Determinition of Radon Concentrations in Surface Water Samples of Aygır Lake in Bitlis (Turkey)

Halime KAYAKÖKÜ¹,*

ABSTRACT: Aygır Lake is located in the province of Bitlis, Adilcevaz, in the east of Turkey. It is located on the south side of Süphan Mountain and is a tectonically formed lake. Since the waters of Aygır Lake are fresh, it is an important water source in terms of meeting the water needs of the agricultural areas in the south. For this reason, it was tried to determine whether the water of the lake would pose a health risk in terms of radon if it was consumed as drinking water and used in agricultural activities and fish farming. In the study, radon (²²²Rn) concentrations, the annual effective dose rate (AED) and the amount of dose the stomach takes (SED) in the surface water samples taken from Aygır Lake were tried to be determined. For this purpose, water samples were taken from 13 different points in the lake. Saphymo Gmbh AlphaGUARD Professional radon monitor was used to measure the radon activities of the water samples. As a result of the measurements, it is seen that the radon concentrations vary between 0.15 ± 0.01 Bq L⁻¹ and 0.71 ± 0.08 Bq L⁻¹. In addition, in the study, AED values ranged from 0.38 ± 0.03 nSv y⁻¹ to 1.81 ± 0.20 nSv y⁻¹, while SED values ranged from 0.05 ± 0.00 nSv y⁻¹ to 0.22 ± 0.02 nSv y⁻¹. When the results obtained are compared with the average international values, it is noticed that the results are below these values.

Keywords: Aygır Lake, radon, alphaGUARD, surface water

Bitlis Aygır Gölü (Türkiye) Yüzey Su Örneklerinde Radon Konsantrasyonunun Belirlenmesi

ÖZET: Aygır Gölü, Türkiye'nin doğusunda, Bitlis'in Adilcevaz ilçesinde yer almaktadır. Süphan Dağı’nın güney tarafında yer almaktadır, tektonik oluşumu bir göldür. Suları tatlı olduğu için güneyindeki tarım alanlarının su ihtiyaçlarını karşılaması bakımından Aygır Gölü önemli bir su kaynağıdır. Bu sebeple, güney suyu olarak tüketilmesi, tarımsal faaliyetlerde ve balık yetiştiriciliğinde kullanılması durumunda, radon açısından, sağlık için risk oluşturmaktadır. Çalışmada, Aygır Gölü’nden alınan su örnekleri radon (²²²Rn) konsantrasyonları, yıllık etkin doz oranı (AED) ve miyeden aldığı doz miktarı (SED) belirlenmeye çalışılmıştır. Su örnekleri, 13 farklı noktadan alınmıştı. Saphymo Gmbh AlphaGUARD Professional radon monitörü kullanılarak radon aktiviteleri ölçülmüştür. Ölçümler sonucunda radon konsantrasyonlarının, 0.15 ± 0.01 Bq L⁻¹ ile 0.71 ± 0.08 Bq L⁻¹ aralığına değiştiği görülüktedir. Ayrıca ölçümlerde AED değerleri 0.38 ± 0.03 nSv y⁻¹ ile 1.81 ± 0.20 nSv y⁻¹, SED değerleri 0.05 ± 0.00 nSv y⁻¹ ile 0.22 ± 0.02 nSv y⁻¹ arasında değişmiştir. Elde edilen sonuçlar ulusal aralıksal önerilen değerler ile kıyasladığında zaman, sonuçların, bu değerlerin altında olduğunu görülmüktedir.

Anahtar Kelimeler: Aygır Gölü, radon, alphaGUARD, yüzey su
INTRODUCTION

Water plays an important role in the life of living beings. The natural radioactivity of the water comes from the radioactive masses or minerals through which water flows. In natural waters, the uranium family is more common than the actinium and thorium family (Şahin, 2004).

$^{238}$U is the main component of natural uranium in the earth's crust (99.275%). Radon ($^{222}$Rn) is the first gas isotope in the $^{238}$U decay chain. In parallel with this, thoron ($^{220}$Rn) and actinon ($^{219}$Rn) appear as the first gas isotopes in the $^{232}$Th and $^{235}$U decay series. The decay of radon by alpha propagation creates three short-lived isotopes. These are $^{218}$Po, $^{214}$Pb and $^{214}$Bi (Valkovic, 2000). Radon is a colorless, odorless radioactive gas that cannot be detected by sensory organs. It is found more or less almost everywhere in nature. Radon has a half-life of 3.82 days (George, 2007). Radon gas spreads through diffusion to the soil and from there to the atmosphere or environment. With the accumulation of the gas, the radon density can reach critical values in closed or poorly ventilated places. Radon poses many dangers, especially lung cancer, when exposed to high doses (UNSCEAR, 1993; WHO, 2004; USEPA, 2011).

There are many methods of measuring radon. Usually, alpha count is used to measure radon gas and radon products. Radon measurement methods are divided into two as active and passive methods (Urban and Piesch, 1981). In the active measurement method, alpha particles are counted. Active measurement method requires devices such as electronic systems, pumps, power supplies. Ion chambers, scintillation cells or spectroscopic counting devices are used in the active system. AlphaGUARD measuring device works on the principle of active measurement method. In the passive measurement method, indirect measurements are made. In the passive measurement method, thermoluminescence detectors or solid state nuclear trace detectors cellulose nitrate (LR-115) or allyl diglycol carbonate (CR-39) are used.

In Turkey, many studies have been made for determining the radon concentration in water. At the same time, in different parts of the world, there are various studies in which the radioactivity of utility water, well water and thermal water are measured resulting dose calculations (Gosink et al., 1990; Al-Masri and Blackburn, 1999; Karahan et al., 2000; Çevik et al., 2006; Ėreş et al., 2006; Baykara and Dogru, 2006; Tarim et al., 2011; Yalcin et al., 2011; Bal et al., 2017).

According to WPCR (Water Pollution Control Regulation), Aygır Lake water was found in the first class quality water. It has been observed that the lake water complies with the limit values given by EPA (500 mg L$^{-1}$) and WHO (1000 mg L$^{-1}$) (Tebbutt, 1998; WPCR, 2004).

The purpose of the present study is to determine the radon concentrations, the annual effective dose rates and the amount of dose the stomach takes of surface water samples taken from Aygır Lake located in Adilcevaz district of Bitlis province. Thus, it will be attempted to determine whether the lake water will pose a health risk in terms of radon if it is consumed as drinking water and used in agricultural activities and fish farming. Radon concentration levels were measured with the Saphymo Gmbh AlphaGUARD Professional radon monitor using the active measurement method.

MATERIALS AND METHODS

Sampling and Measurement

Aygır Lake is located in the province of Bitlis, Adilcevaz, in the east of Turkey. The lake is at the coordinates 38° 50′ 14″ North, 42° 49′ 20″ East, the height of the lake is 1942 m and its area is approximately 1.6 km$^2$ (Dogu and Deniz, 2015; Çavuş, 2018). It is located on the south side of Süphan Mountain and is a tectonically formed lake. The lake is fed by rain and snow waters as well as groundwater. There are no streams or strong springs that constantly carry water to the lake. Since its
waters are fresh, Aygır Lake is an important water resource in terms of meeting the water needs of the agricultural areas in the south. Additionally, this lake, which contains different fish species, plays an important role in terms of fishing.

In this study, samples were taken from 13 different points from the lake in June 2020 from a depth of 20 cm from the surface and placed in 1 liter polyethylene bottles. After the samples brought to the laboratory, they were filtered by filter paper, and then the samples were measured and analyzed immediately. Sampling points are shown in Figure 1.

Figure 1. Water sampling points from Aygır Lake

Figure 2 shows an view of the AlphaGUARD radon measurement system in water.

Figure 2. The AlphaGUARD radon measurement setup in water (GENITRON INSTRUMENTS, 2001; Tanrıverdi, 2016)

Radon measurement system in waters consists of AquaKIT, AlphaPUMP, AlphaGUARD PQ2000 PRO. Radon concentration measurement can be made with AlphaGUARD radon detector in the range of 2–2,106 Bq m$^{-3}$. Despite this wide range, there is a 3% margin of error resulted from the system itself.
The AlphaGUARD detector, which gives the measurement results in Bq m\(^{-3}\), can simultaneously measure three different climatic parameters such as temperature, atmospheric pressure and humidity. The units of these parameters are °C, mbar and rH\%, respectively (Genrich, 2006). The measurement was made for 10 minutes before filling the purification bottle section with the water sample. The result of this measurement is C\(_0\) (natural background value). The clarification vessel was filled with 100 ml of water sample. The measurements made for 10 minutes while the pump was on and 20 minutes while the pump was off which makes 30 minutes in total (Nikolopoulos et al., 2010; Meisenberg et al., 2017). The concentration value obtained as a result of this measurement was also recorded as C\(_{\text{air}}\). Sample and background counts were performed three times for each samples. Before filling each sample, the system, gases etc. are cleaned in order to carry out the measurement process. Cleaning the measuring device continued until the radon value reached ambient concentration. After this step, the measurement procedure was made again for another sample. All data obtained as a result of the measurements were evaluated in the DataEXPERT program.

Radon concentrations of the water samples were calculated using the equation 1.

\[
C_{\text{RnW}} = \frac{C_{\text{air}} (V_{\text{system}} - V_{\text{sample}} + k) - C_0}{1000}
\]

herein, \(C_{\text{RnW}}\) is the radon concentration of the water sample (Bq L\(^{-1}\)); \(C_{\text{air}}\) is the concentration value specified in the measurement result (Bq m\(^{-3}\)); \(C_0\) is the natural background concentration (Bq m\(^{-3}\)); \(V_{\text{system}}\) is the interior volume of the measurement setup (560 mL); \(V_{\text{sample}}\) is the volume of the sample (100 mL); and \(k\) is the radon distribution coefficient (GENITRON INSTRUMENTS, 2007; Davutoğlu, 2008).

According to WPCR, the water of Aygır Lake was found in first class quality water (WPCR, 2004). According to RWIHC (Regulation on Water Intended for Human Consumption), the pH value of the water is between 6.5 and 9.5, so it is suitable for drinking water (Türkman et al., 1999; RWIHC, 2005; Emre and Kürüm, 2007). If the lake water is consumed as drinking water, the annual effective dose (AED) contribution from radon gas to the body for adults can be calculated by using equation 2.

\[
AED = C_{\text{RnW}} \times C_W \times D_{CW}
\]

herein, AED is dose exposed over a period of one year due to drinking water; \(C_{\text{RnW}}\) is \(^{222}\)Rn concentration in water; \(C_W\) is estimated amount of water used over a year for adults (730 L y\(^{-1}\)); \(D_{CW}\) is dose conversion factor (3.5×10\(^{-9}\) Sv Bq\(^{-1}\)).

After drinking the water goes directly to the stomach. As a result of studies conducted in water, it has been stated that if the concentration of radon in drinking water is high, it may pose a risk of cancer in the stomach. Accordingly, it is of great importance to calculate the amount of dose the stomach takes. With the help of equation 3, the dose to which the stomach will be exposed can be calculated.

\[
SED = AED \times W_T
\]

herein, SED is the annual dose that the stomach takes; \(W_T\) is the weight factor used for the stomach in dose calculations (\(W_T=0.12\)) (Prasad, 2008). The tissue weight factor used in dose calculations was taken from the report published by the ICRP in 1993 (ICRP, 1993).
RESULTS AND DISCUSSION

The $^{222}$Rn concentration results ($C_{RnW}$), AED and SED values obtained after measurement and calculations in this study are given in Table 1 and Figure 5. In addition, the analysis results of the sample S-10 in the AlphaGUARD radon measurement system are given in Figure 3 to give an example.

Table 1. $C_{RnW}$, AED and SED values in water samples of Aygır Lake, Turkey

| Sample No | Temperature (°C) | Humidity (%) | Pressure (mbar) | k | $C_{RnW}$ (Bq L$^{-1}$) | AED (nSv y$^{-1}$) | SED (nSv y$^{-1}$) |
|-----------|-----------------|--------------|----------------|---|-------------------------|-------------------|-----------------|
| S-1       | 27.4            | 37.8         | 816            | 0.21 | 0.31 ± 0.03             | 0.79 ± 0.08 | 0.10 ± 0.01     |
| S-2       | 27.3            | 38.8         | 816            | 0.21 | 0.45 ± 0.05             | 1.15 ± 0.13 | 0.14 ± 0.02     |
| S-3       | 27.2            | 38.0         | 816            | 0.21 | 0.15 ± 0.01             | 0.38 ± 0.03 | 0.05 ± 0.00     |
| S-4       | 27.4            | 41.7         | 816            | 0.21 | 0.31 ± 0.03             | 0.79 ± 0.08 | 0.10 ± 0.01     |
| S-5       | 27.3            | 38.6         | 816            | 0.22 | 0.38 ± 0.06             | 0.97 ± 0.15 | 0.12 ± 0.02     |
| S-6       | 26.9            | 40.9         | 816            | 0.22 | 0.64 ± 0.08             | 1.64 ± 0.20 | 0.20 ± 0.02     |
| S-7       | 26.5            | 44.3         | 817            | 0.22 | 0.33 ± 0.06             | 0.84 ± 0.15 | 0.10 ± 0.02     |
| S-8       | 26.8            | 44.0         | 817            | 0.22 | 0.44 ± 0.04             | 1.12 ± 0.10 | 0.13 ± 0.01     |
| S-9       | 27.2            | 47.2         | 817            | 0.21 | 0.37 ± 0.01             | 0.95 ± 0.03 | 0.11 ± 0.00     |
| S-10      | 27.5            | 46.2         | 817            | 0.21 | 0.71 ± 0.08             | 1.81 ± 0.20 | 0.22 ± 0.02     |
| S-11      | 27.1            | 39.2         | 817            | 0.21 | 0.29 ± 0.04             | 0.74 ± 0.10 | 0.09 ± 0.01     |
| S-12      | 27.3            | 39.2         | 817            | 0.21 | 0.56 ± 0.05             | 1.43 ± 0.13 | 0.17 ± 0.02     |
| S-13      | 27.0            | 34.8         | 817            | 0.21 | 0.32 ± 0.02             | 0.82 ± 0.05 | 0.10 ± 0.01     |
| **Average** | **27.2**       | **40.8**     | **817**        | **0.21** | **0.41 ± 0.05**         | **1.03 ± 0.13** | **0.12 ± 0.02** |

Figure 3. The analysis results of the sample S-10 in the AlphaGUARD radon measurement system
In present research, $^{222}\text{Rn}$ activity concentrations of samples ranged from $0.15 \pm 0.01$ Bq L$^{-1}$ to $0.71 \pm 0.08$ Bq L$^{-1}$, with an average activity of $0.41 \pm 0.05$ Bq L$^{-1}$. The AED values ranged from $0.38 \pm 0.03$ nSv y$^{-1}$ to $1.81 \pm 0.20$ nSv y$^{-1}$, while SED values ranged from $0.05 \pm 0.00$ nSv y$^{-1}$ to $0.22 \pm 0.02$ nSv y$^{-1}$.

The $C_{\text{RnW}}$, AED and SED values in water samples are shown in Figure 5.

When Table 1, Figure 4 and Figure 5 are examined together, it is seen that the lowest $C_{\text{RnW}}$, AED and SED values belong to the sample number S-3 and the highest $C_{\text{RnW}}$, AED and SED values belong to the sample number S-10. The higher the concentration of radon in the water, the higher the AED and SED values.
Erdoğdu (2015) collected water samples from 36 different points in the province of Osmaniye (Turkey). As a result of the measurements and calculations performed using the AphaGUARD PQ 2000 PRO radon detector, the average $C_{RnW}$, AED and SED were found as 0.426 Bq L$^{-1}$, 1.088 µSv y$^{-1}$ and 0.131 µSv y$^{-1}$, respectively (Erdoğdu, 2015).

Gyuk et al. (2017) calculated the average $C_{RnW}$ and AED values in 25 well water samples as 9.46 Bq L$^{-1}$ and 0.0721 mSv y$^{-1}$, respectively (Gyuk et al., 2017).

In another similar study, Hussein (2020) made radon measurements in different types of drinking water samples in Egypt using nuclear track detectors (LR-115 Type II). As a result of the study, the average $C_{RnW}$ in water samples was determined as 0.634 Bq L$^{-1}$ and the average AED value for adults was 9.953 µSv y$^{-1}$ (Hussein, 2020).

Table 2. Comparison of the average $^{222}$Rn activity concentration obtained in present study with the averages obtained in similar studies and the recommended limit values

| Lake, Country           | $^{222}$Rn activity concentration (Bq L$^{-1}$) | Reference                                      |
|-------------------------|-----------------------------------------------|------------------------------------------------|
| England (English Lake District) | (53.70 ± 8.15) × 10$^{-3}$, (1130.74 ± 35.92) × 10$^{-3}$ | (Al-Masri and Blackburn, 1999)                 |
| Darbandakhan Lake, Iraq  | 18.17                                         | (Shivakumara et al., 2014)                    |
| Manzala Lake, Egypt     | 1.73 - 6.40                                   | (Yousef et al., 2017)                         |
| Çavuşçu Lake, Turkey    | 0.170 - 32.631                                | (Tüfekcioğlu, 2015)                           |
| Van Lake, Turkey        | (40.43 ± 3.73) × 10$^{-3}$ (Spring), (64.94 ± 5.99) × 10$^{-3}$ (Autumn) | (Kayakökü and Doğru, 2020)                   |
| WHO                     | 100                                           | (WHO, 2004)                                   |
| UNSCEAR                 | 40                                            | (UNSCEAR, 1993)                               |
| USEPA                   | 11.1                                          | (USEPA, 2011)                                 |
| Aygır Lake, Turkey      | 0.41 ± 0.05                                   | This study                                    |

If radon concentrations are compared for this study with studies that have been taken from lakes located in different cities and countries, it is noticed that the result values are generally lower than the results of other studies (According to Table 2).

Zorer et al. (2013) investigated the radon concentrations of the water samples taken from two points in Aygır Lake using CR-39 passive nuclear trace detectors. At the end of the study, they calculated the radon concentrations for these two points as 0.048 and 0.355 Bq L$^{-1}$, respectively (Zorer et al., 2013). These values are consistent with the values obtained in the present study. In addition, radon concentration measurements were made in other lake waters in regions close to the study area. Average radon concentrations were calculated as 0.150 Bq L$^{-1}$ and 0.102 Bq L$^{-1}$ for Arin and Nazik Lakes, respectively, and 0.175 Bq L$^{-1}$, 0.106 Bq L$^{-1}$ and 0.068 Bq L$^{-1}$ for Ilik Lake, Soğuk Lake and Kara Lake respectively, which are from the Nemrut Lakes (Zorer et al., 2013). These results are lower than the average value obtained in present study, 0.41 ± 0.05 Bq L$^{-1}$.

Kayakökü and Doğru (2020) calculated the radon concentrations in Van Lake surface water samples. Experimental studies were carried out using CR-39 passive radon trace detectors and Radosys radon measurement system. The average radon concentration was calculated as 0.040 Bq L$^{-1}$ in spring, whereas as 0.065 Bq L$^{-1}$ in autumn (Kayakökü and Doğru, 2020). Likewise, these average values are lower than the values obtained in this study.

Differences in meteorological parameters may cause different radon content in samples. The rock types of Bitlis and its districts are generally composed of limestone and magmatic granite, granitic gneiss, andesite, decides and some of their features are shaped by basaltic lavas (Bal et al., 2017). When water touches rocks throughout the medium they pass through, some substances are dissolved and carried by the water. Aygır Lake is located on the south side of Süphan Mountain and it is a tectonically...
formed lake. In addition, fault lines pass through the land where the lake is located. This may be the reason for the high concentration of radon in the lake.

CONCLUSION

In this study, the radon concentrations were measured by using the Saphymo GmbH AlphaGUARD Professional radon monitor in Bitlis Eren University Physics Department. While the lowest $C_{RnW}$, AED and SED values belong to the S-3 sample, the highest $C_{RnW}$, AED and SED values belong to the S-10 sample. The southern part of the lake is Pliocene sedimentary units, the western part is Miocene sedimentary units, northern and eastern sections are surrounded by lava flows $(760 \pm 40 - 150 \pm 40) \times 10^3$ years old (Özdemir et al., 2016). In addition, Süphan Volcanic Mountain is located in the northern part of the lake and there is also a fault line passing through the north of the lake. S-3 point, where radon activity is the lowest, is a flat area in the southwestern part of the lake, and is located on the right side of the highway to Aygır village. S-10 point, where radon activity is highest, is in the northeastern part of the lake and this is the mountainous area. This place is close to both the Süphan Mountain and the fault line. It is also a point close to the area where people go for picnics. This region is a region where intensive agricultural activities are carried out. The fact that this area is surrounded by $(760 \pm 40 - 150 \pm 40) \times 10^3$ years old lava flows and the soil structure can be shown among the reasons that affect the high radon level. Radon concentrations obtained from the calculations determined to be lower than 100 Bq L$^{-1}$, 40 Bq L$^{-1}$ and 11.1 Bq L$^{-1}$, which are the limit values for drinking water set by World Health Organization (WHO), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the US Environmental Protection Agency (USEPA).

When the dose taken as a result of ingestion of radon in drinking water is examined, it is seen that the amount of dose changes according to the radon concentration. The International Atomic Energy Agency (IAEA) and World Health Organization (WHO) have determined the total dose for the dose taken from drinking water in one year; this value is 0.1 mSv y$^{-1}$ $(10^5$ nSv y$^{-1}$) (IAEA, 2002; WHO, 2004). When the results obtained in this study are compared with this limit value, it is seen that the results are below this limit value. Therefore, the $^{222}$Rn concentration values determined in the waters of Aygır Lake do not cause any harm to health.

The data obtained as a result of this study show that using the Aygır Lake water in agriculture (irrigation etc.) and fish farming will not result in radiological hazard. Additionally, the natural and artificial radionuclide concentrations and heavy metal contents of the lake can be determined by doing a more detailed study.

ACKNOWLEDGEMENTS

I would like to thank Prof. Dr. Sezai YALÇIN and Assoc. Prof. Sultan ŞAHİN BAL for sharing their knowledge and experiences with me during the measurement and analysis processes.

Conflict of Interest

I declare that there is no conflict of interest during the planning, execution and writing of the article.

Author’s Contributions

I hereby declare that the planning, execution and writing of the article was done by me as the sole author of the article.

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