DOI: 10.2429/proc.2016.10(1)006 2016;10(1)

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NATURAL BACKGROUND GAMMA RADIATION IN THE URBAN SPACE OF WALBRZYCH

NATURALNE TŁO PROMIENIOWANIA GAMMA W PRZESTRZENI MIEJSKIEJ WAŁBRZYCHA

Abstract: Walbrzych is the second most populous city of dolnoslaskie voivodeship, with the population of over 117 000 inhabitants. It is one of the largest cities within the Sudety Mountains with the area of approximately 85 km^2. From the geological point of view it is situated at the junction of three units: the Gory Sowie Massif, the Swiebodzice Basin and the Intra-Sudetic Basin. Each of this unit consists of various rocks which are characterised by various natural radionuclides content, resulting in various gamma dose rates in air within Walbrzych area. The landscape of the city largely is formed by an anthropogenic activity, mainly coal mining. Within the city there are thirty two heaps of wastes after the coal mining. The gamma spectrometric research of natural background gamma radiation in the urban space of Walbrzych was carried out. *In situ* measurements were performed by means of portable gamma spectrometer RS 230 with a BGO detector and dimensions of 259 mm × 81 mm × 96 mm. The device displays potassium K [%], equivalent uranium eU [ppm] and equivalent thorium eTh [ppm] contents, as well as absorbed gamma dose rate in air at the height of 1 meter generated by these radionuclides [in nGy/h]. The investigations were divided into two stages. In the first one, the content of K, eU and eTh in various types of rocks was examined. Measurements were performed on 14 outcrops of various aged rocks within all the three units (from Proterozoic gneisses of the Gory Sowie Massif to Pleistocene sands and gravels covering the Swiebodzice Basin) and on a heap. In the second stage the spatial distribution of natural radionuclides and gamma dose rate within the city was examined. Forty measurements were performed in the nodes of regular grid with the mesh size of 1.5 km. Taking into account that gamma dose rate in air mostly is formed by radionuclides present in the top 30-centimetres ground surface, the type of material covering the ground in measurement points was noted. Performed investigations showed that among rocks occurring within Walbrzych city, late Carboniferous trachyandesites, outcropping in the old quarry in Podgorze II district (the Intra-Sudetic Basin), were the most radioactive. The mean content of K, eU and eTh was 3.8%, 4.0 and 18.3 ppm, respectively which generated absorbed gamma dose rate equal to 121.2 nGy/h. Late Carboniferous conglomerates and sandstones of the Glinik Formation (the Intra-Sudetic Basin) are characterised by the lowest radioactivity. The mean content of K, eU and eTh was 0.6%, 1.5 and 5.1 ppm, respectively which generated absorbed gamma dose rate equal to 29.6 nGy/h. The analysis of spatial distribution of absorbed gamma dose rate showed that Srodmiescie district and the vicinity of Ksiaz Castle are characterised by the highest natural background gamma radiation. Absorbed dose rates with values of over 100 nGy/h were noted in places where the ground was covered by granite cobblestone. The lowest natural background gamma radiation was observed in points situated on the outskirts of the city, in places with relatively natural soils.

Keywords: natural background gamma radiation, gamma radiation, potassium, uranium, thorium, Sudety Mts.

Introduction

Potassium ^{40}K and radionuclides of uranium ^{238}U and thorium ^{232}Th decay series are the main contributors to natural background gamma radiation. Contents of ^{40}K and radionuclides of ^{238}U and ^{232}Th decay series vary depending on the type of rock. Many papers describe radionuclides content in various rocks and analyse results in the context of human exposure on an open space depending on the lithology [1-5]. Whereas estimating

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* Contribution was presented during ECOpole'15 Conference, Jarnoltowek, 14-16.10.2015

gamma dose rate on an open space is relatively simple because of an open field geometry, urban areas are much more complex and less studies are carried out in these environments. Urban areas are places with various geometries resulting from an urban structure. Furthermore, in urban areas the environment is modified by numerous and various building materials used for the construction of buildings, roads and pavements [6-9].

Urban areas are very important for estimating human exposure to gamma radiation. According to data from 2014 published by the Central Statistical Office [10] over 60% of total population in Poland lives in urban environments. The aim of this study was to estimate natural background gamma radiation in the urban space of Walbrzych, the second most populous city of dolnoslaskie voivodeship, with the population of over 117 000 inhabitants and one of the largest cities in Sudety Mountains with the area of approximately 85 km^2. Strzelecki et al [11] estimated gamma dose rate in Walbrzych on the basis of measurements performed in 900 measurment points. The lithological type of the bedrock was assigned to each measurement point. The results were analysed taking into account the geological structure of the area but the influence of building materials used in the urban space was not considered. Koperski [12] analysed background gamma radiation in cities of southern Poland, including Walbrzych, taking into account a type of material covering the ground. This paper presents the analysis of natural background gamma radiation in Walbrzych taking into account the type of rocks outcropping on this area but also considering the influence of building materials covering the roads and pavements. Furthermore, the spatial distributions of radionuclides and gamma dose rate were examined. Radioecological maps of Walbrzych were prepared and are presented in this paper.

Study area

The geology structure of Walbrzych area is very complex. The city is situated at the junction of three units: the Gory Sowie Massif, the Swiebodzice Basin and the Intra-Sudetic Basin. Each of this unit consists of various rocks which are characterised by various natural radionuclides content, resulting in various gamma dose rates in air. The Gory Sowie Massif is the oldest geological unit on the Walbrzych area. It is built of strongly metamorphosed Precambrian, Proterozoic and Archaic rocks which were the protoliths for gneisses. Some of the gneisses were exposed to high pressures and temperatures forming migmatites. The Swiebodzice Basin is a part of early Variscan sedimentary basin, filled in by coarse-grained sediments in late Devonian and early Carboniferous. Within the Swiebodzice Basin there are four formations, two Devonian: (1) Pogorzala Formation (consisted of mudstones, claystones and sandstones with insertions of conglomerates) and (2) Pelcznica Formation (consisted of mudstones and sandstones), and two Carboniferous: (3) Ksiaz Formation (consisted of conglomerates with approximately 80% of gneiss boulders) and (4) Chwaliszow Formation (consisted of conglomerates with approximately 32% of gneiss boulders). The Intra-Sudetic Basin consists of early and late Carboniferous sediments: conglomerates, sandstones, mudstones and claystones. Within the Intra-Sudetic Basin in the Walbrzych area there are two formations of early Carboniferous (Lubomin and Szczawno Formations) and five of late Carboniferous (Walbrzych, Bialy Kamien, Zaclerz, Glinik and Ludwikowice Formations). Within late Carboniferous sediments of Intra-Sudetic Basin there are igneous rocks, such as rhyolites, rhyodacites, volcanic tuffs, pyroclastic breccias, trachyadesites and trachybasalts. Quaternary sediments (from Pleistocene and Holocene) are the youngest rocks of Walbrzych area. The landscape of the city is largely modified by an anthropogenic activity, mainly coal mining. Within the city there are thirty two heaps of wastes after the coal mining [13].

Fourteen outcrops of various aged rocks (from Proterozoic gneisses of the Gory Sowie Massif to Pleistocene sands and gravels covering the Swiebodzice Basin) characteristic for the Walbrzych area and one heap of mineral waste after coal mining were selected (Table 1). Not all of the outcrops were located within the Walbrzych area (Fig. 1).

Table 1

Location and stratigraphic position of the outcrops

ID	Longitude [°E]	Latitude [°N]	Unit	Rock type	System	Epoch	Formation
1	16.2788	50.7543	Intra-Sudetic Basin	Mineral wastes after coal mining	Holocene		
2	16.3114	50.8253	Swiebodzice Basin	Sands and gravels	Pleistocene		
3	16.3259	50.7931	Gory Sowie Massif	Boulder clays			
4	16.3057	50.7409	Intra-Sudetic Basin	Trachyandesites			
5	16.2732	50.7397	Intra-Sudetic Basin	Rhyodacites			
6	16.2188	50.7756	Intra-Sudetic Basin	Rhyolites			
7	16.2596	50.7383	Intra-Sudetic Basin	Conglomerates, sandstones			Glinik Formation
8	16.2847	50.7673	Intra-Sudetic Basin	Conglomerates, sandstones, claystones		Late	Zaclerz Formation
9	16.2477	50.7889	Intra-Sudetic Basin	Conglomerates, sandstones	Carboniferous		Bialy Kamien Formation
10	16.2849	50.7879	Intra-Sudetic Basin	Sandstones, conglomerates			Walbrzych Formation
11	16.2320	50.7997	Intra-Sudetic Basin	Sandstones, conglomerates			Szczawno Formation
12	16.2296	50.8004	Intra-Sudetic Basin	Claystones		Early	
13	16.2979	50.8384	Swiebodzice Basin	Conglomerates			Ksiaz Formation
14	16.2808	50.8189	Swiebodzice Basin	Conglomerates			Chwaliszow Formation
15	16.3404	50.7959	Gory Sowie Massif	Gneisses and migmatites	Proterozoic		

To examine the spatial distribution of natural radionuclides and gamma dose rate within the city, forty measurement points were selected within the city borders. Measurements were performed in the nodes of regular grid with the mesh size of 1.5 km (Fig. 2).

Measurements not always were performed strictly in a node of designed grid. Some points were planned on private properties or places hardly available so measurements were conducted as close designed points as possible. Taking into account that gamma dose rate in air mostly is formed by radionuclides present in the top 30-centimetres ground surface [14] and a bedrock in a city often is covered by a building material, the type of material covering the ground in measurement points was noted (Table 2).

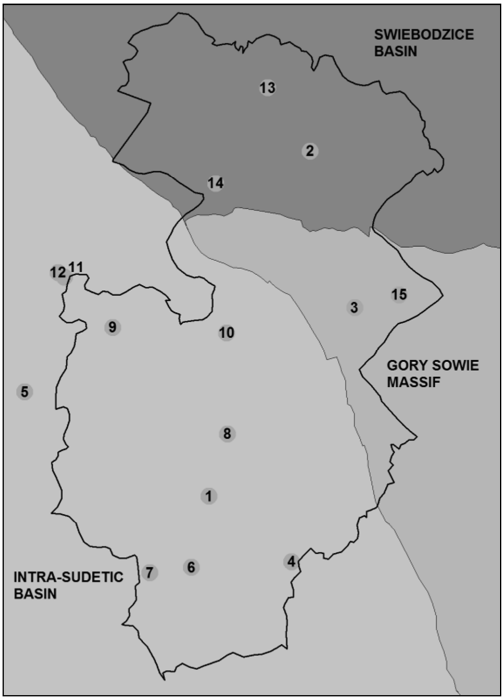

Fig. 1. Location of outcrops on the geological map (after Haydukiewicz et al [15] simplified)

Fig. 2. Location of measurement points

Table 2

Coordinates and ground coverage in measurement points

ID	Longitude [°E]	Latitude [°N]	Ground coverage	ID	Longitude [°E]	Latitude [°N]	Ground coverage
1	16.2579	50.8425	Soil	23	16.2783	50.7802	Asphalt
2	16.2795	50.8470	Soil	24	16.2580	50.7802	Soil
3	16.2976	50.8433	Granite	25	16.2578	50.7938	Asphalt
4	16.3197	50.8453	Soil	26	16.2376	50.7931	Crushed stone
5	16.3405	50.8308	Soil	27	16.2378	50.7805	Soil
6	16.3185	50.8303	Asphalt	28	16.2361	50.7679	Soil
7	16.2981	50.8297	Asphalt	29	16.2581	50.7666	Asphalt
8	16.2779	50.8306	Soil	30	16.2783	50.7678	Granite
9	16.2591	50.8309	Soil	31	16.2981	50.7674	Crushed stone
10	16.2782	50.8182	Asphalt	32	16.3211	50.7688	Soil
11	16.2987	50.8184	Asphalt	33	16.3388	50.7675	Soil
12	16.3163	50.8157	Soil	34	16.3160	50.7569	Soil
14	16.3389	50.8060	Soil	35	16.2975	50.7547	Asphalt
15	16.3180	50.8055	Soil	36	16.2789	50.7543	Soil
16	16.2972	50.8057	Concrete	37	16.2609	50.7557	Soil
17	16.2782	50.8057	Asphalt	38	16.2376	50.7539	Soil
18	16.3002	50.7924	Soil	39	16.2588	50.7420	Soil
19	16.3184	50.7926	Soil	40	16.2782	50.7425	Soil
20	16.3386	50.7929	Soil	41	16.2976	50.7435	Soil
21	16.3181	50.7804	Soil	43	16.2732	50.7294	Asphalt
22	16.3018	50.7796	Soil				

Methods

Portable gamma spectrometers are convenient devices to estimate natural background gamma radiation in urban environments with complex geometry of the source. Measurements of terrestrial background gamma radiation were conducted by means of gamma spectrometer RS 230 with a BGO detector and dimensions of 259 mm × 81 mm × 96 mm. The device displays potassium K [%], equivalent uranium eU [ppm] and equivalent thorium eTh [ppm] contents, as well as absorbed gamma dose rate in air at the height of 1 meter generated by these radionuclides [nGy/h]. Potassium K content is calculated on the basis of gamma photons emitted by ^{40}K (1461 keV). Uranium ^{238}U and thorium ^{232}Th contents are calculated on the basis of gamma photons emitted by ^{214}Bi (1765 keV) and ^{208}Tl (2615 keV), respectively. The secular equilibrium between all of the radioisotopes within the decay series is assumed. Uranium and thorium contents obtained in this way are denoted as equivalent uranium (eU) and equivalent thorium (eTh) content, respectively. Measurements on outcrops were performed placing the device directly on a rock. The result is representative for a sample of a radius of 0.5 m, a thickness of 25 cm and a mass exceeding 100 kg [14]. On each outcrop three measurements were performed. Measurements in regular grid were performed at the standard height of 1 meter above the ground. At this height 90% of photons reaching the gamma spectrometer originates from the area of a radius of 10 m [16]. In each point one measurement was performed. Additionally, equivalent gamma dose rate [μSv/h] generated by both, terrestrial and cosmic, radiations was measured in each point by means of radiometer ECO-D.

Results and discussion

Results of K, eU, eTh content in examined waste after coal mining and rocks, characteristic for the Walbrzych area, as well as absorbed dose rate in air generated by these radionuclides are presented in Table 2. Results varied in wide ranges depending on a type of rock. Mean K content varied from 0.6% for conglomerates and sandstones of Glinik Formation to 4.4% for Carboniferous rhyodacites. Mean eU content ranged from 1.5 ppm for conglomerates and sandstones of Glinik Formation to 6.5 ppm for sandstones and conglomerates of Walbrzych Formation. Mean eTh content varied from 5.1 ppm for conglomerates and sandstones of Glinik Formation to 29.1 ppm for Carboniferous rhyolites. Mean absorbed dose rate in air ranged from 29.6 nGy/h for conglomerates and sandstones of Glinik Formation to 121.2 nGy/h for Carboniferous trachyandesites. Contribution of K, eU and eTh in forming absorbed dose rate varied in ranges 13.7-51.5%, 17.7-33.7% and 25.6-66.0%, respectively. According to Strzelecki et al [11] absorbed dose rate at the Walbrzych area ranges between 24.1 and 138.5 nGy/h. They observed the highest absorbed dose rates on heaps of wastes after coal mining and in Kozice district, in a place with the uranium mineralization within gneisses.

Table 3

Results depending on the bedrock lithology

ID*	Terrestrial absorbed dose rate [nGy/h]	K			eU			eTh		
		[%]	[nGy/h]	Contri-bution [%]	[ppm]	[nGy/h]	Contri-bution [%]	[ppm]	[nGy/h]	Contri-bution [%]
1	109.5	3.1	42.2	38.5	4.9	26.2	23.9	15.3	41.1	37.5
2	53.5	1.7	22.9	42.8	2.1	11.2	20.8	7.3	19.5	36.4
3	66.5	1.9	25.1	37.8	3.0	16.1	24.2	9.4	25.3	38.0
4	121.2	3.8	50.7	41.8	4.0	21.4	17.7	18.3	49.1	40.5
5	114.2	4.4	58.8	51.5	4.4	23.2	20.3	12.0	32.2	28.2
6	118.3	1.2	16.2	13.7	4.5	24.1	20.4	29.1	78.1	66.0
7	29.6	0.6	8.1	27.3	1.5	8.0	26.9	5.1	13.6	45.8
8	83.6	3.0	40.8	48.8	3.7	19.6	23.5	8.6	23.1	27.7
9	87.9	3.2	42.6	48.5	3.0	15.8	17.9	11.0	29.5	33.6
10	102.8	2.7	36.3	35.3	6.5	34.7	33.7	11.9	31.8	30.9
11	52.0	1.6	22.0	42.3	2.3	12.2	23.5	6.6	17.8	34.2
12	111.4	3.7	49.3	44.3	4.6	24.3	21.8	14.1	37.8	33.9
13	78.5	2.7	36.3	46.3	3.3	17.3	22.1	9.3	24.8	31.6
14	90.5	3.1	41.3	45.6	4.4	23.4	25.8	9.7	25.9	28.6
15	94.4	3.3	44.4	47.1	4.9	25.8	27.4	9.0	24.1	25.6

*Description of the lithology in Table 1

Table 4 presents results of measurements performed in measurement points of regular grid. Among 40 measurements, 26 were performed above relatively natural soils, 9 above a ground covered by an asphalt, 2 above a crushed stone, 2 above granite cobblestones and 1 above a ground covered by a concrete (Table 4). Such a large contribution of places with soils is a result of a large contribution of farmlands and forests (almost 70%) and low contribution of urban areas (about 13%) within Walbrzych area [17]. The lowest absorbed dose rate was observed in the places with relatively natural soils. Nevertheless, absorbed dose rate above soils ranged in wide limits, from 22 to 81 nGy/h with a mean of 47 nGy/h. The highest absorbed dose rate was observed in the places with granite cobblestones (mean absorbed dose rate equal to 106 nGy/h). Results obtained by Koperski [12] are similar to the results obtained in this study. The highest absorbed dose rate was noted in places covered by granite cobblestones, lower in places covered by an asphalt and a concrete and the lowest in places with soils.

Mean terrestrial absorbed dose rate in Walbrzych obtained on the basis of 40 measurement points of regular grid was equal to 52 nGy/h. This value is lower than mean absorbed dose rate estimated by Strzelecki et al [11] which was 72.35 nGy/h.

Table 4

Results depending on the ground coverage

	Soil	**Concrete**	**Granite**	**Crushed stone**	**Asphalt**	**Total**
Number of measurements	26	1	2	2	9	40
Mean terrestrial absorbed dose rate [nGy/h]	47	42	106	62	53	52
Standard deviation [nGy/h]	11	-	5	1	9	16
Min [nGy/h]	22	-	100	61	50	22
Max [nGy/h]	81	-	111	63	56	111
Mean contribution of K [%]	38	35	38	37	38	38
Mean contribution of eU [%]	27	33	25	30	26	27
Mean contribution of eTh [%]	35	32	37	33	36	35

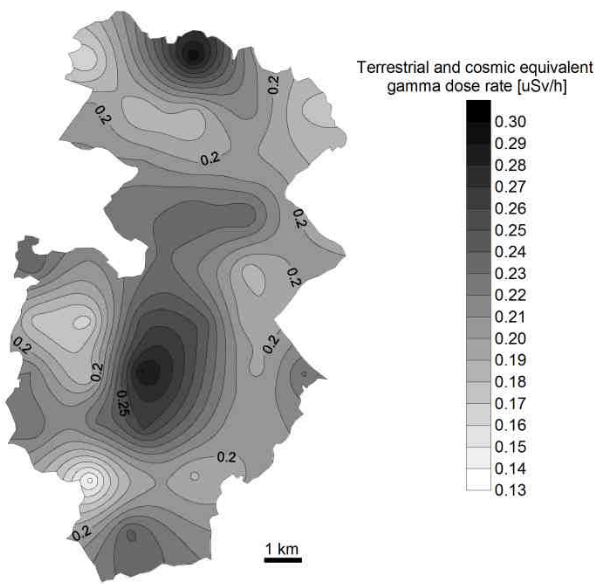

Fig. 3. Spatial distribution map of terrestrial and cosmic equivalent gamma dose rate [μSv/h] measured by means of ECO D radiometer

Figures 3 and 4 present radioecological maps of Walbrzych area. The analysis of spatial distribution of gamma dose rate showed that Srodmiescie district and the vicinity of Ksiaz Castle are characterised by the highest natural background gamma radiation. Also contents of K, eU and eTh are the highest in these places. It is a result of the presence of granite cobblestones used for a construction of roads and pavements. The lowest natural background gamma radiation was observed in points situated on the outskirts of the city, in places with relatively natural soils.

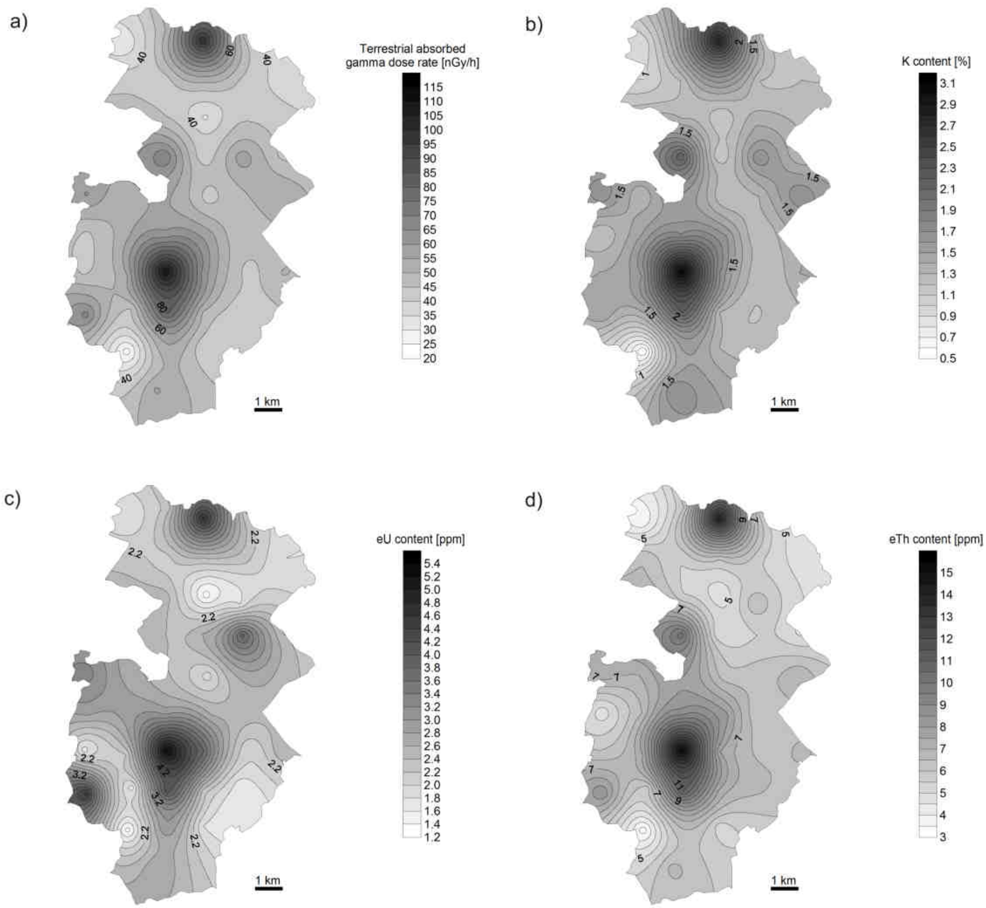

Fig. 4. Spatial distribution maps of: a) terrestrial absorbed gamma dose rate [nGy/h], b) potassium content [%], c) equivalent uranium content [ppm], d) equivalent thorium content [ppm] measured by RS 230 gamma spectrometer

Conclusions

Natural background gamma radiation in Walbrzych ranges in wide limits as a result of a complex geological structure of this area. Nevertheless, the type of the ground coverage plays a significant role in forming gamma dose rate on urban areas. High dose rates are observed on urban areas with a ground covered by granite cobblestones and on heaps of wastes which means that people largely form background gamma radiation in which they live.

Acknowledgements

The project is co-financed by the European Union under the European Social Fund.

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NATURALNE TŁO PROMIENIOWANIA GAMMA W PRZESTRZENI MIEJSKIEJ WAŁBRZYCHA

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Abstrakt: Wałbrzych jest drugim najludniejszym miastem województwa dolnośląskiego, liczącym ponad 117 tys. mieszkańców. Jest jednym z największych miast Sudetów, o powierzchni ok. 85 km^2. Pod względem geologicznym leży na styku trzech jednostek geologiczno-strukturalnych: bloku sowiogórskiego, depresji Świebodzic oraz niecki śródsudeckiej. Każdą z tych jednostek budują różnorodne skały, charakteryzujące się zróżnicowaną zawartością naturalnych pierwiastków promieniotwórczych, co sprawia, że moc dawki promieniowania gamma w powietrzu pochodząca od naturalnych radionuklidów rozproszonych w skałach podłoża i glebie waha się w szerokich granicach na terenie Wałbrzycha. Krajobraz miasta w dużej mierze ukształtowany jest przez działalność człowieka. Pozostałością po eksploatacji węgla kamiennego są 32 hałdy. Przeprowadzono gamma spektrometryczne badania naturalnego tła promieniotwórczego w przestrzeni miejskiej Wałbrzycha. Pomiary *in situ* były wykonywane przy pomocy przenośnego spektrometru gamma RS 230 o wymiarach 259 mm × 81 mm × 96 mm, wyposażonego w detektor BGO. Urządzenie podaje zawartość potasu K [%] oraz równoważne zawartości uranu eU [ppm] i toru eTh [ppm], a także moc dawki pochłoniętej w powietrzu na wysokości 1 metra generowanej przez te radionuklidy [nGy/h]. Badania składały się z dwóch etapów. W pierwszym zbadano zawartość K, eU i eTh w różnych typach skał podłoża, wykonując pomiary na 14 wychodniach różnowiekowych skał w obrębie trzech jednostek geologiczno-strukturalnych (od proterozoicznych gnejsów bloku sowiogórskiego po plejstoceńskie piaski i żwiry pokrywające depresję Świebodzic) oraz na hałdzie odpadów powęglowych. W drugim etapie zbadano przestrzenny rozkład zawartości naturalnych radionuklidów oraz mocy dawki promieniowania gamma na terenie miasta, wykonując 40 pomiarów w węzłach regularnej siatki o wielkości oczek 1,5 km. Uwzględniając fakt, że moc dawki promieniowania gamma w powietrzu kształtują głównie radionuklidy znajdujące się w 30-centymetrowej wierzchniej warstwie podłoża, zanotowano rodzaj pokrycia gruntu w badanych punktach. Przeprowadzone badania wykazały, że wśród skał występujących na terenie Wałbrzycha najbardziej radioaktywne są późnokarbońskie trachyandezyty odsłaniające się w starym kamieniołomie w dzielnicy Podgórze II (niecka śródsudecka). Zawartość K, eU i eTh wynosi średnio 3,8%, 4,0 i 18,3 ppm, odpowiednio, generując moc dawki pochłoniętej w powietrzu równą 121,2 nGy/h. Najniższą radioaktywnością charakteryzują się późnokarbońskie zlepieńce i piaskowce formacji z Glinika (niecka śródsudecka). Zawartość K, eU i eTh wynosi średnio 0,6%, 1,5 i 5,1 ppm, odpowiednio, generując moc dawki pochłoniętej w powietrzu równą 29,6 nGy/h. Analiza przestrzennego rozkładu mocy dawki pochłoniętej wykazała, że najwyższym tłem promieniowania gamma charakteryzuje się dzielnica Śródmieście oraz rejon zamku Książ. Moc dawki pochłoniętej o wartości ponad 100 nGy/h odnotowano w miejscach, w których grunt pokryty został kostką granitową. Najniższe tło promieniowania gamma zaobserwowano natomiast w punktach znajdujących się na obrzeżach miasta, w miejscach występowania względnie naturalnej gleby.

Słowa kluczowe: naturalne tło promieniotwórcze, promieniowanie gamma, potas, uran, tor, Sudety