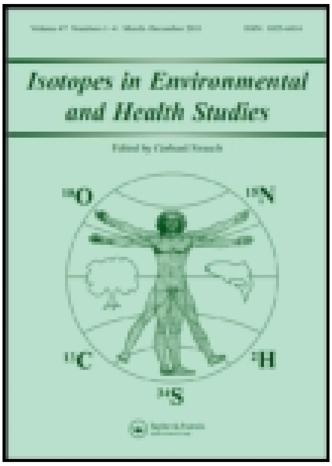

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Measurements of radon concentration levels in thermal waters in the region of Konya, Turkey

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^{222}Rn (radon) is one of the most important sources of natural radiation to which people are exposed. It is an alpha-emitting noble gas and it can be found in various concentrations in soil, air and in different kinds of water. In this study, we present the results of radon concentration measurements in thermal waters taken from the sources in the region of Konya located in the central part of Turkey. The radon activity concentrations in 10 thermal water samples were measured by using the AlphaGUARD PQ 2000PRO radon gas analyser in spring and summer of the year 2012. We found that radon activity concentrations range from 0.60 ± 0.11 to 70.34 ± 3.55 kBq m^{-3} and from 0.67 ± 0.03 to 36.53 ± 4.68 kBq m^{-3} in spring and summer, respectively. We also calculated effective doses per treatment in the spas for the spring and summer seasons. It was found that the minimum and maximum effective doses per treatment are in the range of 0.09–10.13 nSv in spring and in the range of 0.1–5.26 nSv in summer.

Keywords: effective dose; natural radioactivity; radiation exposure; radon-222; thermal waters

1. Introduction

The natural radiation is mainly produced through the decay of radioactive elements and their products in the crust of the Earth and cosmic rays from outer space. Radon has a half-life of 3.82 days and is generated from radioactive transformation of ^{226}Ra (radium) in the decay chain of uranium-238. Its radioactive daughter isotopes ^{214}Po (polonium) and ^{218}Po decay by emitting 7.69 and 6.00 MeV α particles, respectively. They also contribute over 90% of the radiation dose received by people due to radon exposure. Radon and its short-lived decay products in the atmosphere are the most important contributors to human exposure from natural sources [1,2].

It is well known that radon is soluble in water and its solubility increases rapidly with decreasing temperatures. Therefore, much attention has been given to the dissolved radon concentration in the water sources due to radon's potential public health hazard. It is noteworthy that the radon concentration also depends on salinity even though its effect has been largely ignored [3]. In order to assess the effect of radon, some authors evaluated the radon concentration levels in drinking water samples and various surface water samples [4–6], while some authors have measured the radon concentration levels in the water, indoor air and soil gas [7]. There is also some research on radon gas dealing with well waters [8–10], ground waters [11–13] and thermal waters [14–19] since the radon concentration levels in ground and thermal waters are generally higher than those in surface waters. When we regard the geologic formations (including faults), we realise that the

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fault zones are preferential pathways for liquid transport. During transport of the liquid, radon gas escapes from the rocks and minerals to the surrounding liquid phase such as ground and thermal waters. Therefore, ground water circulating in active volcanic areas displays high radon content, especially if issued from geothermal systems [11]. Eventually, the high concentrations of radon in the ground and thermal waters may cause a great risk not only for people who ingest it, but also in the air for people who inhale it [12].

The evaluation of radon concentrations is important not only for the public health but also for many other applications. For example, monitoring radon concentrations is used for predicting earthquakes since it is highly related to the geologic formation [20]. Radon concentration measurements have also been used for investigating the groundwater–surface water interaction processes [21], monitoring the groundwater motions and estimating the ground water flow velocities [22]. It is also used as a tracing agent in applications related to contamination and rehabilitation of groundwater [23,24].

This paper reports the results of radon concentrations of thermal waters measured during spring and summer 2012 in Konya. There are no previous reports in the literature regarding the radon concentrations in thermal waters of this region. This study draws a general picture of the natural radioactivity of thermal waters in different regions in Konya and evaluates the doses to the populations resulting from their consumption. Therefore, the results are very important for public health as a lot of people use thermal waters for therapeutic purposes.

2. Study area and sampling procedure

Konya is a province with an area of 38,873 km^2 (excluding the lakes) and its estimated population is 2 million. Its latitude and longitude are 36°41′–39°16′ North and 31°14′–34°26′ East. The average altitude is around 1050 m above sea level [25]. Konya has rich thermal water resources. The most important thermal water locations in the region of Konya are Ilgın (samples 1–4), Köşk (samples 5–6), Seydişehir (samples 7–9), and İsmil (sample 10) thermal regions as shown in the map in Figure 1. Ilgın, Köşk and İsmil thermal areas have some hotels for health tourism. Beside those hotels, some new ones are planned to be built in Seydiþehir thermal area for health tourism. The most popular thermal sites of this region are located in Ilgın area. In this region, there is an intensive outflow of mineral and thermal waters. Every year, many people having orthopaedic, rheumatic and neurological diseases visit Ilgın in order to recover their health.

The water samples, except the fourth one, were collected from 10 different thermal water sources and they were directly taken from the pumping sites of the wells which have different depths during spring and summer 2012 in Konya. The 4th sample was taken from bathing water of a hotel and is fed by a collection of other thermal water sources (samples 1–2) in this region. Because samples 1 and 2 have relatively high levels of radon concentration, we have also sampled the bath water of the thermal hotel that is fed by these sources. Water samples were put into 500 ml polyethylene terephthalate bottles that were completely filled and immediately closed tightly in order to avoid bubbles and radon escape. Following the collection of the samples from their sources, they were immediately transported to the Nuclear Physics Laboratory in Selcuk University to determine the radon concentration level.

3. Brief geology of thermal area

Ilgın, a rich area in terms of geothermal waters, is a district of the Konya province and is located in the north-west of Konya. The thermal region of Ilgın is close to active fault zones (samples 1–4). The water has mainly meteoric character and the source of heat is the geothermal gradient.

Figure 1. Map of Konya showing the locations of geothermal water resources considered in this study.

The thermal water aquifer is formed by Permian aged marbles and Pliocene aged limestones in the Ilgın area. The geothermal system is governed by a reverse fault oriented from north to south. The second geothermal area for collecting samples was Köşk. The Köşk geothermal area is located in the south-west of Konya city (samples 5–6) on Quaternary deposits and is fed by a normal fault. This fault is a boundary between the Sultandağı formation, consisting of more than 1 km thick schists and quartzite with plenty of metamorphic hematite, and young deposits. Zedef [26] correlated the Sultandağı formation with the well-known banded iron formation. Samples 7–9 were collected from Seydişehir, which is a district located 85 km to the south-west of Konya city. Ilıcatepe thermal source is in downtown Seydiþehir (sample 7). Other thermal sources are located in Kavak village of Seydişehir (samples 8–9). The geothermal springs and wells in the Seydişehir region are controlled by a normal fault. The fault is a contact between Mesozoic aged Middle Taurid belts and Tertiary aged travertine formations. The travertine formation, however, is covered by younger alluviums and extra formational conglomerates. The last sample belongs to the İsmil geothermal area which is located in the south-east of Konya (sample 10). In this area, Paleozoic-aged marbles serve as reservoir rock and the geothermal system is again controlled by a fault [26,27].

4. Experimental techniques

The experimental technique employed in this study is briefly summarised below. A detailed description and discussion of this method can be found in Kochowska et al. [10] and Schubert et al.[28] Radon concentration in water was measured using a professional radon monitor Alpha-GUARD PQ 2000PRO (Genitron-Saphymo, Frankfurt, Germany). This is an ionisation chamber

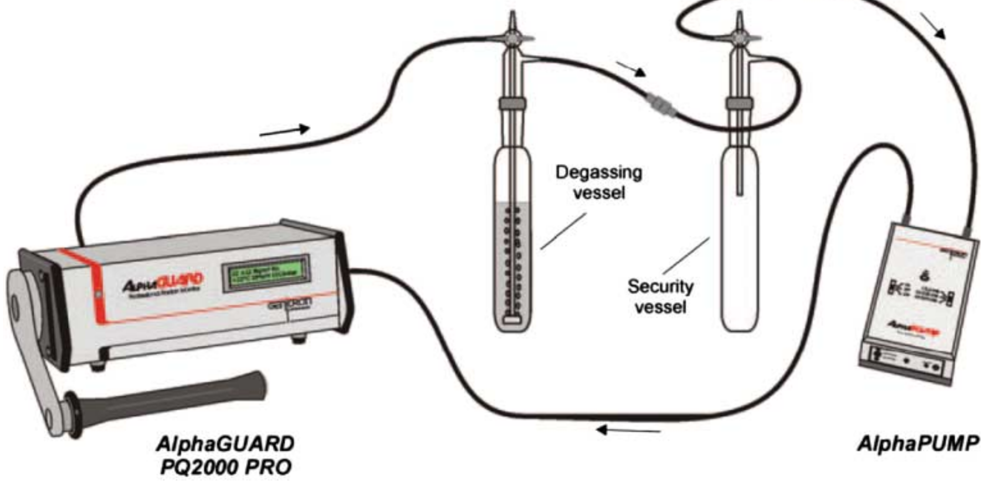

Figure 2. Schematic view of the experimental set-up.

designed for measuring radon in air, water and soil gas. It is suitable for continuous measurements of radon and has a measurement range of 2–2,000,000 Bq m^{-3}. For water measurements, the additional equipment AquaKIT is used. Figure 2 shows the set-up for radon measurements in water samples. In a closed gas cycle, radon was expelled from the water samples (placed in a degassing vessel) using a pump. The security vessel was connected with the degassing vessel. All water droplets would deposit in it if they had got into the gas cycle during the degassing process. The pressure of the water vapour was thus minimised for the radon monitoring. The background of the empty set-up was measured for 10 minutes before every water-sample measurement. After that, the water was injected into the degassing vessel, and the AlphaGUARD and AlphaPUMP were switched on. After 10 minutes, the pump was switched off and the AlphaGUARD remained switched on for another 20 minutes, so the radon measurement was continued. This cycle was repeated three times in order to obtain a better precision. The AlphaGUARD monitor worked in a 'flow' mode and the radon concentration was recorded every minute. The flow rate of the pump was 0.5 l min^{-1}. The AlphaGUARD ionisation chamber is a part of this gas cycle as well.

The radon concentration in the water samples was determined with the AlphaGUARD. The value measured by the AlphaGUARD is not the radon concentration in the water sample since the radon driven out had been diluted in air within the measurement set-up, and a small part determined by the partition coefficient of the radon remained diluted in the aqueous phase. For quantifying the dilution effect, the exact interior volume in the measurement set-up (V_{system}) is required. The amount of radon remaining in the sample can be determined by the introduction of the partition coefficient k which describes the temperature and salinity dependence of the radon remaining chemically dissolved in the sample. Kochowska et al. [10] and Schubert et al. [28] showed that the radon concentration in the measured water samples can be determined by the following equation:

$$C_{water} = \frac{C_{air}((V_{system} - V_{sample})/V_{sample}) + k) - C_0}{1000}, \quad (1)$$

C_{water} is the Rn concentration in water sample (Bq l^{-1}), C_{air} the radon concentration (Bq m^{-3}) in the measuring set-up after expelling the radon indicated by the AlphaGUARD), C_0 the Rn concentration in the measuring set-up before sampling (zero level) (Bq m^{-3}), V_{system} the interior volume of the measurement set-up (ml), V_{sample} the volume of the water sample (ml), k the radon partition coefficient.

Calibration of the measuring system has been carried out by Genitron Instruments, Germany, recently, with a guaranteed stability for 5 years.

5. Results and discussion

The radon concentration levels of the thermal water samples obtained from each one of the sources were measured three times and then averaged. The results of the measurements are given in Tables 1 and 2. Radon concentration results varied from 0.60 ± 0.11 to $70.34 \pm 3.55\,\mathrm{kBq\,m^{-3}}$ in spring and from 0.67 ± 0.03 to $36.53 \pm 4.68\,\mathrm{kBq\ m^{-3}}$ in summer. One of the samples from Ilgın (sample 2) had the highest radon concentrations with 70.34 and $36.53\,\mathrm{kBq\ m^{-3}}$ in spring and summer, respectively. This result can be related to the geological structure and active fault zones as the thermal water sources are located in these active zones. The lowest radon contents of 0.60 and $0.67\,\mathrm{kBq\,m^{-3}}$ were measured for the sample 8 (from Seydişehir region) in spring and summer 2012, respectively. If we exclude the results for the samples from Ilgın region (samples 1–4), there seems to be a positive correlation between radon concentrations of thermal water sources and their depths. However, we do not observe this correlation for the samples from

Table 1. ^{222}Rn activity concentrations and the effective doses for inhalation for thermal water sources in Konya, Turkey.

	Spring		Summer	
Sample code	Radon activity ($\mathrm{kBq\,m^{-3}} \pm$SD)	Effective dose (nSv)	Radon activity ($\mathrm{kBq\,m^{3}} \pm$ SD)	Effective dose (nSv)
1	31.75 ± 4.13	4.57	16.82 ± 0.96	2.42
2	70.34 ± 3.55	10.13	36.53 ± 4.68	5.26
3	17.17 ± 2.54	2.47	15.81 ± 0.65	2.28
4	14.31 ± 1.67	2.06	16.0 ± 0.68	2.30
5	3.23 ± 0.28	0.47	3.25 ± 0.17	0.47
6	1.86 ± 0.29	0.27	0.95 ± 0.06	0.14
7	2.93 ± 0.20	0.42	3.15 ± 0.37	0.45
8	0.60 ± 0.11	0.09	0.67 ± 0.03	0.10
9	1.21 ± 0.05	0.75	0.89 ± 0.14	0.13
10	6.84 ± 0.33	0.98	1.34 ± 0.53	0.20

Table 2. Electrical conductivity, pH and depth for thermal water sources in Konya, Turkey.

Sample code	Electrical conductivity ($\mathrm{mS\ cm^{-1}}$)	pH	Depth (m)
1	1.03	6.15	300.5
2	1.08	5.31	130.0
3	1.02	6.56	130.0
4	1.08	6.50	–
5	1.25	5.88	350.0
6	1.22	5.67	112.0
7	0.86	7.80	395.0
8	2.50	7.73	182.0
9	2.52	9.10	317.0
10	3.83	7.20	Unknown

Ilgın; this difference may be a result of the higher activity of the reverse fault in this zone. pH and electrical conductivity of these water samples were measured as well. We do not observe any correlation between the radon content of thermal water samples and their pH and electrical conductivity.

In previous reports, radon levels in thermal waters of different regions of Turkey were measured and our results are contained in the same range. For example, the radon activity of thermal waters around Bursa city were reported to be 2.51–82.55 $kBq\,m^{-3}$ [14], while it was reported as 0.14–5.77 $kBq\,m^{-3}$ [15] for thermal waters of Western Anatolia, and for the ones around Afyonkarahisar city as 0.09–44.57 $kBq\,m^{-3}$ [16]. There are also reports regarding the radon activity of thermal waters in some other countries, the reported values are generally higher than those obtained in this study for Konya (Turkey); for example, Greece (10–304 $kBq\ m^{-3}$) [17], Venezuela (1–576 $kBq\,m^{-3}$) [18] and Spain (824 $kBq\,m^{-3}$) [19]. There is also some research on radon activity concentrations of ground waters in different countries. In these studies, measured radon activity concentrations have ranged from 3.20 to 22.70 $kBq\,m^{-3}$ in the Afyonkarahisar area of Turkey [8], from 1.44 to 27.45 $kBq\,m^{-3}$ in the Konya area of Turkey [9], from 1.80 to 52.70 $kBq\,m^{-3}$ in the Mt. Etna area of Italy [11] and from 7.00 to 34.20 $kBq\,m^{-3}$ in the state of Chihuahua in Mexico [12].

Radon in water may lead to exposures from the ingestion of drinking water and from the inhalation of radon released to air when water is used. The conversion coefficient of radon in water to air depends on many factors [5,14]. As a rule of thumb, it is supposed that 10 $kBq\,m^{-3}$ of ^{222}Rn in water contributes about 1 $Bq\,m^{-3}$ of ^{222}Rn to the indoor air [2]. The average contributions of radon concentration in thermal water to indoor radon can easily be obtained from the radon concentration values given in Table 1. Accordingly, the increase in the indoor-air radon concentration induced by thermal waters ranges from 0.06 ± 0.01 to 7.03 ± 0.36 $Bq\,m^{-3}$ in spring and from 0.07 ± 0.01 to 3.65 ± 0.47 $Bq\,m^{-3}$ in summer. In order to estimate the effective indoor dose, one has to take into account the conversion coefficient from an absorbed dose of air to the effective dose and the indoor occupancy factor. In the UNSCEAR report [2], a value of 9 $nSv\,h^{-1}$ per $Bq\,m^{-3}$ was used for the conversion factor (effective dose received by adults per unit ^{222}Rn activity per unit of air volume), 0.4 for the equilibrium factor of ^{222}Rn indoors and 0.8 for the indoor occupancy factor [5,14]. A treatment session in these thermal waters generally lasts about 30 minutes; therefore the calculated effective doses presented in Table 1 for inhalation are for a 30 minute treatment period in thermal water. Calculated effective doses range from 0.09 to 10.13 nSv in spring and from 0.10 to 5.26 nSv in summer, as shown in Table 1. Gurler et al. [14] calculated the effective dose to be in the range of 0.36–11.89 nSv per treatment due the inhalation of released radon for thermal waters of the Çekirge region of Bursa.

6. Conclusions

We have carried out the first measurements of the radon content of thermal water sources with different depths in the region of Konya. From the results of these measurements, it is seen that there is a weak correlation between the radon content of the thermal waters and their depth. In the measurements, the highest level of radon concentrations was found in the Ilgın thermal region of Konya. The USEPA [29] has recommended 11.11 $kBq\,m^{-3}$ of radon in water as the safe limit for drinking. However, the World Health Organization (WHO) [30] has recommended 100 $kBq\,m^{-3}$ of radon activity in water as the safe limit for drinking purposes. Considering the USEPA [29] limits, only thermal water samples from the Ilgın thermal region were found to be above the safe limit for drinking. On the other hand, if we consider the WHO [30] limits, all of the water samples were found to be within the safe limit. After all, the thermal water sources are not used for drinking, therefore, we believe that radon concentration levels of thermal water samples in the Ilgın region do not create a hazardous situation for public health.

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