Population doses from terrestrial gamma exposure in Serbia

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SUMMARY

Background: *Terrestrial radiation emitted from naturally occurring radionuclides, such as ^{40}K and radionuclides from the ^{238}U and ^{232}Th series and their decay products represent the main external source of irradiation to the human body. The purpose of this study was to provide a preliminary assessment of the doses from terrestrial exposure of population in Serbia and to estimate a potential radiation hazard for population inhabiting investigated areas.*

Methods: *The gamma dose rates, external hazard indexes, and annual effective doses due to terrestrial naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) were calculated based on their activities in soil samples in Serbia as determined by gamma-ray spectrometry.*

Results: *The total absorbed gamma dose rate due to these radionuclides varied from 16.9 to 125 nGy h^{-1}, with a mean of 62.8 nGy h^{-1}. Assuming a 20% occupancy factor, the corresponding annual effective dose varied from 2.07 to 15.4×10^{-5} Sv with the mean value of 7.7×10^{-5} Sv, i.e. annual effective dose was in range of the world wide average values.*

Conclusion: *According to the values of external hazard index obtained in this study (mean H_{ex} = 0.35), the radiation hazard was insignificant for the population living in investigated areas.*

Key words: *Soil; Radioactivity; Gamma Rays; Environmental Exposure; Radiation Dosage; Potassium; Thorium; Uranium; Non MeSH Serbia*

INTRODUCTION

There is a considerable need for radioecological characterization of soils in order to evaluate radionuclide concentrations with respect to natural background levels, to estimate the potential health impact to man and to reveal their spatial distribution. This characterization is also needed for implementation of precautionary measures whenever the dose is found to be above the recommended limits. Besides exposure from cosmic rays which is about 30 nGy h^{-1} at sea level everywhere in the world, primordial radionuclides ^{238}U, ^{232}Th and ^{40}K give a major contribution to the total dose from natural sources (1). Their specific levels are related to geological composition of the site. Magmatic rocks of granitic composition are strongly enriched in thorium (Th) and uranium (U) (15 ppm of Th and 5 ppm of U), compared to rocks of basaltic or ultramafic composition (less than 1 ppm of U) (2).

Several studies of natural radioactivity were done in Serbia; some of them were confined only to Serbian northern province of Vojvodina (3,4). In last few years investigations on natural radioactivity levels in surface soils all over the territory of Serbia were performed (5,6). The area with mineralized uranium on the mountain Stara planina (Serbia) has currently been investigated to assess the radiological hazard for the population inhabiting this area (7). An estimation of gamma exposure due to terrestrial radionuclides based on radioactivity measurements of surface soils in different regions of Serbia is presented in this paper.

MATERIALS AND METHODS

Soil samples were collected from 37 regions in Serbia in 2003-2006. Samples were crushed, dried to constant weight, sieved and placed in Marinelli beakers, which were sealed hermetically and kept aside for about one month to ensure equilibrium between ^{226}Ra and its decay products prior to radioactivity measurements. The activities of ^{238}U, ^{232}Th and ^{40}K were determined using a HPGe gamma-ray spectrometer ORTEC-AMETEK with 34% relative efficiency and 1.65 keV FWHM for ^{60}Co at 1.33 MeV. A typical gamma-ray spectrum recorded after 60 ks of measurement is shown in Figure 1.

The radiological hazard due to terrestrial radionuclides was estimated using external gamma dose rate, external hazard index and annual effective dose.

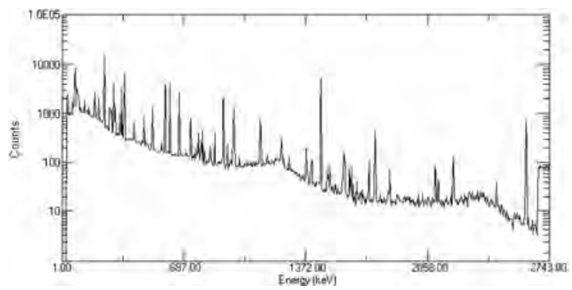

Figure 1. A typical gamma-ray spectrum of the soil sample

The external gamma dose rate in the air at 1 m above ground level was calculated from measured specific activities according to the following equation (1):

$$D = 0.462A_U + 0.604A_{Th} + 0.042A_K \quad (1)$$

where D is the dose rate in nGy h^{-1} and A_U, A_{Th} and A_K are the specific activities (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K, respectively.

From measured activities of terrestrial radionuclides the external hazard index, H_{ex}, was calculated (8):

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (2)$$

where A_U, A_{Th} and A_K are the specific activities (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K, respectively. The value of this index must be less than unity to keep the radiation hazard insignificant. The estimated absorbed dose rate was also converted into annual effective dose (1):

$$\textit{Annual effective dose (Sv)} = D \times 0.7 \times 24 \times 365 \times 0.2 \quad (3)$$

where 0.7 is the quotient of absorbed dose rate in air to annual effective dose received by adults (Sv/Gy) for environmental exposures to gamma rays and 0.2 is the outdoor occupancy factor.

RESULTS

The gamma dose rates in the air at 1 m above ground level due to ^{238}U, ^{232}Th and ^{40}K (Table 1) varied from 4.90 to 36.6 nGy h^{-1} for ^{238}U, from 5.76 to 50.9 nGy h^{-1} for ^{232}Th and from 4.58 to 37.8 nGy h^{-1} for ^{40}K. The calculated total gamma dose rate due to primordial radionuclides varied between 16.9 and 125 nGy h^{-1} (mean: 62.8 nGy h^{-1}). Descriptive statistics for gamma dose rates, external hazard index and annual effective dose are given in Table 2.

Table 1. Gamma dose rates of ^{238}U, ^{232}Th and ^{40}K in different regions of Serbia

	Region	^{238}U	^{232}Th	^{40}K	Total	H_{ex}	Annual effective dose (10^{-5} Sv)
1	Aranđelovac	21.2	29.4	27.2	77.8	0.45	9.54
2	Beograd	19.6	26.2	23.8	69.6	0.40	8.54
3	Avala	14.4	24.5	28.8	67.7	0.38	8.30
4	Beljanica	15.2	28.7	21.9	65.8	0.38	8.07
5	Bukulja	17.4	26.9	27.4	71.7	0.41	8.79
6	Čačak	27.2	36.8	33.0	97.0	0.56	11.9
7	Gornji Milanovac	20.0	29.7	27.3	77.0	0.44	9.44
8	Inđija	5.04	7.25	15.6	27.9	0.15	3.42
9	Jastrebac	36.6	50.9	37.8	125	0.73	15.4
10	Kopaonik	10.5	21.7	24.4	56.6	0.32	6.94
11	Kosmaj	15.4	26.6	29.9	71.8	0.41	8.81
12	Kragujevac	16.8	25.0	29.0	70.8	0.40	8.68
13	Kraljevo	19.4	25.4	19.7	64.4	0.37	7.90
14	Kruševac	21.2	23.7	34.7	79.5	0.45	9.75
15	Kukavica	14.2	27.0	31.7	72.9	0.41	8.94
16	Loznica	11.7	22.6	23.1	57.4	0.33	7.04
17	Markovac	17.0	17.0	28.9	62.9	0.35	7.71
18	Niš	18.4	28.5	24.7	71.6	0.41	8.79
19	Novi Sad	8.87	12.5	12.0	33.4	0.19	4.09
20	Pančevo	6.47	9.36	14.1	29.9	0.17	3.67
21	Paraćin	12.0	32.5	36.9	81.4	0.46	10.0
22	Požega	5.64	8.58	10.1	24.3	0.14	2.98
23	Ralja	18.3	16.9	18.1	53.3	0.30	6.54
24	Šabac	12.7	15.8	10.8	39.3	0.23	4.81
25	Slankamen	14.9	23.7	26.5	65.1	0.37	8.00
26	Sombor	11.6	15.5	17.2	44.3	0.25	5.43
27	Stara planina	13.2	19.9	25.2	58.4	0.23	7.16
28	Subotica	13.4	16.1	17.4	46.9	0.27	5.75
29	Topola	19.6	24.8	32.0	76.4	0.43	9.37
30	Surdulica	17.2	28.7	27.3	73.2	0.42	8.98
31	Užice	4.90	5.76	6.26	16.9	0.10	2.07
32	Valjevo	29.7	37.6	30.3	97.6	0.56	11.9
33	Vranje	23.3	32.8	25.8	81.9	0.47	10.0
34	Vrnjačka Banja	15.8	21.2	26.8	63.8	0.36	7.82
35	Vršac	13.7	20.1	32.4	66.2	0.37	8.11
36	Vršačke planine	13.7	20.3	32.0	66.0	0.37	8.09
37	Zlatibor	5.91	8.09	4.58	18.6	0.11	2.28

Table 2. Descriptive statistics of gamma dose rates of ^{238}U, ^{232}Th and ^{40}K for analyzed soil samples, external hazard index and annual effective dose due to these radionuclides

Parameter	Gamma dose rate (nGy h^{-1})				H_{ex}	Annual effective dose (10^{-5} Sv)
	^{238}U	^{232}Th	^{40}K	Total		
Range	31.7	45.1	33.2	108	0.63	13.3
Mean	15.7	22.9	24.2	62.8	0.35	7.70
Standard deviation	6.74	9.36	8.40	22.7	0.13	2.78
Minimum	4.90	5.76	4.58	16.9	0.10	2.07
Maximum	36.6	50.9	37.8	125	0.73	15.4
Median	15.2	23.7	26.5	66.0	0.37	8.09

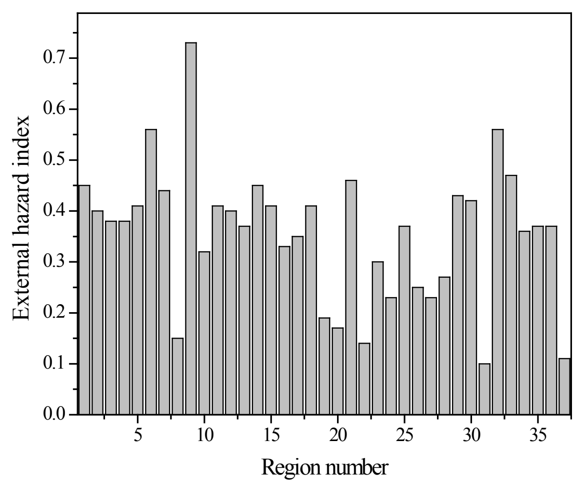

Figure 2. Bar diagram showing the values of external hazard index in different regions of Serbia

Table 3. Summary of gamma dose rates, external hazard indexes and annual effective doses derived from reported values of specific activities in soil samples from European-wide investigations

Country	Gamma dose rate (nGy h^{-1})	H_{ex}	Annual effective dose (10^{-5} Sv)
Albania (1)*	40	0.23	4.94
Belgium (10)	43	0.25	5.27
Bulgaria (11)	70	0.32	8.58
Croatia (1)	99	0.57	12.1
Cyprus (12)	8.7	0.06	1.07
Denmark (13)	52	0.21	6.38
Greece (1)	56	0.22	6.87
Hungary (14)	61	0.27	7.48
Ireland (15)	47	0.27	5.83
Lithuania (1)	48	0.26	5.85
Luxembourg (1)	49	0.42	6.01
Norway (16)	73	0.49	8.95
Poland (17)	45	0.24	5.52
Portugal (18)	84	0.49	10.3
Romania (19)	59	0.34	7.24
Russian Federation (1)	49	0.28	5.98
Slovakia (1)	60	0.34	7.31
Spain (20)	76	0.31	9.32
Switzerland (1)	45	0.28	5.52

* Reference numbers are given in brackets

The outdoor annual effective dose in investigated regions ranged from 2.07 to 15.4 x 10^{-5} Sv. The mean annual effective dose was 7.70 x 10^{-5} Sv which is close to the world average (7 x 10^{-5} Sv).

The H_{ex} values for investigated regions varied from 0.10 to 0.73, pointed out insignificant radiation hazard. Bar diagram showing the values of external hazard index in different regions of Serbia is shown in Figure 2.

In Table 3, a summary of results on gamma dose rate, external hazard indexes and annual effective doses derived from similar investigations conducted in Europe is presented. Values of these radiological parameters fall within the range of values reported for neighboring countries as well as for other European countries.

DISCUSSION

The contribution of each radionuclide to the total gamma dose rate varied with sampling location and reflected the geographical origin of the analyzed soils. Terrestrial radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological composition and geographic conditions, and appear at different levels in the soils of each region in the world (1). The specific levels of terrestrial environmental radiation are related to the composition of each lithologically separated area, and to the content of the rock from which the soils originate. Geologically, the territory of Serbia includes a variety of rock complexes (magmatic, sedimentary and metamorphic rocks) which are markedly different with respect to age, genesis, mineral content, and petrochemical characteristics (9). The differences in natural radioactivity of soils arise from this complexity. The highest gamma dose rates were found in soil samples that stem from magmatic rock complexes which belong to the category of silica oversaturated usually associated with high U and Th concentrations (Jastrebac). High gamma dose rates are also found in regions belonging to sedimentary formations (Čačak, Valjevo). The results reported for Stara planina were obtained based on investigations of north-west side of the mountain. Higher gamma dose rates are expected to be found in the vicinity of abandoned uranium mine Kalna.

The values of external hazard index obtained in this study, regardless of the location and soil composition, did not exceed the safety limits, pointing out to the insignificant radiation hazard arising from terrestrial naturally occurring radionuclides.

The results of this study are useful as a data baseline for preparing a radiological map of the studied area as well as for enrichment of the world's data bank. Before more definite conclusions of hazards of population exposure to natural radionuclides are drawn, an extended and more systematic survey of the area is needed.

Acknowledgements

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Conflict of interest

We declare no conflicts of interest.

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