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Radionuclides ^{137}Cs and ^{40}K in the soils of the Tatra National Park (TPN, Poland)

Barbara Kubica, Stefan Skiba, Marek Drewnik, Marcin Stobiński, Małgorzata Kubica, Janusz Gołaś, Ryszard Misiak

Abstract. The paper presents the results of radioactivity determination of artificial ^{137}Cs and natural ^{40}K in soil samples taken from the Tatra Mountains in Poland (Tatra National Park – TPN). Soil samples were collected as the cores of 10 cm in diameter and 10 cm in depth. These cores were divided into 3 slices. It has been found that the content of ^{137}Cs was the highest at the sites of the altitude over 1300 m a.s.l. The values of ^{137}Cs concentration in the soils examined varied – from 55.8 Bq·kg^{-1} (dry mass) (417.8 Bq·m^{-2}) for the Tomanowa Pass (1685 m a.s.l.) to 5111 Bq·kg^{-1} (dry mass) (8400 Bq·m^{-2}) for the Krzyżne Pass (2112 m a.s.l.). In most cases, the values were lower than the average radiocaesium concentration established for Poland.

Key words: ^{137}Cs • ^{40}K • the Tatra mountains • gamma spectrometry • maps of the radioisotopes

B. Kubica✉
The Henryk Niewodniczański Institute of Nuclear Physics of Polish Academy of Sciences,
152 Radzikowskiego Str., 30-341 Kraków, Poland
and Faculty of Fuels and Energy,
AGH University of Science and Technology,
30 A. Mickiewicza Ave., 30-059 Kraków, Poland,
Tel.: +48 12 662 8394, Fax: +48 12 662 8458,
E-mail: Barbara.Kubica@ifj.edu.pl

S. Skiba, M. Drewnik
Faculty of Biology and Earth Sciences,
Jagiellonian University,
7 Gronostajowa Str., 30-387 Kraków, Poland

M. Stobiński, M. Kubica, R. Misiak
The Henryk Niewodniczański Institute of Nuclear Physics of Polish Academy of Sciences,
152 Radzikowskiego Str., 30-341 Kraków, Poland

J. Gołaś
Faculty of Fuels and Energy,
AGH University of Science and Technology,
30 A. Mickiewicza Ave., 30-059 Kraków, Poland

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Introduction

Among the radioisotopes, one could distinguish some that are natural and those, which are derived from human activities (artificial isotopes). In the earth crust, there are about 60 natural radionuclides, and additionally few of them are generated by cosmic radiation [6]. Artificial radionuclides are produced by nuclear weapon tests (mostly performed in the atmosphere), nuclear industry (neutron activation in reactors) and as the result of accidents of nuclear power plants. The most serious event occurred in the Chernobyl nuclear reactor in April 1986. The reactor was destroyed and the amounts of radioactive material (more than 10^{19} Bq in total) were released to the environment [7, 12, 19]. The radioactive gases and airborne particles released in the accident were initially carried by the wind in westerly and northerly directions.

The pattern contamination from radionuclides was divided into two types: drop condensing mode and "fuel-like" drop mode [9]. The radioactive fuel-like drop deposition consisted mainly of plutonium (Pu) and other actinides, the lanthanides like cerium (Ce) and europium (Eu), also niobium (Nb), zirconium (Zr), ruthenium (Ru) and strontium (Sr). These elements were associated and formed "hot particles fuel-like drop" [1, 2, 9]. The main component of radioactive deposition found in the area of Poland (condensation drop mode) is the long half-life (30.7 y) caesium-137 [8, 13]. The other source of artificial ^{137}Cs in the environment, except for Chernobyl accident, was the atmospheric nuclear weapon tests performed at the beginning of the sixties of the last century [20]. The nuclear weapon trials resulted in releasing also significant quantities of other radionuclides, for instance, ^{90}Sr, ^{241}Am and plutonium isotopes.

All aspects of radioactive contamination are still of vivid interest. Numerous reports were focused on the monitoring of ^{137}Cs, ^{134}Cs, ^{106}Ru, ^{144}Ce, ^{125}Sb, ^{90}Sr, ^{238}Pu, $^{139+240}$Pu, ^{241}Pu, ^{241}Am levels in the forest litter collected from the area of Poland. Among those surveys, the most striking issue was the contamination of natural environment with caesium-134 and caesium-137 [14]. The authors compared the level of ^{137}Cs and natural radionuclide K (^{40}K) in soil and plant samples collected in the Tatra National Park (the Polish part of the Tatra Mts) [5, 10, 11, 17, 18].

Material

Tatra Mts are the highest Carpatian range (Gerlach, 2655 m a.s.l.). Their specific features are the complex geological structure and the alpine relief. The Tatra Mts are High Mountains having fully developed climat-plant vegetations and provide the barrier for the moving air masses.

In the Tatras, like in other mountain areas, the soil spatial diversity strictly depends on the geological bedrock, the intensity of geomorphological processes and also on the height mediated diversification of climat-plant conditions [15]. Massive and hard bedrock (granitoids, metamorphic rocks and carbonate rocks) cause the formation of soils that are similar in mineral composition to bedrocks. Finally, this leads to generation of flat structures containing the amount of rock pieces in the soil. Intensity of geomorphological events results in establishing fragmented (dainty) soil cover. The soils possess weakly developed initial stage of profile and also erosive rocky or rubble structures that have no organic soil horizons. Mountain topography is dealing with lateral movement of soil solutions and growing amounts of the acidic and faint decomposed organic material with altitude [16].

The aim of this work is to demonstrate distribution and the concentration of radionuclides (natural ^{40}K and artificial ^{137}Cs) in the Tatras soils.

Methodology

To monitor the level of radioisotope contamination, we chose the 60 sampling points that represented either spatial or altitudinal variability of soil cover in the TPN area. The samples were collected with cylindrical samplers that provide “soil cores” about 10 cm heigh (Fig. 1). These cores were sliced into three patch-like parts that represented different layers starting from the soil surface: 0–3, 3–6 and 6–10 cm (samples: *a*, *b*, *c*, respectively). The procedure allows the collection of three samples from each sampling point. The soil samples were dried at 105°C to stable mass, then the

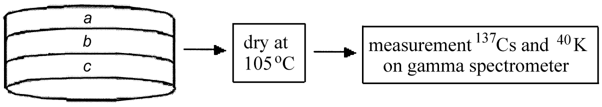

Fig. 1. The methodology of sampling.

volume density was designated and the samples were sieved (mesh diameter = 1 mm). The residual activity of radionuclides was measured by a gamma-ray spectrometer (Silena HPGe detector, efficiency 10%. Full width at half maximum (FWHM) = 1.8 keV for 1173 keV of Co-60. The analyses were performed within 72 h. As control, the standards IAEA-375 and IAFA-154 were used. Minimum detectable activity (MDA), according to the definition by Curie [3], were about 10 and 100 Bq/kg for ^{137}Cs and ^{40}K, respectively.

The concentration of artificial ^{137}Cs and natural ^{40}K are shown in two modes:

1. The activity of ^{137}Cs in the upper core part (up to 10 cm) [Bq·m^{-2}];
2. The concentration of ^{137}Cs per mass unit [Bq·kg^{-1}] in each of the examined patch-like parts (samples *a*, *b*, *c*).

These data presentations allow to compare the total radioactivity between all the sampling points and the isotope concentration per mass unit in respect to the soil depth. The results are also presented in the form of maps. Having in mind that the examined radioisotopes have limited life-time and that the monitoring has lasted a few years, the data were recalculated for September 1, 2000.

Results and discussion

The data indicate a significant variability in radioisotope concentration in the soil cover in the TPN area. The ^{137}Cs level in the mountain soils ranged between 55.8 Bq·kg^{-1} (417.8 Bq·m^{-2}) for the Tomanowa Pass (1685 m a.s.l.) to 5111 Bq·kg^{-1} (8400 Bq·m^{-2}) for the Krzyżne Pass (2112 m a.s.l.). The level of ^{137}Cs and ^{40}K in soil samples collected from the five main valleys in the TNP is shown in Table 1 and on the maps (Figs. 2 and 3). There is no relation between the radiocaesium level and the soil type (see the map ‘Concentration of artificial ^{137}Cs and natural ^{40}K in the soil surface layers collected from Tatra National Park’ – Fig. 2). Also, there is no significant correlation between the ^{137}Cs concentration and the localization of sampling points. For instance, one does not observe any increase in radiocaesium activity in the western part of TPN, what can be expected due to western circulation dominance and the amount of deposited air pollution.

We demonstrated a weak, but increasing trend line of ^{137}Cs concentration with altitude, however that correlation is not statistically significant (Fig. 4). The correlation coefficient reaches the highest value (about 18%) for the ^{137}Cs level in the soil surface (3 cm) in relation to the altitude (Fig. 5).

We noticed a strong link between the radiocaesium activity and the volume density of soil samples (Fig. 6). This correlation is observed for each of the three examined layers (Fig. 7), the higher soil volume density, the lower radioisotope concentration.

Table 1. Activity of ^{137}Cs and ^{40}K in the soil samples taken from five main valleys localized in the Polish part of Tatra Mts (West--East direction – Chochołowska Valley, Kościeliska Valley, Bystra Valley, Sucha Woda Valley and Rybi Potok Valley)

Places from which the samples were taken in:	Altitude a.s.l. (m)	D (g/cm^3)	Activity ^{137}Cs (Bq/kg) dry mass Activity ^{40}K (Bq/kg) dry mass			Activity ^{137}Cs (Bq/m^2) Activity ^{40}K (Bq/m^2)
		a	a	b	c	
Chochołowska Valley						
Near pathway to Iwaniacka Pass	1061	0.708	308.9 ± 6.8 388.2 ± 5.6	109.9 ± 1.5 457.4 ± 5.5	33.9 ± 1.2 461.7 ± 5.2	7062.7 27 302.2
Chochołowska Valley near shelter-home near pathway to Wołowiec Mt	1180	0.27	873.6 ± 71.4 296.9 ± 4.7	348.8 ± 3.0 483.1 ± 6.1	48.1 ± 1.7 524.4 ± 6.3	5491.9 8508.7
Bobrowiecka Pass	1355	0.17	1782.2 ± 13.4 2.7 ± 0.1	1926.5 ± 9.2 133.8 ± 1.9	247.2 ± 2.1 464.8 ± 5.7	13 095.8 5390.2
Grześ Mt	1653	0.38	1584.2 ± 6.9 346.9 ± 5.5	682.6 ± 4.6 278.9 ± 3.8	– –	11 152.8 3202.359
Wyżnia Chochołowska Glade	1720	0.16	301.7 ± 4 1.2 ± 2.5	570.6 ± 4.3 636.1 ± 27	197.6 ± 2.4 814.0 ± 34.1	5849.1 12 901.7
Pathway to Grześ Mt	1150	0.33	680.9 ± 3 177.3 ± 6	194.2 ± 1.1 470.1 ± 20.7	27.4 ± 1.4 474.2 ± 20.3	9736.6 19 677.3
Rakoń Mt	1879	0.17	1562.3 ± 8 51.0 ± 3.7	493.5 ± 3.4 385.5 ± 16	36.7 ± 1.4 498.4 ± 21	7511.8 10 582.1
Upłaz Mt	1794	0.58	265.98 ± 2.6 265.98 ± 2.6	41.5 ± 1.1 41.5 ± 1.1	10.74 ± 14 10.74 ± 14	2506.2 26 962.2
Starorobociańska Valley	1434	0.46	385.1 ± 4.3 230.1 ± 10	272.2 ± 2.0 506.4 ± 21	– –	4255.6 9389.9
Chochołowska Valley near Lejowa Valley	1224	0.62	148.7 ± 1.7 760.6 ± 8.3	141.1 ± 1.9 939.4 ± 10.4	42.9 ± 1.1 815.7 ± 8.6	7423.0 64 754.2
Kościeliska Valley						
Kościeliska Valley near chapel	1005	0.49	316.25 ± 11 987.0 ± 6	213.7 ± 4.7 1725.4 ± 55.5	– –	3825.0 22 007.3
Pisana Glade	1012	0.77	143.0 ± 12 488.0 ± 28.3	120.0 ± 13.1 772.4 ± 60.2	95.1 ± 7 742.2 ± 16.4	3741.0 21 719.5
Smreczyński Lake	1192	0.44	577.1 ± 35 226.2 ± 6.1	274.4 ± 48.3 314.3 ± 14	67.2 ± 48.1 344.3 ± 23.1	5938.0 6258.1
Ornak Glade	1094	0.45	447.5 ± 5.9 447.0 ± 4	455.3 ± 7.9 598.8 ± 24.1	52.0 ± 0.1 694.3 ± 23.5	8818.0 19 315.6
Chuda Pass	1853	0.63	729.3 ± 17.2 521.8 ± 85.1	179.7 ± 8.4 694.3 ± 28.4	78.0 ± 3.2 722.3 ± 15.9	12 496.0 32 133.4
Upłaz Glade	1353	0.75	194.0 ± 5.1 365.0 ± 36.2	163.0 ± 4.0 377.0 ± 17.6	189.0 ± 5.1 455.4 ± 46	8471.0 18 795.2
Piec Glade	1474	0.44	1294.1 ± 26.1 226.0 ± 2.5	507.0 ± 9.7 219.1 ± 1.2	306.0 ± 6.1 207.4 ± 2	14 452.0 5176.7
Ciemniak Mt	2076	0.56	631.5 ± 14 873.3 ± 7.8	60.0 ± 1.2 1158.0 ± 11.1	16.0 ± 1 1181.0 ± 11.5	6636.0 42 763.8
Lejowa Valley	927	0.61	538.0 ± 12 84.1 ± 21	423.8 ± 7.1 85.3 ± 22	123.0 ± 3 611.0 ± 22.2	12 586.0 9939.4
Lejowa Valley	913	0.72	301.0 ± 7 761.3 ± 69	233.0 ± 5.2 804.1 ± 84.3	107.1 ± 3.4 30.0 ± 13	7007.0 20 323.8
Lejowa Valley	960	0.52	87.0 ± 2.1 348.1 ± 33.1	121.0 ± 3.0 452.2 ± 18.1	97.0 ± 2 514.0 ± 49.1	3435.0 15 155.9
Tomanowa Pass	1685	0.63	55.8 ± 2 791.0 ± 33.1	12.2 ± 1.0 806.2 ± 34	4.16 ± 0.6 930.1 ± 39.3	1016.0 39 274.6
Przysłop Miętusi Glade	1115	0.79	66.7 ± 1.4 1105.1 ± 46.3	46.2 ± 1.2 1219.0 ± 81.2	46.1 ± 1.3 1140.0 ± 48	2157.0 46 540.9
Iwaniacka Pass	1455	0.79	229.5 ± 2.3 1124.8 ± 47.1	64.4 ± 1.33 1089.1 ± 45.3	57.0 ± 1.5 1162.1 ± 48	6974.0 65 667.9
Ornak Mt (middle)	1837	0.60	147.7 ± 1.6 344.7 ± 14.1	5.3 ± 0.6 416.6 ± 17.2	6.7 ± 1 512.8 ± 21	1671.0 15 184.1

Table 1. *continued*.

Places from which the samples were taken in:	Altitude a.s.l. (m)	D (g/cm^3)	Activity ^{137}Cs (Bq/kg) dry mass Activity ^{40}K (Bq/kg) dry mass			Activity ^{137}Cs (Bq/m^2) Activity ^{40}K (Bq/m^2)
		a	a	b	c	
Bystra Valley						
Kopa Kondracka Mt	2079	0.7946	339.5 ± 22 389.4 ± 21	210.1 ± 21 316.2 ± 17.1	13.3 ± 3 432.8 ± 30	9893.8 25 181.6
Hala Kondratowa Glade	1333	0.4586	506.5 ± 21 471.9 ± 16.1	117.7 ± 12.1 599.8 ± 23	35.2 ± 4 616.4 ± 33.1	9596.1 31 812.1
Kalatówki Glade	1260		112.5 ± 1.4 572.1 ± 24	88.8 ± 1.3 707.9 ± 30	46.3 ± 1 773.1 ± 32.2	3017.7 26 088.0
Near pathway to Kondracka Pass	1509		5.2 ± 0.5 482.16 ± 20	1.3 ± 0.3 631.8 ± 26	2.2 ± 0.2 583.45 ± 24	173.7 33 917.7
Pathway Nad Reglami from Kalatówki Glade to Biały Valley	1336		185.2 ± 2.2 535.3 ± 22	182.5 ± 2.2 592.8 ± 25	339.8 ± 5.0 683.2 ± 29	5471.1 13 803.0
Baiły Valley	1033		44.2 ± 1 403.6 ± 17	7.9 ± 1 422.1 ± 18	4.5 ± 0.4 413.7 ± 17	893.9 18 692.2
Sucha Woda Valley						
Hala Gąsienicowa Glade	1553	0.4666	285.2 ± 11.1 487.9 ± 21	60.2 ± 8 539.1 ± 34.1	31.9 ± 3 550.3 ± 33.5	4776.1 26 599.8
Skupniów Upłaz Mt	1334	0.7957	500.2 ± 14 5.2 ± 0.6	525.3 ± 13 271.4 ± 11.2	66.2 ± 3 256.59 ± 10.8	10 861.1 4415.4
Skupniów Upłaz Mt near path way from Jaworzynka Valley	1448	0.6	285.5 ± 3.5 981.9 ± 41	83.8 ± 1.8 750.8 ± 31	41.7 ± 1.6 884.0 ± 37	2830.9 25 932.7
Czarny Staw Gąsienicowy Lake	1623	0.231	284.7 ± 12.1 163.2 ± 11	259.2 ± 31 393.9 ± 12	70.4 ± 8 613.3 ± 4.0	5882.4 12 561.5
Jaworzynka Valley	1207	0.5388	284.7 ± 10.1 510.8 ± 54.2	198.7 ± 11 262.9 ± 33.1	71.1 ± 5 339.7 ± 17.2	7154.7 14 134.7
Kasprowy Wierch Mt	1986	0.95	54.2 ± 1.2 659.2 ± 28.1	100.0 ± 1.2 303.5 ± 13.2	40.5 ± 1.1 529.5 ± 22.1	2747.3 20 967.4
Myślenickie Turnie Mt	1360	0.17	328.3 ± 5.6 149.3 ± 18	397.2 ± 13 696.4 ± 8.7	65.2 ± 1.8 884.4 ± 9.1	4708.4 15 508.9
Kuźnice pathway to Myślenickie Turnie Mt	1200	0.17	238.6 ± 7 85.0 ± 1.1	158.0 ± 4 142.7 ± 2	63.9 ± 1.5 328.5 ± 4.0	1695.9 4268.0
Kasprowa Polana Glade	1250	0.71	155.7 ± 2.1 750.0 ± 8.1	152.9 ± 1.5 808.1 ± 8.2	56.3 ± 1.3 834.5 ± 9.0	4501.8 29 946.6
Kozia Dolinka Valley	1958	1.01	64.0 ± 1.1 1079.2 ± 45	5.5 ± 0.6 639.5 ± 27	3.5 ± 0.4 664.7 ± 28.1	978.0 34 686.2
Kozia Dolinka Valley	1958	0.585	231.1 ± 2.7 509.5 ± 21	33.2 ± 1.4 647.7 ± 27	– –	2141.2 21 753.4
Zmarzły Staw Lake	1852	0.35	556.1 ± 6.3 707.6 ± 29	94.1 ± 1.8 554.1 ± 23	12.9 ± 1.1 493.4 ± 21	3874.5 18 047.4
Świnicka Pass	1962	0.57	639.0 ± 3.3 819.0 ± 34	81.8 ± 1.5 870.0 ± 36	37.6 ± 1.2 817.0 ± 34	7449.3 30 671.2
Pathway near Zadni Staw Gąsinicowy Lake	1813	0.26	1016.8 ± 9 736.3 ± 31.1	608.6 ± 5.3 317.2 ± 13	5.0 ± 1 837.0 ± 35	13 161.0 27 853.9
Pathway from Kasprowy Mt	1786	0.18	1534.6 ± 18 211.5 ± 8	799.5 ± 7.5 190.5 ± 8	407.8 ± 5.1 390.7 ± 16.1	11 485.0 3672.2
Pięć Stawów Gasienicowych Valley	1649	0.26	590.9 ± 4.5 6.1 ± 1	184.9 ± 1.8 463.2 ± 19	10.3 ± 1 564.9 ± 24	3775.5 11 832.5
Glade near Kopieniec Mt	1242	0.85	52.0 ± 1 388.1 ± 16	33.3 ± 1 417.9 ± 17.1	59.7 ± 1 389.0 ± 16.1	1739.6 15 085.6
Olczyska Glade	1032	0.61	151.4 ± 35 382.9 ± 16	84.7 ± 11.2 383.6 ± 16	– –	3278.7 12 580.4

Table 1. *continued.*

Places from which the samples were taken in:	Altitude a.s.l. (m)	D (g/cm^3)	Activity ^{137}Cs (Bq/kg) dry mass Activity ^{40}K (Bq/kg) dry mass			Activity ^{137}Cs (Bq/m^2) Activity ^{40}K (Bq/m^2)
		a	a	b	c	
Rybi Potok Valley						
Opalony Mt	2124	0.2595	790.2 ± 11 96.0 ± 5.2	177.1 ± 4.6 321.6 ± 14.5	36.3 ± 2.7 290.3 ± 12	3986.7 5543.1
Pięć Stawów Polskich Valley	1740	0.335	881.5 ± 11.5 42.4 ± 2.2	264.8 ± 3.9 422.9 ± 17.8	41.3 ± 2.3 416.0 ± 16	5539.8 8957.0
Szpiglasowa Pass	2114	0.436	396.8 ± 5.1 181.0 ± 9	368.0 ± 7.1 373.3 ± 15.7	37.1 ± 1.1 563.9 ± 6.5	6758.5 11 661.5
Za Mnichem Valley	1900	0.48	1935.0 ± 33 227.0 ± 12.1	390.1 ± 8 229.1 ± 17	83.0 ± 2 349.0 ± 14	17 538.5 12 010.0
The still of Za Mnichem Valley	1770	0.24	782.1 ± 14.1 42.0 ± 28	1167.2 ± 19.1 96.0 ± 28	675.0 ± 10 452.0 ± 18	8962.1 2814.6
Palenica Białczańska Glade	980	0.23	161.0 ± 4 138.0 ± 20	205.0 ± 4 690.0 ± 26	7.9 ± 0.5 25.1 ± 1.1	3531.2 10 984.6
Czarny Staw Lake near Rysy Mt	1580	0.54	922.2 ± 20.4 801.9 ± 37	94.0 ± 2 1020.0 ± 32	– –	9101.7 20 379.5
Morskie Oko Lake	1393	0.3	591.1 ± 13.3 60.1 ± 9	713.0 ± 15.7 428.0 ± 19	15.0 ± 0.9 557.2 ± 26.7	9073.9 9193.4
Roztoka Valley	1031	0.63	482.6 ± 11.5 557.0 ± 22.6	84.0 ± 0.2 814.0 ± 11.7	7.0 ± 0.7 826.0 ± 12.7	6969.8
Wrota Chalubińskiego Pass	2022	1.13	149.3 ± 1.3 771.5 ± 32	123.0 ± 1.22 772.9 ± 32	191.2 ± 1.5 799.6 ± 33	7058.0 35 897.2
Gęsia Szyja Mt	1480	0.61g	187.5 ± 1.7 95.6 ± 4	104.5 ± 1.6 145.8 ± 6	58.3 ± 1.2 139.7 ± 7	3619.6 3932.5
Gęsia Szyja near Rusinowa Polana Glade	1248	0.53	115.3 ± 2.1 364.6 ± 15	93.8 ± 1.2 334.1 ± 14	65.1 ± 1 372.3 ± 16	2948.5 12 340.0

The relations between the ^{137}Cs level, altitude and the soil volume density are interconnected. It is well documented that the mountain soil properties are altering with altitude, in particular, the features of the upper soil layers (O horizon, first 10 cm) change. In these surface layers, the level of organic material increases with altitude (included the subalpine zone). Moreover, one could notice not only changes in the quantity of organic mass, but also in its decomposition stages, the huminification level and the content of humic and fulvic acids (the ratio of humic acids in humus (organic matter) [4]. The humus modification also implies changes in soil volume density. The relation between the soil volume density and the radiocaesium activity could then reflect the interdependence between the altitude and ^{137}Cs level and might suggest an indirect secondary phenomenon.

The concentration of caesium-137 is the highest in the O horizon of the examined soils and its quantity declines with soil depth (Fig. 8) what is shown on a map ‘Concentration of artificial ^{137}Cs and natural ^{40}K in soil upper layers collected from Tatra National Park’ (Fig. 2). Elevated accumulation of radiocaesium in the surface layers indicates its atmospheric deposition on one side and also could be the result of strong sorption by organic components of the soil.

The concentration of ^{40}K is directly dependent on the total potassium (1 g of potassium shows 31.7 Bq of ^{40}K) and its quantity reflects the presence of aluminosillicate particles in the soil. The noticeable feature of Tatras soils is the accumulation of well-decomposed organic material the amount of which gradually decreases with depth of the soil. The level of radiopotassium significantly increases with depth because K is the major component of the soil mineral layer (Fig. 9). This observation is confirmed by the experimental data shown on a map (Figs. 2 and 3).

There is no correlation between the ^{40}K concentration and the altitude of the sampling sites (Fig. 10).

The activity of radiocaesium for the soil samples ranged from 0 to 1000 Bq·kg^{-1} (dry mass), (Fig. 11).

In view of the fact that the average range of measured ^{137}Cs concentration for Poland varies from 300 to 500 Bq·kg^{-1} (dry mass) [10], the obtained data appear to lie within the average for Poland.

Both ^{40}K and ^{137}Cs belong to the lithium group (Group IA, alkali metals) and possess similar chemical and physical properties. For this reason, one could expect very much alike behaviour of those elements in the soil sorption complex. The competition of the elements have already been demonstrated in the distribution analysis data where the ^{137}Cs level declines and, at the same time, the ^{40}K concentration increases with depth of the soil. Recently, some reports pointed out the mechanisms of the competition phenomenon between elements [10], now we could also add the competitiveness of these two radioisotopes. The notion is likewise supported by the data revealed on maps (Figs. 2 and 3) where the concentration of the radioisotopes in the surface layer is indirectly proportional to the area unit.

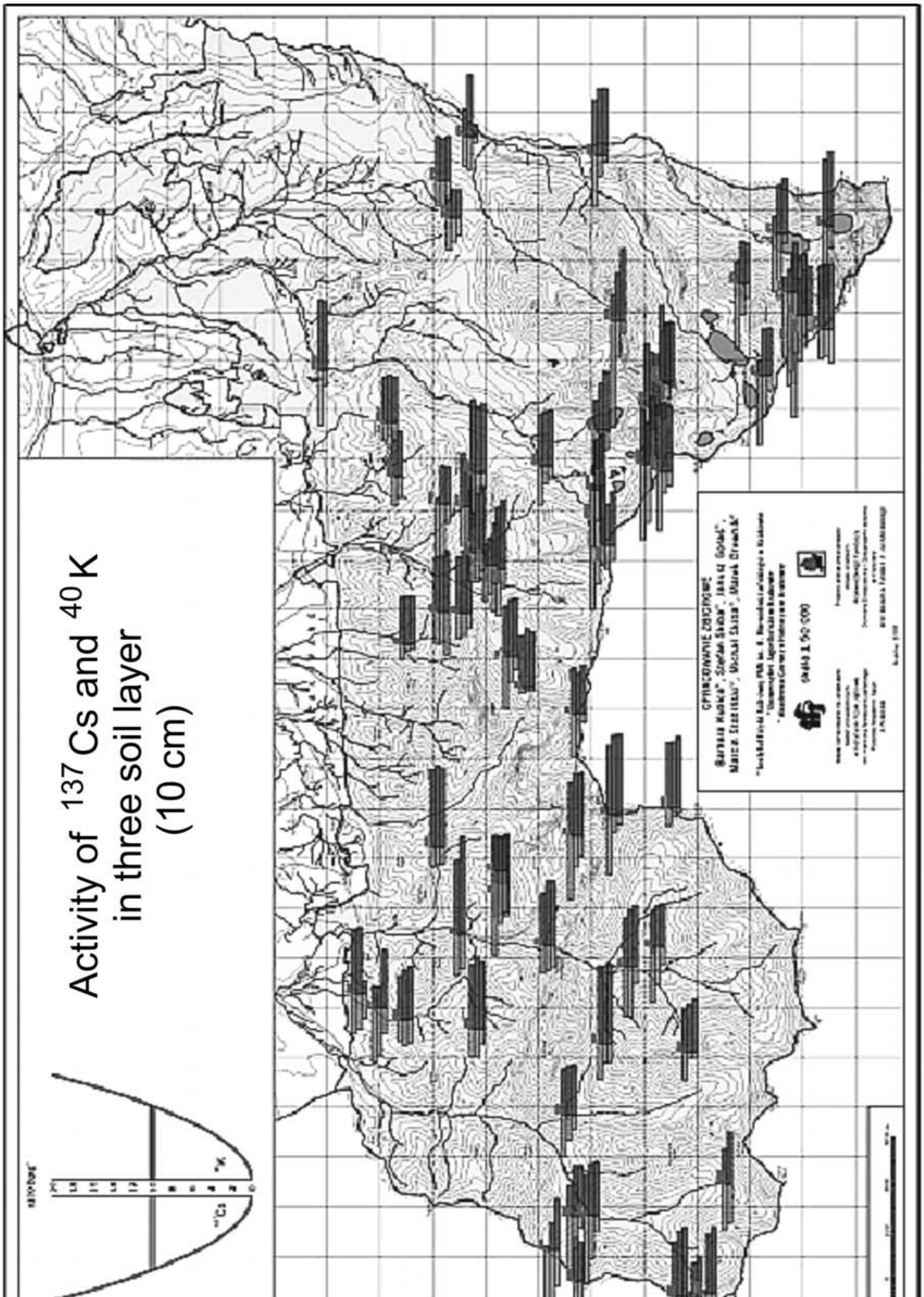

Fig. 2. Concentration of ^{137}Cs and ^{40}K [Bq/kg] (dry mass) in soil surface of three layers collected from the Tatra National Park.

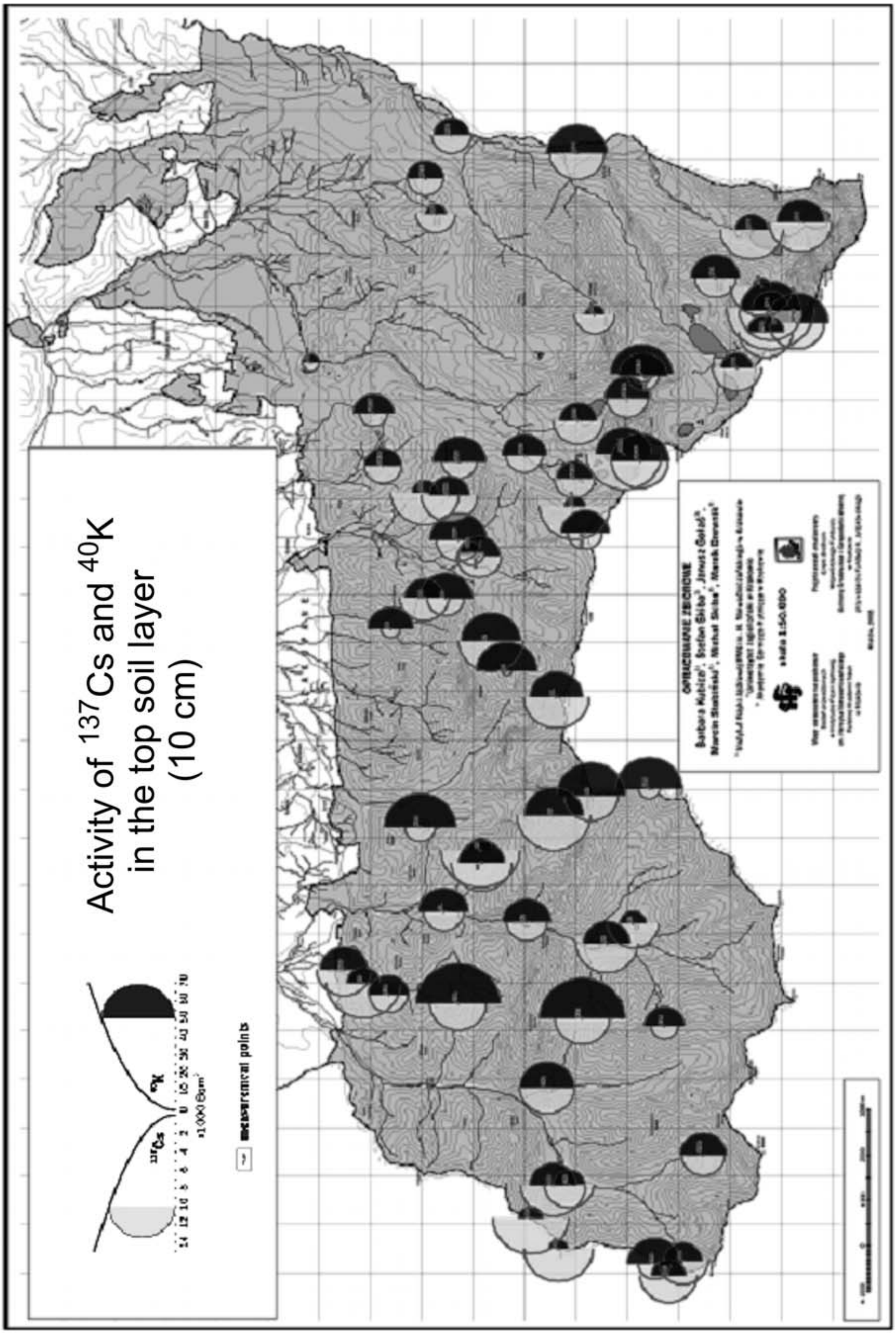

Fig. 3. Concentration of ^{137}Cs and ^{40}K [Bq/m^2] in the 10 cm thick top layers collected from the Tatra National Park.

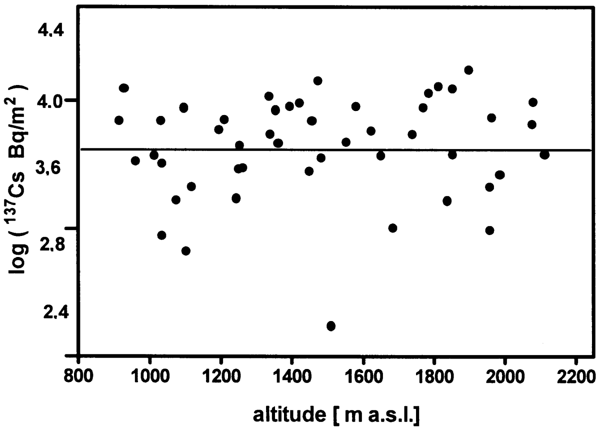

Fig. 4. The correlation between the altitude of sampling points and the ^{137}Cs activity concentration.

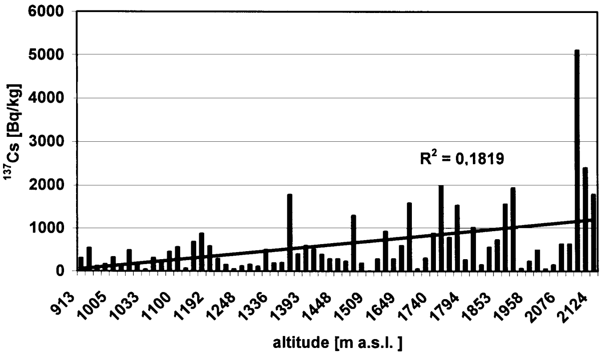

Fig. 5. The relation between the sampling point altitude and the ^{137}Cs activity concentration in the surface soil layer "a" (0–3 cm).

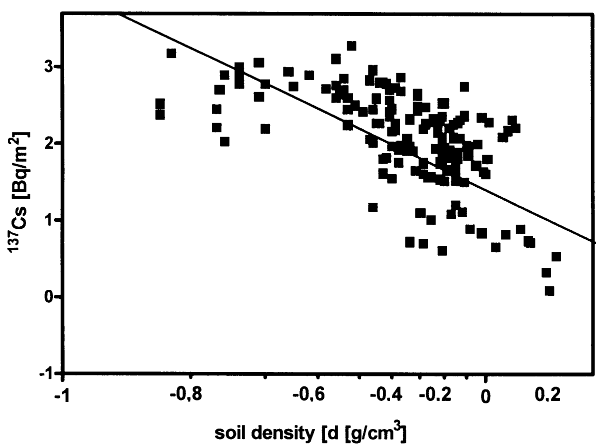

Fig. 6. Correlation between the radiocaesium activity and the volume density of soil samples.

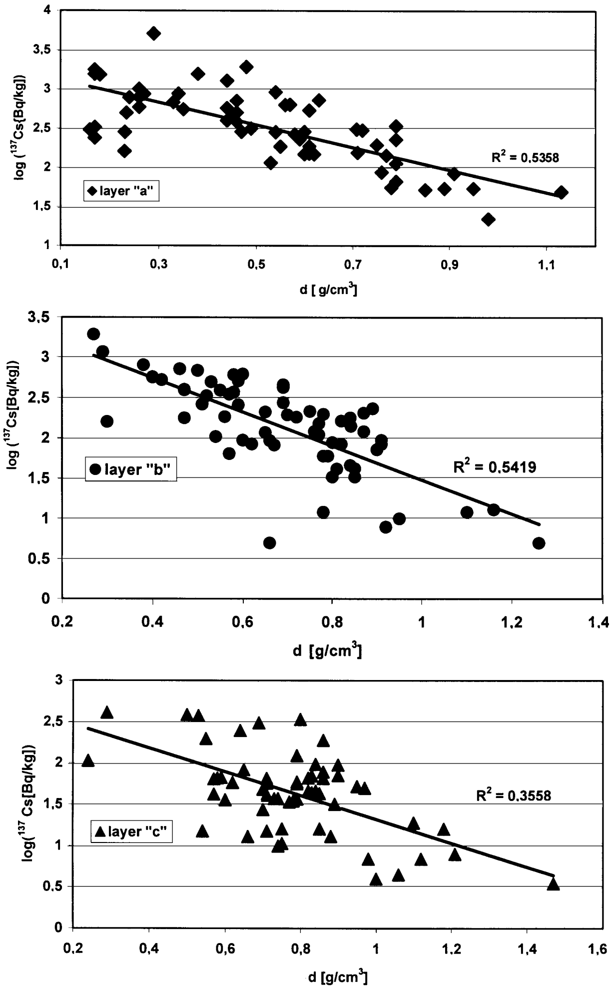

Fig. 7. Correlation between the radiocaesium activity and the soil density for layers a, b and c.

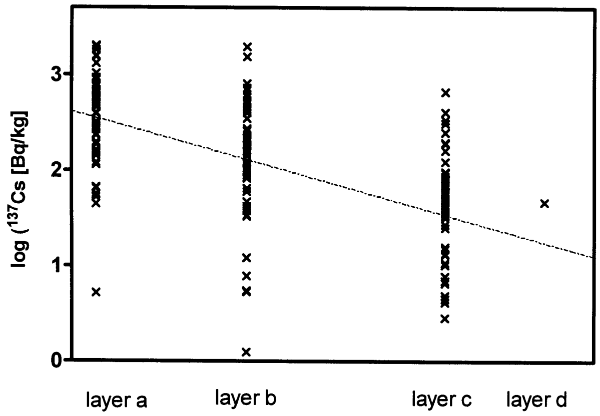

Fig. 8. The ^{137}Cs activity as a function of the depth of sampling points.

Conclusions

Based on the obtained data, we conclude that:

– The concentration of ^{137}Cs in Tatras soils varies – from 55.8 Bq·kg^{-1} (dry mass) (417.8 Bq·m^{-2}) for the Tomanowa Pass (1685 m a.s.l.) to 5111 Bq·kg^{-1} (8400 Bq·m^{-2}) for the Krzyżne Pass (2112 m a.s.l.). In most cases, the values are not high, moreover, they are lower than the average radiocaesium concentration found for Poland.

– Variation of ^{137}Cs level in the TPN soil samples depends mostly on the soil volume density and on the concentration of organic material, what is the main factor of the soil sorption complex. We observed the secondary effect of ^{137}Cs augmentation in the soils that appears with altitude. There was no other notion regarding to radiocaesium spatial distribution.

– The methodology of ^{137}Cs determination in soils should take into account soil volume density and the level of organic components, whereas soil type is not a crucial factor.

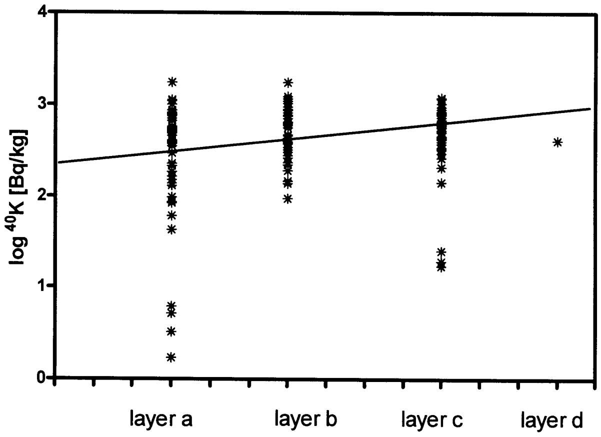

Fig. 9. The ^{40}K concentration as a function of the depth of sampling points.

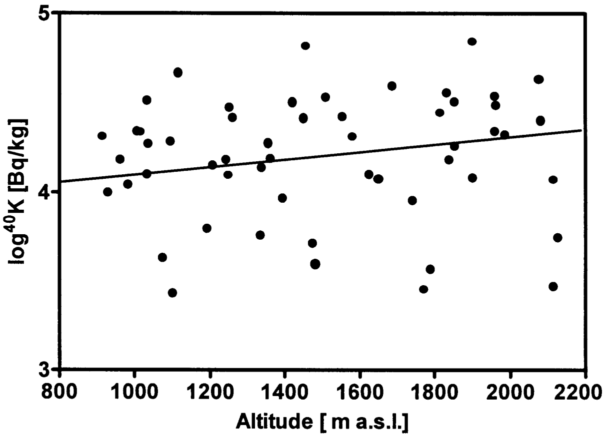

Fig. 10. The ^{40}K concentration as a function of the altitude.

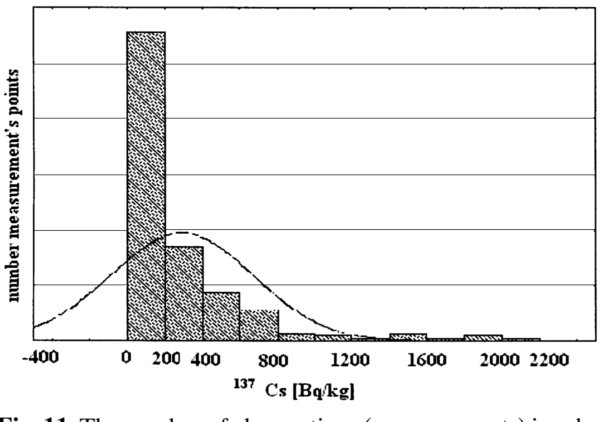

Fig. 11. The number of observations (measurements) in relation to the ^{137}Cs level.

– The ^{40}K concentration increases with depth of the soil, whereas the ^{137}Cs concentration declines with soil depth in the 10 cm thin layer. The result supports the hypothesis that the radiocaesium involved is derived mostly from the atmospheric deposition. On the other hand, the data obtained could also confirm the competitiveness of Cs and K due to their similar chemical properties.

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