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THE MEASUREMENT OF RADON ACTIVITY CONCENTRATIONS IN TAP WATER IN SOME DWELLINGS OF KONYA PROVINCE – TURKEY

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Abstract: Radon (Rn-222) concentration was determined in selected 27 tap water samples collected during autumn and winter seasons in 2012 around city of Konya, Turkey. While 11 tap water samples were taken from dwellings with water reservoir, other tap water samples were taken from dwellings without water reservoir. Radon measurements were performed by an AlphaGUARD radon gas analyzer. All determined the mean radon concentrations for the autumn and winter seasons were found to be 3.15 Bq l^{-1} for the samples collected from dwellings with water reservoir and 10.20 Bq l^{-1} for the samples collected from dwellings without water reservoir. The calculated effective doses for ingestion were 0.17 for minimum and 3.67 μSv a^{-1} for maximum and for inhalation of radon in indoor air caused by these waters 2.18 μSv a^{-1} for minimum and 45.84 μSv a^{-1} for maximum.

Keywords: environmental radioactivity; radon-222; annual effective dose; tap water

1. INTRODUCTION

Radon (^{222}Rn) is an alpha-emitting noble gas and one of the most important sources of natural radiation to which people are exposed (UNSCEAR, 1993). It has a half-life of 3.82 days and is generated from radioactive transformation of ^{226}Ra (Radium) in the natural ^{238}U decay series. Two of the α emitting short-lived decay products of radon, ^{218}Po (Polonium) and ^{214}Po, contribute over 90% of the total radiation doses received by people due to radon exposure (Gillmore et al., 2001). Radon can be found in various concentrations in soil, air and in different kinds of water. Radon is soluble and its solubility decreases at higher temperatures (UNSCEAR, 1993). Radon concentration in water also depends on salinity even though its effect has largely been ignored (Schubert et al., 2012). People are exposed to radon in two ways that are ingestion and inhalation. The ingestion of water containing radon can cause an additional exposure dose to the stomach and the whole body (Khattak et al., 2011). High level of radon in domestic water can make major contribution to the indoor radon exposure (Kearfott, 1989). In this case, high level of indoor air radon concentration can be health hazard to humans, primarily being a cause of lung cancer (Folger et al., 1994). For this reason, much attention has been given to the dissolved radon concentration in the drinking water.

There is also many positive applications assessment of radon concentrations as well. One of these, monitoring radon concentrations is used for predicting earthquakes since it is highly related to the geologic formation (Virk & Singh, 1993). Radon concentration measurements have also been used as environmental tracer or indicator for various applications. For examples, the localizations and evaluation of non-aqueous phase liquid contamination in soils and aquifers (Schubert et al., 2001; Schubert et al., 2011), estimating the ground water flow velocities (Hamada, 2000), and investigating the ground water/surface water interaction process (Schubert et al., 2008).

In order to assess the effect of radon, many researchers have conducted studies to measure radon in water samples from different region of Turkey (Oner et al., 2009; Yiğitoğlu et al., 2010; Tarim et al., 2011; Erdogan et al., 2013a; Erdogan et al., 2013b) and some other countries (Xinwei 2006;

Cosma et al., 2008; Khattak et al., 2011; Moldovan et al., 2013).

In this study we present the results of radon concentrations in tap water samples from dwellings with and without water reservoir collected during autumn and winter of 2012 in Konya city. There is no previous study (and the paper of Erdogan, 2013b mentioned below) related to radon concentration in tap waters in Konya. This study draws a general picture of the natural radioactivity of tap waters consumed by people living in Konya and provides the doses to the populations resulting from their consumption.

2. STUDY AREA AND SAMPLING PROCEDURE

Konya is a city having a surface area of 38,873 km^2 (excluding the lakes) and an estimated population of 1,100,000 people in the city center. The latitude and longitude of Konya city are 36^{o}41´-39^{o}16´ North and 31^{o}14´- 34^{o}26´ East with an average altitude is around 1050 m above sea level. In this study, radon concentrations of tap water samples taken from dwellings in the central districts of Konya, which are called Selçuklu (S1-S8 samples), Meram (M1-M8 samples) and Karatay (K1-K11 samples), were measured as shown Figure 1. In Figure 1, while the dots are showing sampling locations of Selçuklu, Meram and Karatay, the bold dot shows K1, K5, K9-K11 locations in the Karatay region. Tap water of the dwellings is supplied from the same well water and dams in Konya. Radon concentration levels in well water of Konya have previously been measured and given in Erdogan et al., 2013b. Konya region is located within the Bolkardağı subunit (Özgül, 1976) of Major Taurid Tectonic units which are described in detail by Ketin (Ketin, 1966). Konya region is the subject of an intensive tectonic regime giving rise to some folding and faulting. The geological structure of the Konya region was also discussed in detail elsewhere (Ekdur, 2008: Erdogan et al., 2013b).

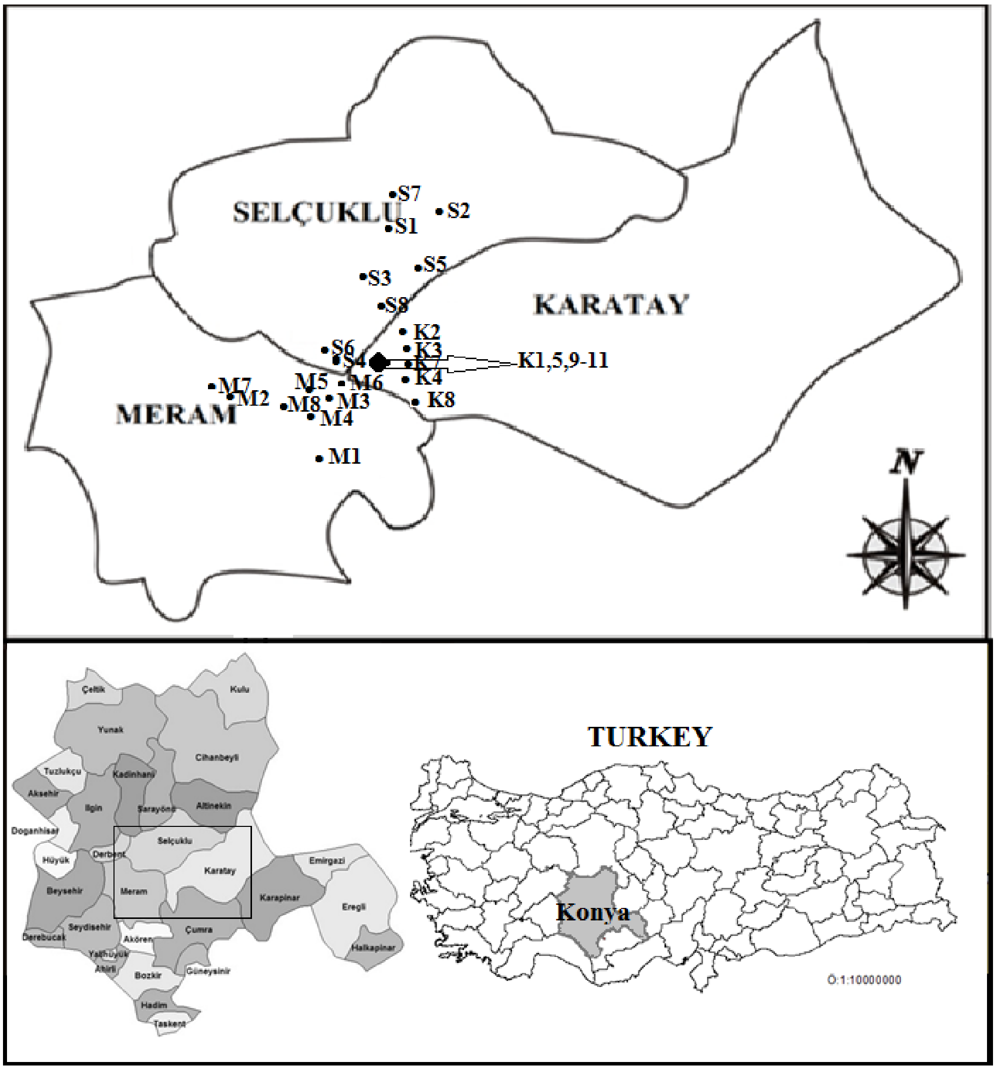

Figure 1. Map of sampling location

The tap water samples were collected from 27 different dwellings and analyzed for their radon concentration levels during autumn and winter seasons in the city of Konya. While eleven of the 27 tap water samples were collected from the dwelling with a water reservoir other water samples were collected from the dwelling without water reservoirs. For each water sample, three measurements were taken and averaged. The tap water samples were taken from dwellings in as similar populated areas of Konya city as possible and were collected in December and February.

Water samples were put into 500 ml polyethylene bottles that were completely filled and immediately closed tightly in order to avoid bubbles and radon escape. All samples were immediately transported to the Nuclear Physics Laboratory in Selçuk University to determine radon concentration level.

3. MATERIALS AND METHODS

The experimental technique employed in this study is briefly summarized below. A detailed description and discussion of this method can be found in Schubert et al., 2006. Radon concentration in water was measured using a professional radon monitor

AlphaGUARD PQ 2000PRO (GENITRON-SAPHYMO, Frankfurt, Germany). This is an ionization chamber, 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} (0.05 – 50,000 pCi l^{-1}) with a sensitivity of 5 cpm for 100 Bq m^{-3} (3 pCi l^{-1}). For water measurements an additional equipment AquaKIT was used. In a closed gas cycle, radon was expelled from the water samples (placed in degassing vessel) using a pump. The security vessel was connected with the degassing vessel. All drops would deposit in it if they had got into the gas cycle during the degassing process.

The pressure of the water vapor was thus minimized for the radon monitoring. The background of the empty setup was measured for 10 minutes before every water-sample measurement with using carbon filter. 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 radon concentration was recorded every minute. The flow rate of the pump was 0.5 L/minute. The AlphaGUARD ionisation chamber is a part of this gas cycle as well.

Radon concentration in the water samples was determined with the AlphaGUARD. The value measured by 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 quantity of radon remaining in the sample can be determined by the introduction of the partition coefficient k which describes the temperature dependent quantity of the sample which remains chemically dissolved. It was shown in the article (Schubert et al., 2006) that radon concentration in the measured water samples can be determined by the following equation

$$C_{water} = \frac{C_{air}\left(\frac{V_{system}-V_{sample}}{V_{sample}}-k\right)-C_0}{1000} \qquad (1)$$

where C_{water} is radon concentration in water sample (Bq l^{-1}), C_{air} is radon concentration in the measuring set-up after expelling the radon from the water indicated by AlphaGUARD (Bq m^{-3}), C_0 is the background radon concentration measured just before sampling for an empty set-up (Bq m^{-3}), V_{system} is the interior volume of the measurement set-up (ml), V_{sample} is the volume of the water sample (ml) and k is the partition coefficient which depends on the temperature of the water sample.

4. RESULTS AND DISCUSSION

The arithmetic mean value of radon concentration levels of the tap water samples collected from dwellings is varying from 0.87 to 18.34 Bq l^{-1} for autumn and winter seasons as shown in table 1. The reason for the seasonal variation of radon concentration levels in the water samples can be related to seasonal factors and waiting-period of the water in the water supply network. For this study, while eleven of twenty seven tap water samples, which are S1-S5, M1-M3 and K1-K3, were collected from dwellings with water reservoir, the remaining samples, which are S6-S8, M4-M8 and K4-K11, were collected from dwellings without water reservoir. The mean value of the radon concentrations of the tap water samples with a water reservoir is 3.15 Bq l^{-1}, while for the others; this value is found 10.20 Bq l^{-1} for the two seasons. It is seen that radon activity of the tap water samples of dwellings with water reservoir is higher than other water samples for two seasons as shown table 2. According to the results obtained in this work, it is clear that all determined mean value of radon concentrations of those eleven samples with water reservoirs were well below the levels of the other samples. This difference might be due to fact that dissolved radon gas with a half-life of 3.82 days in the water reservoir decays into radioactive ^{218}Po (Polonium-218) and escapes to air (UNSCEAR, 2000). We have also investigated seasonal variation of radon activity of the water samples for two seasons. The ratio of radon activities of the water samples for the autumn and winter seasons is seen in table 1. These ratios are higher than 1 except for S7, K2, K4, K5 and radon activity of the water samples generally was decreased in winter season. This situation can be interpreted as follows: during winter time there is less consumption of water, thus water spends longer times in the water supply network thus allowing time for the radon activity removal. Also, pH and electrical conductivity of these water samples were measured, the electrical conductivities varied between 0.33 – 0.9, and the pH values ranged from 6.79 to 10.48. No correlation was observed between the radon contents of the water samples and their pH values, and electrical conductivities.

The United States Environmental Protection Agency (USEPA, 1999) has recommended a maximum level of 11.1 Bq l^{-1} radon activity level in water as safe limit. However, the World Health Organization (WHO) has recommended a level of 100 Bq l^{-1} in drinking-water for public water supplies (WHO, 2008). The mean value of the radon concentrations of eight of 27 samples were above the safe limit as recommended by USEPA. On the other hand, all water samples taken from dwellings with a water reservoir were well below the 11.1 Bq l^{-1} level recommended by the USEPA. Therefore, all the measured concentrations were also below the 100 Bq l^{-1} which is the recommended WHO safe level for household use and drinking.

Table 1. ^{222}Rn concentration levels in tap water samples of the city of Konya, Turkey ([a]SD, standard deviation, [b]AM, arithmetic mean, [*]with water reservoir).

	Radon concentration ± SD[a] (Bq l^{-1})					
Sample code	Autumn	Winter	Autumn /Winter	AM[b] of radon for two seasons (Bq l^{-1})	Effective dose for ingestion (µSv)	Effective dose for inhalation (µSv)
S1*	2.66 ± 0.40	0.72 ± 0.04	3.69	1.69	0.34	4.23
S2*	2.73 ± 0.18	0.89 ± 0.28	3.07	1.81	0.36	4.53
S3*	3.68 ± 0.26	1.40 ± 0.12	2.63	2.54	0.51	6.35
S4*	7.16 ± 1.43	0.33 ± 0.07	21.70	3.75	0.75	9.36
S5*	1.47 ± 0.11	0.82 ± 0.04	1.79	1.15	0.23	2.86
S6	10.38 ± 0.66	3.57 ± 0.22	2.91	6.98	1.40	17.44
S7	1.30 ± 0.26	1.74 ± 0.11	0.75	1.52	0.30	3.80
S8	18.21 ± 0.92	12.90 ± 2.59	1.41	15.56	3.11	38.89
M1*	5.67 ± 0.15	0.36 ± 0.05	15.75	3.02	0.60	7.54
M2*	3.00 ± 0.28	2.85 ± 0.36	1.05	2.93	0.59	7.31
M3*	5.39 ± 0.15	4.00 ± 1.19	1.35	4.70	0.94	11.74
M4	14.58 ± 0.49	12.32 ± 0.68	1.18	13.45	2.69	33.63
M5	14.31 ± 0.51	4.24 ± 0.50	3.38	9.28	1.86	23.19
M6	16.05 ± 0.71	9.16 ± 1.12	1.75	12.61	2.52	31.51
M7	3.65 ± 0.24	2.20 ± 0.17	1.66	2.93	0.59	7.31
M8	0.89 ± 0.15	0.85 ± 0.13	1.05	0.87	0.17	2.18
K1*	8.16 ± 0.61	4.63 ± 0.28	1.76	6.40	1.28	15.99
K2*	1.29 ± 0.02	2.09 ± 0.40	0.62	1.69	0.34	4.23
K3*	6.47 ± 0.18	3.52 ± 0.20	1.84	5.00	1.00	12.49
K4	10.37 ± 2.05	14.62 ± 1.02	0.71	12.50	2.50	31.24
K5	4.59 ± 0.76	11.10 ± 1.25	0.41	7.85	1.57	19.61
K6	19.17 ± 3.12	13.62 ± 0.31	1.41	16.40	3.28	40.99
K7	23.22 ± 2.12	13.45 ± 1.03	1.73	18.34	3.67	45.84
K8	16.97 ± 1.08	12.78 ± 0.70	1.33	14.88	2.98	37.19
K9	14.26 ± 0.64	5.66 ± 0.22	2.52	9.96	1.99	24.90
K10	10.56 ± 0.44	4.73 ± 0.11	2.23	7.65	1.53	19.11
K11	12.52 ± 0.28	12.24 ± 0.69	1.02	12.38	2.48	30.95

Table 2. Radon activity concentration of the tap water samples from dwellings with and without reservoir (averaged over all samples for the regions).

	Mean of Radon Activity (Bq l^{-1})	
Location Region	With water reservoir	Without water reservoir
Selçuklu	2.01	8.02
Meram	3.55	7.83
Karatay	4.36	12.50

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 (Xinwei, 2006). 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 (UNSCEAR, 2000). The average contribution of radon concentration from tap water of dwellings to the indoor environment can easily be obtained from the mean value of radon concentration given in table 1. 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 (UNSCEAR, 2000), 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 7,000 hours for the indoor occupancy factor per year. We calculated annual effective doses for inhalation 2.18 µSv a^{-1} as a minimum and 45.84 µSv a^{-1} as a maximum due to the radon in the waters as shown in table 1.

Also, for these effective doses for ingestion, the annual weighted estimate of consumption rate and the dose coefficient of the concerned radon isotope per unit intake which is equal to 3.5 nSv.Bq^{-1} were used. According to the UNSCEAR report (UNSCEAR, 2000), it has been estimated that the consumption rate of the tap water is 60 l a^{-1}. Thus, we assessed the expected doses 0.17 µSv a^{-1} for minimum and 3.67 µSv a^{-1} for maximum due to the radon activity in the water samples as show in table 1. These doses are acceptable according to UNSCEAR (2000) report.

5. CONCLUSIONS

In this study, we have carried out the first measurements of the radon concentration level of the tap water in the dwellings of Konya city. It is noteworthy that these measurements are highly important for public health since tap water is used for drinking and household purposes. It can be seen that radon concentration level of the tap water taken from the dwellings with water reservoir are generally lower than those water samples without water reservoir. However, all the water samples analyzed in this study were acceptable for the household use according to UNSCEAR (2000) report.

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