) and 106 μSv (standard deviation: 29), respectively for indoor and outdoor data. The sum of these two doses is 629 μSv, which exceeds the global average of 480 μSv [11]. Annual effective dose values range from 289 to 1,072 μSv for indoor, and from 63 to 195 μSv for outdoor. Average dose values counted in this study are generally higher than in other Turkish provinces [13, 14, 21–24].

The results of gross alpha and gross beta measurements of water samples are shown in Table 3. Alpha activity is generally higher than beta activity. Average total alpha activity is 0.091 Bq/L (standard deviation: 0.005) and ranges from 0.009 to 0.219 Bq/L. Average total beta activity is 0.037 Bq/L (standard deviation: 0.002) and ranges from 0.006 to 0.084 Bq/L. The lowest gross alpha and gross beta radioactivity levels were found in samples from Alacakaya and Sivrice, respectively. The highest gross alpha and gross beta radioactivity levels were in Karakoçan and Arıcak, respectively. The lowest gross alpha and gross beta radioactivity levels were seen in regions rich in ultrabasite rocks, whereas the highest gross

Table 2 Indoor and outdoor gamma absorbed dose in air and comparison with literature

District	Indoor absorbed dose (nGy/h)	Outdoor absorbed dose (nGy/h)	Indoor effective dose (μSv/year)	Outdoor effective dose (μSv/year)	References
City center	58.4 ± 9.3	64.6 ± 12.3	289 ± 46	80 ± 15	Present study
Sivrice	95.6 ± 35.3	63.6 ± 28.7	473 ± 175	79 ± 36	Present study
Maden	67.8 ± 30.5	64.6 ± 33.2	335 ± 151	80 ± 41	Present study
Baskil	105.8 ± 46.6	158.1 ± 96.3	523 ± 230	195 ± 119	Present study
Keban	138 ± 34.5	114.6 ± 41.9	682 ± 171	142 ± 52	Present study
Ağın	126.2 ± 12.6	79.7 ± 5.8	624 ± 62	99 ± 7	Present study
Alacakaya	61.9 ± 22.9	51 ± 20.7	306 ± 113	63 ± 26	Present study
Kovancılar	102.2 ± 15.4	71.2 ± 7.3	506 ± 76	88 ± 9	Present study
Arıcak	122.7 ± 18.4	88.9 ± 11.8	607 ± 91	110 ± 15	Present study
Karakoçan	216.7 ± 54.1	125 ± 18.1	1072 ± 268	155 ± 22	Present study
Palu	112.3 ± 8.3	73.6 ± 4.3	555 ± 41	91 ± 5	Present study
Elazığ (average)	105.8 ± 23.1	85.4 ± 23.1	523 ± 114	106 ± 29	Present study
İstanbul-Turkey		65 (32–94)			[21]
Manisa-Turkey	113–244	78–136			[13]
Kastamonu-Turkey	55 (45–69)	48 (36–85)			[14]
Kirklareli-Turkey		118		144	[22]
Adana-Turkey		67		82	[23]
Trabzon-Turkey		59 (12–191)		66 (23–204)	[24]

Note The ranges corresponding to data are given in parentheses

Table 3 Gross alpha and gross beta radioactivity levels in drinking water and comparison with literature

District	Gross alpha (Bq/L)	Gross beta (Bq/L)	References
City center	0.102 ± 0.003	0.034 ± 0.001	Present study
Sivrice	0.048 ± 0.006	0.006 ± 0.002	Present study
Maden	0.038 ± 0.005	0.037 ± 0.002	Present study
Baskil	0.123 ± 0.006	0.049 ± 0.002	Present study
Keban	0.019 ± 0.006	0.039 ± 0.002	Present study
Ağın	0.023 ± 0.008	0.044 ± 0.002	Present study
Alacakaya	0.009 ± 0.005	0.069 ± 0.003	Present study
Kovancılar	0.180 ± 0.008	0.022 ± 0.002	Present study
Arıcak	0.061 ± 0.005	0.084 ± 0.004	Present study
Karakoçan	0.219 ± 0.005	0.007 ± 0.002	Present study
Palu	0.107 ± 0.006	0.036 ± 0.002	Present study
Elazığ (average)	0.091 ± 0.005	0.037 ± 0.002	Present study
İstanbul-Turkey	0.023 (0.007–0.045)	0.066 (0.02–0.13)	[26]
Kastamonu-Turkey	0.009 (0.0014–0.026)	0.271 (0.0162–2.241)	[14]
Sanlıurfa-Turkey	0.038 (0.0018–0.4323)	0.132 (0.006–0.9247)	[27]
Gaziantep-Turkey	0.049	0.128	[28]
Batman-Turkey	0.034	0.080	[29]
Adana-Turkey	0.010	0.086	[30]
Tekirdağ-Turkey	0.044	0.100	[31]
Samsun-Turkey	0.052	0.078	[32]
Trabzon-Turkey	0.007	0.101	[33]
Giresun-Turkey	0.007	0.097	[33]
Rize-Turkey	0.008	0.083	[33]

Note The ranges corresponding to data are given in parentheses

alpha radioactivity levels were seen in regions rich in volcanic rocks, and the highest gross beta radioactivity levels were seen in regions rich in volcanic and sedimentary rocks.

Average gross alpha and gross beta activities for drinking waters are lower than the limits of 0.5 Bq/L (alpha activity) and 1 Bq/L (beta activity) suggested by the WHO [25]. Average gross alpha activity is higher than the findings of previous studies in other regions of Turkey and gross beta activity is lower [14, 26–33]. In order to estimate total annual effective dose from the average gross alpha activity, a dose conversion coefficient of 2.8×10^{-4} mSv/Bq for ^{226}Ra (an alpha emitter) can be used, assuming that an adult consumes an average of 2 L of water per day [25]. This leads to an annual effective dose of 18.6 μSv from drinking water.

The results of gross alpha and gross beta measurements of soil sample are shown in Table 4. Average value of gross alpha activity is 289.7 Bq/kg (standard deviation: 13.6) and ranges from 126.7 to 551.8 Bq/kg. Average value of gross beta activity is 143.2 Bq/kg (standard deviation: 6.8) and ranges from 58.8 to 360.3 Bq/kg. The lowest gross alpha and gross beta radioactivity levels are in Alacakaya and Sivrice, respectively. The highest gross alpha and gross beta radioactivity levels are in Baskil and Arıcak, respectively. The lowest gross alpha and gross beta radioactivity levels are seen in regions rich in ultrabasite rocks, the highest alpha radioactivity level is seen in regions rich in volcanic rocks, and the highest beta radioactivity level is seen in regions rich in volcanic and sedimentary rocks.

Table 4 Gross alpha and gross beta radioactivity levels in surface soils

District	Gross alpha (Bq/kg)	Gross beta (Bq/kg)
City center	248.3 ± 5.5	83.3 ± 1.4
Sivrice	206.5 ± 22.5	58.8 ± 10.5
Maden	279.6 ± 18.0	206.6 ± 9.5
Baskil	551.8 ± 19.7	67.8 ± 11.3
Keban	474.0 ± 22.9	151.6 ± 14.3
Ağın	273.2 ± 17.0	265.5 ± 9.9
Alacakaya	126.7 ± 20.7	320.7 ± 12.2
Kovancılar	303.3 ± 19.5	211.9 ± 10.4
Arıcak	418.0 ± 18.5	360.3 ± 9.6
Karakoçan	215.3 ± 17.6	82.8 ± 7.6
Palu	396.0 ± 20.0	62.1 ± 12.7
Elazığ (average)	289.7 ± 13.6	143.2 ± 6.8

Conclusion

In this study, natural background radiation levels of Elazığ district, located in the Eastern Anatolian Region of Turkey, were determined via different radioactivity measurements. It was seen that indoor radon levels and absorbed dose values were higher than global averages. It was determined that gross alpha and gross beta levels of waters were within natural limits. When the results of the study were compared with data from other provinces of Turkey, no significant differences were seen.

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