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MEASUREMENT OF RADON CONCENTRATION IN WATER SAMPLES FROM THE KELBAJAR DISTRICT OF AZERBAIJAN AND RISK ASSESSMENT OF ITS RADIATION DOSE

F.Y. Humbatov[1,2*], **G.F. Aslanova**[1], **R.I. Khalilov**[1,3]

[1]Institute of Radiation Problems, Ministry of Science and Education, Baku, Azerbaijan
[2]Azerbaijan University of Architecture and Construction, Baku, Azerbaijan
[3]Department of Biophysics and Biochemistry, Faculty of Biology, Baku State University, Baku, Azerbaijan

Abstract. This study aims to determine the concentrations of radon activity in water sources available in the Kalbajar region of Azerbaijan and to assess the risks associated with radon activity for different age groups, using both direct measurements and calculations recommended by the International Atomic Energy Agency (IAEA). The study results indicate that radon activity and radiation levels in the Kalbajar region differ by location. Radon concentration in water samples was measured using a RAD-7 detector with a RAD H_2O accessory. The annual effective dose from radon exposure when using water sources was calculated for adults, children, and infants. The values of total annual effective dose for all age groups in Source 2 and infants in Source 4 significantly exceed the reference dose level of 1 mSv/y recommended for the public by WHO and UNSCEAR. It should be noted that direct consumption of untreated water from these sources may increase the risk of stomach and lung cancer. The relatively high electrical conductivity of the studied water sources indicates the high mineralization of these sources. The conducted analyses confirm a direct proportional relationship between the radiation background observed around the studied water sources in the Kalbajar region and the radon concentration in the sources.

Keywords: Radon measurement, Thermal water, Annual effective dose, Kalbadjar district, RAD7, water consumption.

*__Corresponding author:__ Famil, Humbatov, Institute of Radiation Problems, Ministry of Science and Education, Baku, Azerbaijan, Tel.: +994505738315, e-mail: *hfamil@mail.ru*

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1 Introduction

It is known that of the total radiation dose to the population, natural sources of radiation account for approximately 82%, and artificial sources account for the remaining 18%. Natural Radiation Sources consist Radon, Internal,Terrestrial and Cosmic radiation sources. Artificial sources are: Medical X-rays, Nuclear Medicine, Consumer Products and other sources (NCRP Report No. 93, 1987).

As shown in Figure 1, Radon sources are responsible for 55% of the radiation dose received from Natural Radiation Sources.According to the National Council on Radiation Protection and Measurements (NCRP), Radon sources are responsible for 37% of the radiation dose received from Natural Radiation Sources in the U.S. (NCRP Report No.160., 2006). UK Health Security Agency estimated this value as 48% for UK (UK Radon). All of this data suggests that radon plays a significant role in people's radiation exposure and may pose a greater health risk (Risk Assessment of Radon in Drinking Water, 2005., National Research Council, 1998).

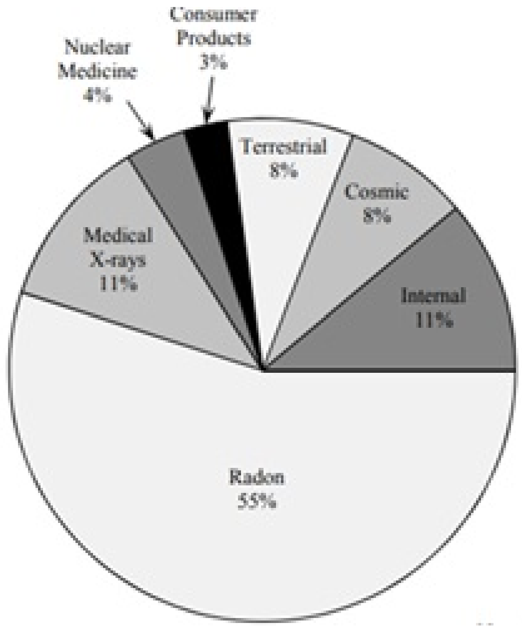

Figure 1: Exposure to Ionizing Radiation for the Public

Radon is a radioactive gas with no colour, smell or taste. It is released from bedrock material and passes through the soil. It then tends to dilute in the air, so outdoors, radon poses no harm to human health (IAEA, What is Radon, 2021). Radon is a radioactive gas that results from the natural decay of uranium and radium found in nearly all rocks and soils. Elevated radon levels have been found in the different points of the world. Radon is in the atmosphere and can also be found in ground water (EPA, Radionuclide Basics, 2024). Radon is one of the most radioactive and toxic gases, a known as carcinogen and is considered by the World Health Organization (WHO) to be the second leading cause of lung cancer after smoking (Madureira et al., 2016). Radon is the main risk factor among the nonsmokers (Feyzullaev et al., 2015). Meanwhile, very high level of radon in drinking water can be a significant risk of the gastrointestinal and stomach cancer (Zhuo et al., 2001). In addition, the radon in drinking water is associated with stomach cancer, contributing up to 30 deaths per year (Wedin et al., 2013; Effects and Risks of Ionizing Radiations, 2000). Both ground and fresh water usually contain a variety of radionuclides. One of the most frequently studied natural radionuclides is 222Rn since it delivers the highest doses to humans after its intake via ingestion of drinking water (Oliveira et al., 2001). Radon (222Rn), formed during radium disintegration, is a naturally occurring radioactive element, an odourless, colourless and tasteless noble gas that provides the largest contribution to the effective dose absorbed by the population. It has a half-life of 3.82 days, decays by emitting $5.49 MeV \alpha$ particles, and generates radioactive progeny. Two of the 222Rn decay products, 214Po and 218Po, are α emitters, and they contribute over 90% to the total radiation dose received due to radon exposure (Marques et al., 2004). Radon is soluble in water, its solubility decreases rapidly with increasing temperature (theoretically calculated values are $510, 220$ and $130 cm^3 \cdot l^{-1}$ at $0, 25$ and $50^0 C$, respectively) (UNSCEAR, Exposures From Natural Sources of Radiation, 1993). Radon is extremely volatile and is readily released from water. Water coming from deep geological zones and underground water stemming from uranium-rich soil are the first candidates for high radon and radium concentrations (NCRP Report No. 93, 1987). The radon concentration levels in surface water are generally very low, whereas the highest concentrations of dissolved radon are usually found in many groundwater systems flowing through granite or granitic sand and gravel formations, in aquifer and sedimentary rocks, in very deep wells and in crystalline rocks (Ali et al., 2010).

Considering the above facts, the measurement of 222Rn concentration in water has attracted many researchers in different parts of the world. The main objective of this study is to measure the 222Rn concentration in various water sources widely used as drinking water sources in the Kalbajar region of Azerbaijan. The work also aims to know the changes in radon concentration and to estimate the radiation dose for the population consuming this water and to assess whether the 222Rn concentration in water is within the permissible limits. This type of study has been recorded in a small number in Azerbaijan (Feyzullaev et al., 2015; Humbatov, 2020) so far and this assessment is being carried out for the first time in the Kalbajar region.

From the other hands, in the last 30 years, monitoring and research works have not been carried out in the territory of Karabakh and Eastern Zangezur economic regions, which include Kalbajar region. During this period, the deliberate change of the topography of the region, merciless looting of natural resources, and the use of heavy military equipment and various types of explosives polluted the area, disturbed the ecological balance, and caused pollution of existing water sources.

For this reason, it is of particular importance to measure the radiation background in the area, and to determine the physico-chemical and biological characteristics of the water sources in order to control the water quality.

2 Materials and methods

Kalbajar is the highest mountainous region of Azerbaijan.Kalbajar is located at an altitude of 1500-3800 meters above sea level, in the valley of the Tartar River, in the Lesser Caucasus Mountains.Kalbajar region borders the Republic of Armenia to the west, Dashkesan, Goygol, Goranboy to the north, Tartar to the northeast, Aghdam, Khojaly to the east, and Lachin to the south.Jurassic, Cretaceous, Paleogene, Neogene and anthropogenic sedimentary, volcanogenic-sedimentary and volcanic rocks are widespread in the territory of Kalbajar region. The largest river is the Tartar and its tributaries - the Lev River and Tutgunchay. The source of the Bazarchay is also in the territory of Kalbajar region. There are lakes in the area: Alagollar, Garagol, Zalkha Lake, etc. There are more than thirty thousand springs and hundreds of mineral springs in Kalbajar. It should be noted that there are up to 412 mineral water deposits in the basin of the Tartar River alone.

Istisu mineral springs in the Kalbajar region were formed as a result of swelling and cracking of the earth during a strong earthquake in 1138 year. Istisu mineral spring water is hyperthermal, carbon dioxide, hydrocarbonate-chloride-sulfate-sodium. Istisu mineral waters located in the Kalbajar region are particularly distinguished by their favorable gas and chemical composition, high temperature, and large natural resources. Its waters can treat both external and internal human diseases.

Since the waters of the mentioned sources are used for various purposes, especially as drinking water, it is of particular importance to assess the concentration of Radon in these sources and the radiation dose that people may receive when using these waters.

Drinking water is the most important food. Therefore, its availability, quality, and regulation are delicate and important topics. In 1991, EPA proposed an MCL for radon of 11 Becquerel's per liter (about 300 pCi per liter) for radon in drinking water (Risk Assessment of Radon in Drinking Water, 2005; Assessment of Exposure to Radon in Drinking Water 1999). The European Commission recommends for 222Rn, that a reference level should be appointed above an activity concentration of 100 Bq/l (Guidelines for Drinking-water Quality 2004).

3 Sample collection and analysis

The present study was conducted to investigate Radon contents in water samplesand the radiation dose that people may receive using these waters. We collected samples from 11 different points in the territory of Kalbajar region (Figure 2).

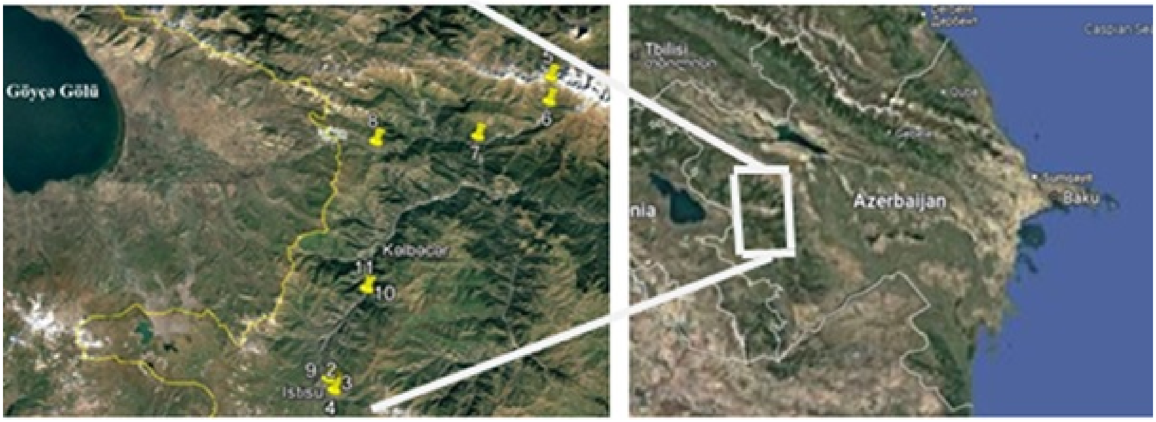

Figure 2: Location of sources from which water samples were taken in the Kalbajar region of Azerbaijan

Table 1: The coordinates of the sampling points and water parameters

N:	**Name of sampling location**	Coordinates NE	pH	COND μ S/cm	TDS mg/L	SAL%	T, ^{o}C
1	Kalbajar, Istisu, Well 26	39.933367° 45.970450°	8	5080	2540	0.27	58.5
2	Kalbajar, Istisu, Well 20	39.927500° 45.970250°	7	4400	2200	0.23	45.2
3	Kalbajar, Istisu, Well 5.7	39.927233° 45.970567°	8	6300	3150	0.33	17.0
4	Kalbajar, Istisu, spring 5.8	39.928425° 45.969523°	8	5170	2580	0.27	16.0
5	Kalbajar, Omar Pass - spring	40.288848° 46.291084°	7.78	119	59	0.01	2.8
6	River Meydanchay point 1	40.262058° 46.290236°	8.37	155	78	0.01	7.9
7	River Meydanchay point 2	40.221672° 46.183624°	8.54	257	129	0.01	13.1
8	A tributary of the Lev river from Zod	40.213227° 46.028791°	8.01	538	269	0.03	10.5
9	Istisu sanatorium, hot spring	39.940954° 45.961611°	6.92	5440	2720	0.29	47.5
10	Istisu, Thermal water (circular pool)	40.042629° 46.016388°	6.83	6130	3065	0.32	51.0
11	Tartar river, near the circular pool of thermal water	40.042653° 46.016665°	7.23	552	225	0.02	15.1
	WHO (World Health Organization)		**6.5-8.5**	**500-1000**	**500**		

During the sample collection, handling, and preservation, the standard procedures recommended by the EPA and ASTM were followed to ensure data quality and consistency. All water samples were analyzed for water parameters (pH, Conductivity, Salinity, TDS, and T.) by portative equipment in sampling points. To enhance precision, measurements are iterated multiple times, ensuring reliable data collection. The results obtained from the water samples are tabulated, providing a comprehensive overview of their respective characteristics (Table 1). This approach guarantees accurate assessment of the water's composition and quality. As shown in Table 1, the electrical conductivity and TDS measured for the samples taken from the sampling points 1,2,3,9 and 10 have a higher value than other sources, exceed the recommended limit according to the guidelines of the World Health Organization (WHO) and cannot be recommended as drinking water sources. The relatively high electrical conductivity of the mentioned water sources indicates the high mineralization of these sources. Hence, it's not advisable to utilize the mentioned water sources (sampling points 1,2,3,9 and 10) directly for drinking purposes without processing.

Different methods are adopted in different parts of the world to measure the 222Rn concentration in water (Feyzullaev et al., 2015; Victor et al., 2016; Manzoor et al., 2008; Suomela, 1993). In this study, RAD − 7, Portable Radon Detector is used (RAD-7 Electronic Radon Detector User Manual, 2023).

The RAD7 device works according to the energy of the alpha particles emitted by radon and Thoron. The RAD method uses a closed-loop aeration design where the volume of air and water is constant and independent of the low velocity. The air recirculates through the water and continuously removes radon until an equilibrium state is reached. The RAD-7 system reaches this equilibrium state in approximately 5 minutes, after which no more radon can be removed from the water. This device has two glass bottles of 40 and 250 cc, based on which two protocols (watt 40 and 250 watts) are designed. In this study, the watt 250 protocol was used. According to this protocol, the first 5 minutes of bubble blowing was performed automatically. During the bubble blowing phase, 94% of the radon gas dissolved in the water was removed and the pump stopped automatically after 5 minutes. The system waited 5 minutes for the gas to reach equilibrium. Then, alpha particles were counted and the first reading was taken after 5 minutes. The system waited for 5 minutes for the gas to reach equilibrium. Then, alpha particles were counted and the first reading was taken after 5 minutes. In fact, the first reading was taken 15 minutes after starting the operation. This meant that the radon concentration was measured in four 5-minute stages. The nuclei of Rn-222 decay in the RAD7 section and form positively charged ions of Po-218. The electric current in the section causes the ions to drift towards the detector. The short-lived Po-218 nucleus decays on the active surface of the detector and emits alpha particles. This particle will enter the detector, and the machine generates a signal proportional to the intensity of the alpha particles. The device then records the alpha particle at its corresponding energy and determines the radon concentration based on the number of particles recorded (Pb-214 and Po-210 emit alpha particles in addition to Po-218). To remove radon from the device, it was in a purge phase for 10 minutes after each sample was read. In fact, the time required for each sample, including the time needed for purge, was 40 minutes. The radon concentration was measured multiple times for each sample, and the minimum, maximum, and average radon activity (average of five measurements) were recorded (Table 2).

In all investigated water samples Rn-222 isotope was observed, which changes in range 0.014-1000 Bq/l.

The highest concentration of radon was found in water from well ? 20 (> 1000 Bq / L) and the lowest concentration was found in water from the Meydanchay River- point 1 (0.014 Bq/L).

In 1991, EPA proposed an MCL for radon of 11Becquerel's per liter (about 300 pCi per liter) for radon in drinking water (Risk Assessment of Radon in Drinking Water, 2005; Risk Assessment of Exposure to Radon in Drinking Water, 1999). The European Commission recommends for 222Rn, that a reference level should be appointed above an activity concentration of 100 Bq/l (Guidelines for Drinking-water Quality, 2004). Values of radon concentration for water sources 2 and 4 exceed the EPA recommended level of 11 Bq/l, and the action level of 100 Bq/l recommended by WHO. It means that if people will use this water sources for a long time as drinking water, so it is possible they may have lung and stomach cancer risks in the future. However, it is recommended to boil the noted water before use for drinking to decrease the level of radon concentration.

Table 2: Radon concentration in water samples taken from the Kalbajar region of Azerbaijan

N:	Name of sampling location	Coordinates NE	Elevation (h), m	Radon Bq/L	Radiation Background μ R/h
1	Kalbajar, Istisu, Well 26	39.933367° 45.970450°	2363	2.86	8.6
2	Kalbajar, Istisu, Well 20	39.927500° 45.970250°	2381	>1000	296
3	Kalbajar, Istisu, Well 5.7	39.927233° 45.970567°	2398	8.3	82.5
4	Kalbajar, Istisu, spring 5.8	39.928425° 45.969523°	2364	442	286
5	Kalbajar, Omar Pass - spring	40.288848° 46.291084°	2604	0.071	3.6
6	River Meydanchay point 1	40.262058° 46.290236°	2113	0.014	2.5
7	River Meydanchay point 2	40.221672° 46.183624°	1350	0.186	2.8
8	A tributary of the Lev river from Zod	40.213227° 46.028791°	2037	0.673	3.6
9	Istisu sanatorium, hot spring	39.940954° 45.961611°	2220	1.38	7.1
10	Istisu Thermal water (circular pool)	40.042629° 46.016388°	1597	0.817	4.4
11	Tartar river, near the circular pool of thermal water	40.042653° 46.016665°	1596	0.042	4.7
	Minimum		**1350**	**0.014**	**2.5**
	Maximum		**2604**	**>1000**	**296**
	Average		**2093**	**105.122**	**61.89**

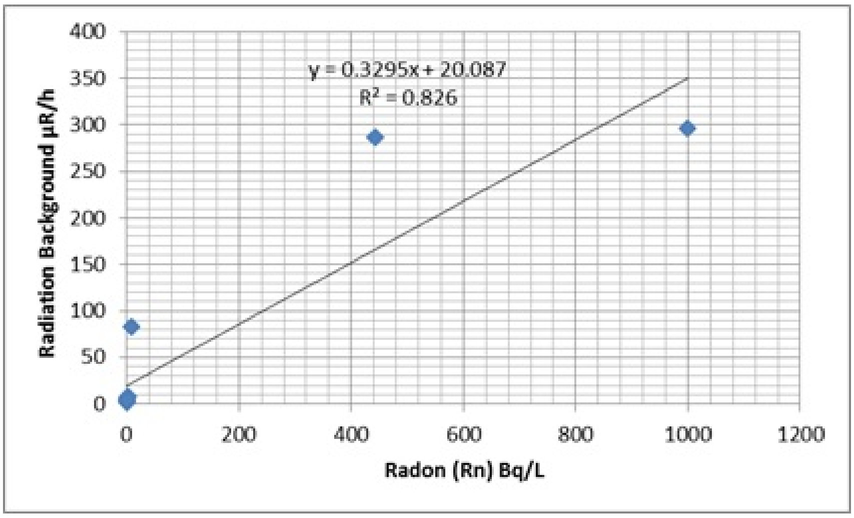

Figure 3: The relationship between the radiation background and the radon content in waters Kalbajar region of Azerbaijan

During the study, additional radiation background measurements were conducted at 11 locations in the Kalbajar region where water sources are located in order to assess radioecological risk. Gamma radiation exposure dose rates were measured using the IndetiFINDER-2 dosimeter-spectrometer according to the recommendations of the International Atomic Energy Agency (UNSCEAR, 1988, 1993, 2000a, 2000b). Measurements were made according to standard operating procedures, and the average radiation background was determined to be $61.8 \mu R/h$, with the natural radiation background observed for these locations varying in the range of $2.5 - 296 \mu R/h$. Relatively high radiation levels were observed in the area around sampling point N:2 and 4 (Kalbajar, Istisu, Well N:20 and Kalbajar, Istisu, spring 5.8), which necessitates continuous monitoring. Overall, the observed results for background radiation measurements indicate that there may be risks when people stay for a long time at measurement points 2, 3 and 4 in the studied area in terms of radiation safety (Table 2).

The conducted analyses confirm that there is a direct proportional relationship between the radiation background (Figure 3) observed around the studied water sources of the Kalbajar region and the concentration of radon observed in the sources. This fact allows us to say that both measured quantities vary due to the geochemical characteristics of the area and that radon water sources have a significant impact on the change in the radiation background in the surrounding areas.

4 Dose estimation methods

The annual effective dose to an individual person due to ingestion of radon from drinking water is evaluated using the following equation (Effects and Risks of Ionizing Radiations, 2000).

$$AED_{ing} = C_W L_W EDC,$$

where AED_{ing} is the annual effective dose ($mSvy^{-1}$ due to ingestion of radon from the consumption of water; C_W is radon concentration in drinking water ($BqL^{-1}; L_W$ is annual intake of drinking water (Ly^{-1}, the values of L_W suggested by UNSCEAR for adult, child and infant are $500Ly^{-1}$, $350Ly^{-1}$ and $150L^{-1}$ respectively; EDC is the dose conversion factor for radon ingestion (mSv Bq^{-1}). The dose conversion factor (EDC) varies for different age groups, and the values of EDC recommended by UNSCEAR Report 2000, (Effects and Risks of Ionizing Radiations, 2000; UNSCEAR, 2000) for adult (more than 17 years), child (more than 7 years to 12 years) and infant (1 year – 2 years) are 3.5×10^{-6} mSv Bq^{-1}, 5.9×10^{-6} mSv Bq^{-1}, and 2.3×10^{-5} mSv Bq^{-1} respectively. For evaluation of AED_{ing}, the sesuggested values of L_W and EDC were used in this study.

The annual effective dose resulting from inhalation of radon released from water and mixed into the air can be calculated using the following equation (UNSCEAR, 2000; Duggal et al., 2017; Tan et al., 2019).

$$AED_{inh} = CW \times f \times F \times t \times DCF_{inh},$$

where AED_{inh} is the annual effective dose due to inhalation (mSv y^{-1}); CW is the average radon concentration in water (BqL^{-1}); f is the transfer coefficient of radon from water to air; F is the equilibrium factor between indoor radon and its progeny; t is the average annual indoor occupancy time in hours, assumed to be 7000 h; DCF_{inh} is dose conversion factor for radon inhalation. The UNSCEAR 2000 Report recommends a value of 1×10^{-4} for transfer coefficient of radon from water to air (f). The equilibrium factor between indoor radon and its progeny (F) recommended by UNSCEAR and ICRP is 0.4 (UNSCEAR, 2000; ICRP, 2010). Dose conversion factor for radon inhalation (DCF_{inh}), a value of 9×10^{-9} Sv $(Bqhm^{-3})^{-1}$ is suggested in the UNSCEAR Report 2000. In current study this value was used for all ages of the public.

It is known that a small amount of radon dissolved in blood via inhalation can also result in a certain radiation dose, and the annual effective dose of this part can be evaluated by the following equation (UNSCEAR, 2000):

$$AED_{dis} = CW \times f \times t \times DCF_{dis},$$

where AED_{dis} is the annual effective dose due to radon dissolved in the blood through inhalation ($mSvy^{-1}$); CW is the concentration of radon in water (BqL^{-1}); f is the coefficient of transfer of radon from water to air; t is the average annual duration of indoor exposure, 7000 hours; DCF_{dis} is the dose conversion factor for radon dissolved in the blood, the value of $0.17 \times$

$10^{-6}mSv(Bqhm^{-3})^{-1}$ is recommended by the UNSCEAR Report 2000. This value was used for the estimation of AED_{dis} in current study.

5 Results and discussion

The calculated values of annual effective dose (AED_{ing}) for three age groups (infants, children and adults) related to radon intake in 11 water samples are presented in Table 3.

Table 3: The annual effective dose to an individual person due to ingestion of radon from drinking water

N/N	C_W Radon (Rn)	**EDC** Adult	**EDC** Child	**EDC** infant	L_W Adult	L_W Child	L_W infant	AED_{ing} Adult	AED_{ing} Child	AED_{ing} infant
	Bq/L	mSv Bq^{-1}	mSv Bq^{-1}	mSv Bq^{-1}	Ly^{-1}	Ly^{-1}	Ly^{-1}	mSv y^{-1}	mSv y^{-1}	mSv y^{-1}
1	2,86	3,50E-06	5,90E-06	2,30E-05	500	350	150	5,01E-03	5,91E-03	9,87E-03
2	1000	3,50E-06	5,90E-06	2,30E-05	500	350	150	1,75E+00	2,07E+00	3,45E+00
3	8,3	3,50E-06	5,90E-06	2,30E-05	500	350	150	1,45E-02	1,71E-02	2,86E-02
4	442	3,50E-06	5,90E-06	2,30E-05	500	350	150	7.74E-01	9.13E-01	1.52E+00
5	0,071	3,50E-06	5,90E-06	2,30E-05	500	350	150	1,24E-04	1,47E-04	2,45E-04
6	0,014	3,50E-06	5,90E-06	2,30E-05	500	350	150	2,45E-05	2,89E-05	4,83E-05
7	0,186	3,50E-06	5,90E-06	2,30E-05	500	350	150	3,26E-04	3,84E-04	6,42E-04
8	0,673	3,50E-06	5,90E-06	2,30E-05	500	350	150	1,18E-03	1,39E-03	2,32E-03
9	1,38	3,50E-06	5,90E-06	2,30E-05	500	350	150	2,42E-03	2,85E-03	4,76E-03
10	0,817	3,50E-06	5,90E-06	2,30E-05	500	350	150	1,43E-03	1,69E-03	2,82E-03
11	0,042	3,50E-06	5,90E-06	2,30E-05	500	350	150	7,35E-05	8,67E-05	1,45E-04

For the adult, AED_{ing} value varies from $0.0245\mu Svy^{-1}$ to $1.75mSvy^{-1}$ with an average value of $0.232mSvy^{-1}$; for the child, AED_{ing} value ranges from $0.0289\mu Svy^{-1}$ to $2.07mSvy^{-1}$ with an average of $0.273mSvy^{-1}$; for the infant, AED_{ing} value is in the range of $0.0483\mu Svy^{-1}$ to $3.45mSvy^{-1}$ with an average value of $0.457mSvy^{-1}$. As can be seen from Table 4, the annual effective doses for adults, children and infants from source 2 in the study area are well above the WHO (2008) reference dose level of $0.1mSvy^{-1}$ from drinking water consumption. Although the annual effective doses for adults and children from source 4 are safe, they are well above the reference dose level for infants. The annual effective doses for water intake from other sources are well below the recommended reference dose level for all age groups. However, for health reasons, it is recommended that water in the study area, especially from sources 2 and 4, be boiled to remove dissolved radon before drinking.

The annual effective dose (AED_{ih}) values due to inhalation of radon released from water into the air were also calculated and presented in Table 4.

The value of AED_{ih} for all age group varies from $3.53 \times 10^{-8}mSvy^{-1}$ to $2.52 \times 10^{-3}mSvy^{-1}$ with an average value of $3.34 \times 10^{-4}mSvy^{-1}$. It should be noted that to reduce the effects of radon released from water, it is better to take measures to increase ventilation in enclosed areas and capture radon decay products in the air through filters.

In the next step, the annual effective dose (AED_{dis}) from radon dissolved in the blood through inhalation was calculated and is given in Table 5.

The value of AED_{dis} ranges from $1.67 \times 10^{-9}mSvy^{-1}$ to $1.19 \times 10^{-4}mSvy^{-1}$ with an average value of $2.44 \times 10^{-5}mSvy^{-1}$ for all ages. As can be seen, the annual effective dose from inhaled radon dissolved in the blood is smaller than that from AED_{ih} and AED_{ing}.

Thus it could be concluded that the ingestion of radon from drinking water is a substantial part of radiological hazard in the study area and $AED_{ing} > AED_{ih} > AED_{dis}$.

The estimated total annual effective dose values (sum of AED_{ing}, AED_{ih}, and AED_{dis}) were calculated and presented in Table 6.

Table 4: The annual effective dose, resulted from inhalation of indoor air radon released from water for all age groups

N/N	Radon (Rn)	t,	f	F	DCF$_{inh}$	AED$_{inh}$
	Bq/L	hours			mSv $(Bqhm^{-3})^{-1}$	mSv y^{-1}
1	2.86	7.00E+03	1.00E-04	4.00E-01	9.00E-06	7.21E-06
2	1000	7.00E+03	1.00E-04	4.00E-01	9.00E-06	2.52E-03
3	8.3	7.00E+03	1.00E-04	4.00E-01	9.00E-06	2.09E-05
4	442	7.00E+03	1.00E-04	4.00E-01	9.00E-06	1.11E-03
5	0.071	7.00E+03	1.00E-04	4.00E-01	9.00E-06	1.79E-07
6	0.014	7.00E+03	1.00E-04	4.00E-01	9.00E-06	3.53E-08
7	0.186	7.00E+03	1.00E-04	4.00E-01	9.00E-06	4.69E-07
8	0.673	7.00E+03	1.00E-04	4.00E-01	9.00E-06	1.70E-06
9	1.38	7.00E+03	1.00E-04	4.00E-01	9.00E-06	3.48E-06
10	0.817	7.00E+03	1.00E-04	4.00E-01	9.00E-06	2.06E-06
11	0.042	7.00E+03	1.00E-04	4.00E-01	9.00E-06	1.06E-07

Table 5: The annual effective dose caused by radon dissolved in the blood through inhalation for all age groups

N/N	Radon (Rn)	t,	f	DCF_{dis}	AED_{dis}
	Bq/L	hours		mSv$(Bqhm^{-3})^{-1}$	mSv y^{-1}
1	2.86	7.00E+03	1.00E-04	1.70E-07	3.40E-07
2	1000	7.00E+03	1.00E-04	1.70E-07	1.19E-04
3	8.3	7.00E+03	1.00E-04	1.70E-07	9.88E-07
4	442	7.00E+03	1.00E-04	1.70E-07	5.26E-05
5	0.071	7.00E+03	1.00E-04	1.70E-07	8.45E-09
6	0.014	7.00E+03	1.00E-04	1.70E-07	1.67E-09
7	0.186	7.00E+03	1.00E-04	1.70E-07	2.21E-08
8	0.673	7.00E+03	1.00E-04	1.70E-07	8.01E-08
9	1.38	7.00E+03	1.00E-04	1.70E-07	1.64E-07
10	0.817	7.00E+03	1.00E-04	1.70E-07	9.72E-08
11	0.042	7.00E+03	1.00E-04	1.70E-07	5.00E-09

Table 6: Total annual effective dose caused by Radon for different age groups

N/N	Radon (Rn)	Total AED for adult	Total AED for child	Total AED for infant
	Bq/L	mSv y^{-1}	mSv y^{-1}	mSv y^{-1}
1	2.86	5.01E-03	5.91E-03	9.87E-03
2	1000	1.75E+00	2.07E+00	3.45E+00
3	8.3	1.45E-02	1.71E-02	2.86E-02
4	442	7.74E-01	9.13E-01	1.52E+00
5	0.071	1.24E-04	1.47E-04	2.45E-04
6	0.014	2.45E-05	2.89E-05	4.83E-05
7	0.186	3.26E-04	3.84E-04	6.42E-04
8	0.673	1.18E-03	1.39E-03	2.32E-03
9	1.38	2.42E-03	2.85E-03	4.76E-03
10	0.817	1.43E-03	1.69E-03	2.82E-03
11	0.042	7.35E-05	8.67E-05	1.45E-04

The estimated total annual effective dose value for adults ranged from $2.45 \times 10^{-5} mSvy^{-1}$ to $1.75 mSvy^{-1}$ with an average value of $0.232 mSvy^{-1}$; for the child ranged from $2.89 \times 10^{-5} mSvy^{-1}$ to $2.07 mSvy^{-1}$ with an average of $0.273 mSvy^{-1}$; for the infant ranged from $4.83 \times 10^{-5} mSvy^{-1}$ to $3.45 mSvy^{-1}$ with an average value of $0.457 mSvy^{-1}$. These values significantly exceed the reference dose level of $1 mSvy^{-1}$ recommended for the public by WHO (2008) and UNSCEAR (2000) for all age groups in source 2 and for infants in source 4. Considering that other radiation sources may also affect the formation of the total annual effective dose, it is necessary to monitor the study area and inform the population.

6 Conclusion

In this study, samples taken from 11 water sources in the Kalbajar region of Azerbaijan were analyzed for water parameters and Radon concentration, and radiation background measurements were performed around 11 water sources. In addition, we evaluated the radiation doses received by people via the ingestion and inhalation of radon from the consumption of water. The results show that 2 samples have radon concentration higher than the USEPA's MCL value, and that the radon level in water varies significantly spatially in the region. Measurements of water parameters indicate that almost all samples have high mineralization

The magmatic activity and magmatic-hydrothermal system in the area, which create a relatively high uranium background, lead to relatively high levels of radon in groundwater. In addition, different geological and mineralization levels can cause significant variations in radon concentrations in groundwater samples. The conducted analyses confirm that there is a direct proportional relationship between the radiation background observed around the studied water sources of the Kalbajar region and the concentration of radon observed in the sources. This fact allows us to say that both measured quantities vary due to the geochemical characteristics of the area and that radon water sources have a significant impact on the change in the radiation background in the surrounding areas. The results for background radiation measurements indicate that there may be health risks when people stay for a long time at measurement points 2, 3 and 4 in the studied area in terms of radiation safety.

The values of total annual effective dose for all age groups in Source 2 and infants in Source 4 significantly exceed the reference dose level of $1 mSvy^{-1}$ recommended for the public by WHO (2008) and UNSCEAR (2000). It should be noted that direct consumption of untreated water from these sources may increase the risk of stomach and lung cancer. Considering that other radiation sources may also affect the formation of total annual effective dose, it is recommended to conduct regular monitoring and inform the population in the study area.

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