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Exposure assessment of the radon in residential tap water in Kastamonu

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▸ ***Short report***

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ABSTRACT

Background: It is considered that if radon gas is inhaled and ingested, it is the primary health risks for lung and stomach cancers. This paper presents the measurement results of radon activity concentrations both residential tap water and dam water for Kastamonu city Centre-Turkey. ***Materials and Methods:*** The radon activity concentrations of water samples collected from 60 tap waters at four locations and 12 dam water of study area were determined. Radon concentrations were measured using the professional radon monitor AlphaGUARD PQ2000 PRO (Genitron Instruments). ***Results:*** The mean value for all residential tap water samples and dam water samples were ascertained as 0.050 Bq l^{-1} and 0.741 Bq l^{-1}, respectively. The annual effective doses were calculated for the inhalation of radon released to air when water is used and the ingestion of drinking water. The mean values for inhalation and ingestion were found to be 0.1266 µSv y^{-1} and 0.0105 µSv y^{-1}, respectively. For the radon exposure from ingestion, the annual effective doses were calculated for infants, children, and adults, separately. ***Conclusion:*** When the results compared with the internationally recommended safe limits, the tap waters of Kastamonu city Centre is safe for drinking purposes in terms of radon activity concentrations.

Keywords: *Radon exposure, tap water, effective dose, Kastamonu.*

INTRODUCTION

Human beings are exposed to natural radiation constantly everywhere. The exposure of human body from natural radiation sources is external and internal. Internal exposures originate from the intake of naturally occurring radioactive materials (NORM) by inhalation and ingestion. The major contribution to this human exposure comes from Radon (^{222}Rn). Radon and its short-lived decay products constitute about 53% of the total dose originating from natural sources [(1)]. Radon is the heaviest, colorless, odorless and tasteless and only radioactive member of noble gas group with a half-life of 3.82 days. It belongs to the ^{238}U decay series. Radon is present in soil, rocks, building materials and waters. Radon can get into the human body through inhalation radon in the air and ingestion radon in drinking water. Radon and its daughter emit ionizing alpha and beta radiations that may cause cancers in human organs [(2, 3)].

Radon is soluble gas in the water, thus the radon gas generated of the decay of uranium in the rocks and soil underground can easily pass underground water sources. Radon is similar to carbon dioxide in a soda bottle that is dissolved and then released when soda bottle is opened. Some radon may be left in the water and also, soil, building materials and underground water are the main sources of radon gas emanation [(4)]. Therefore, domestic water can make variable contributions to indoor radon level [(5)]. Radon concentrations can be highly significant for health risk especially at certain regions which drinking water comes from underground sources and where uranium-rich rocks situated.

According to USEPA (2010), the primary health risks from radon in drinking water are lung cancer, from inhaling radon discharged from water used in the home, and stomach cancer, from ingesting radon in drinking water [6]. When radon is inhaled or ingested, the alpha particles from its radioactive decay can interact with the biological tissues leading to DNA damage [7]. Because of all these reasons, the evaluation studies of the radiation dose from radon ingestion and inhalation in drinking water are conducted continuously all over the World. All of these studies are improving the understanding of the environmental processes that effect radon exposure.

The aim of this study is to describe the findings from ^{222}Rn activity concentrations of residential tap water samples for drinking purposes and to determine the annual effective dose due to waterborne radon in Kastamonu city Centre. Also, this region is the 1st degree earthquake zone [8]. The results obtained from this study will contribute to a database of environmental radioactivity measurements and will be useful for assessing of safety of the drinking water.

MATERIALS AND METHODS

Study area

Kastamonu is a city on the western Black sea region of Turkey and this region is an earthquake zone (figure 1).

The province has a total area of 13,108 km^2 and it is bordered by the provinces of Bartın, Karabük, Çankırı Çorum and Sinop. In accordance with statistics in Republic of Turkey, Kastamonu Governorship, the total area is 74.6% mountains and forests, 21.6% plateaus and 3.8% plains. The population of the city is about 368,000. The latitude and longitude of Kastamonu city are 41°21′ N and 33°46′ E, the altitude is 775 m above sea level. The mean annual rainfall is about 461, 6 mm for the area [9]. In Kastamonu, the household water is supplied from Karacomak Dam which is filled by water from surroundings streams and rainwater.

Radon activity in water

The study area is divided into 4 regions namely as Kuzeykent, City Centre, Esentepe and Olukbaşı, respectively and 15 water samples were taken from each region. Total 60 residential tap water measurements have been performed in city Centre of Kastamonu province. Sampling was done at random depending on who permitted us to carry out the study in his or her house. Water taps were opened for 5 minutes and water poured down the drain before sampling. Tap water samples were collected in 0.5 l linear polypropylene bottles and these bottles were completely filled slowly and immediately closed tightly under the water in order to avoid air bubbles. In addition, the

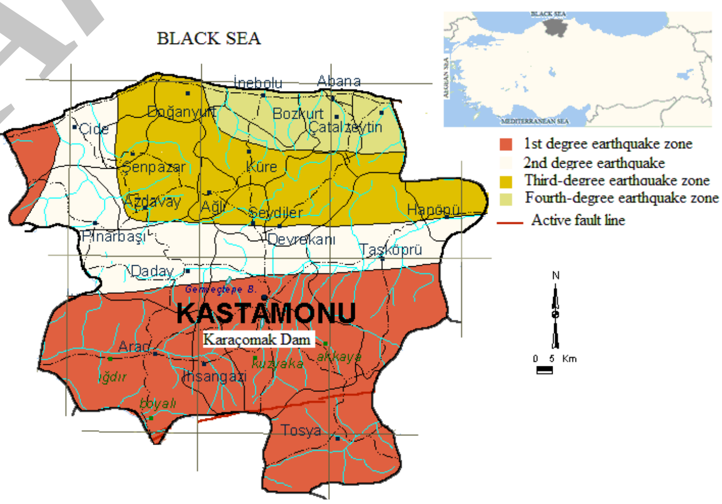

Figure 1. The location of sampling sites and earthquake map of Kastamonu [8].

radon activity concentrations in the 12 water samples collected from Karaçomak Dam which is household water supply were determined. All the water samples measurements were made in the Nuclear physics laboratory at Kastamonu University. Laboratory measurements were performed on the same day after drawing the samples. The results were recorded in units Bq m^{-3} and converted to Bq l^{-1}. Whole water samples were collected during winter season in 2014.

Radon concentrations of the water samples were measured using the professional radon monitor AlphaGUARD PQ2000 PRO which is a portable radon monitor with high storage capacity. This is an ionization chamber (0.62 l), designed for measuring radon in air, soil and water. AquaKIT, the additional equipment of AlphaGUARD, was used for the water measurements.

AlphaGUARD has ionization chamber whose was also a part of gas cycle. Radon was expelled from water samples (placed in emanation vessel) using the pump in a close gas cycle. The safety vessel was connected with the emanation vessel. All drops would deposit in it if they had got into the gas cycle during the degassing process. This way the stress of the water vapor was minimized for the radon monitor. After that the water was injected into the emanation vessel, and the AlphaGUARD and AlphaPUMP were switched on. The flow rate of the pump was 0.3 l min^{-1}. After 10 min the pump was switched off and the AlphaGUARD remained switched on for another 20 min, so the radon measurement was continued. The AlphaGUARD monitor worked in a 'flow' mode in a 1 minute. Before every water sample measurement, for a few minutes, the background of empty set-up was measured. Calibration of the measuring system has been carried out by Saphymo (Genitron Instruments, Germany), with a guaranteed stability and accuracy for 5 y. Briefly, this measuring system is portable, offers faster reading and accurate measurements. The following equation was used to determined radon concentrations in the water samples [10];

$$A_{water} = \frac{A_{air}\frac{(V_{system} - V_{sample})}{V_{sample}} + k) - A_0}{1000}$$

where A_{water} is radon concentration in water sample (Bqm^{-3}), A_{air} is radon concentration in the set-up after expelling radon from water (Bqm^{-3}), A_0 is background (Bqm^{-3}), V_{system} is interior volume of the measurement set-up (mL), V_{sample} is volume of the water sample (mL), and k is radon distribution coefficient.

$$k = 0.105 + 0.405e^{-0.502 \times T(^{\circ}C)}$$

RESULTS

The radon activity concentrations in the residential tap water samples were analyzed for 60 samples in Kastamonu city Centre. In the study area, residential tap water is obtained from surface water. The results for 60 samples categorized into four locations. Table 1 reports the results for the mean radon activity concentrations in residential tap water samples collected from each region of the study area. In dam water the radon activity concentrations were found to range from 2.28±0.113 Bq l^{-1} to 0.034±0.007 Bq l^{-1}, with a mean ^{222}Rn activity concentration of 0.741±0.046 Bq l^{-1}.

As shown in table 1, the radon activity concentrations of the residential tap water samples were found to range from 0.025±0.006 Bq l^{-1} to 0.128±0.025 Bq l^{-1}, with a mean ^{222}Rn activity concentration of 0.050±0.003 Bq l^{-1}.

As related with radiation dose which people are exposed to, waterborne radon may be a higher risk than all other contaminants in water [13]. In tap water, radon may cause to exposures from the inhalation of radon released to air when the water is used and from the ingestion of drinking water. The annual effective dose equivalent AEDE (μSv y^{-1}) for inhalation is calculated using equation 1:

$$AEDE\ (\mu Sv\ y^{-1}) = A(Bq\ l^{-1}) \times AWC x\ O \times EF \times DCF \times 1000\ (l/m^3) \quad (1)$$

where, A is the ^{222}Rn activity concentration in water (Bq l^{-1}), AWC is the is air water concentration ratio (10^{-4}), O is indoor occupancy of 7,000 hours per year, EF is the equilibrium factor (0.4) between radon and its decay products and DCF is the is the dose conversion factor for radon exposure 9 (nSv/$Bqm^{-3}h$) [14].

The annual effective dose equivalent AEDE ($\mu Sv\ y^{-1}$) for ingestion is calculated using equation 2:

$$AEDE\ (\mu Sv\ y^{-1}) = A\ (Bq\ l^{-1}) \times 60\ (l/y) \times 3.5\ (nSv\ Bq^{-1}) \quad (2)$$

where 60 ($l\ y^{-1}$) is weighted estimate of water consumption and 3.5 ($nSv\ Bq^{-1}$) is the effective dose coefficient for ingestion [14].

According to UNSCEAR (2000) report, the ingestion of tap water was estimated in the UNSCEAR (1993) Report to be 100, 75, and 50 $l\ y^{-1}$ by infants, children, and adults, respectively. Assuming the proportion of these groups in the population to be 0.05, 0.3, and 0.65, the weighted estimate of consumption was determined as 60 $l\ y^{-1}$ [14].

By using the information given above, the annual effective dose equivalent AEDE ($\mu Sv\ y^{-1}$) for inhalation, ingestion and total were calculated for the study area (table 1).

The annual effective dose equivalent values for first, second, third and fourth regions varied from 0.0630 to 0.3226 $\mu Sv\ y^{-1}$, 0.0756 to 0.1739 $\mu Sv\ y^{-1}$, 0.0882 to 0.1814 $\mu Sv\ y^{-1}$ and 0.0882 to 0.1588 $\mu Sv\ y^{-1}$ for inhalation; 0.0053 to 0.0269 $\mu Sv\ y^{-1}$, 0.0063 to 0.0145 $\mu Sv\ y^{-1}$, 0.0074 to 0.0151 $\mu Sv\ y^{-1}$ and 0.0074 to 0.0132 $\mu Sv\ y^{-1}$ for ingestion, respectively. The mean values for first, second, third and fourth regions were found to be 0.1534, 0.1243, 0.1186 and 0.1100 $\mu Sv\ y^{-1}$ for inhalation and 0.0128, 0.0104, 0.0099 and 0.0092 $\mu Sv\ y^{-1}$ for ingestion, respectively (table 1). In addition, for the radon exposure from ingestion, the annual effective dose equivalents were calculated separately for infants, children, and adults (table 2).

DISCUSSION

The results (table 1) show that, for Kastamonu city Centre, the mean ^{222}Rn activity concentration of the residential tap waters is relatively low. Also, both the measured radon activity concentrations in all the residential water samples and the mean value of all the samples were below the internationally recommended safe limit of 4-40 Bg l^{-1} [11], the maximum contaminant level (MCL) (300 pCi l^{-1}= 11.1 Bq l^{-1}) of the US Environmental Protection Agency [3] and the European Union recommended level of 100 Bql^{-1} [11], hence the tap waters of Kastamonu city Centre safe for drinking purposes in terms of radon activity concentrations.

The results from this research indicate that the annual effective dose equivalents due to radon in drinking water are below the WHO

Table 1. ^{222}Rn activity concentrations in the residential tap water and the annual effective doses.

Region	Sample No	^{222}Rn Concentrations ($Bq\ l^{-1}$)			Annual Effective Dose Equivalent ($\mu Sv\ y^{-1}$)		
		min (±uncertainty)	max (±uncertainty)	mean (±SD)	Inhalation	Ingestion	Total
First	15	0.025±0.006	0.128 ±0.025	0.061±0.004	0.1534	0.0128	0.1662
Second	15	0.030±0.004	0.069±0.008	0.049±0.003	0.1243	0.0104	0.1347
Third	15	0.035±0.007	0.072±0.011	0.047±0.001	0.1186	0.0099	0.1285
Fourth	15	0.035±0.005	0.063±0.009	0.044±0.001	0.1100	0.0092	0.1192
Mean		0.050±0.003			0.1266	0.0105	0.1371

Table 2. The annual effective dose equivalent from ingestion for infants, children, and adults.

Region	Number of Samples	Annual Effective Dose Equivalent $\mu Sv\ y^{-1}$ (ingestion)								
		infants			children			adults		
		min	max	mean	min	max	mean	min	max	mean
First	15	0.0088	0.0448	0.0213	0.0066	0.0336	0.0160	0.0044	0.0224	0.0107
Second	15	0.0105	0.0242	0.0173	0.0079	0.0181	0.0130	0.0053	0.0121	0.0086
Third	15	0.0123	0.0252	0.0165	0.0092	0.0189	0.0124	0.0061	0.0126	0.0082
Fourth	15	0.0123	0.0221	0.0153	0.0092	0.0165	0.0115	0.0061	0.0110	0.0076
mean		0.0176			0.0132			0.0088		

recommended reference level of 0.1 mSv y^{-1} for water samples [15]. Thus, the tap water can be used as drinking water without any radioactive contaminants. A comparison with the radon activity concentrations of tap waters from different studies conducted around the globe is given in table 3.

A comparison of the concentrations obtained in this research with other parts of world indicates that ^{222}Rn activity concentration of the tap water samples is very low except Istanbul [24]. The low radon concentrations in water of Kastamonu may be due to a number of factors, e.g. the geological structure, porosity of the soil, meteorological parameters, providing surface reservoirs, etc. On the other hand, the radon values in this study are lower than the action levels recommended by different monitoring agencies of the world, e.g. US EPA, UNSCEAR, EU. Therefore, radon poses comes from waterborne radon no threat to the lives of the people in this locality.

CONCLUSION

The ^{222}Rn activity concentrations were determined by AlphaGuard PQ 2000 Pro in 60 different residential tap water and 12 dam water samples collected from Kastamonu province. The mean activity concentrations of ^{222}Rn was found for all residential tap water samples and dam water samples. The mean annual effective dose equivalents were calculated. The results may be useful in assessment of exposures and ^{222}Rn doses from tap water using drinking purposes. Also, the results obtained from this research is baseline which can be used to evaluate possible future changes and will be provide a good baseline for setting standards for water quality.

Conflict of interest: *Declared None*

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Table 3. ^{222}Rn activity concentrations in tap waters from different parts of world, compared with those of the present study.

Country	Radon Activity (Bq l^{-1})	References
Jordan	2.5-4.7	Al-Bataina *et al.* [16]
Venezuela	0-2	Horvath *et al.* [17]
Brazil	0.39-0.47	Marques *et al.* [18]
Kenya	0.80–4.70	Otwoma and Mustapha [19]
Algeria	0.26–2.28	Amrani and Cherouati [20]
Cyprus	0.1–2.00	Sarrou and Pashalidis [21]
Egypt	0.007-2.33	Abbady *et al.* [22]
India	0.084-0.83	Kant *et al.* [23]
Cities of Turkey		
İstanbul	0.019-0.048	Karahan *et al.* [24]
Denizli	0.67-25.90	Ereeş *et al.* [25]
Afyonkarahisar	0.7-31.7	Yalım *et al.* [26]
İzmir-Dikili	0.029-3.08	Yarar *et al.* [27]
Bursa	0.91-53.64	Tarım *et al.* [28]
Amasya	0.28-2.4	Öner *et al.* [29]
Tokat	0.09-1.30	Yiğitoğlu *et al.* [30]
Kütahya	0.1-48.6	Şahin *et al.* [31]
Konya	1.44-27.45	Erdoğan *et al.* [32]
Zonguldak	0.32-88.22	Koray *et al.* [33]
Yalova	0.21-5.82	Tabar and Yakut [34]
Kastamonu/Turkey	0.025-0.128	Present Study

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