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SPATIAL PATTERN OF ^{137}Cs DISTRIBUTION IN SOIL IN THE MARGINAL ZONE OF THE CARPATHIAN FOOTHILLS BETWEEN THE VALLEYS OF RABA AND USZWICA

Abstract: The content of radioactive ^{137}Cs in soils was measured in the northern edge of the Carpathian Foothills and the neighbouring fragment of the Sandomierz Basin; between the valleys of the Raba and Uszwica rivers. To compensate for other radioactive fallout factors potentially affecting the spatial distribution of ^{137}Cs, the sites that were chosen for sampling represented similar physical-geographical conditions. These were locally flat areas: hilltops or plains used as pasturelands, meadows, orchards or barren lands with undisturbed soil profiles. In spite of that the spatial pattern of ^{137}Cs distribution showed large differentiation of caesium content with the highest values detected in the western part of the area. The reason for this is probably the larger radioactive fallout connected with atmospheric precipitation on the orographically exposed hills above the Raba valley.

1. Introduction

Radioactive contamination of the human environment is one of many present-day ecological problems. Interest in artificially introduced isotopes grew up rapidly after the Chernobyl disaster in April 1986, however nuclear tests in the fifties and sixties, culminating in 1961-1962, resulted in comparable inputs of radioactive isotopes into the atmosphere. One of the isotopes is ^{137}Cs, which - due to its relatively long half-life (30.2 years) - is still present in various components of the environment: soils, plants and animal tissues.

As a result of the many nuclear test explosions which took place in different regions during the fifties and sixties, the radioactive fallout was distributed relatively evenly all over the world. The distribution of the fallout after the single event that was the Chernobyl disaster was less uniform and depended on the track of the radioactive cloud and the occurrence of rainfalls depositing the radioactive contamination from the cloud on days following the disaster. According to Radioecological Maps of Poland

Fig. 1. Dominating processes influencing ^{137}Cs distribution in soil.

Ryc. 1. Dominujące procesy wpływające na rozmieszczenie ^{137}Cs w glebie.

(Strzelecki et al., 1993) and the report by the National Inspection of Environmental Protection (Zmiany sytuacji..., 1996), the areas of the highest ^{137}Cs contamination in Poland generally coincide with areas affected by rainfall that occured on the last days of April and the first days of May 1986. Five years after the Chernobyl disaster (1991) the mean value of ^{137}Cs radioactivity for the whole of Poland was 4.67 kBq m^{-2} with the maximum value being 96 kBq m^{-2} (Strzelecki et al., 1993).

After deposition onto the earth's surface, ^{137}Cs is strongly bound to fine soil particles and does not easily diffuse down the profile. This results in a vertical distribution pattern with relatively high radioactivity close to the soil surface, rapidly diminishing with depth.

Very often the assumption of uniformity of ^{137}Cs fallout distribution within small areas is not supported by evidence gathered in the field. It has been documented by many authors (eg. Martz, De Jong, 1987; Loughran, Campbell, Elliott, 1990; Walling, Quine, 1990; Quine et al., 1997) that on slopes, even within small distances ranging from a few metres to a few tens of metres, ^{137}Cs content in superficial layers of soil changes greatly. This suggests that the isotope fallout was, or still is, followed by the redistribution of radioactive particles by slope geomorphological processes: soil washout, erosion and redeposition (Chełmicki, Klimek, Krzemień, 1995). Being bound to soil particles ^{137}Cs can be used as a tracer and indicator of the extent and intensity of soil erosion and deposition (Martz, De Jong, 1987; Loughran R.J., 1989; Walling, Quine, 1990, 1992; Lobb et al., 1995). The general rule is, that in places undergoing soil erosion the vertical distribution of ^{137}Cs is characterized by the lack, or very small concentrations of the isotope, at all depths. In places where the soil is deposited the concentration is relatively high, even at a depth of several tens of centimetres or more. The depth depends on the thickness of the accumulated deposit at the base of slopes and in valley bottoms (Fig. 1).

Recent studies carried out in the vicinity of the Institute of Geography Research Field Centre in Łazy have focused on the small scale differences in ^{137}Cs content in soil and the use of the isotope as a tracer in geomorphological research (Chełmicki, Święchowicz, 1992). Studies on typical slopes in the area have documented generally high levels of radioactivity in the deposits accumulated in the valley bottoms, while the midslope soils exhibit lower levels of radioactivity as a result of the most intensive processes of washout and erosion. For example, the variations in measured radioactivity between the various parts of a forested slope catena were as large as 10,000 kBq m^2, which was more than half of the maximum value measured (Chełmicki et. al., 1993-1994).

The aim of this study is to recognize the spatial pattern of soil radioactivity on a larger scale (ca. 100 km^2). The area investigated was the northern edge of the Carpathian Foothills and the neighbouring fragment of the Sandomierz Basin situated between the valleys of the Raba and Uszwica rivers.

2. Area

The area is about 160 square kilometres in extent with an elevation of between 194 and 364 metres a.s.l. (Fig. 2). The southern limit of the Sandomierz Basin comprises Miocene deposits; mostly silts, sands and gypsum. The foothill area consists of two steps. The lower one at an elevation of 200-280 m a.s.l. comprises folded Tertiary deposits (silts, marls, marly clays, gypsum, sandstones) of the Bochnia unit and the higher one, reaching 364 m, comprises Cretaceous and Tertiary flysch deposits of the Silesian unit. Bedrock geology is covered by very fine grained loess-like deposits of Quaternary age and flysch regolith. The thickness of the loess-like deposits is variable and can be as much as 20 metres in depth. The thickness decreases with increasing elevation or where the loess cover is completely removed. The dominating soils in the foothills are *Haplic Luvisols* and *Stagnic Luvisols* covering almost 80 per cent of the area (Skiba, Drewnik, Klimek, 1995), while in the Sandomierz Basin section - *Cambisols* and *Fluvisols*

Fig. 2. Study area.

Ryc. 2. Obszar badań.

Fig. 3. Grain-size diagram for typical fine grained soils (after Klimek, 1995).

Ryc. 3. Uziarnienie typowych gleb pyłowych (wg Klimka, 1995).

dominate. Fine sized granulometry of the superficial material (Fig. 3) along with soil organic matter favours strong adsorption of ^{137}Cs. Thus the spatial distribution of caesium may result from the primary (original) deposition, the extent and intensity of slope processes, the spatial and vertical distribution of organic matter in soil as well as the granulometry of the soil particles. According to the literature (Schuller, Handl, Trumper, 1988) there are also other parameters, like soil pH and exchangeable potassium content, that may influence the rate of ^{137}Cs adsorption and, consequently, the pattern of spatial distribution.

The annual precipitation totals for the area under investigation are about 600-650 mm. Due to prevailing rain-bearing winds from the west and north-west and the orographic effect the hills dominating the Raba valley receive probably more precipitation then the central and eastern parts of the area, however because of the lack of meteorological posts (the only one is in Łazy) it cannot be documented.

3. Method

3.1. Sampling sites

To recognize the large scale pattern of the spatial distribution of ^{137}Cs in soils it was important to measure ^{137}Cs content at sites with comparable physical-geographical characteristics. To avoid the influence of geomorphological position on ^{137}Cs content, all sampling sites were located in flat areas of the Sandomierz Basin or, in case of the Foothills - on flat areas as hilltops and platforms. Thus the potential influence of soil washout or erosion on ^{137}Cs distribution was excluded. Another condition was to exclude areas disturbed by agricultural practices or other activities causing vertical redistribution of soil material. Therefore the sampling sites were located on pasturelands, meadows, in orchards or derilict land. Due to their variable humus content, forested areas were also excluded from the research. The sampling took place in July 1994.

3.2. Sampling techniques

At each site three cores reaching to a depth of 10 cm were taken using a special core-sampler of a diameter of 45 mm. The three cores were mixed and taken to the laboratory where they were dried, and roots, plant remnants and other macroscopic objects were removed. This was followed by sample disintegration and seiving through a 1 mm mesh. Following this processing the samples were ready for radioactivity measurement.

3.3. Radioactivity and additional analyses

The measurements were performed at the Laboratory of Radioactive Contamination of Environment, Institute of Nuclear Physics, Cracow using low-background gamma spectrometers with germanium detectors, shielded by Pb walls plus Cd and Cu additional shielding. The spectra were evaluated using the P.I.M.P. computer code (Mietelski, 1989). The results were decay corrected for September 1, 1994 and expressed both in Bq kg^{-1} and Bq m^{-2}. The recalculation from Bq kg^{-1} into Bq m^{-2} was to make the results comparable with the values presented in other papers or maps, eg Radioecological Maps of Poland (Strzelecki et al., 1993). The recalculation was based on the assumption that all detectable ^{137}Cs in soil is found within a layer 10 cm thick.

Additional analyses were grain-size distribution, soil pH measurements, the organic matter and exchangeable potassium content of the soil.

4. Results and discussion

Spatial distribution of ^{137}Cs expressed in Bq kg^{-1} and Bq m^{-2} is shown in Fig. 4. The pattern of ^{137}Cs distribution in both cases is the same and does not depend on the units. In spite of the relatively small extent of the investigated area ^{137}Cs concentrations

Fig. 4. Distribution of ^{137}Cs in soils in the Carpathian Foothills between the Raba and Uszwica rivers.

Ryc. 4. Rozkład ^{137}Cs w glebach Pogórza Karpackiego między Rabą a Uszwicą.

Tab. 1. Comparison between the ^{137}Cs radioactivity of soil in the marginal zone of the Carpathian Foothills and Poland (kBq m^{-2}).

Tab. 1. Porównanie aktywności ^{137}Cs gleb progu Pogórza Karpackiego i Polski (kBq m^{-2}).

Value Wartość	Carpathian Foothills Pogórze Karpackie	Poland* Polska*
average - średnia	3.7	4.67
standard deviation- odchylenie standardowe	2.3	5.51
maximum - najwyższa	15.5	96
minimum - najniższa	1.1	0

* after Strzelecki et al., 1993

are highly differentiated ranging from 11.0±1.1 Bq kg^{-1} (1.07±0.1 kBq m^{-2}) at the site situated east of the Uszwica valley to 160.8±3.8 Bq kg^{-1} (15.5±0.5 kBq m^{-2}) at the site situated in the western part of the foothill area. Mean concentration for all measured samples was 45 Bq kg^{-1} with standard deviation 24 Bq kg^{-1} or 3.6 and 2.33 kBq m^{-2} respectively. The mean value expressed in kBq m^{-2} can be compared with the mean for Poland as a whole which is about 30% higher than for the investigated area (Tab. 1). Generally the highest ^{137}Cs concentrations were measured in the western part of the area while in the central and eastern parts ^{137}Cs content varied and at first glance did not show any regularity. Generally, lower concentrations were found in the Sandomierz

Fig. 5. ^{137}Cs concentration vs. grain-size, soil pH, K_2O and humus content.

Fig. 5. Zależność koncentracji ^{137}Cs od granulometrii, pH gleby, zawartości potasu wymiennego (K_2O) i humusu.

Basin section. Comparison of the radioactivity of soil samples with their physical-chemical parameters (grain-size distribution, exchangeable potassium content and soil pH) did not establish any significant relationships (Fig. 5). The reason for this is the generally low differentiation of soil properties. The only parameter correlating (r=0.55) with concentration of ^{137}Cs is organic matter content. The more organic matter the higher caesium concentration.

In order to generalize the spatial pattern of ^{137}Cs distribution, the method of surface trend was used. The tool applied was the GIS package *Idrisi for Windows v. 1.0*. The values for the isotope concentration were placed into the raster layer covering the whole area and then the trend surfaces of 1st, 2nd and 3rd order were created using the module TREND and the results are shown at Fig. 6.

Fig. 6. Surface trend of ^{137}Cs distribution of 1st (A), 2nd (B) and 3rd (C) order (Bq kg^{-1}).

Ryc. 6. Trend powierzchniowy rozkładu ^{137}Cs w glebie; A - trend 1. stopnia, B - trend 2. stopnia, C - trend 3. stopnia (Bq kg^{-1}).

The trend surfaces support the first impression of higher caesium content in the western part of the area and generally a lower content in the eastern part. The only explanation for this general difference can be the larger precipitation totals in the western part of the region introducing radioactive ^{137}Cs after the Chernobyl disaster. Due to the lack of meteorological posts (the only one in the area is at Łazy) we can not provide conclusive evidence of this, but the general rule for this part of Poland is that hills and slopes exposed to air-masses advecting from W and NW receive more precipitation than hills and slopes which are not exposed to air-masses from W and NW. The hills dominating the Raba valley fulfil this condition.

The results also suggest one more conclusion. As a result of the many studies on post-Chernobyl radioactive contamination that were carried out in Poland over recent years, isoline maps of ^{137}Cs concentration were published (Mapy..., 1992). This study has demonstrated that due to the extensive differentiation of ^{137}Cs content in soil, even within small distances, these isoline maps give an extremely generalized picture of the distribution which, when applied to small areas, may lead to false conclusions.

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Przestrzenne zróżnicowanie koncentracji ^{137}Cs w glebach progowej części Pogórza Karpackiego między dolinami Raby i Uszwicy

Streszczenie

Przestrzenne zróżnicowanie koncentracji ^{137}Cs w powierzchniowej warstwie gleby określono dla progowej części obszaru Pogórza Karpackiego między Rabą a Uszwicą oraz dla przylegającego do niej od północy - fragmentu Kotliny Sandomierskiej.

Dla uniknięcia wpływu położenia morfologicznego na koncentrację ^{137}Cs w wyniku zachodzących na stokach procesów erozji, transportu i depozycji materiału glebowego, punkty

poboru prób wybrano w miejscach położonych jedynie w obrębie wierzchowinowych partii wzniesień pogórskich oraz w obszarach równinnych Kotliny Sandomierskiej.

Stwierdzono znaczne zróżnicowanie koncentracji ^{137}Cs (od 11,5 do 160,8 Bq kg^{-1}), przy czym najwyższe wartości stwierdzono w obrębie wzniesień górujących ponad doliną Raby w zachodniej części badanego obszaru. Generalną tendencję spadkową koncentracji cezu w glebie z zachodu na wschód ukazują powierzchnie trendu 1.,2. i 3. stopnia uzyskane przy pomocy programu GIS - *Idrisi for Windows*. Prawdopodobną przyczyną podwyższonej na zachodzie koncentracji ^{137}Cs, jest większy niż gdzie indziej opad radioaktywny, który nastąpił wraz z opadami atmosferycznymi po katastrofie elektrowni atomowej w Czarnobylu w 1986 r.