Cumhuriyet Sci. J., 46(4) (2025) 931-936
DOI: https://doi.org/10.17776/csj.1746864

Cumhuriyet Science Journal

| csj.cumhuriyet.edu.tr | Founded: 2002 ISSN: 2587-2680 e-ISSN: 2587-246X Publisher: Sivas Cumhuriyet University

Estimation of Radiation Dose and Lifetime Risk from Gross Alpha/Beta Radioactivity in Drinking Water in Şırnak City, Türkiye

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Research Article

History
Received: 21/07/2025
Accepted: 23/09/2025

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ABSTRACT

The research aimed to evaluate the radiological quality of drinking water in Şırnak city, Türkiye. A gas proportional α/β counter (Berthold, LB 770 model) was employed to quantify the gross α and β activities **in a** total of seven drinking water samples. The findings revealed that the average gross α and β activities were 27 mBq/L (range: 19-35 mBq/L) and 117 mBq/L (range: 24-534 mBq/L), respectively. The age-dependent annual effective dose (AED) resulting from the ingestion of drinking water in Şırnak was meticulously estimated. The calculated average total AED values (alpha+beta) were 9.5 µSv/y for infants, 22.1 µSv/y for children, and 46.2 µSv/y for adults. The average lifetime risk of radiation-induced cancer (LTR) for the population was found to be 1.7×10^{-4}. Overall, the study concluded that the radiological parameters in Şırnak city's drinking water were within the permissible limits recommended by the World Health Organization (WHO). These findings provide significant assurance that the drinking water in the region is safe for consumption, concerning radiation exposure. Furthermore, the results imply that existing water treatment and monitoring systems are effective in maintaining radiation levels within safe limits. The study highlights the importance of regular testing and evaluation of water quality to protect public health.

Keywords: Gross α/β, Drinking water, Annual effective dose, Lifetime risk

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Introduction

Ionizing radiation has played a crucial role in the existence of life on Earth. Over the course of 4 billion years, living organisms have been exposed to natural ionizing radiation from high-energy particles in the atmosphere and radionuclides in the Earth's crust. Moreover, human activities such as electricity generation at nuclear power plants, nuclear weapons testing, and the use of radionuclides in industry, medicine, and research have contributed to increased radiation exposure. The presence of ionizing radiation is indispensable for life as we know it [1-3]. Ionizing radiation, which includes alpha particles, beta particles, and gamma rays, possesses enough energy to dislodge tightly bound electrons from atoms and form ions. Prolonged exposure to ionizing radiation, especially through ingestion, can cause significant harm to living organisms by inducing DNA damage, potentially resulting in various diseases, including cancer [4-5].

Given the critical role of ionizing radiation in both natural and human-induced contexts, understanding its presence in drinking water supplies is essential for public health and safety. Radionuclides, naturally occurring in rocks and soil, can enter water supplies through leaching and the Earth's crust's decay [6]. The presence of radioactivity in water is linked to the activity concentrations of natural and artificial radionuclides [7], due to alpha and beta decay processes. The quantity of radioactive components dissolved and released depends on factors such as soil geochemical composition, mineralogical structure, and water chemical composition [8]. These radionuclides enter the food chain through water that people drink directly and also through groundwater or surface water used to irrigate field crops. The World Health Organization (WHO) recommends maintaining alpha and beta activity levels in drinking water below 0.5 Bq/L and 1 Bq/L, respectively [6]. Monitoring and comparing radioactivity levels in water samples with these standards helps countries identify potential issues and take appropriate measures to address them.

Recently, gross alpha and beta radioactivity levels in various water samples have been analyzed worldwide to assess radioactivity and annual effective dose levels [8-21]. Şırnak province, located in the southeastern Anatolia region of Turkey, has a rich historical background. The city is expected to grow in the near future due to the recent discovery of large reserves of high-quality oil in the province. A comprehensive review of the literature

highlights a significant paucity of published data concerning the radioactivity levels in Şırnak's drinking water. Prior to this study, the only recorded measurements in Şırnak province were confined to gross alpha and beta activities in spa waters [22]. Therefore, the present study aims to (i) determine the concentrations of gross alpha and beta radioactivity in drinking water samples collected from various locations within Şırnak province, and (ii) estimate age-specific annual effective doses and the lifetime risk of radiation-induced cancer using internationally accepted radiological health models. These objectives are pursued to provide a scientific basis for evaluating the potential health risks associated with exposure to naturally occurring radionuclides in drinking water. The findings will support public health authorities and regional policymakers in developing evidence-based water safety regulations. Moreover, this study addresses a critical gap in the literature by generating region-specific radiological risk data, thereby contributing to the protection of public health and the assurance of safe drinking water for the residents of Şırnak.

Materials and methods

Study area

Şırnak Province is situated in the southeastern region of Turkey. It has a population of 570,745, according to the 2024 population census by the Turkish Statistical Institute (TurkStat) [23], and spans a total surface area of 7,172 km². Geographically positioned at 37°31' north latitude and 42°28' east longitude, it lies at a considerable altitude, averaging 1,400 meters above sea level. Şırnak comprises the central district and seven local districts: Cizre, Silopi, Güçlükonak, Uludere, İdil, and Beytüşşebap, along with one other district [24]. Figure 1 depicts the sampling sites. Additionally, Table 1 provides detailed information on the geographical features of the research region. Its mountainous and rugged terrain adorns the region with natural beauty.

Figure 1. Sampling Locations Representing Şırnak Province, Türkiye.

Table 1. Population and geographic features in the research region

Locations	Sample Code	Latitude	Longitude
Şırnak (city center)	1	37°30'44.20" N	42°27'8.75" E
Beytüşşebap	2	37°34'15.76" N	43°10'7.01" E
Uludere	3	37°26'43.00" N	42°51'6.72" E
Silopi	4	37°14'57.71" N	42°27'40.26" E
Cizre	5	37°19'25.83" N	42°11'17.89" E
İdil	6	37°20'21.69" N	41°52'52.67" E
Güçlükonak	7	37°28'17.88" N	41°54'51.57" E

Sampling

Two-liter sterile polyethylene containers were used to meticulously collect water samples. Each container underwent three thorough washes with water before receiving the samples, followed by double-distilled water. To ensure no stagnant water remained in the pipes, the tap was briefly turned on prior to sample collection. Once collected, the samples were acidified with nitric acid to prevent precipitation on the container walls and to inhibit microbial growth. These labeled containers were then carefully transported to the laboratory for further analysis. The Global Positioning System (GPS) precisely recorded the sampling sites, as illustrated in Figure 1.

Experimental procedure

The quantification of gross α activity in the water samples was performed using the Standard Methods (SM7110) precipitation technique [25], while the measurement of gross β activity was conducted according to the Environmental Protection Agency (EPA-900) evaporation method [26]. Each drinking water sample was meticulously prepared for analysis in accordance with these standardized methods. Several studies [8, 11, 27-31] have comprehensively detailed these methodologies. The radioactivity concentrations of gross α and β in the water samples were analyzed using a low-background multiple detector gas proportional α/β counter (Berthold LB 770) to ensure precise measurements. This counter can measure alpha and beta activities simultaneously on 10 samples. The sample detector is designed with counters featuring the gas-flow windows' design, each with a diameter of about 5 cm, optimizing the detection of radioactivity. An argon-methane (90–10%) gas mixture was used in the instrument to improve its detection of radioactivity. The detector of this counter had an operating voltage of 1650 V, and it was set up using ^{241}Am (for alpha) and ^{90}Sr/^{90}Y (for beta) standards [8, 11, 27–31]. The average counting efficiency for alpha and beta activities was 19–21% and 71–73%, respectively. This was very important for accurately determining the levels of radioactivity. Lead shielding equips the instrument to effectively minimize background radiation, thereby enhancing the result's accuracy and reliability. Background readings were obtained by counting an empty planchet for 100 minutes, and sample residues were counted twice for the same amount of time to ensure the results were reliable and consistent [31].

Annual Effective Dose and Lifetime Cancer Risk Calculations

Annual effective dose (AED) and lifetime risk (LTR) associated with radiation exposure through the ingestion of water were estimated to assess the radiological risks for different age groups. AED and LTR resulting from the ingestion of a given radionuclide were calculated using equations 1 and 2, respectively.

$$AED_{\alpha/\beta} = \sum_i A_{i(\alpha/\beta)} \times AWC \times DCF_{(\alpha/\beta)} \quad (1)$$

$$LTR = RCC \times \sum_i AED_{i(\alpha/\beta)} \times T_{(i)} \quad (2)$$

where $A_{i(\alpha/\beta)}$ represents the gross alpha/beta activity (Bq/L), AWC is the annual water consumption taken as 150, 350, and 730 L for infants (<1 y), children (1-17 y), and adults (>17 y), respectively [19], the dose conversion coefficients for ingestion (DCF) are denoted as DCF(α/β), with average values of 3.4×10−4 mSv/Bq for alpha-emitting radionuclides and 4.6×10−4 mSv/Bq for beta-emitting radionuclides (The dose conversion coefficients (DCFs) of ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Po, and ^{232}Th for alpha-emitting radionuclides, and ^{210}Pb, ^{228}Ra, and ^{40}K for beta-emitting radionuclides were averaged. This averaging approach was adopted because the measurements were based on gross alpha and beta activities, without identifying individual radionuclides.) [8], RCC is the risk conversion coefficient for the entire population (5.5×10^{-2} 1/Sv) [32] and T_i is 1 year for infants, 16 years for children and 60.3 years for adults, based on a life expectancy of 77.3 years in Türkiye, as reported by the Turkish Statistical Institute (TurkStat) in 2024 [33].

Results and Discussions

The radioactivity concentrations in drinking water samples from various locations within Şırnak Province, Turkey, are presented in Table 2. The measured gross alpha activities ranged from 0.019 Bq/L to 0.035 Bq/L, with an average of 0.027 Bq/L. Meanwhile, gross beta activities ranged from 0.024 Bq/L to 0.534 Bq/L, with an average of 0.117 Bq/L. Notably, gross beta activities consistently exceeded gross alpha activities across all samples. This could be attributed to ^{40}K, a beta-emitting radionuclide, naturally occurring in the environment at constant ratio with respect to stable potassium. Due to the pervasive presence of potassium, ^{40}K often predominates as the principal contributor to gross beta radioactivity in potable water sources [21]. The lowest activity concentrations were recorded in the city center, whereas the highest values were observed in the Cizre district. The variation in activity concentrations can be attributed to differences in geological formations, mineral compositions, and hydrogeological processes. Factors such as the presence of natural radionuclides, rock types, and groundwater flow patterns significantly influence the gross alpha and beta activities in the water samples [17, 34]. The high gross beta activity observed in Cizre may suggest that beta-emitting radionuclides originate from local sources, possibly associated with geological formations or agricultural activities. Agricultural practices in the region, including the potential use of phosphate-based fertilizers, could be contributing factors to elevated beta activity levels in soil and groundwater. These findings highlight the importance of continuous and rigorous monitoring to ensure the radiological quality of drinking water remains within safe limits, thereby providing reassurance to the residents of Şırnak.

Table 2. Gross α and β activity concentrations and comparison with studies in the literature.

Locations	Gross Alpha (mBq/L)	Gross Beta (mBq/L)	
Şırnak (city center)	19±6	24±8	
Beytüşşebap	21±7	39±11	
Uludere	30±8	69±13	
Silopi	27±8	63±16	
Cizre	35±9	534±33	
İdil	26±7	54±14	
Güçlükonak	34±9	38±11	
Average	**27**	**117**	
Region	Gross Alpha (mBq/L)	Gross Beta (mBq/L)	Reference
Nevşehir (Türkiye)	88	305	[8]
Bartın (Türkiye)	39	135	[13]
Siirt (Türkiye)	26	104	[11]
Trabzon (Türkiye)	18	43	[16]
Hatay (Reyhanlı, District) (Türkiye)	13	201	[17]
Ankara (Türkiye)	105	195	[20]
Diyarbakır (Türkiye)	41	99	[31]
Mersin (Türkiye)	59	120	[34]
Guilan (Iran)	52	110	[9]
Shano and Bagwai (Nigeria)	142	285	[10]
District of Abidjan (Cote d'Ivoire)	13	174	[15]
Ma'an (Jordan)	401	297	[19]
Irbid (Jordan)	295	611	[36]
Goias state (Brazil)	30	58	[37]
Vojvodina region (Serbia)	300	210	[38]
Seven Chinese geographical regions (China)	29	91	[39]
Global average	**103**	**190**	
WHO	500	1000	[6]
Average	**27**	**117**	Present Study

Table 3. Radiological parameters in drinking water for each location

Locations	AED (μSv/y)									LTR (x10^{-4})
	Infants			Children			Adults			
	Alpha Emitters	Beta Emitters	Total	Alpha Emitters	Beta Emitters	Total	Alpha Emitters	Beta Emitters	Total	
Şırnak (city center)	1.0	1.7	2.7	2.3	3.9	6.2	4.7	8.1	12.8	0.5
Beytüşşebap	1.1	2.7	3.8	2.5	6.3	8.8	5.2	13.1	18.3	0.7
Uludere	1.5	4.8	6.3	3.6	11.1	14.7	7.4	23.2	30.6	1.1
Silopi	1.4	4.3	5.7	3.2	10.1	13.3	6.7	21.2	27.9	1.0
Cizre	1.8	36.8	38.6	4.2	86.0	90.2	8.7	179.3	188.0	7.0
İdil	1.3	3.7	5.0	3.1	8.7	11.8	6.5	18.1	24.6	0.9
Güçlükonak	1.7	2.6	4.3	4.0	6.1	10.2	8.4	12.8	21.2	0.8
Average	**1.4**	**8.1**	**9.5**	**3.3**	**18.9**	**22.1**	**6.8**	**39.4**	**46.2**	**1.7**

The measured activities of the present study have been compared with those reported in the literature and are delineated in Table 2. In this study, the average gross alpha and beta activities were determined to be 27 mBq/L and 117 mBq/L, respectively. These values are significantly lower than the global average (gross alpha: 103 mBq/L and gross beta: 190 mBq/L) and the World Health Organization's (WHO) recommended limits of 500 mBq/L for gross alpha and 1000 mBq/L for gross beta activities; indicating a minimal radiological risk to the local population. Compared to other regions, Şırnak's gross alpha activity is significantly lower than those recorded in Nevşehir (88 mBq/L) and Ankara (105 mBq/L) within Türkiye and markedly lower than the values observed in Irbid, Jordan (295 mBq/L) and Ma'an, Jordan (401 mBq/L). Similarly, Şırnak's gross beta activity is lower than that reported in Nevşehir (305 mBq/L), Ankara (195 mBq/L), and several international locations, including Irbid, Jordan (611 mBq/L) and Shano and Bagwai, Nigeria (285 mBq/L).

Table 3 presents the calculated annual effective dose (AED) and lifetime cancer risk (LTR) values. The estimated AED values for α-emitters range from 1.0 to 1.8 μSv/y for infants, 2.3 to 4.2 μSv/y for children, and 4.7 to 8.7 μSv/y for adults. For β-emitters, the AED values range from 1.7 to 36.8 μSv/y for infants, 3.9 to 86.0 μSv/y for children, and 8.1 to 179.3 μSv/y for adults. The total average AED values (alpha + beta) are 9.5 μSv/y for infants, 22.1 μSv/y for children, and 46.2 μSv/y for adults. These average values are lower than those reported for Nevşehir (Türkiye) (43 μSv/y for infants, 60 μSv/y for children, and 124 μSv/y for adults) [8]. Similarly, they are lower than the values reported for Shanono and Bagwai (Nigeria) (171 μSv/y for infants, 342 μSv/y for children, and 685 μSv/y for adults) [10]. The LTR values varied from 0.5×10^{-4} to 7.0×10^{-4}, with an average of 1.7×10^{-4}. This average value

is observed to be lower than that of other provinces of Türkiye, such as Nevşehir (5.5×10^{-4}) [35] and Diyarbakır (2.5×10^{-4}) [31], yet higher than that of Artvin (1.0×10^{-4}) [28], and aligns with the value reported for Mersin (1.7×10^{-4}) [34]. The World Health Organization [6] recommends that the annual exposure to natural radioactivity in drinking water should not exceed 0.1 mSv. Considering a typical human lifespan of 70 years, this equates to a cumulative lifetime exposure limit of 7 mSv (70 years × 0.1 mSv/year). Based on these guidelines, the lifetime risk attributable to drinking water should not exceed 3.85×10^{-4}, calculated as 7 mSv × (5.5×10^{-2}) 1/Sv [19]. Adherence to these limits is crucial for ensuring public health and safety. These total average AED and LTR values are below the permissible limits set by the World Health Organization, which are 0.1 mSv/y, and 3.85×10^{-4}, respectively. The AED and LTR values observed in water samples from the Cizre district (sample code 5) exceed the permissible limits. Therefore, it is imperative to conduct periodic monitoring by collecting additional water samples from this region. This will ensure the continuous assessment and effective management of water quality in Cizre. Consequently, all water samples collected in Şırnak city, except for those from the Cizre district, are deemed safe for consumption. This indicates that the radioactivity levels in the drinking water of Şırnak city do not pose significant health risks.

Conclusions

This study conducted a thorough evaluation of the radiological health risks associated with drinking water in Şırnak province by examining gross alpha and beta activities. The average gross alpha and beta activities were determined to be 27 mBq/L and 117 mBq/L, respectively, both of which are significantly below the World Health Organization's recommended limits of 500 mBq/L for gross alpha and 1000 mBq/L for gross beta activities. These findings were contextualized through comparison with data obtained from other regions in Turkey and internationally. The age group's annual effective dose (AED) and lifetime cancer risk (LTR) values were computed, indicating that the average values are below the World Health Organization's (WHO) recommended ingestion dose limit of 100 µSv/y for AED and the reference value of 3.85×10^{-4} for LTR, respectively. The results indicate minimal health risks from radioactive contamination in Şırnak city's drinking water. Based on these insights, local authorities should focus on sustaining current gross alpha and beta activity levels through effective measures. Additionally, ongoing monitoring and regular testing are crucial to ensure that radioactivity levels remain within safe limits. This study provides essential data for public health officials and policymakers, enhancing efforts to protect the health and well-being of residents by mitigating potential risks associated with radioactive pollution in drinking water.

Conflict of interest

The authors declare that there is no conflict of interest.

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