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Radioactivity measurements in spas of central and Eastern Black Sea region, Turkey

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ABSTRACT

Background: The aim of this study is to measure the level of radon gas in the thermal springs of the four seasons in the Black Sea Region and to determine the gamma activity levels in the soils around them. ***Materials and Methods:*** Indoor radon activity concentrations of four spa facilities, namely Ladik, Havza, Ilıcaköy, and Ayder, were measured using CR-39 passive radon dosimeters and active radon monitoring AlphaGUARD for all four seasons. Radon activity concentrations in the soil in the vicinity of these spa facilities were measured using AlphaGUARD. Radionuclides in the soil samples collected from the spa regions were also determined using gamma-ray spectroscopy. ***Results:*** The highest radon value in the air environment in the spa facility was measured in swimming pools. Indoor radon levels in the spa's swimming pool vary within a wide range, (30–2118) Bq·m^{-3}. The average radon gas levels in the soil around the Ayder, Havza, Ladik and Ilıcaköy hot springs were measured as 38±1 kBqm^{-3}, 9±1 kBq m^{-3}, 50±3 kBqm^{-3}, 955±5 kBqm^{-3}, respectively. ***Conclusion:*** The annual effective doses due to indoor radon sources changed from 0.6 mSv to 13.4 mSv for workers, and from 1 x10 -4 mSv to 3x10-1 mSv for patients. The annual effective dose equivalents from the soils around the spa were calculated to be between 82-558 µSv y-1. The results were compared with those of other measurements performed in different parts of the world.

Keywords: *Radon spa, radioactive nuclides, annual effective dose.*

INTRODUCTION

Radon and its progeny is responsible for about 50 % of the indoor exposure for the public [(1)]. It is well documented that exposure to high level of radon concentration can increase the change of getting lung cancer risk after cigarette smoking [(2)]. The proportion of lung cancers attributable to radon is estimated to range from 3% to 14% [(3)]. There are a number of mechanisms through which radon diffuse into the indoor environments. Since people spend most of their time indoors, it is necessary to monitor radon level regularly to estimate the dose received by the people and take precautions if necessary. One of the most important indoor environments other than houses is geothermal spas. Large reservoirs of underground water dissolve radon; after the underground water reaches the water surface, radon can easily diffuse into the atmosphere, yielding high radon concentrations in some geothermal spas [(4)]. The concentration of radon in groundwater varies considerably (1–10000

Bq/l), depending mostly on the concentration of uranium in the surrounding rock and on the circulation of water [5]. Moreover, in some spa centers, people expose themselves to elevated level of radon concentration for therapeutic purposes. Both users and workers in geothermal spas are exposed to high concentration of radon, which should be monitored and assessed in terms of health concerns since.

Natural and artificial radionuclide analyzes of air, soil [6,7] and plants [8] were carried out in the Eastern Black Sea region and are still being carried out. In addition, radon concentration studies were performed in home and outside air environments [9,10]. In addition, radionuclide activity measurements, total alpha and beta analyzes were performed in drinking and natural spring waters [11,12] in the Central and Eastern Black Sea Region. However, as to our best knowledge, a systematic study of the spas in this region has not been found in the literature. For this reason, the radon level in the Central and Eastern Black Sea Region (Ayder, Ilıcaköy, Havza, Ladik) has been performed. Also, radionuclide measurements in the soil samples collected from the vicinity of the spa centers were also carried out and annual effective doses due to radon inhalation were estimated and presented.

The main objective of the current study was to measure the radon concentrations in the air and soil for four thermal spas of the Central and Eastern Black Sea regions of Turkey. In addition, the natural radioactivity levels in the soil samples of spa areas were calculated by gamma ray spectroscopy using HPGe detector. The annual effective doses received by the spas' workers and patients were evaluated.

MATERIALS AND METHODS

Study area

The radioactivity and radon measurements were performed in four spas in the Central and Eastern Black Sea regions of Turkey, namely the Ladik and Havza spas in the Samsun province and the Ilıcaköy and Ayder spas in the Rize province; the locations of these spas are shown in figure 1a. Many hotels have been built near these spas, where spa bathing has become a key point of business development for attracting tourists. The spa water in these hotels is distributed to the baths inside each hotel room as well as to the pools.

In Rize, where Ayder and Ilıca hot springs are located, Liassic volcano-sedimentary rocks and Jurassic-Early Cretaceous aged carbonate rocks constitute the base units. Late Cretaceous aged volcanic rocks and limestone overlay these units (figure 1b). While Paleocene-Eocene aged granites cover Late Cretaceous aged units unconformably, Eocene aged sediments and volcanic rocks constitute the youngest units in the study area [13]. Ladik and Havza hot springs are located in Samsun city. Jurassic volcanic rocks constitute the oldest units in the study area which is divided in two by North Anatolian Fault along the southeast-northwest direction (figure 1c). Cretaceous-Late Cretaceous aged clastic and carbonate rocks overlay this base unit. Eocene aged volcanic rocks and Miocene-Late Miocene aged limestone, marl and evaporites unconformably overlay the Cretaceous units. Pliocene aged volcanic rocks and Quaternary alluvium are the youngest units in the region [14].

Reproduced with permission of the Republic of Turkey, Ministry of Energy and Natural Resources. Four research facilities are used for thermal tourism purposes. Located in Ilıcayköy, Rize, the facility is the largest thermal facility in the Eastern Black Sea region. Located in Samsun province, Havza and Ladik thermal springs are the most visited thermal tourism centers. The spa facility in Ladik is located in the North Anatolian Fault Zone.

Radon concentration measurements using active dosimeters

Using the AlphaGUARD PQ 2000PRO instrument, short-term radon activity concentration values as well as air temperature humidity and pressure were measured inside the four spas. Using this portable instrument, radon activity concentrations can be measured in the 2–2000000 $Bq.m^{-3}$ range [16]. Data analysis, processing, and storage were performed using the DataEXPERT software, especially written for AlphaGUARD. Active radon measurements in the spas were performed monthly, from August 2009 to July 2010, and from August 2011 to July 2012. During these measurements, the device was operated in the diffusion mode for 10 minutes. For each spa, the measurements were performed at three locations: the spa's reception area, the spa's dressing room, and the spa's main pool. The measurements were performed for 24 h in the main pool and for 6 h in other parts.

Indoor radon levels and dose estimation

The indoor radon levels of the spa were measured with active and passive radon detectors.

Using the measured activity concentration results, the annual effective doses were estimated using equation 1 [17], with the parameters given in UNSCEAR.

$$AEDE\ (mSv/y) = C_{Rn} \times F \times O \times D_{CF} \quad (1)$$

Where, C_{Rn} is the radon activity concentration, F is the equilibrium factor between radon and its decay products, which is taken to be 0.4, O is the occupation factor (an average of 2000 h spent indoors for workers), and D_{CF} is the dose conversion coefficient, taken as 7.9×10^{-6} mSv h^{-1} $(Bq.m^{-3})^{-1}$ [17].

Radon activity concentration in soil

Radon activity concentration measurements in the soil surrounding the spas were performed using AlphaGUARD PQ 2000PRO with instillation of soil radon measurement probes. Soil radon measurements were performed by pumping the soil gas through a continuously operating ionisation chamber (AlphaGuard PQ2000 pro), using an external pump, at a nominal flow rate of 1 l/min [16].

The soil gas consisted of an iron rod and a capillary column placed perpendicularly at a depth of 1 m from the surface of the probe. This probe was pushed to the depth of ~1 m. The first switch on the AlphaPump device was set to 'ON' to ensure continuous pumping. The other switch was set to 0.3 (0.03) l/min, for pumping 0.3 l of gas per minute. After the connection was established, 10 min of FLOW was selected from the AlphaGUARD menu to allow a 6-hour-long recording of the radon concentration measured over a 10-minute-long period.

Concentration of radionuclides in soil

Gamma ray spectrometry was employed for determining the radioactivity of the studied samples. The spectrometry system consisted of an HPGe detector (CANBERRA model GC 1519) with a relative efficiency of 15%. To acquire data for analysis, a multichannel analyser (MCA) with an inbuilt power supply, preamplifier, and amplifier, was installed on a personal computer. The resolution of the system was 1.2 keV at the 1332.5 keV peak of ^{60}Co. To reduce the gamma-ray background, the detector was shielded in a 10 cm thick lead well internally lined with 2 mm Cu foils. The output of the detector was linked to a spectroscopy amplifier. Spectral analysis was performed using the Genie 2000 software that was obtained from CANBERRA [18].

For a nuclide having more than one peak in the spectrum, the activity concentration was derived with the arithmetic mean of activities obtained by means of several different peaks in the spectrum. The activity of ^{238}U was obtained from line peaks from 351.9 keV of ^{214}Pb, 609.3 keV of ^{214}Bi. Activity concentration of ^{232}Th was determined using the gamma-ray lines at 911.1 keV (^{228}Ac) and 583.1 keV (^{208}Tl). The activity concentration of ^{40}K was measured directly using its own gamma photo peak of 1460.8 keV, and ^{137}Cs was measured directly by using its own gamma-ray photo peak at 661.7 keV. The activity concentrations for the natural radionuclides in the measured samples were computed using equation 2;

$$Cs = Na / \varepsilon P_r M_s t \quad (Bq\ kg^{-1}) \quad (2)$$

Where Na is the net counting rate of the gamma ray, ε is the detector efficiency of the specific gamma ray, P_r is the absolute transition probability of gamma decay, M_s is the mass of the sample (kilogram) and t is the counting time

(18).

In this study, top surface soil samples up to a depth of 15–20 cm were collected at each spa. After the samples' collection, organic matter, pebbles, roots, and vegetation were separated from the soil samples, and all samples were crushed into fine powders. The soil samples for gamma spectrometry analysis were dried at room temperature; each dried soil sample was packed in a 100 ml beaker to allow a uniform distribution of ^{220}Rn and ^{222}Rn decay products.

These sample containers were stored for a period of one month before performing gamma spectrometry analysis, so as to allow the establishment of secular equilibria between ^{238}U, ^{232}Th, and their decay products [19]. Each sample was deposited into the shielded HPGe detector and measurements were performed for 50.000–80.000 s.

Absorbed dse rate in air and annual effective dose

If soil radionuclide activities are known, the rate of absorption ata height of one meter from the ground could be determined. Using the radionuclide activities obtained in soil sample analysis, the soil sample gamma dose (D) values were calculated with equation (3) in the present study.

The dose rates and annual effective doses were estimated using equation 3:

$$D\ (nGy.h^{-1}) = (0.462\times C_U)+(0.604\times C_{Th})+(0.0417\times C_K) \quad (3)$$

Where D ($nGyh^{-1}$) is dose rate, C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th, ^{40}K (in Bq kg^{-1}), respectively. The conversion factors used to calculate the dose rate are proposed by UNSCEAR 2000[19].

The annual effective dose equivalent (AEDE), that is, the individuals are exposed to annually, the dose that they are exposed to the radiation emitted by different radiation sources could be found using the calculated gamma doses. Equation (4) was used to calculate the annual effective dose equivalent as follow:

$$AEDE\ (\mu Sv.y^{-1}) = \text{Dose rate} \times DCC \times \text{Occupation factor} \times \text{Time} \quad (4)$$

The coefficients in equation (3) were obtained from UNSCEAR 2000 [19]. The dose conversion coefficient (DCC) in equation(4) was taken to be 0.7 Sv Gy^{-1}. The occupation factor was taken to be 0.2, assuming that people spend 20% of their time outdoors and 80% indoors. The time was taken to be 8760 seconds per year. World mean values of activity concentrations for ^{238}U, ^{232}Th, and ^{40}K are 35, 30, and 400 Bq kg^{-1}, respectively [19].

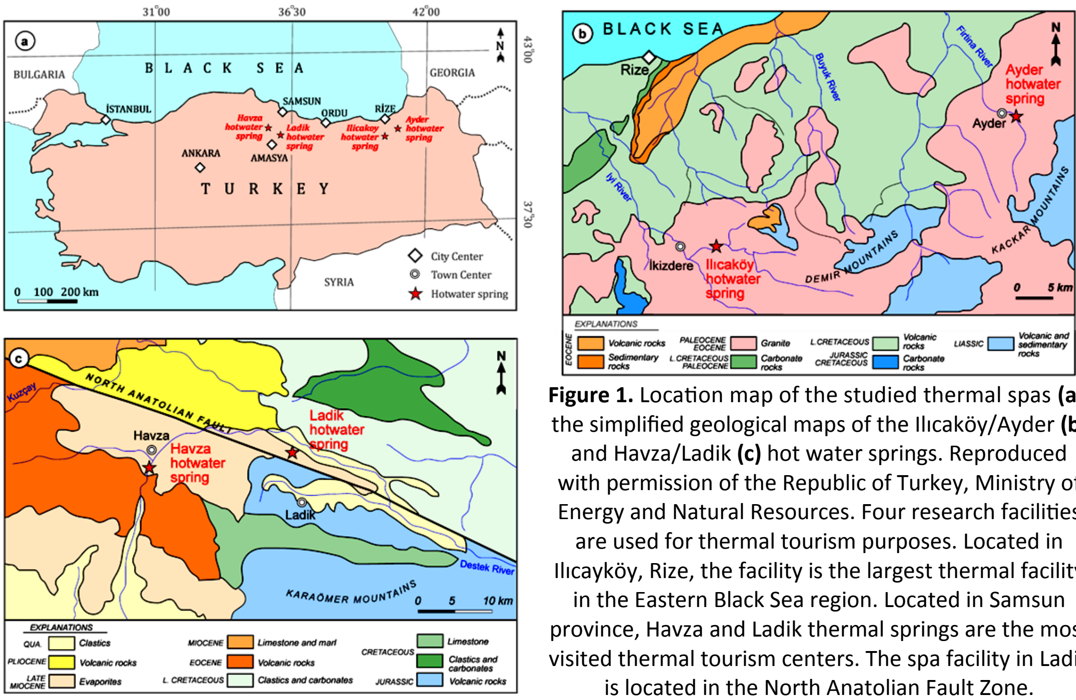

Figure 1. Location map of the studied thermal spas **(a)**, the simplified geological maps of the Ilıcaköy/Ayder **(b)** and Havza/Ladik **(c)** hot water springs. Reproduced with permission of the Republic of Turkey, Ministry of Energy and Natural Resources. Four research facilities are used for thermal tourism purposes. Located in Ilıcayköy, Rize, the facility is the largest thermal facility in the Eastern Black Sea region. Located in Samsun province, Havza and Ladik thermal springs are the most visited thermal tourism centers. The spa facility in Ladik is located in the North Anatolian Fault Zone.

RESULTS

Radon concentration in air and estimated doses

Seasonal radon concentrations measured using active and passive devices in the Ayder, Ilıcaköy, Havza, and Ladik thermal springs are listed in table 1.

The time spent in the spa by the patients and the workers and the annual effective doses are listed in table 2. The annual affective doses were estimated using the radon activity concentration results obtained using both the CR-39 and Alpha GUARD detectors.

Table 1. Seasonal radon concentration results with CR-39 dosimeter (in Bq.m^{-3}).

		CR-39 (Bq.m^{-3})				AphaGUARD (Bq.m^{-3})			
Spa		Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
Ayder	Minimum	40±6	77±8	117±12	70±6	40±8	45±9	63±12	68±13
	Maximum	105±9	156±14	217±18	165±13	117±21	141±28	124±23	119±21
	Mean	76±2	128±2	190±3	108±3	80±3	87±4	106±11	79±8
Ilıcaköy	Minimum	69±9	132±13	157±12	156±12	67±27	159±43	67±32	90±5
	Maximum	1519±40	1877±43	2091±46	1962±45	2310±130	2397±146	2056±128	2788±74
	Mean	460± 10	577± 10	706± 11	584±10	716±12	940±14	1138±45	1001±47
Havza	Minimum	27±3	31±4	58±7	39±4	14±4	26±6	38±8	17±4
	Maximum	44±5	67±8	150±12	77±9	34±7	63±13	67±14	54±11
	Mean	34±1	49±2	88±3	56±2	19±3	34±7	51±8	29±5
Ladik	Minimum	103 ±10	112±10	145±13	113±11	40±17	76 ±23	124±30	60±15
	Maximum	617 ±50	643±53	701±60	609±51	646±76	653 ± 53	710±58	505±101
	Mean	285± 17	328± 19	362± 20	319± 17	228±17	269±14	395±20	298±21

Table 2. Estimated annual effective doses for patients and workers.

Spa	Room	CR-39					AphaGUARD				
		Spa personnel			Patients		Spa personnel			Patients	
		Rn (Bq.m^{-3})	Time (h.year^{-1})	AEDE (mSv.y^{-1})	Time (m.day^{-1})	AEDE (mSv.y^{-1})	Rn (Bq.m^{-3})	Time (h.year^{-1})	AEDE (mSv.y^{-1})	Time (m.day^{-1})	AEDE (m Sv.y^{-1})
Ayder	S. pool	156±2	2000	1	120	45x10^{-4}	99±4	2000	0.9	120	1.3 x10^{-2}
	D. room	90±3	2000	0.6	5	7 x10^{-4}	68±4	2000	1	5	4 x10^{-4}
	Reception	116±3	2000	0.7	10	1 x10^{-3}	104±4	2000	0.7	10	1.2 x10^{-3}
Havza	S. pool	44±1	2000	0.3	120	6 x10^{-3}	30±6	2000	0.2	120	4 x10^{-3}
	D. room	43±2	2000	0.3	5	2 x10^{-4}	42±9	2000	0.3	5	2 x10^{-4}
	Reception	40±2	2000	0.3	10	4 x10^{-4}	32±3	2000	0.2	10	4 x10^{-4}
Ladik	S. pool	642±5	2000	4.1	120	8 x10^{-2}	525 ±23	2000	3.3	120	7 x10^{-2}
	D. room	362±5	2000	2.3	480	1 x10^{-4}	313 ±15	2000	2	5	7 x10^{-4}
	Reception	122±2	2000	0.8	10	1 x10^{-3}	89±8	2000	0.6	10	1 x10^{-3}
Ilıcaköy	S. pool	1862±3	2000	12	120	25x10^{-2}	2118±31	2000	13.4	120	3 x10^{-1}
	D. room	974±1	2000	6.2	10	10 x10^{-3}	606±27	2000	3.8	5	3.3 x10^{-3}
	Reception	264±3	2000	1.7	5	10 x10^{-3}	124±16	2000	0.8	5	7 x10^{-4}

Soil radon and radionucide activities and estimated doses

While indoor radon measurements were performed in spa environments using the CR-39 and AlphaGUARD detectors, soil radon activity concentrations were also measured in the spas' vicinities using AlphaGUARD PQ 2000PRO. The results are listed in table 3. These measurements were performed three times and the mean values are reported.

Soil samples were collected from areas in the vicinity of the studied spas. The number of samples collected was 15, 16, 12, and 27 for the Ayder, Ilıcaköy, Havza, and Ladik spas, respectively. Activity concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs were measured, and the corresponding mean values are listed in table 3.

Using the measured activity concentrations, dose rates and annual effective doses were estimated and are listed in the same table.

The comparison of average activity concentrations with the reports of different studies carried out in Turkey and the world were given in table 4. As can be seen, the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs radionuclides determined in this study are comparable to other studies from other part of Turkey and world.

Table 5 presents the results for radon activity concentration in air, soil, and the annual effective doses in the spas under investigation and in different parts of Turkey, as well as in different parts of the world.

Table 3. Activity concentration of radionuclides in soil of spa vicinities and estimated dose rates.

Spa	Soil Radon Concentration (kBq.m^{-3})	^{238}U (Bq.kg^{-1})	^{232}Th (Bq.kg^{-1})	^{40}K (Bq.kg^{-1})	^{137}Cs (Bq.kg^{-1})	D (nGy.h^{-1})	AEDE (µSv.y^{-1})
Ladik	50±3	57±1	21±2	663±6	6±1	67	82
Havza	9±1	65±2	22±1	669±3	5±0.5	72	88
Ilıcaköy	955±5	743±10	131±11	776±14	11±1	455	558
Ayder	38± 1	65±1	26±2	699±8	21±1	75	92

Table 4. Radioactivity concentration of radionuclides in the soils of different parts of the world and in the soils of current study.

Regions	^{238}U *(^{226}Ra)(Bq.kg^{-1})	^{232}Th Bq.kg^{-1}	^{40}K Bq.kg^{-1}	^{137}Cs Bq.kg^{-1}	References
Serbia (Niska Banja)	20±5	20.3±1.4	361±16	-	(17)
Serbia (Therapy mud)	83±10	104±13	1210±40	2±0.4	(17)
Greek(Ikarıa Island)	241±410	43±18	1130±823	-	(20)
Serbia (Niska Banja)	*259±6	-	219±4	0.5±0.2	(21)
Iran (Mahallat)	*1300-*7300	15-41	364-873	-	(22)
Turkey (İzmir-5 Spas)	*64±2.81-*287±10.33	-	-	-	(23)
Turkey(Dikili-	28.7	17.6	579.2	-	(24)
Turkey (Ayder)	65±0.7	26±2	699±8	21±1.4	Current study
Turkey (Ilıcaköy)	743±10	131±11	776±14	11±1	Current study
Turkey (Havza)	65±2	22±1.2	669±3	5±0.5	Current study
Turkey (Ladik)	57±1.3	21±1.5	663±5.6	6±0.5	Current study
World average	35	30	400	-	19

Table 5. Activity concentrations of radon in air and soil in different spas and the annual effective doses.

Spa	Rn in air (Bq.m^{-3})	Rn in soil (kBq.m^{-3})	AEDE (mSv.y^{-1}) Personnel	References
Turkey (İzmir-5 Spas)	31-280	0.8-2.85	2.62	(23)
Turkey(Kestanbol Çanakkale)	65±8	-	1.91	(25)
Turkey (Armutlu Yalova)	-	116-148	-	(26)
Turkey(Dikili)	-	0.098-8.594	-	(24)
Spanish (Cantabria)	5000	-	-	(27)
Tunisia	33-589	-	0.2-1.7	(28)
Greek (Eftalou)	250-782	-	4.55	(29)
Greek (Polichnitos)	156-328	-	2.09	(29)
Greek (Thermis)	99±4.5	-	0.76	(29)
Brazilian(Termas ve Araxa)	258 - 1634	-	1.7-7.5	(30)
China(Guangdong)	30-2144	-	-	(31)
Indian	429		-	(32)
Greek(Loutra Edipsou)	30-1100	1±0.6-690±22	0.26-30	(33)
Serbia (Niška Banja)	140-2810	-	3- 18	(17)
Northern Venezuela	400-54000	122	0.12-4.2	(34)
Serbia (Niška Banja)	775 -5780	63.7±2.2>2000	16.2- 6.8	(35)
Iran (Mahallat)	275-700	-	5.6	(22)
Slovenia	25-279	-	-	(36)
Portuguese (17 Thermal Spa)	73-3479		0,30-1,29	(37)
Italy(Ischia Island-16 Thermal Spa)	30-3983	-	0.01-7.03	(38)
Turkey (Ayder)	108	38	0.9	Current study
Turkey (Ilıcaköy)	3216	955	13.4-20.3	Current study
Turkey (Havza)	30	9	0.2	Current study
Turkey (Ladik)	691	50	3.3	Current study

DISCUSSION

Table 1 shows that the mean values obtained for the Ayder, Havza, Ilıcaköy, and Ladik spas are below the recommended upper limit. According to the new recommendations by the International Commission on Radiological Protection Statement on Radon, from November 2009, the recommended upper limit for radon gas in dwellings is 300 Bq m^{-3}. Considering that there is a nearly factor of three difference between the lengths of time spent in homes and workplaces, the level of radon gas at~1000 Bq m^{-3} defines the entry point for applying occupational protection for existing exposure situations [39]. The results for the Ayder, Havza, and Ladik spas, including the maximal values, are below the recommended upper limit. In the Ilıcaköy spa, the average level of radon gas in the three zones within the plant was found to be below the recommended upper limit. However, the annual average radon gas level in the swimming pool area was higher than the recommended upper limit.

As seen from table 2, the annual effective doses changed from 0.6 mSv to 13.4 mSv for workers, and from 1 $\times 10^{-4}$ mSv to 3 $\times 10^{-1}$ mSv for patients. The limits recommended by ICRP are 20 mSv for workers and 1 mSv for the general public [40]. It is understood that the estimated annual effective dose equivalents do not pose a threat to human health.

As recognised by the ICRP, the risk due to the inhalation of ^{222}Rn can be estimated by the annual effective dose expressed in mSv y^{-1} [39]. The calculated annual effective doses received by the workers and by the patients in the thermal spas are listed in table 2.

As seen from Table 3, the highest activity concentration of radon was observed in the soil near the Ilıcaköy spa, and it was 955 kBq m^{-3}. On the other hand, the lowest activity concentration was 8.6 kBq m^{-3}, as measured in the soil near the Havza spa.

When the results in table 4 were analyzed, it became clear that the activity concentrations of ^{238}U and ^{40}K measured in the soils collected around the Ayder, Havza, and Ladik spas were higher than the reference world mean values. In particular, the activity concentration of ^{238}U in the soil around Ilıcaköy was found to be 24 times higher than the world mean value. The activity concentrations of ^{232}Th and ^{40}K were 4.5 and 1.5 higher than the respective world mean values.

Besides naturally occurring radionuclides, ^{137}Cs was also detected in the analyzed soil samples. The presence of radiocesium could be linked to the Chernobyl accident which occurred in 1986 as it was shown that the Eastern

Black Sea Region of Turkey was highly affected by that accident [41]. Analysis of the results in tables 1, 2, and 3 clearly shows that the Ilıcaköy spa exhibited the highest values for all measurements. Therefore, special care should be given to the workers and patients who spend their time in this spa environment.

Table 4 presents the activity concentrations of naturally occurring radionuclides and ^{137}Cs in soil samples collected from the spas under investigation and from other parts of the world. As seen from table 4, the highest activity concentration of ^{238}U was measured in Iran, while the lowest values were measured in Serbia. The highest and the lowest values for ^{232}Th and ^{40}K were measured in the Ilıcaköy spa (current study) and Iran; Serbia and Ilıcaköy; different parts of Serbia, respectively.

Analysis of the results in table 5 shows that the highest radon activity concentrations are observed in the spas of North Venezuela, Serbia, Spain, and the Ilıcaköy spa of the current study.

As shown in table 6, using all the variables obtained in the study, the correlation between the variables and the correlation analysis was investigated. Statistically significant relationships were found between all the variables examined. It is seen that there is a strong positive relationship between the uranium level in the spas' waters and the uranium levels in the spas' soil. As radon is one of the decay products of uranium, it is expected that the areas showing high uranium concentration also shows elevated radon levels.

Table 6. Pearson Correlation yield statistics.

	^{238}U Soil(Bq.kg^{-1})	Radon Soil (Bq.m^{-3})	Radon Air (Cr-39) (Bq.m^{-3})	Radon Air (AG) (Bq.m^{-3})
^{238}U Soil (Bq.kg^{-1})	1			
Radon Soil (Bq.m^{-3})	.999[2]	1		
Radon Air (Cr-39) (Bq.m^{-3})	.945[1]	.958[1]	1	
Radon Air (AG) (Bq.m^{-3})	.956[1]	.968[1]	.999[2]	1

[2]Correlation is significant at the 0.01 level (2-tailed)
[1]Correlation is significant at the 0.05 level (2-tailed)

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