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Assessment of outdoor radiation dose and radiological health hazards

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▶ ***Original article***

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ABSTRACT

Background: All generations of living beings have been and will be exposed to ionizing radiation. Until the discovery of radioactivity, man was not aware that ionizing radiation was a part of him and his environment. Humans are mainly exposed to gamma and beta radiation from terrestrial radionuclides, which represent the main source of irradiation of the human body. ***Materials and Methods:*** This paper presents the research overview of the dose rates of gamma and beta radiation, measured outdoors in the research locations by the Gamma–Scout device. The measurements were performed at fifteen locations in the area of Tuzla Canton, Bosnia and Herzegovina. The Gamma–Scout device was mounted outside on the table, at a height of 50 cm above ground in the vicinity of residential buildings in periods of 30 minutes. ***Results:*** The results presented include gamma, gamma+beta, and beta dose rate measurements. Based on these results, the annual effective doses originating from gamma and beta radiation were estimated. Results of measurements taken by this method showed that the values of the annual effective dose of gamma and gamma+beta radiation were in the interval of (0.21-0.32) mSv and (0.22-0.33) mSv, respectively. The estimated annual effective dose received by beta radiation was in the interval of (0-0.04) mSv. ***Conclusion:*** For all investigated locations, excess lifetime cancer risk (ELCR) was below the recommended risk value.

INTRODUCTION

Most of the radiation received by the humans comes from natural sources. The Earth is constantly exposed to the natural radiation that comes from cosmic sources, but also to the widespread natural active radionuclides. Ambient radioactivity and cosmic rays are typically larger than that of cosmic sources, due to the natural background ionization radiation and the variability in external terrestrial radiation. The exposure to the most part of this radiation is inevitable. People are irradiated externally and internally, which means that radioactive substances can remain outside the body and irradiate it from the outside, or they can be inhaled with air and swallowed with food and water. Although the entire population of the Earth receives natural radiation, some people absorb much larger quantities than the others. At certain places, such as radioactive rocks or land sites, the doses are much higher than the average and at other places these rates are lower than the average. Natural radiation is the usual occurrence in the rocks and the land forming our planet, but also in waters and oceans, building materials, and in our homes. The sedimentary rocks usually have a smaller activity concentration of primordial radionuclides than the igneous types of rocks. But the sedimentary rocks, like shale and phosphate rocks, are highly radioactive. An estimation of radiation activity in a certain place, including its variability in space and time, must take into consideration many factors, such as regional geology, chemical and physical mobility of natural radionuclides, and human impact on the environment [1-3].

Major components of the natural sources of ionizing radiation are cosmic rays, cosmogenic radionuclides, terrestrial gamma rays, ingestion and inhalation of long-lived radionuclides and radon inhalation. Terrestrial sources that are responsible for the largest part of human exposure to natural radiation, account for more than five-sixths of the annual effective dose, mostly through internal radiation ingestion. The concentrations of terrestrial radionuclides in the Earth's crust vary considerably, depending on the geological and geographical features of a region. These radionuclides are present in air, soil, rock, water, and building materials, in significant amounts. The remaining part refers to cosmic rays, being mostly an external source of radiation. Cosmic radiation that comes from space to Earth contains particles of very high energy. Passing through the Earth's atmosphere, the intensity of cosmic radiation decreases, which means that the intensity of the radiation, and thus the equivalent dose, depends on the altitude. On average, humans receive two-thirds of an effective equivalent dose from natural sources, originating out of radioactive

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materials contained in the air, food, and water. Naturally present radioactivity comes primarily from three known natural radioactive series whose progenitors are ^{232}Th, ^{238}U, and ^{235}U, but also ^{40}K. Natural radioactive sources are responsible for the annual effective equivalent dose of 2.4 mSv, of which more than half comes from radon inhalation, thoron and its descendants, and the rest comes from cosmic radiation, cosmogenic radionuclides, terrestrial gamma radiation, and radionuclides in the body. Significant contribution to the average annual background radiation arises from natural sources that are present in the atmospheric environment. Beta and gamma radiation are emitted by different radioactive materials and have different energies and penetrating power [4, 5].

Gamma rays are highly penetrating rays, being able to penetrate dozen centimeters of heavy metal objects while traveling large distances in the air without being absorbed. Considering that beta radiation is not as penetrating as gamma radiation is, its doses at 1m of height above the Earth surface decline for 50%-75% in relation to those appearing at 1cm above the Earth surface. Gamma and beta radiation exposure contributes to the collective dose of the world population, from all sources. Contribution to the total annual effective dose is mainly provided by the natural background gamma radiation, whose worldwide annual effective dose is 0.86 mSv, while in Europe it is 0.84 mSv [6, 7]. Unlike the large doses that can cause tissue damage, some of the stochastic effects (cancer and hereditary effects) may occur at lower doses of radiation at the naturally occuring background. Natural background doses may cause cellular damage and/or deoxyribonucleic acid (DNA) [8]. Gamma and beta radiation risk assessment is very important in order to optimize human exposure to the most acceptable level.

The outdoor radiation dose also depends on the meteorological parameters such as temperature, atmospheric pressure, and humidity. The main objective of this study was to measure the outdoor gamma and beta radiation doses. In this paper, one of the aims of the results was to evaluate any correlation between gamma, gamma+beta, and beta radiation doses and the meteorological parameters such as temperature, pressure, and relative outdoor humidity. Accordingly, the annual effective dose and the lifetime excess cancer risk were estimated. Obtained values were compared to the results from similar studies in other countries in Europe and the world.

MATERIALS AND METHODS

Study area

Tuzla Canton is located in northeastern part of Bosnia and Herzegovina, and with total area of 2649 km^2, it occupies around 5.2% of the territory. Researched locations where gamma and beta radiation dose rates were measured were Banovići and Živinice municipalities, both part of Tuzla Canton. The outdoor dose rates were measured at fifteen locations in Banovići and Živinice, as shown in figure 1.

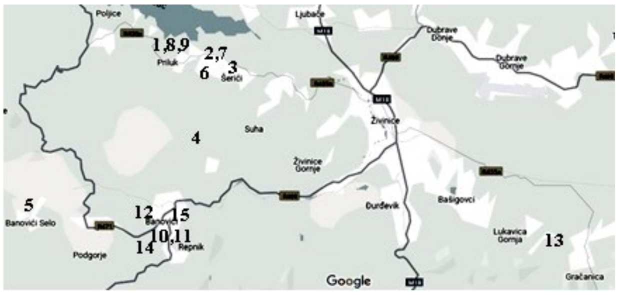

Figure 1. Map of the investigated locations in Banovići and Živinice.

The City of Živinice is located at 232 m above sea level. Živinice territory is in the region where a moderate–continental climate prevails, with moderately cold winters and relatively warm summers. This region is surrounded by mountains that prevent any effect of the Mediterranean climate. The river Spreča valley enables air masses to penetrate Živinice from the Posavina plain. The temperature normally decreases with an altitude, with an average gradient of 0.6 °C on every 100 m of elevation. The maximum measured temperature was 40.7 °C, while the minimum was -25.8 °C. The Spreča valley region is also where a moderate–continental climate prevails, with moderate winds and a vegetative period starting from half of March untill the end of September. Summers are relatively warm, while springs and autumns have almost identical temperature values. An average annual relative humidity is 76% [9].

Banovići Municipality is located on the northeastern foothills of the Konjuh Mountain in the depression located south of the Spreča valley and belongs to the southeastern part of the Spreča river [10]. As a result of the continental and moderate–continental climate, Banovići municipality is majorly affected by warm summers followed by the occasional heavy rain showers and harsh, windy winters with a lesser amount of snowfall. Autumn is warmer than spring. There is a lot more atmospheric precipitation due to terrain height, especially during winter in the form of snow. Rainy periods are more frequent during spring and autumn, but the falls are rather equally arranged. Air humidity is quite high, due to significant evaporations occurring during summer, so the relative humidity is around 73% for this region. Also, the region is quite foggy, particularly during cold, clear days, with significantly dense fog in the areas where the air is polluted with smoke and dust particles. The winds predominantly blow from north and east. Stronger winds do not

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occur. Winds usually occur during autumn and winter, with less strength and visibility during spring and summer. Annual temperature changes often occur but rather gradually. Maximum temperatures are measured during July and minimum ones during January. The annual average temperature measured in spring time is 8.8 °C and 9.3 °C in autumn. In relation to soil composition, Banovići municipality area and surroundings are characterized by differences between tertiary basins and primal highlands. A special basin is characterized by the mildly undulated, rounded, and significantly divided foothills covered with forest. The mild undulation of these foothills is a result of radial and tangential motions, as well as the erosive effects of water. Morphological features of an entire region are closely related to its geological formations [11]. The oldest rocks are serpentine, and they form a base for all other rocks. A much wider prevalence belongs to marl, clay, and gravel types of rocks.

Experimental setup and procedure

The Gamma-Scout device, manufactured by GAMMA-SCOUT GmbH & Co. KG, Germany, was used for the measurement of beta and gamma radiation. The Gamma-Scout is a handheld Geiger's counter that is applied for a very precise alpha, beta, and gamma radiation measurement. This device is calibrated across a wide scale, from 0.01 μSvh^{-1} up to 1000 μSvh^{-1}, and it's usually used for sporadic field measurements but also for long-term measurements. The Gamma–Scout device enables a natural environment radiation measurement but also a measurement of an elevated artificial radiation. The radiation selection switch, located on the upper part of the device, provides a simple blocking of alpha and beta radiation to penetrate the probe, which further ensures a device to measure only gamma radiation. It is possible to set up desired logging intervals, depending on how much data one wants to access in a specific timeframe. All such data are automatically stored in the device's internal memory, and using the GAMMA-SCOUT® TOOLBOX software (GAMMA-SCOUT GmbH & Co. KG, Germany), this data can be read out and transferred to the computer for further processing. When in measuring mode, one can directly read the current radiation dose on the device display [12].

By using a portable analogue meteorological station in this study, the current outside air temperature, pressure, and humidity were simultaneously measured, with the measurement of gamma and beta radiation dose rates at the researching locations. Monitoring of gamma and gamma+beta radiation dose rates was performed in periods of 30 minutes each by using the Gamma-Scout device. The device was mounted outside on the table at the height of 50 cm above ground in the vicinity of residential buildings during the measurement of gamma and beta radiation dose rates at the researched locations (figure 2).

Figure 2. Gamma Scout placed in investigation location.

Estimation of the annual effective dose and excess lifetime cancer risk

The annual effective dose (AED) that originates from gamma and beta radiation is calculated according to equation (1):

$$AED = D \cdot O \cdot T \quad (1)$$

Where; *D* is a dose rate expressed in nSvh^{-1}, *O* is an occupancy factor that is 0.2 for an outdoor and *T* is an average number of hours during one year (8760 h) [13].

The excess lifetime cancer risk (ELCR) is calculated using equation (2):

$$ELCR = AED \cdot DL \cdot RF \quad (2)$$

Where; *AED* is the annual effective dose (mSv) according to equation (1), *DL* is an average duration of life (estimated to be 70 years), and *RF* is the risk factor (0.055) [14].

Statistical analysis

The statistical analysis of the data collected during the measurement was carried out using Excel Data Analysis ToolPak (Microsoft Office). For the purposes of data analysis and comparison, both descriptive and inferential statistics methods were used. Mean value and standard deviation were computed for the gamma and gamma+beta radiation dose rates and annual effective dose. The Pearson's correlation coefficient was computed to examine the relationship between the meteorological parameters (pressure, temperature and relative humidity of outdoor air) and gamma and gamma+beta dose rate. As a statistical measure of the strength of a linear relationship between paired data the Pearson's correlation coefficient, denoted by *r*, can be negative or positive which indicates negative or positive linear correlation. For verbally describing the strength of the correlation the following suggests for the absolute value of *r* were used: very weak correlation for a value between 0 and 0.2, relative weak correlation for a value between 0.2 and 0.5, moderate

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strong correlation for a value between 0.5 and 0.8, strong correlation for a value between 0.8 and 1 and perfect correlation for a value 1. For all of the performed statistical tests the significance level was set to 0.05.

RESULTS

The results of the gamma dose rate measurements, at all locations, are presented in table 1. The minimum, maximum, and mean values of the gamma dose rate with the corresponding standard deviations, as well as the annual effective dose, are presented.

Table 1. Dose rates and annual effective doses of outdoor gamma radiation at the investigated locations.

Location	D_{min} (nSvh^{-1})	D_{max} (nSvh^{-1})	D_{mean} (nSvh^{-1})	*AED* (mSv)
1	102	249	164±35	0.29±0.06
2	83	240	177±43	0.31±0.08
3	65	249	167±39	0.29±0.07
4	92	249	169±41	0.30±0.07
5	47	175	120±33	0.21±0.06
6	83	194	145±29	0.25±0.05
7	83	267	178±38	0.31±0.07
8	92	249	170±38	0.30±0.07
9	65	203	128±30	0.22±0.05
10	74	185	136±34	0.24±0.06
11	55	203	138±34	0.24±0.06
12	65	222	127±38	0.22±0.07
13	83	259	181±42	0.32±0.07
14	83	249	164±43	0.29±0.08
15	55	203	124±40	0.22±0.07
Mean value	75	226	152±37	0.27±0.07

D_{min}-Minimum gamma dose rate, D_{max}-Maximum gamma dose rate, D_{mean}-Mean gamma dose rate, *AED*-Annual effective dose.

The mean values of outdoor gamma dose rates are in the interval from 120 nSvh^{-1} to 181 nSvh^{-1} with a mean value of 152 nSvh^{-1}. Minimum values at the measuring locations are in the interval from 47 nSvh^{-1} to 102 nSvh^{-1}, with a mean value of 75 nSvh^{-1}, while the maximum values are in the interval from 175 nSvh^{-1} to 267 nSvh^{-1} with a mean value of 226 nSvh^{-1}. The lowest mean value of gamma radiation dose rate of 120 nSvh^{-1} was measured at location 5, while the highest mean value of gamma radiation dose rate in the amount of 181 nSvh^{-1} was at location 13. The mean value of outdoor gamma dose rate in the areas of Banovići and Živinice was 152 nSvh^{-1}. An annual outdoor effective gamma dose received by the Banovići and Živinice population outside residential buildings, is based on the gained values of the measured dose rates.

The results of the gamma+beta dose rate measurements, at all locations, are presented in table 2. The lowest mean value of the outdoor gamma+beta dose rate in the area of Banovići and Živinice of 125 nSvh^{-1} was measured at location 5, and the highest mean value of 189 nSvh^{-1} was at location 7, with the mean value of 161 nSvh^{-1} for all locations. The lowest minimum value of gamma+beta radiation dose rate of 55 nSvh^{-1} was measured at location 9, while the highest value of 139 nSvh^{-1} was at location 3. The mean minimum value of the outdoor dose rate of gamma+beta radiation was 96 nSvh^{-1}. Maximum values of the dose rates of gamma+beta radiation in this area are in the interval from 194 nSvh^{-1} at location 15, up to 295 nSvh^{-1} at location 4, with a mean value of 256 nSvh^{-1}. The lowest mean value of the outdoor gamma+beta dose rate of 125 nSvh^{-1} is measured at location 5, while the highest value of 189 nSvh^{-1} was at location 7.

Table 2. Outdoor dose rates and annual effective doses of gamma+beta radiation at the investigated locations.

Location	D_{min} (nSvh^{-1})	D_{max} (nSvh^{-1})	D_{mean} (nSvh^{-1})	*AED* (mSv)
1	83	267	187±50	0.33±0.06
2	129	277	182±39	0.32±0.07
3	139	277	186±32	0.33±0.06
4	120	295	175±37	0.31±0.06
5	65	249	125±44	0.22±0.08
6	102	222	149±27	0.26±0.05
7	120	259	189±36	0.33±0.06
8	120	249	175±36	0.31±0.06
9	55	230	136±41	0.24±0.07
10	83	240	142±39	0.25±0.07
11	83	249	145±49	0.25±0.09
12	65	259	129±39	0.23±0.07
13	120	287	187±37	0.33±0.06
14	83	287	170±47	0.30±0.08
15	74	194	139±31	0.24±0.05
Mean value	96	256	161±39	0.28±0.07

D_{min}-Minimum gamma+beta dose rate, D_{max}-Maximum gamma+beta dose rate, D_{mean}-Mean gamma+beta dose rate, *AED*-Annual effective dose.

Based on the obtained values of the outdoor gamma+beta dose rates, the annual effective dose received by the Banovići and Živinice population was estimated to be 0.28 mSv. The lowest estimated annual effective dose of gamma+beta radiation measured outside residential buildings in this area of 0.22 mSv is recorded on location 5, while the highest values are recorded on locations number 1, 3, 7 and 13 in the amount of 0.33 mSv.

The lowest assessment outdoor annual gamma effective dose of 0.21 mSv was at location 5, while the highest value in amount of 0.32 mSv was at location 13. The mean value of an annual outdoor gamma effective dose at investigated locations in Banovići and Živinice is 0.27 mSv. The mean values of the outdoor beta dose rates in the area of Banovići and Živinice were calculated by using values of gamma+beta and gamma dose rates. Those values range from 2 nSvh^{-1} to 23 nSvh^{-1} with the mean value of 9 nSvh^{-1}. The dose rates of beta radiation are shown on figure 3. An estimated beta radiation dose is in the interval between 0-0.04 mSv. The mean annual outdoor effective beta radiation dose in the area of Banovići and Živinice is estimated to be 0.02 mSv.

Lifetime excess cancer risk of outdoor gamma radiation in the area of Banovići and Živinica is in the

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interval from $0.82{\cdot}10^{-3}$ at location 5 to $1.24{\cdot}10^{-3}$ at location 13, with a mean value of $1.05{\cdot}10^{-3}$. Furthermore, the lifetime excess risk due to exposure to gamma+beta outdoor radiation in the area of Banovići and Živinice is in the interval from $0.86{\cdot}10^{-3}$ at location 5 to $1.30{\cdot}10^{-3}$ at location 7, with a mean of $1.11{\cdot}10^{-3}$. Natural beta irradiation received by the population is rather low and therefore lifetime excess cancer risk due to exposure to it is also extremely low. In general, the lifetime excess risk due to outdoor beta radiation in the area of Banovići and Živinice during the lifetime period is very low, and it's in the interval from $0.02{\cdot}10^{-3}$ at location 12 to $0.16{\cdot}10^{-3}$ at location 1, with a mean of $0.06{\cdot}10^{-3}$ (figure 4).

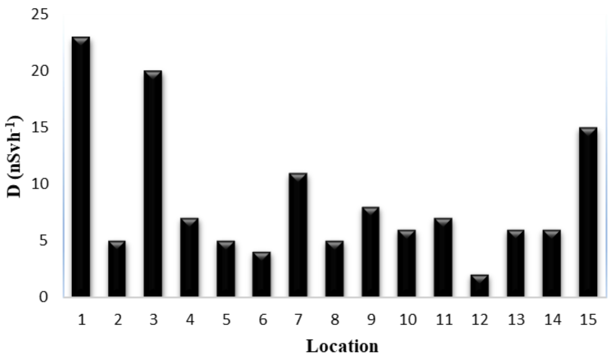

Figure 3. Dose rate of beta radiation on investigated locations.

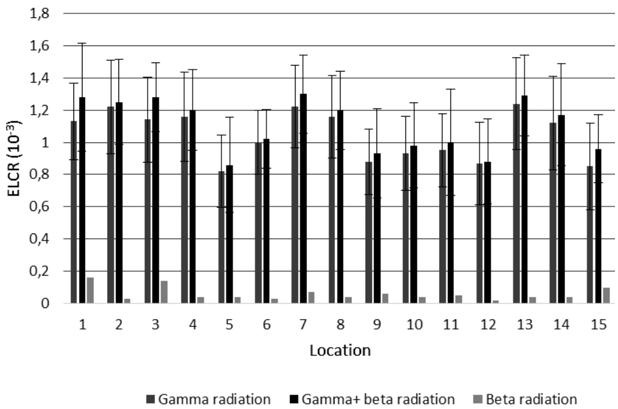

Figure 4. Lifetime excess cancer risk of gamma, gamma+beta and beta radiation (mean value with standard deviation bars).

The values of the meteorological parameters measured at investigated locations are presented in table 3. As can be seen from the data in table 3, the outdoor air temperature ranged from 21 °C to 33 °C, the atmospheric pressure was in the range of 965-994 hPa and the air humidity was in the range from 56-92%.

DISCUSSION

The results obtained by Gamma Scout showed that the gamma outdoor dose rate in investigated locations was lower than the value of the gamma outdoor dose rate in Lorestan province, Iran [5]. When comparing these measurement results of the gamma outdoor dose rate with results of the measurements in Tuzla City, Bosnia and Herzegovina, it can be stated that results from the present study are a little higher than in the area in Tuzla City, 102 nSvh^{-1} [15].

Table 3. Values of the meteorological parameters on investigation locations.

Location	*t* (°C)	*p* (hPa)	*r* (%)
1	28	985	64
2	29	985	68
3	28	990	58
4	24	988	66
5	21	965	82
6	26	992	64
7	30	988	66
8	24	981	82
9	27	985	72
10	33	966	56
11	24	981	88
12	31	994	56
13	20	992	92
14	27	980	80
15	25	987	70
Mean value	24.5	984	71

p-pressure, *t*-temperature, *r*- relative humidity.

The lowest assessment of outdoor annual gamma effective dose as seen from table 1 is identical to the annual outdoor effective dose in Croatia [16] and similar to the annual outdoor effective dose in Ondo state, Nigeria [6], while the highest value is comparable with the values in the Czech Republic [17]. The mean value of an annual outdoor gamma effective dose at investigated locations in Banovići and Živinice is comparable to the mean value of 0.24 mSv obtained in Serbia [18] and Akwanga towns, central Nigeria [2]. A comparison of the annual outdoor gamma dose of the present study with similar studies in the other countries of Europe is presented in table 4. The mean annual outdoor effective beta radiation dose in the area of Banovići and Živinice is considerably lower than the recommended annual effective dose of 1 mSv according to EU Directive 2013/59/Euratom [19].

The values of excess lifetime risk cancer of gamma, gamma+beta, and beta radiation are below the recommended risk of $3.45{\cdot}10^{-3}$ (figure 4) [21].

The correlation analysis shows that the outdoor air pressure has a relatively weak positive correlation with the gamma and gamma+beta dose rates, with Pearson's correlation coefficient r=0.36 and r=0.37, respectively (figures 5 and 6). According to the p values (p=0.19 and p=0,17) this correlation is not significant at confidence level of 95%.

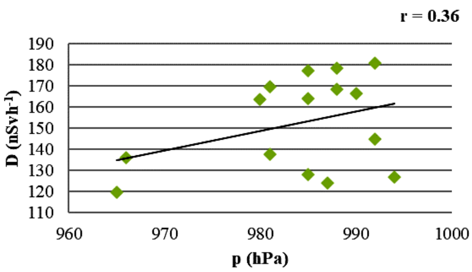

Figure 5. Pearson's correlation coefficient between the mean value of gamma dose rate and air pressure.

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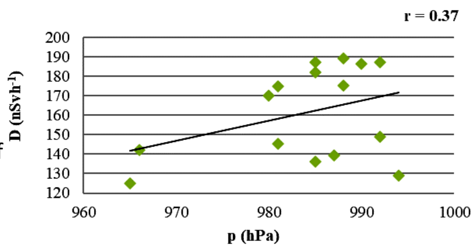

Figure 6. Pearson's correlation coefficient between the mean value of gamma+beta dose rate and air pressure.

Table 4. Comparison of annual gamma dose of the present study with the similar studies in the other countries of Europe.

Country	*AED* (mSv)	References
Croatia	0.21	(16)
Italia	0.23	(20)
Serbia	0.24	(18)
Sweden	0.24	(18)
Finland	0.09-0.21	(17)
Czech Republic	0.05-0.35	(17)
Bosnia and Herzegovina	0.27	Present study

AED-annual effective dose.

The values of the correlation coefficient are negative between air temperature and gamma dose rate (r=-0.04; p>0.05) and air temperature and gamma+beta dose rate (r=-0.01; p>0.05), but positive between air relative humidity and gamma dose rate (r=0.12; p>0.05) and between air relative humidity and gamma+beta dose rate (r=0.05; p>0.05

The outdoor air relative humidity has a negative, relatively weak correlation with the beta radiation dose rate, with coefficient r=-0.26, but considering the p value (p=0.35) this correlation is not significant at confidence level of 95%. After statistical correlation analysis, it should be noted that the outdoor air temperature (r=0.12; p>0.05) and air pressure (r=0.15; p>0.05) do not have any major impact on beta outdoor radiation dose rate changes in the area of Banovići and Živinice. According to Pearson's coefficient, a correlation between outdoor air temperature and dose rates, but also air humidity and dose rates, is negligible.

CONCLUSION

This paper presents the results of outdoor gamma, gamma+beta, and beta radiation dose rate measurements. Based on the results, the annual effective dose and excess lifetime cancer risk were estimated. The mean estimated annual outdoor effective dose of the gamma, gamma+beta and beta radiation in the area of Banovići and Živinice is considerably lower than the recommended annual effective dose of 1 mSv, according to EU Directive 2013/59/Euratom [19]. The values of excess lifetime risk cancer of gamma, gamma+beta, and beta radiation are also below the recommended risk value.

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Ethical consideration: Not applicable.

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Author Contribution: A.K., conceived the idea for experiments, drafted the manuscript and participated in data analysis. Z.S., contributed by collecting data of measurements and participated in data analysis. A.K., participated in writing the manuscript and data analysis.

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