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SPATIAL DISTRIBUTION OF THE AMBIENT DOSE EQUIVALENT OF GAMMA RADIATION IN THE RAŠKA REGION

Biljana Vučković

University of Priština in Kosovska Mitrovica, Faculty of Sciences and Mathematics, Kosovska Mitrovica, Serbia

Ivana Penjišević

University of Priština in Kosovska Mitrovica, Faculty of Sciences and Mathematics, Kosovska Mitrovica, Serbia

Corresponding author: ivana.penjisevic@pr.ac.rs

Ivan Potić

Institute of Social Sciences, Belgrade, Serbia

Abstract

Natural background radiation, registered under standard environmental conditions, originates from cosmic rays and naturally occurring radionuclides. Its intensity is influenced by geological characteristics and the measurement altitude. What defines the strength of gamma radiation is the value of the ambient dose equivalent of gamma radiation. The ambient dose equivalent was measured using a Radex RD1503+ digital Geiger counter. This study presents the spatial distribution of ambient dose equivalent values recorded across the Raška region. The Raška region, located in southwestern Serbia, covers an area of 666 km^2 and extends between 43°10′ and 43°29′ north latitude and 20°27′ and 20°40′ east longitude.

Keywords**:** ambient dose equivalent, Raska region, geology of the soil, spatial distribution

Introduction

Radiation originating from radioactive sources in an undisturbed natural environment is referred to as *natural background radiation*. It originates from cosmic rays as well as from both natural and anthropogenic radionuclides present in the Earth's crust, atmosphere, and hydrosphere (UNSCEAR, 2000). Background ionizing radiation is unavoidable and continuously affects the entire population. On average, the annual dose of natural background radiation is 2 mSv/year. The decay of radionuclides in the soil generates ionizing radiation fields that extend beyond the soil-air interface. Once released into the atmosphere, these radionuclides may undergo further decay during transport or remain on the Earth's surface through wet or dry deposition. Initially, radionuclides accumulate on the soil surface but are rapidly deposited into the top few centimeters of the soil, particularly if deposited by precipitation. The half-lives of certain radionuclides are comparable to the age of the Earth, ranging from 10^5 to 10^6 years (Draganić, 1996; Abdel-Rahman et al., 2010). Throughout their prolonged decay period, radionuclides present on the Earth's surface continuously emit ionizing radiation, which can have harmful effects on organisms and can cause a change in the genetic structure (Janković-Mandić et al., 2007; Župunski et al., 2009). These radionuclides are present in all natural environments, though in varying percentages. Since outdoor radiation dose levels depend largely on the composition of the soil and the concentration of radionuclides in it, the terrestrial component of gamma radiation plays a dominant role in contributing to total external radiation dose. It is believed that 75% of the total radiation dose received by the global population originates from natural sources. It is characteristic for a certain area and depends on the geology of the terrain and altitude. That is why it is very important to know the level of background radiation, which would enable the calculation of additional exposure of the population in accidental situations. In case the soil is rich in rocks of volcanic origin (granites, diabases, crystalline schists), the value of background radiation will be higher, but therefore the strength of the radiation will be lower if the soil is dominated by sedimentary rocks (Stojanovska et al., 2016; Abba et al., 2017) and quaternary geological soil structures (Sannusi et al., 2014). It is known that the annual natural radiation at sea level for granite is 1.43 mSv/y, while the annual dose for sedimentary rock is 0.76 mSv/y (UNSCEAR, 2008).

Cosmic radiation represents another significant component of natural background radiation, accounting for approximately 13% of the total natural radiation. Primary galactic cosmic radiation originates from solar energy and consists of charged particles of very high energy (UNSCEAR, 2000). It rarely reaches the Earth's surface, but creates secondary cosmic radiation and radionuclides (Draganić, 1996). The total cosmic radiation on Earth has a greater influence at the poles than at the equator, due to the stronger electromagnetic influence that transforms the radiation. Also, with an increase in altitude, the radiation increases due to the diluted air, so that at 4000-12000 m above sea level, the radiation is higher, about 25%. On the other hand, the variability of geographic latitudes does not have such a pronounced effect - the total radiation dose is about 10% lower at the geomagnetic equator than at high latitudes due to the variability of solar cycles in these areas (UNSCEAR, 2008).

What defines the strength of the radiation is the value of the ambient dose equivalent of gamma radiation, denoted as H*. In this paper, the measurement of the ambient dose equivalent in an outdoor environment was carried out with a digital Geiger counter RADEX RD1503 + at 26 locations within both rural and urban areas of the Raška region. Afterward, an assessment was performed regarding the extent of radiation exposure to which the local population was exposed.

Study Area

The Raška region is situated in the southwestern part of Serbia, centrally located within the Ibar Valley and bordered by Kopaonik and Golija. The region's shape is approximately square, extending between 43°10' and 43°29' north latitude and 20°27' and 20°40' east longitude, encompassing an area of 666 km². Administratively, it shares borders with the municipalities of Vrnjačka Banja, Kraljevo, Novi Pazar, and Tutin. According to the 2022 Census, 21.498 inhabitants live in this area, with an average population density of 32.2 inhabitants per km² (SORS, 2023).

The geological structure of the Raška region is notably complex. The oldest rocks are Paleozoic shales, including prominent phyllites, sandstones, and quartz shales. Intense geological processes during the Tertiary period resulted in the formation of large masses of igneous, i.e. volcanic rocks, among which the following stand out: granites, diorites, granodiorites, diabases,and basalites, while tuffs and typhites are observed as accompanying rocks (Filipović, 2003; Penjišević, 2010). Due to deposition during volcanic eruptions, sediments - pyroclasts - are present in the ground. The base of the Kopaonik massif is an intrusive mass of tonalitic granite, which is separated from the serpentine mass by a schist zone. The composition of the terrain includes Mesozoic limestones and sandstones, then andesite and dacite, as well as eruptive rocks with occurrences of lead, zinc and iron (Vasović, 1988).In smaller depressions within the area, sedimentary rocks also significantly contribute to the geological composition.

The research was conducted in both rural and urban areas of the Raška region. A total of 26 measurement locations were selected, comprising 23 sites in rural settings and 3 sites in urban areas (Figure 1).

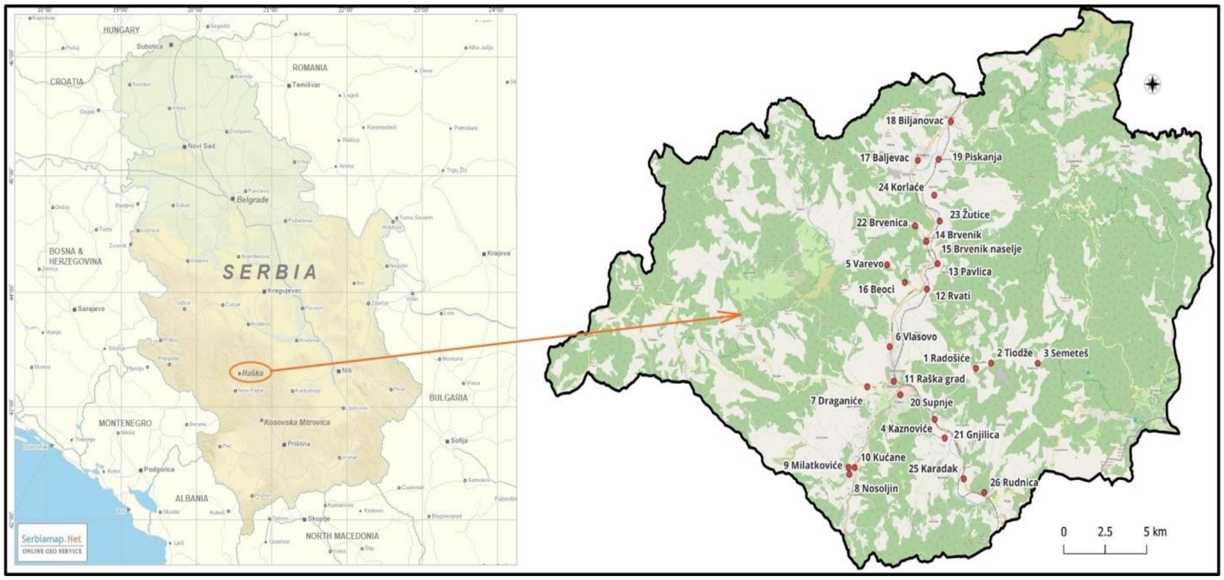

Figure 1. Map of investigated locations in the Raška region.

Measurement Methods

Measurements were conducted in April 2025. On the day of the measurements, as well as during the two preceding days, no precipitation occurred, ensuring that radon exhalation from the soil was not elevated, which could have compromised the reliability of the data. In order to avoid diurnal variations in dose equivalent (Vučković et al., 2018), the measurements were performed between 12:00 p.m. and 4:00 p.m. The first step during the measurement was to place the detector directly on the ground to measure the radiation from terrestrial radionuclides. The ground beneath the detector was grassy at some locations and concrete-covered at others. The second step was to measure the value of the parameter at the same location at a height of one meter, in order to detect gamma radiation present in the air.

The measurement of the ambient dose equivalent of gamma radiation outdoor environment was conducted using a RADEX RD1503+ digital Geiger counter at 26 locations across rural and urban areas of the Raška region. The working principle of this detector is simple and rapid, based on four consecutive measurements within 40 seconds (PCE Instruments Ltd, UK). The Radex RD1503+ detector operates within the range of 0.00 to 9.99 mSv/h. The uncertainty of the gamma radiation measurement is ±15% with a linear response between 100 KeV and 1.25 MeV, which covers most of the gamma rays emitted from terrestrial sources. Factory calibration was perfomed using with Cs-137 at 5 mSv/h. If a value above 0.2 mSv/h appears on the screen, elevated concentrations of radionuclides are likely present (UNSCEAR, 2000).

GPS coordinates, altitude and metrological parameters – temperature, air humidity and wind speed were recorded at each location at the time of measurement. The objective was to determine the correlation between the ambient dose equivalent and altitude, as well as the ambient dose equivalent and meteorological variables.

Results and Discussion

Table 1 presents the results of research at 26 selected locations. The current meteorological parameters are shown in addition to the values of the ambient dose equivalent of gamma radiation, as well as the altitude at which the measurement site is located. Of the selected 26 measuring points, 23 are in the rural area and only three are in urban areas – 11, 17 and 18. The data shows that the dose equivalent values in the urban part do not differ much compared to the values measured in rural areas.

Table 1. Value of the ambient dose equivalent of gamma radiation and current meteorological parameters in the rural and urban part of the Raška region.

No location	h (m)	H^* (nSv/h)		T (ºC)	Wind velocity (km/h)	Humidity (%)
		on the ground	1m above the ground			
1	617	100	140	17.1	9	58
2	976	160	130	17.2	8	57
3	1000	200	160	17.0	8	59
4	469	240	160	21.1	9	54
5	388	80	120	16.8	4	59
6	211	20	90	17.0	4	59
7	423	20	20	17.3	3	58
8	515	80	160	17.3	3	58
9	457	80	100	17.2	4	59
10	634	120	130	17.1	4	58
11	497	120	140	17.0	3	58
12	566	120	160	23.1	8	54
13	650	120	180	23.3	7	53
14	610	200	120	24.0	8	54
15	625	120	80	23.7	8	54
16	398	160	160	25.1	4	52
17	206	280	160	24.0	8	54
18	445	200	220	24.2	5	55
19	631	160	130	23.1	5	55
20	532	80	100	26.0	8	50
21	512	160	170	25.2	5	65
22	494	200	160	19.0	2	66
23	610	240	170	19.3	2	64
24	582	140	100	19.1	2	65

25	580	100	120	25.1	5	66
26	441	180	230	25.3	5	64
Max	1000	280	230	26.0	9	66
Min	206	20	20	17.0	2	50
AM*		141	139	20.8	5.4	58
SD*		65	44	3.5	2.3	4.6
GM*		122	129	20.5	4.8	57

*AM – arithmetical mean, SD – standard deviation, GM – geometrical mean

Out of the 26 selected locations, measuring point 3 was located at the highest altitude of 1000 m, while measuring point 17 2 was located at the lowest point of the survey. The temperature ranged from 17.0 ºC to 26.0 ºC, with a mean value of 20.8 ºC. The weather was calm and windless, as evidenced by the average wind speed of 5.4 km/h. The average relative humidity recorded during the measurements was 58%.

The ambient dose equivalent values ranged from 20 nSv/h to 280 nSv/h, with an average value of 139 nSv/h. Based on this mean value, it can be concluded that there is no evidence of increased radiation levels within the studied area. However, variations corresponding to the geological composition of the terrain were observed at certain locations. Specifically, measurements taken directly on the ground revealed slightly elevated dose equivalent values at three sites: 240 nSv/h (site 4), 280 nSv/h (site 17), and 240 nSv/h (site 23). Additionally, measurements conducted at a height of one meter above ground level indicated moderately increased values at two points: 220 nSv/h (site 18) and 230 nSv/h (site 26). The data further indicate that at ten measuring points, the ambient dose equivalent recorded directly at ground level was higher than the values measured at one meter above the ground. Specifically, at measuring points 2, 3, and 4, the soil composition is predominantly granite and diabase rocks. At points 14, 15, and 17, in addition to the rich geological composition, it is likely that radionuclides are present in elevated concentrations within the surface soil layers. Measurement point 19 is situated adjacent to a coal processing and separation plant. Furthermore, at measuring points 22, 23 and 24, the increased presence of radionuclides in the rocks causes a higher value of the dose equivalent, which is characteristic of the Raška mining area At 15 measuring points, a lower ambient dose equivalent value was recorded at ground than measured at a height which suggests that radionuclides are present in lower concentrations within the soil, while the higher values measured at height indicate an increased presence of radionuclides in the air. Notably, only at measuring point 6 was the lowest dose equivalent value of 20 nSv/h recorded both at ground level and at height, indicating an area with a small amount of radionuclides. The highest recorded value of 280 nSv/h was measured at ground level at the lowest altitude of 206 meters. The measured values of the ambient dose equivalent are somewhat more pronounced in relation to the values presented in the Republic Report on the level of exposure of the population to ionizing radiation from the environment in 2023 (*https://www.srbatom.gov.rs/srbatomm/wp-content/uploads/2024/07/Izvestaj-Monitoring-2023-konacni.pdf*), which is a consequence of the geological structure of the soil of the examined region.

Frequency distributions of measured dose equivalent values and the spatial distribution of the measured values of the ambient dose equivalent in both cases are shown in fig 2and fig 3.

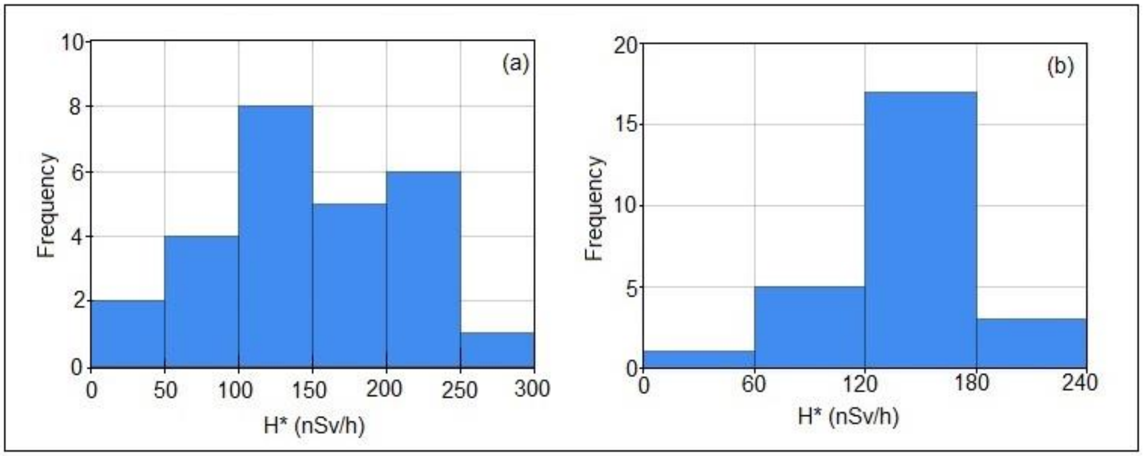

Figure 2. Frequency distribution of the value of the ambient dose equivalent of gamma radiation - on the ground (a) and at 1m above (b).

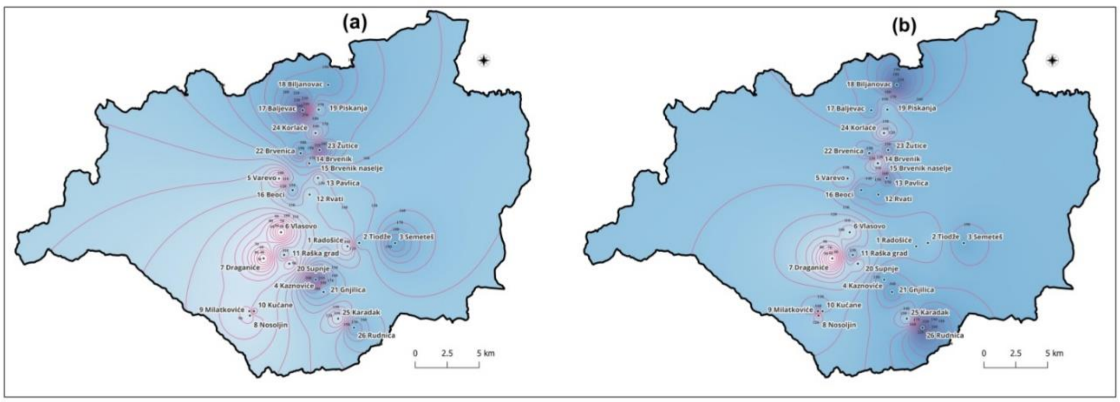

Figure 3. Spatial distribution of ambient dose equivalent gamma radiation at the measured sites - on the ground (a) and at 1m above (b).

The relationship of the ambient dose equivalent measured on the ground and at a height of 1m is expressed by the Pearson coefficient (r^2) and is 0.4. The correlation between the value of the ambient dose equivalent and the altitude is not pronounced: 0.05 (on the ground) and 0.01 (1m above the ground). The correlation between the dose equivalent measured on the ground and at a height of one meter is also not pronounced: 0.1 in both cases, while the correlation between the measured values of the dose equivalent on the ground and at a height of one meter and air humidity is even less pronounced: 0.0003 and 0.008, respectively. Correlation between the wind speed at the measuring points and the value of the dose equivalent of gamma radiation measured on the ground and at a height of one meter: 0.05 and 0.08, respectively.

Conclusion

This paper presents the results of ambient dose equivalent measurements conducted at 26 locations within the Raška region. The recorded ambient dose equivalent values ranged from 280nSv/h to 20 nSv/h, with a mean value of 139 nSv/h. The Raška region is characterized as a mining area with a rich geological composition, which is reflected in the observation that at ten measurement points, higher dose equivalent values were recorded at ground level compared to measurements taken at a height of one meter. Furthermore, at three locations on the ground (240 nSv/h, 280 nSv/h, and 240 nSv/h) and two locations at a height of one meter (220 nSv/h and 230 nSv/h), the dose equivalent valuesthat were measured slightly exceeded the recommended UNSCEAR value . However, these deviations are minor, and it can be concluded that the ambient dose equivalent values of gamma radiation in the surveyed area generally correspond to the UNSCEAR recommended value of 200 nSv/h. Analysis indicates a significant correlation only between ambient dose equivalent values measured at ground level and at one meter height, in other cases correlations were found to be weak.

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