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ORIGINAL PAPER

Comparison of radon hazard to inhabitants of the Augustów Plane sandr and inhabitants of the Suwałki region of fluvioglacial sands and gravels

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Abstract In a region of two lithologic units: the Augustów Plane sandr and the Suwałki sands and fluvioglacial gravels, 134 measurements of radon concentrations in dwelling houses were performed. An integral method of solid state nuclear trace detectors (SSNTD) was used in the studies. Statistically significant differences in the radon concentrations in both geological units were obtained. The radon concentration arithmetic mean was 197 Bq m^{-3}, geometric mean – 119 Bq m^{-3}, median – 111 Bq m^{-3}, the maximal value being 1225 Bq m^{-3} in the region of the Suwałki fluvioglacial sands and gravels. The Augustów Plane sandr revealed arithmetic mean of radon concentration equal to 123 Bq m^{-3}, geometric mean – 80 Bq m^{-3}, and median equal to 67 Bq m^{-3}, maximal value 695 Bq m^{-3}. The annual effective dose of the radon obtained by inhabitants of the Augustów Plane sandr is 1.7 mSv and for inhabitants of the Suwałki fluvioglacial sands and gravels it is 2.5 mSv.

Key words building • geology • radon

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Introduction

Radon is a naturally occurring radioactive gas, which provides the largest contribution to the effective dose absorbed by the population. In the Polish conditions the dose is equal approximately to 1.3 mSv/year [13].

The main source of radon in dwelling houses is the subsoil. As a result of diffusion and thermal convection, which are frequently intensified by the so called "chimney effect", the radon occurring in the soil gas is transported to the building through all, even microscopic, leaks in the construction [12, 16]. Permeability of soil for the soil gas, which is strongly dependent on geological structure of the ground, is one of the most important factors influencing radon concentration in buildings. It may be an indicator of regions of increased radon risk [2, 5, 6, 15].

The northeastern part of Poland has been formed by postglacial quaternary sediments of the latest glaciation with high lithologic changeability. From the geochemical point of view, the formations of the latest glaciation are characterized by markedly higher concentrations of many elements as compared to those of older glaciations as they have undergone a rainfall leaching process over a much shorter period of time than those of the older glaciations [11]. This fact is of great importance from the radioecological point of view since uranium, the first in the uranium–radium series in which radon is located, can easily migrate in the hypergenic environment. The studies were carried out in two regions of fairly different genesis and lithologic development: the Augustów Plane sandr and the Suwałki region of fluvioglacial sands and gravels.

The Augustów Plane is an extensive region spreading from Augustów and Suwałki in the west, the Wigry Lake to the border of Poland–Lithuania–Belarus and further to the east. It consists of varigrained sands with the prevalence of fine-grained sands and the addition of gravels. The thickness of these formations in the Augustów sandr extends for tens of meters, with the mean value of 20–30 meters. They were formed in the Poznań–Dobrzyń and Pomeranian phases of Northern Polish glaciation in the valleys of glacial outflows from the period of areal deglaciation. The following villages, situated in the region, have been investigated: Okółek, Frącki, Macharce, and Płaska (Fig. 1).

Fluvioglacial sands and gravels of the Suwałki region are the formations in the valleys of glacial outflows from the period of areal glaciation. They are formed of varigrained sands with single gravel intercalations. Petrographic composition is made of predominantly quartz accompanied by feldspar and fragments of the northern rocks, fragments of crystalline rocks carried in by the Scandinavian ice-sheet, granites, gneisses, and mica schists. The thickness of the above formations ranges from 5 to 10 meters. The villages examined were Marianka and Kamionka (Fig. 1).

The Augustów sandr deposits are made almost exclusively from quartz whereas the other unit deposit composition is much more diversified. The differences in geological structure of the regions are reflected by the radiogenic potential. In the region of sands and fluvioglacial gravels, gamma dose rate varies in the range from 40 to 60 nGy h^{-1} whereas in the Augustów sandr it does not exceed 20 nGy h^{-1}. According to G. Åkerblom classification, based on the measurements of radon concentration in soil gas, the division is made into areas of low (up to 10 kBq m^{-3}), medium (from 10 to 50 kBq m^{-3}), and high (above 50 kBq m^{-3}) radon risk [1]. The Suwałki sands and gravels are of medium radon potential [8]. There is no data concerning radon concentration in the soil of the Augustów Plane sandr, but geological structure of this region points to the possibility of low radon potential.

Methods

The time integral method of SSNTD was used to investigate ^{222}Rn concentration. CR-39 foils were placed in diffusion Karlsruhe-type chambers equipped with paper filters cutting off all radon decay products and, to a great extent, thoron [3, 18]. The exposure time was 6 months (March–September). After exposure, the chambers were transported to the Central Laboratory for Radiological Protection (CLRP), where CR-39 detectors were subjected to chemical etching in a 10 N NaOH solution at 70°C for 8 hours. The densities of tracks were calculated with the use of an automatic computerised reader over 100 visual fields of the total area of 39 mm^2. The diffusion chambers were calibrated at the Standard Radon Unit at the CLRP. Low level detection was estimated to be 34 kBq h m^{-3} with uncertainty of 15% at 68% confidence level. As most reports describe radon distribution in a given area as lognormal [8, 20, 21], for statistical analysis we used the Mann–Whitney non-parametrical test for two independent samples to verify the hypothesis that two analyzed samples were taken from different populations.

Results and discussion

We performed 134 measurements of radon concentrations in the air of dwelling houses constructed in the region of the Augustów Plane sandr and fluvioglacial sands and

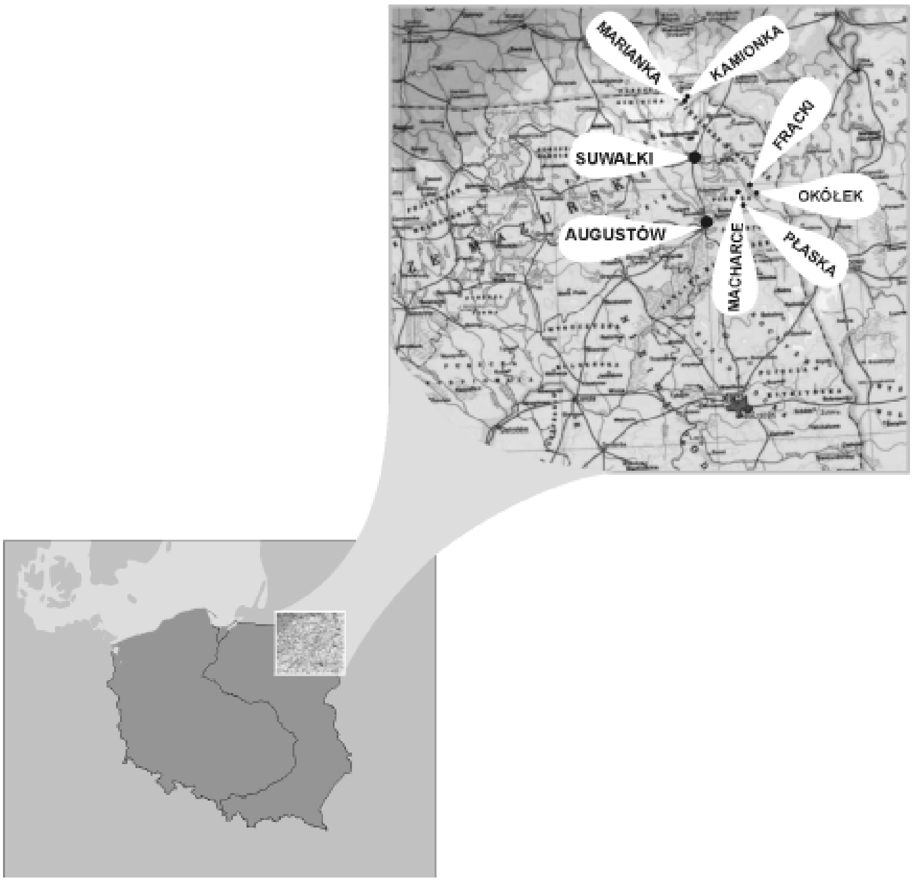

Fig. 1. Localization of radon measured sites.

Table 1. The percentage of radon concentration measurements in particular ranges.

Radon concentration ($Bq\ m^{-3}$)	Percentage of measurements Sands and gravels	 Sandr
0–50	16.2	36.4
50–100	29.7	31.8
100–200	29.7	18.2
200–400	13.5	6.7
Above 400	10.8	6.8

Table 2. Statistical parameters of radon concentration distribution in buildings of the Augustów Plane sandr and the Suwałki fluvioglacial sands and gravels.

Whole building		Sands and gravels	Sandr
Arithmetic mean	($Bq\ m^{-3}$)	197	123
Geometric mean	($Bq\ m^{-3}$)	119	80
Median	($Bq\ m^{-3}$)	111	67
Geometric standard deviation		2.5	2.4
Range	($Bq\ m^{-3}$)	27–1225	20–696
Number of measurements		72	62

gravels of the Suwałki region. Table 1 shows the percentage of measurements of radon concentration values (in %) in both lithologic divisions.

The statistical analysis was carried out using the non-parametric Mann–Whitney test. Statistically significant differences between the radon concentrations in both units ($p < 0.03$) were obtained. The statistical parameters of radon concentration distribution in buildings in both investigated units are shown in Table 2. The statistical parameter values of radon concentration distribution in dwelling houses on the ground floor are presented in Table 3.

Most buildings constructed in the region of the Augustów Plane sandr had no basements (57.4%). It was shown that there were no significant differences between radon concentrations on the ground floors of the buildings with and without basements. The results are presented in Table 4.

Table 3. Statistical parameters of radon concentration distribution on the ground floor of the Augustów Plane sandr and the Suwałki fluvioglacial sands and gravels.

Ground floor		Sands and gravels	Sandr
Arithmetic mean	($Bq\ m^{-3}$)	137	65
Geometric mean	($Bq\ m^{-3}$)	83.8	56
Median	($Bq\ m^{-3}$)	69	50
Geometric standard deviation		2.29	1.74
Range	($Bq\ m^{-3}$)	27–1131	20–160
Number of measurements		62	47

Table 4. Radon concentrations obtained on the ground floors of buildings in the Augustów Plane sandr with and without basements.

		Buildings without basements	Buildings with basements
Arithmetic mean	($Bq\ m^{-3}$)	64	67
Geometric mean	($Bq\ m^{-3}$)	57	55
Median	($Bq\ m^{-3}$)	53	50
Geometric standard deviation		1.6	1.9
Range	($Bq\ m^{-3}$)	27–140	20–160
Number of measurements		27	20

The absence of differences between radon concentrations measured on the ground floors of buildings with and without basements may be due to the high homogeneity of sandr formations, in which the phenomenon of accumulation of gases along privileged migration paths does not occur. The gas emission takes place relatively equally on the whole surface. Thus, basements cannot cross the path of migration. In the North-Eastern region of Poland the radon concentration in basements is significantly higher than on ground floors [20]. A basement, especially with a leaky floor, is not a barrier for entering radon [9]. High radon concentration in basements together with a direct communication with dwelling space is a hazard of radon concentration increase on the ground floors. This phenomenon was not observed (in the cases of radon concentrations measured) in buildings in the Augustów Plane sandr. In the Suwałki region of fluvioglacial sands and gravels, most buildings (approximately 90%) had basements, so the comparison is difficult. However, there is a tendency of radon concentration, measured on the ground floor, to increase by about 20% in buildings with basements as compared to those without them. The comparison of radon concentration obtained in dwelling houses built in the Augustów Plane sandr and the Suwałki region of fluvioglacial sands and gravels is presented in Fig. 2.

Radon concentration values in sandr are lower and have a lower dispersion than the values obtained in the region of fluvioglacial sands and gravels. The arithmetic means of radon concentrations on the ground floors of the buildings in both lithologic divisions are higher than those appointed for Poland (49.1 $Bq\ m^{-3}$) [7]. The maximum permissible radon concentration in the air of dwelling buildings for inhabitants was determined by the Regulation by President of the National Atomic Energy Agency. It cannot exceed

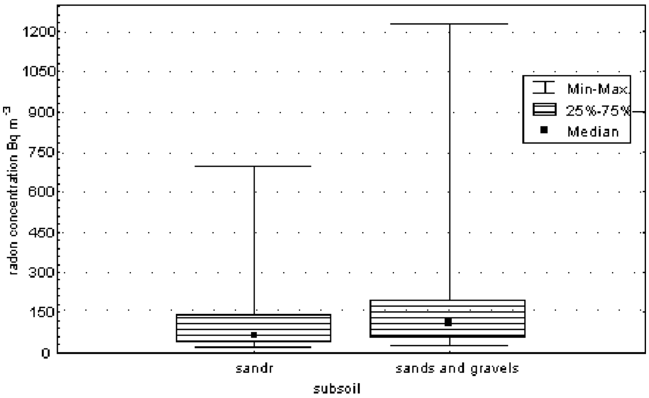

Fig. 2. Radon concentration in the air of dwelling houses of both lithologic units.

400 Bq m^{-3} in buildings constructed before 01.01.1998 and 200 Bq m^{-3} in buildings constructed after this date [10]. Radon concentration values above 200 Bq m^{-3} and 400 Bq m^{-3} were observed in habitable parts of the buildings only in the Suwałki region. Radon concentrations above 200 Bq m^{-3} were observed in 6 cases, out of which 3 showed over 400 Bq m^{-3}. Since radon concentration undergoes seasonal changes, the mean annual radon concentration should be determined to assess the annual effective dose. In some countries in the world seasonal corrective coefficients are estimated and used [14, 19]. Unfortunately, we do not have such data for Poland. In one published paper an observation is reported that in Poland the radon concentration measured in spring and winter was close to the annual mean [4]. If we consider radon concentration changeability schemes to be approximate in England and Poland (both countries are situated in the moderate climate) we can use the English seasonal corrective coefficient, whose value is 1.2, for the exposure which has begun in March [14]. This means that to obtain the mean annual we should multiply the 6-month exposure value by 1.2. On the basis of radon mean concentrations on the ground floor, we determined the annual effective dose values (E) of inhaled radon per a statistical inhabitant. It was accepted that the equilibrium coefficient for closed room is $F = 0.4$ and the dose conversion factor of unit equivalent exposure (1 Bq m^{-3} (EEC)) per effective dose is $k = 9$ nSv/(Bq m^{-3}), and the inhabitation time coefficient is $n = 0.8$ [17], then the effective dose is

$$E = F \cdot k \cdot n \cdot c \cdot t \tag{1}$$

where: c is the concentration of radon; t is the number of hours in year.

The annual effective dose of radon assessed on the basis of the geometric mean values of radon concentration sand with the use of correction value of 1.2 is approximately 1.7 mSv per an inhabitant of the Augustów Plane sandr and approximately 2.5 mSv per an inhabitant of the Suwałki region of sands and fluvioglacial gravels.

Conclusions

The difference between the radon concentrations inside buildings situated in the examined areas is most probably connected with the differences in basement complexes. The arithmetic means of radon concentrations on the ground floors in the buildings in both lithologic divisions are higher than those appointed for Poland. Radon concentration on the ground floors in buildings in the area of the Augustów Plane sandr is equal to 65.1 Bq m^{-3} and in the respective dwelling houses situated in Suwałki region – 136.8 Bq m^{-3}. The effective dose obtained by the inhabitants of the Augustów Plane sandr is 1.7 mSv and for the inhabitants of the Suwałki fluvioglacial sands and gravels is equal to 2.5 mSv.

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