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DETERMINATION OF RADON CONCENTRATIONS IN SOME SCHOOLS IN TATVAN DISTRICT OF BITLIS PROVINCE

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ABSTRACT

Schools are essential social infrastructures where children spend a significant part of their time and require close attention to ensure a safe and healthy environment. In this study, ^{222}Rn concentration measurements and annual effective dose calculations were conducted in 20 schools in Tatvan district of Bitlis province using LR-115 (Type-2) nuclear track detectors. Measurements were conducted over two periods: spring (March, April, May) and autumn (September, October, November). Indoor radon concentrations ranged from 23.39 to 222.06 Bq/m³ in spring and 42.68 to 308.38 Bq/m³ in autumn, with arithmetic means of 83.68 Bq/m³ and 126.49 Bq/m³, respectively. In addition, the effect of floor level on indoor radon concentration was investigated. A clear floor-level variation was observed, with ground-floor rooms (mean: 120.77 Bq/m³) showing higher radon levels than upper-floor rooms (mean: 89.40 Bq/m³). Moreover, the annual effective dose due to radon exposure for teachers and students in the schools were estimated to range from 0.19 and 1.51 mSv/y. Annual effective dose measurements showed that although most schools fall within acceptable radiological ranges, two schools (S1 and S5) recorded annual effective doses slightly above the 1.15 mSv/y global average reported by UNSCEAR (2000). These findings highlight the need for continued monitoring and preventive measures to ensure radiological safety in educational environments.

Keywords: Annual effective dose, Bitlis, LR-115, Radon.

1 INTRODUCTION

^{222}Rn (Radon) is currently under more intensive study than other environmental radionuclides because of the link between radon and lung cancer demonstrated by epidemiological studies in underground miners [1].

The primary source of public exposure to radiation in indoor spaces is thought to be inhalation of ^{222}Rn and its decay products. Radon-222, produced by α-decay of ^{226}Ra (a decay product of ^{238}U), has a half-life of 3.82 days, whereas its parent ^{226}Ra has a half-life of 1620 years [2], [3]. Radon is a radioactive noble gas with a half-life of 3.82 days [4], [5]. When radon undergoes radioactive decay, it produces several radioactive decay products, such as polonium (^{218}Po and ^{214}Po), lead (^{214}Pb), and bismuth (^{214}Bi) [6]. Among these radon daughters, the most important alpha emitters ^{218}Po (6.0 MeV) and ^{214}Po (7.69 MeV), with penetration depths of 47 and 70 μm, respectively, contribute to more than 90% of the maximum radiation dose resulting from radon exposure [6], [7].

Radon decay products are in solid form and adhere to water molecules, other atmospheric gases and natural aerosol particles [8]. These particles reach the lungs with inhaled air and can damage DNA chains in tissues by emitting alpha radiation. If radiation exposure through inhalation reaches high doses, it can lead to the development of bronchogenic cancer in the lungs [9].

The main source of ^{222}Rn in indoor air is the rock and soil under buildings. Radon in soil and rocks can enter the building through cracks in the building floor, cracks in the walls, gaps around water pipes, and gaps inside the walls. Also, another important source is building materials [10], [11].

Since schools are the indoor environment where children spend most of their time outside of home, monitoring radon concentrations in schools is of great importance. According to WHO (2009) [12], it is ideal to keep indoor radon levels below 100 Bq/m³, but in some cases a maximum of 300 Bq/m³ can be considered an upper limit. On the other hand, the US Environmental Protection Agency (USEPA) recommends that radon levels should not exceed 148 Bq/m³, and the European Union (EU) recommends that annual average radon concentrations in mixed-use buildings such as residences, primary schools and kindergartens should be kept below 300 Bq/m³ [13], [14].

In the present study, radon concentration measurements were performed with LR-115 (Type-2) nuclear track detectors in the ground and upper floors of some schools in Bitlis-Tatvan

district in spring and autumn periods. The values obtained from indoor radon concentration measurements were used to calculate the annual effective dose values to which students, teachers and other personnel were exposed in these schools.

2 MATERIAL AND METHODS

2.1 Study Area

Tatvan (38° 29′ 31″ N - 42° 16′ 57″ E) is a district of Bitlis Province in the Eastern Anatolia Region of Türkiye. It is bordered by Bitlis city center to the west, Ahlat district to the north, Hizan district to the south and Lake Van, Türkiye's largest lake, to the east. The area of the district is 1235 km², the population is 89185 and the altitude is 1690 m. The topography of Tatvan is mostly mountainous, and the western and northwestern parts are surrounded by Mount Nemrut and the southern and southeastern parts are surrounded by the Southeastern Taurus Mountains.

2.2 Sampling and Analysis

In this study, radon concentrations in 20 schools located in the Tatvan district were determined using the solid-state nuclear track detector (SSNTD) technique. The locations of the schools selected for the study are shown in Figure 1.

Radon concentration measurements were carried out in two three-month periods covering the spring season (March-April-May) and autumn season (September-October-November). The location coordinates and codes of the selected schools are listed in Table 1, together with the current number of students and teachers.

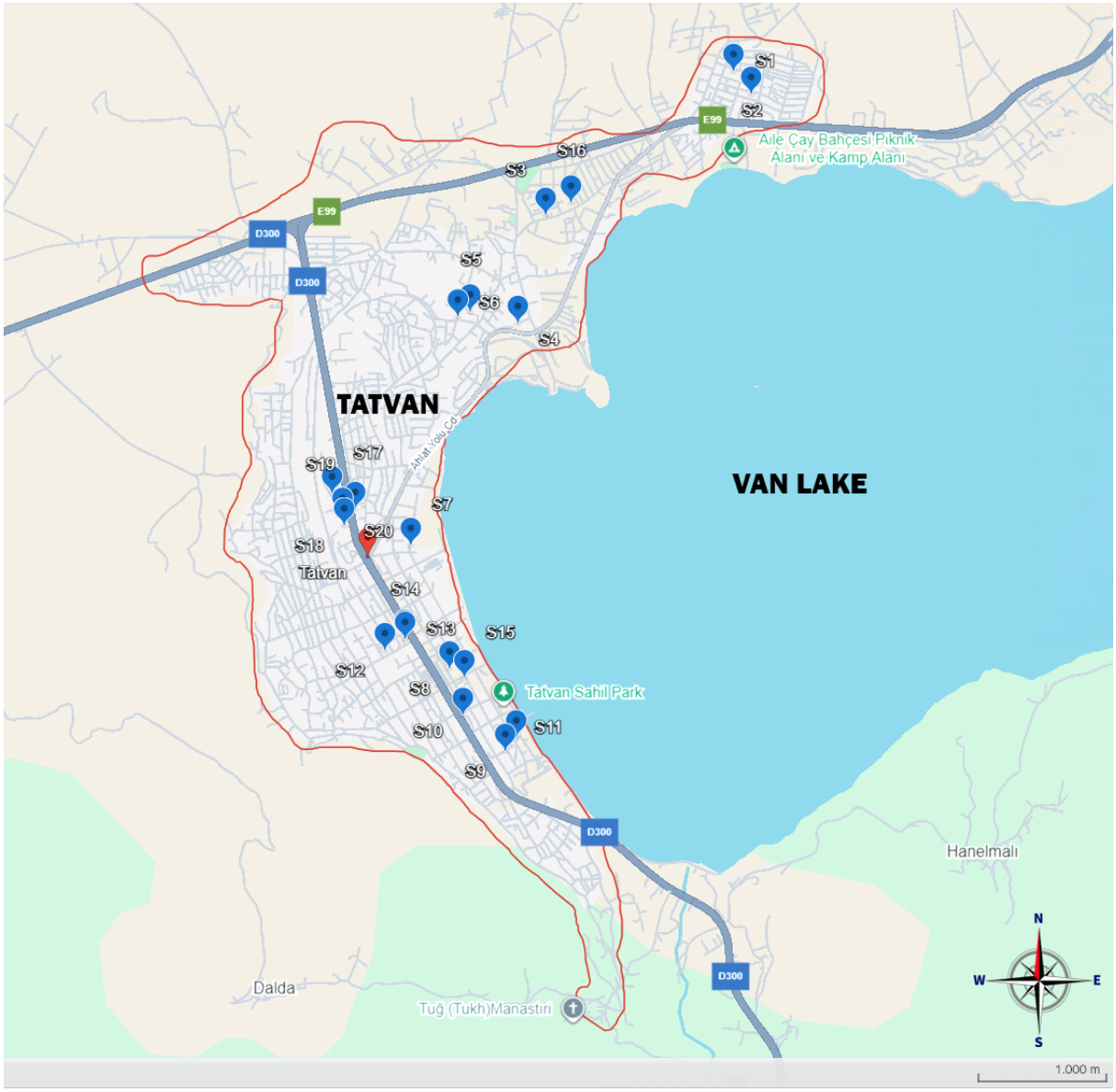


Figure 1. Locations of the schools studied (modified from Google Earth, accessed March 09, 2025).

Table 1. Codes, coordinates and student-teacher numbers in the study

School name	Code	Coordinates		Number of students	Number of teachers
		Latitude	Longitude		
Toki Prof. Dr. Fuat Sezgin Anatolian High School	S1	38.535831	42.313283	606	43
Cumhuriyet Elementary and Middle School	S2	38.534085	42.314785	382	20
Tatvan Science High School	S3	38.525684	42.296717	365	27

Table 1 (continued). Codes, coordinates and student-teacher numbers in the study

School name	Code	Coordinates		Number of students	Number of teachers
		Latitude	Longitude		
Van Gölü Elementary and Middle School	S4	38.518297	42.294507	346	21
Tatvan Vocational and Technical Anatolian High School	S5	38.518750	42.290430	405	22
Nene Hatun Vocational and Technical Anatolian High School	S6	38.519036	42.291074	293	15
Seydi Ali Reis Vocational and Technical Anatolian High School	S7	38.502984	42.284787	440	30
Valide Sultan Vocational and Technical Anatolian High School	S8	38.494352	42.288428	307	28
Şehit Mehmet Ali Kılıç Anatolian High School	S9	38.488991	42.293188	438	28
Uluer Elementary School	S10	38.490007	42.290505	978	38
Hüseyin Çelik Anatolian High School	S11	38.489881	42.292426	902	54
Tuğ Elementary School	S12	38.495717	42.283167	1076	66
Tatvan Kız Anatolian High School	S13	38.496061	42.283489	523	29
Tatvan Sultan Alparslan Middle School	S14	38.496397	42.284111	532	35
Selahaddin Eyyubi Elementary School	S15	38.493752	42.289722	214	15
Selahaddin Eyyubi Middle School	S16	38.526140	42.299023	1234	74
Saadettin Aka Middle School	S17	38.506220	42.278163	680	32
İstasyon Elementary School	S18	38.504007	42.278962	758	32
Tatvan Anatolian High School	S19	38.505233	42.280202	762	42
Sadullah Gencer High School	S20	38.504830	42.279097	288	25

LR-115 detectors were prepared as 1.5 × 1.5 cm² squares and fixed to the bottom of plastic cups using double-sided tape. The cups were placed at a height of 1.5 m above the floor and at least 10 cm away from the walls to minimize additional contributions from thoron (^{220}Rn, half-life: 55.6 s) emitted from building materials. In each school, two detectors were deployed: one on the ground floor and the other on the upper floor. On the ground floor, the detector was most frequently placed in the canteen, while in a few cases it was located in the teachers' room, guidance office, or vice principal's office. On the upper floor, the detector was most commonly placed in the vice principal's office, but in some schools it was located in the library, chemistry laboratory, sports hall, or, in one case, the canteen. Rooms were selected based on their accessibility and frequency of use, ensuring that areas where both students and staff spend considerable time were represented in the measurements. The prepared plastic cups were labeled by writing the name of the school and the floor information on which they would be placed. Then, the detectors were placed in the schools for a period of three months covering the spring and autumn seasons. At the end of these periods, the samples were collected and analyzed in the laboratory. Solutions containing 10% NaOH were prepared using 25 ml of distilled water for each film. The films were placed in the solution in such a way that they did not touch each other or the surfaces of the beakers. The beakers were subjected to chemical etching in a magnetic stirrer at a constant temperature of 60°C at 120 rpm for 100 minutes. The films were then rinsed in another magnetic stirrer at 120 rpm for 20 min. The rinsed films were then left to dry. The tracks of alpha particles on the surface of the detectors were counted using an optical microscope with 100X magnification (Figure 2).

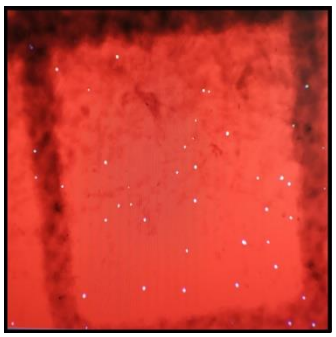


Figure 2. Tracks on the LR-115 detector.

Using the track counts obtained from the measurements, the radon concentration was calculated using the Equation 1 [15]:

$$C_{Rn} = k_f . \rho / d \quad (1)$$

where C_{Rn} is the radon activity concentration (Bq/m^3), ρ is the surface density of tracks on the LR-115 (tracks/cm^2), d is the exposure time (90 days), k_f is the calibration factor to convert track density to the radon concentration (kBq.cm^2.g/track.m^3) [16], [17].

The annual effective dose (D_{eff}) can be calculated using Equation 2 [18].

$$D_{eff}(mSvy^{-1}) = C_{RN} \times E \times F \times T \times D \quad (2)$$

where, E is the equilibrium factor (0.4), F is the occupancy factor in schools (0.18), T is time (8760 h), and D is the dose conversion factor (**9** nSv / Bq.h.m^{-3}).

3 RESULTS AND DISCUSSION

The radon and average radon concentration values and effective dose values measured in schools in Tatvan are given in Table 2, and the annual average radon concentration distribution is presented in Figure 3. As shown in Table 2, the radon concentration values ranged from 23.39 (S7) to 222.06 (S5) Bq/m³ in the spring season and from 42.68 (S11) to 308.38 (S5) Bq/m³ in the autumn season. The highest average radon concentration value was observed in S5 (265.22 Bq/m^3) and the lowest value was observed in S11 (33.76 Bq/m^3) (Figure 3). The elevated radon concentrations observed in S1 and S5 schools are likely influenced by multiple factors, including the age of the school buildings, the nature of building materials, insulation conditions, limited ventilation, and prolonged occupancy of ground-floor rooms [18].

Table 2. The radon concentration and D_{eff} values in the schools

	$C_{Rn\text{-}spring}$ (Bq/m^3)			**$D_{eff\text{-}spring}$ (mSv)**	**$C_{Rn\text{-}autumn}$ (Bq/m^3)**			**$D_{eff\text{-}autumn}$ (mSv)**	**C_{Rn} (Bq/m^3)**	**D_{eff} (mSv)**
Codes	Ground	Upper	Spring	Spring	Ground	Upper	Autumn	Autumn	**Annual Average**	**Annual Average**
S1	317.06	110.91	213.99	1.21	391.08	199.40	295.24	1.68	254.61	1.45
S2	21.94	94.27	58.11	0.33	28.93	96.93	62.93	0.36	60.52	0.34
S3	50.39	36.17	43.28	0.25	53.29	35.68	44.49	0.25	43.88	0.25
S4	63.41	16.64	40.02	0.23	58.35	41.71	50.03	0.28	45.03	0.26
S5	230.50	213.62	222.06	1.26	375.17	241.59	308.38	1.75	265.22	1.51
S6	183.00	151.18	167.09	0.95	246.42	171.67	209.04	1.19	188.07	1.07
S7	22.42	24.35	23.39	0.13	83.18	72.82	78.00	0.44	50.69	0.29

Table 2 (continued). The radon concentration and D_{eff} values in the schools

	$C_{Rn\text{-}spring}$ (Bq/m^3)			$D_{eff\text{-}spring}$ (mSv)	$C_{Rn\text{-}autumn}$ (Bq/m^3)			$D_{eff\text{-}autumn}$ (mSv)	C_{Rn} (Bq/m^3)	D_{eff} (mSv)
Codes	Ground	Upper	Spring	Spring	Ground	Upper	Autumn	Autumn	**Annual Average**	**Annual Average**
S8	39.30	66.55	52.92	0.30	50.39	71.13	60.76	0.34	56.84	0.32
S9	232.67	16.88	124.78	0.71	361.43	198.19	279.81	1.59	202.29	1.15
S10	76.19	28.21	52.20	0.30	197.71	130.20	163.96	0.93	108.08	0.61
S11	13.50	36.17	24.83	0.14	46.29	39.06	42.68	0.24	33.76	0.19
S12	54.49	45.57	50.03	0.28	82.46	48.46	65.46	0.37	57.75	0.33
S13	40.27	160.34	100.30	0.57	49.19	207.36	128.27	0.73	114.29	0.65
S14	96.44	66.55	81.50	0.46	115.73	71.13	93.43	0.53	87.46	0.50
S15	176.49	22.42	99.46	0.56	230.98	27.25	129.12	0.73	114.29	0.65
S16	171.43	37.13	104.28	0.59	168.78	50.15	109.46	0.62	106.87	0.61
S17	50.15	77.64	63.89	0.36	67.75	131.16	99.46	0.56	81.68	0.46
S18	40.02	34.96	37.49	0.21	71.37	79.08	75.23	0.43	56.36	0.32
S19	56.66	82.46	69.56	0.39	71.37	167.81	119.59	0.68	94.58	0.54
S20	42.68	46.29	44.49	0.25	101.99	126.82	114.41	0.65	79.45	0.45
Average values	98.95	68.42	83.68	0.48	142.59	110.38	126.49	0.72	105.9	0.60

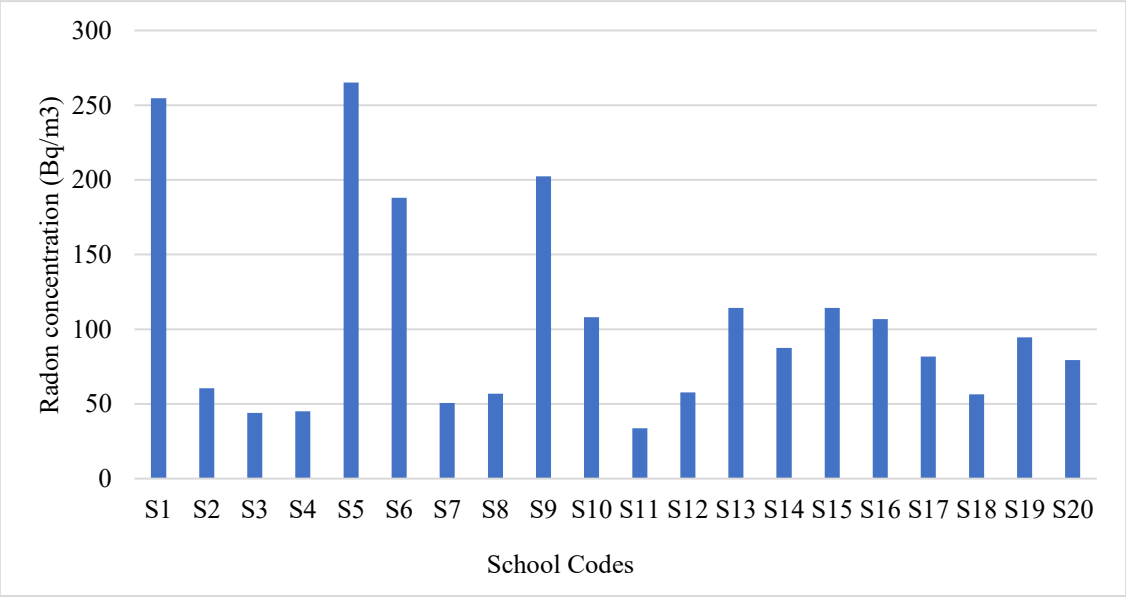


Figure 3. Average radon concentration distributions of schools.

The seasonal distribution of average radon concentrations in schools is shown in Figure 4. The high radon concentrations observed during autumn can be attributed to the closing of doors and windows, the use of heating systems, and the decrease in ventilation as temperatures begin to decrease in September [19].

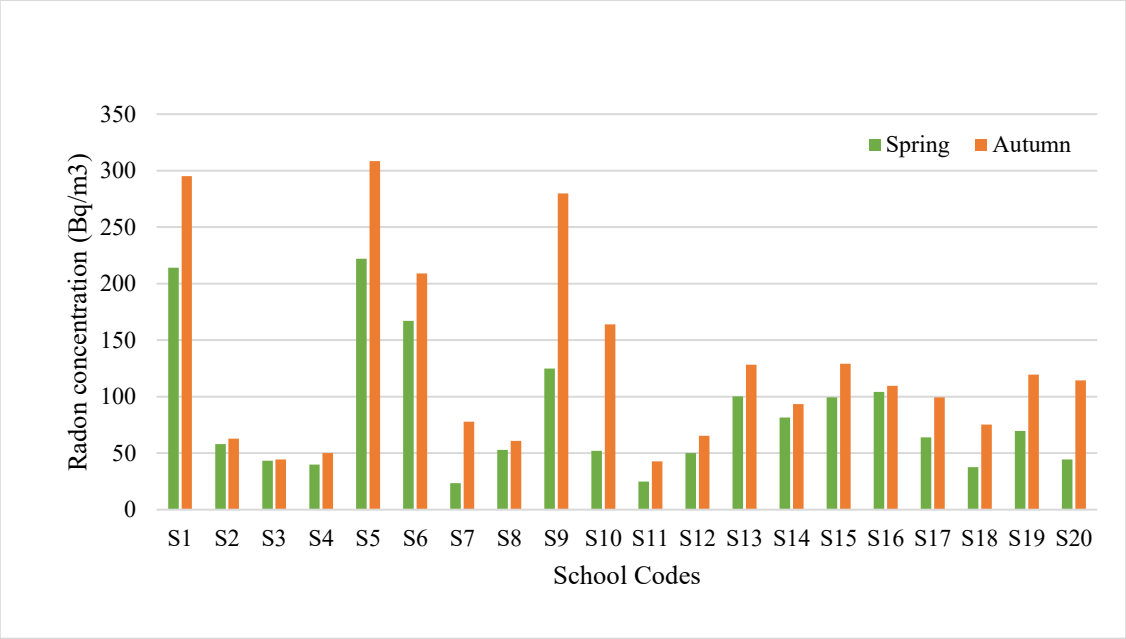


Figure 4. Average radon concentrations of schools in the autumn and spring seasons.

In this study, the arithmetic mean of the average radon concentrations in schools was determined as 105.09 Bq/m³. If the obtained results are categorized as low (0-49 Bq/m³), medium (50-100 Bq/m³) and high (>100 Bq/m³) according to the frequency distribution of annual mean radon concentrations, 15% of the schools can be classified as low level, 45% as medium level and 40% as high level. In a similar study conducted in Greece, the arithmetic mean radon concentration in 512 schools was reported to be 135 Bq/m³ [20].

Figure 5 shows that radon concentrations are generally higher in the basement and ground floors of schools, and decrease progressively at higher floor levels. This trend is primarily due to radon emanation from the soil and its easier accumulation in lower levels with limited ventilation, while upper floors benefit from dilution and greater distance from radon sources. Similar patterns have been reported in previous studies [21], [22], [23].

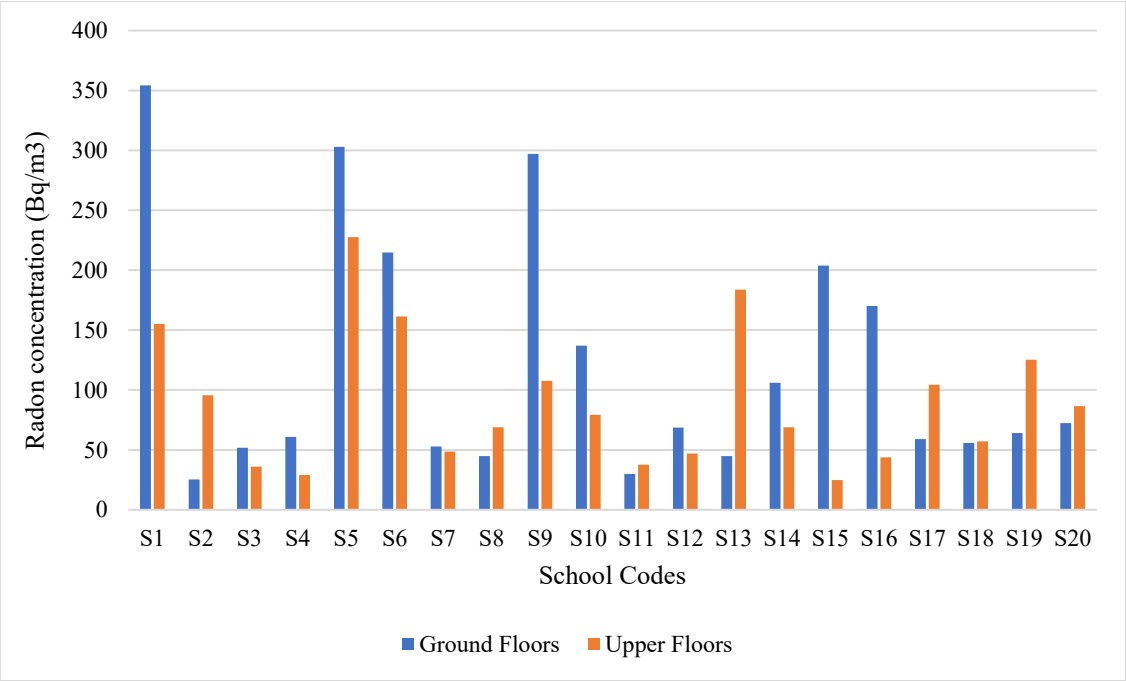


Figure 5. Average radon concentrations in schools across various floors.

The annual effective dose calculation (D_{eff}) was performed using Equation 2, and the results are presented in Table 2 and Figure 6. The average annual effective dose was calculated as 0.48 mSv for the spring semester and 0.72 mSv for the fall semester, with an overall average of 0.60 mSv/year for both seasons. The International Commission on Radiological Protection (ICRP) defines the D_{eff} limit as 3–10 mSv [24], while the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports a global average annual effective dose of 1.15 mSv [18]. The annual effective dose values for all schools were below the threshold recommended by the ICRP [24]. However, the average D_{eff} values for the S1 and S5 schools exceeded the global average (Table 2, Figure 6).

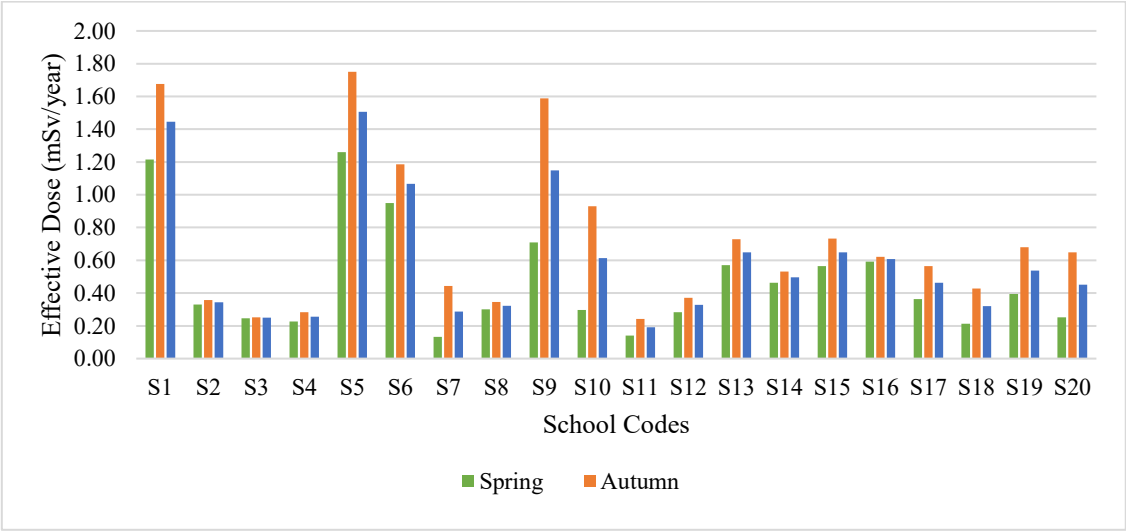


Figure 6. Spring, autumn and annual average effective dose values in schools.

4 CONCLUSIONS

In this research, indoor air ^{222}Rn concentrations were measured using LR-115 detectors in selected schools in Bitlis-Tatvan region, and the potential radiological risk assessment was performed. The measurements revealed that radon concentrations varied seasonally, with higher levels observed in autumn compared to spring. In addition, analysis of the data suggested a general decrease in radon levels with increasing floor height; however, some schools deviated from this trend, suggesting that factors such as building characteristics and ventilation may influence indoor radon levels.

The estimated annual effective doses ranged from 0.19 to 1.51 mSv/year, with an arithmetic mean of 0.60 mSv/year. Most schools showed values below the global average dose of 1.15 mSv/year; however, two schools (S1 and S5) exceeded this benchmark, underscoring the need for targeted monitoring and potential mitigation measures in those cases. Overall, the findings suggest that radon exposure in most surveyed schools is likely to be low, but continued monitoring is recommended to ensure that concentrations remain within acceptable limits over time.

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This study was approved by the Van Yüzüncü Yıl University Committee on Publication Ethics for Science and Engineering (Decision No: 2022/02-01).

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

Contributions of the Authors

Burcu BOZOVA AYDIN: Conceptualization, Material supply, Experiment; Nergiz YILDIZ YORGUN: Theory, Original drafting, Experiment, Revision and Editing; Ömer Faruk ÖZDEMİR: Data analysis, Drafting, Revision and Editing; Halime ERZEN YILDIZ: Experiment, Data analysis.

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