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ANALYSIS OF SNOW POLLUTANTS IN AN INDUSTRIAL URBAN ZONE NEAR THE CITY OF OSTROWIEC SWIETOKRZYSKI

ANALIZA ZANIECZYSZCZEŃ ŚNIEGU W UPRZEMYSŁOWIONEJ STREFIE MIEJSKIEJ W REJONIE OSTROWCA ŚWIĘTOKRZYSKIEGO

Abstract: In melted snow samples collected in the vicinity of the ironworks in Ostrowiec Swietokrzyski, physicochemical properties and chemical composition were determined for heavy metals (Pb, Cd, Co, Cr, Cu, Mn, Ni, Zn, Al, Fe) as well as major cations and anions. The industrial plant was the centre of the field studies, and the remaining snow sampling sites were located along the north-south and east-west axis. In total, 18 snow samples were collected on 31st Jan. 2017 (Fig. 1). At that time, a snow cover had been remaining in the vicinity of the plant for over four weeks, which allowed for deposition of pollutants, including metallurgical dust containing, among others, heavy metals. Concentrations of dissolved metal forms were analysed using an ICP-MS-TOF spectrometer. The highest concentrations were reported for iron (mean value: 62.50 $\mu g \cdot dm^{-3}$), zinc (57.14 $\mu g \cdot dm^{-3}$), manganese (15.51 $\mu g \cdot dm^{-3}$), aluminium (8.10 $\mu g \cdot dm^{-3}$) and copper (1.72 $\mu g \cdot dm^{-3}$). Concentrations of lead, cadmium, chromium, cobalt and nickel did not exceed 1 $\mu g \cdot dm^{-3}$. The results of analyses as well as spatial distribution of concentrations of some heavy metals in the collected snow samples indicated a clear impact of the emission of air pollutants by the ironworks in Ostrowiec Swietokrzyski on its immediate surroundings.

Keywords: precipitation chemistry, anthropopressure, snow cover

Introduction

Snow cover is a valuable source of information about the state of air quality. Its use as an accumulator of potential pollutants is widely known in Europe and in the world. Nevertheless, there is still a deficit of studies on the concentrations of heavy metals in snow in cities and industrial areas. So far, such studies have been conducted, among

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others, in Innsbruck (Austria) [1] where sampling sites were located near communication routes of various road standards and traffic, which are the main sources of heavy metals in snow samples. In the Czech Ostrava [2], the presence of heavy metals resulted from the North Moravian industrial basin's operations, whose activity is based on the treatment of hard coal and iron metallurgy. In the city of Ferrara and suburbs of Codigoro (Italy), it was found that snow pollution in the urban zone (city centre, near roads, parking lot and park) and suburban area with dispersed development was correlating with the intensity of car traffic [3]. In one of the industrial districts of Quebec (Canada), the air quality was affected by industrial activities related to the processing of crude oil and copper [4]. The impact of the functioning of cities of various sizes (Santiago de Chile and Chillan) on the chemical composition of snow cover in the Chilean Andes was demonstrated by the studies carried out in the Cerro Colorado and Nevados de Chillan [5]. Heavy metals accumulated in the snow layer may originate from both local sources (home furnaces, car fumes, combined heat and power plants) as well as remote ones, being transferred from considerable distances. Their source in the air may be, for example, dust of natural origins (Fe, Al) associated with the weathering of rocks and minerals [6]. The increase in Ni, Cr, Mn, Zn and Cu concentrations is, in turn, associated with the combustion of fossil fuels, especially hard coal [7, 8]. Increased Cu and Zn concentrations occurring along communication routes result from the abrasion of tires and vehicle brake pads [9]. However, as numerous studies show, an important source of emissions of these metals is constituted by the metallurgical industry, including the processing of iron and non-ferrous metals [6]. In addition, the studies conducted by Jarzyna et al. [10] show that the iron industry significantly influences the increase in calcium and sulphate concentrations.

The aim of this article was to determine the impact range of air pollution emitters located in Ostrowiec Swietokrzyski (Poland) based on the analysis of physicochemical and chemical properties of the snow cover lingering in the study area.

Methodology

The field studies were conducted on 31st Jan. 2017 within a radius of 7–9 km around the ironworks CELSA "Huta Ostrowiec" which, along with the Municipal Heating Company in Ostrowiec Swietokrzyski, belongs to the largest air pollution emitters in the county of Ostrowiec Swietokrzyski. Additionally, according to the data of the Central Statistical Office in the Swietokrzyskie Province, they are particularly troublesome to the natural environment.

The study area is located in the Kamienna river valley and within the borders of the Kielecka Upland.

In total, 18 snow samples were collected. The material collected in the field was transported in polyethylene containers to the Environmental Research Laboratory of the Chair of Environmental Protection and Modelling at the Jan Kochanowski University in Kielce. Then, the physicochemical properties and chemical composition of water samples originated from melted snow were analysed. In order to analyse the chemical composition, a DIONEX ICS 3000 Ion Chromatograph (Ca, Mg, Na, K, NH_4, Cl, SO_4,

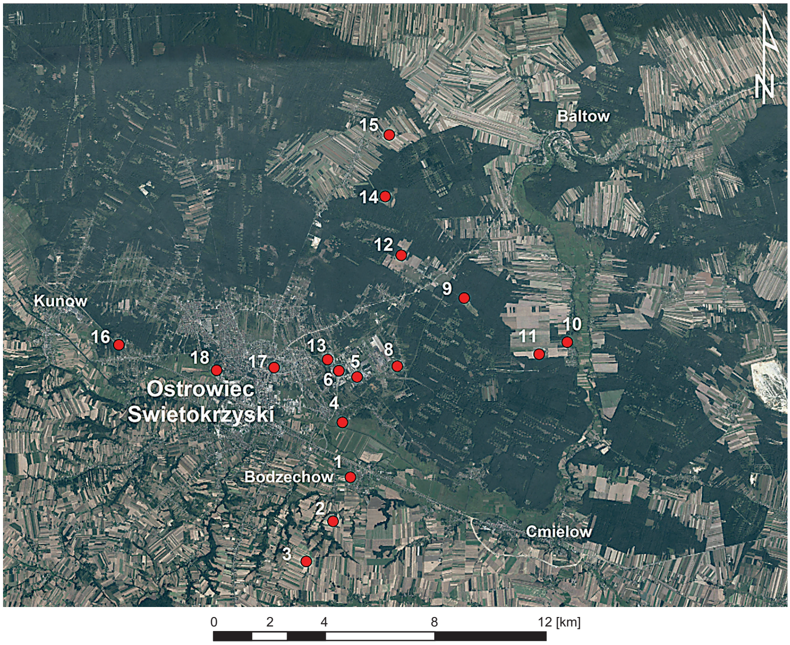

Fig. 1. Location of sampling sites [11]

NO_3) equipped with an IonPac CS16 3 × 250 mm analytical column (cations) and IonPac AS18 2 × 250 mm (anions) was used. Detection level for individual parameters was: 0.4 mg · dm^{-3} for Ca^{2+}, and 0.1 mg · dm^{-3} for other ions. In order to determine the concentrations of heavy metals, the ICP-MS-TOF (OptiMass 9500 GBC) spectrometer was used. For measuring pH and conductivity, a Hach HQ 40d multi-parameter water quality meter with electrodes calibrated before each measuring series according to the Hamilton's parameters of 4.0 pH, 7.0 pH and 9.0 pH, as well as conductivity of 15 μS · m^{-1}, was used.

In order to control the quality of obtained results, such certified reference materials as KEIJM-02 produced by the *Environment Canada* and ERM-CA713 produced by the *Institute for Reference Materials and Measurements in Belgium* were used. Obtained concentration values of the analysed components are included in Table 1.

In order to assess the meteorological background for air pollution deposition in the area of Ostrowiec Swietokrzyski, the data gathered by the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB) from a precipitation station in Nosow and two synoptic stations in Kielce-Sukow and Sandomierz were used. Such daily data as minimum and maximum air temperature as well as snow cover thickness along with hourly wind direction data were used.

Basic statistics of obtained results were developed using the Statistica 13 program. Then, the values of Spearman's rank correlation coefficient among all determined characteristics of snow physicochemical properties and chemical composition were calculated. The Spearman's rank correlation coefficient was selected because the

Table 1

Obtained and expected concentration values of selected components in certified reference materials

Analyte	ERM-CA713		ICP MS TOF		*Dev.*[b]
	concentration	± uncertainty	concentration	±*SD*[a]	
	[μg · dm^{-3}]				[%]
Mn	95.0	4.0	91.0	1.2	–4.2
Fe	445.0	27.0	450.0	0.6	1.1
Cu	101.0	7.0	97.0	2.1	–3.9
Cd	5.09	0.2	4.9	2.3	–3.7
Pb	49.7	1.7	48.1	1.1	–3.2
Zn	78.0	—	73.0	1.4	–6.4
Cr	20.9	1.3	22.0	3.1	–5.0
Ni	50.3	1.4	48.8	2.8	–3.1

Analyte	KEIJM-02		ICS 3000		*Dev.*[b]
	concentration	± uncertainty	concentration	±*SD*[a]	
	[mg · dm^{-3}]				[%]
Ca	0.852	0.085	0.824	1.3	–3.2
Mg	0.467	0.038	0.450	1.2	–3.6
K	0.224	0.032	0.230	1.4	2.6
Na	3.80	0.32	3.880	1.0	2.2
Cl	5.79	0.41	5.620	0.7	–2.9
SO_4	2.420	0.038	2.350	2.0	–2.8

[a] standard deviation; [b] relative difference between the measured (c_z) and certified concentration (c_c), $Dev = 100\% \cdot (c_z - c_c) / c_c$.

analysed series of variables did not meet the criterion of normal statistical distribution. The table only shows those coefficient values being statistically significant at the level of 0.05. The Ward's agglomeration procedure was also used. It was applied with the Manhattan distance as a measure of the similarity of unit clusters in order to separate the groups of analysed snow samples differing from each other in the concentrations of heavy metals. The statistical significance of differences among the separated clusters was assessed with the non-parametric Mann-Whitney U test. Moreover, W-E and N-S profiles were made for the pH values and concentrations of selected heavy metals.

Analysis and discussion of results

Based on the meteorological data from the IMGW-PIB precipitation station in Nosow (lying 10 km towards WSW from Ostrowiec Swietokrzyski), the number of days with snow cover was calculated, which amounted to only 46 days in the 2016/2017 season. The first day with the snow cover (thickness ≥ 1 cm) was on 3rd Dec. 2016 and the last one on 15th Apr. 2017. Between those dates, the snow cover disappeared several times. The snow samples were collected on 31st Jan. 2017. On that day the snow cover in the study area had been constantly existing for 4 weeks; thus, during that time, it was a collector for pollutants provided by both precipitation and solid particles depositing on its upper layer (Fig. 2a). The maximum thickness of the snow cover in Nosow in January 2017 was only 5 cm (Fig. 2a). According to the meteorological data from the nearest IMGW-PIB synoptic stations (Kielce-Sukow and Sandomierz), the minimum daily air temperature remained below 0.0 ^{o}C almost in the entire period (Fig. 2a). This contributed to the consolidation of the snow cover and probably increased the emission of pollutants from the communal-living sector. During the period of lingering snow cover, preceding the collection of snow samples (3rd–31st Jan. 2017), the analysed meteorological stations were characterised with predominance of winds from the west (Kielce-Sukow – 20.2 %) and south-west (Sandomierz – 19.4 %). During that time, silent periods constituted 6.8 % and 2.2 % of observations, respectively (Fig. 2b).

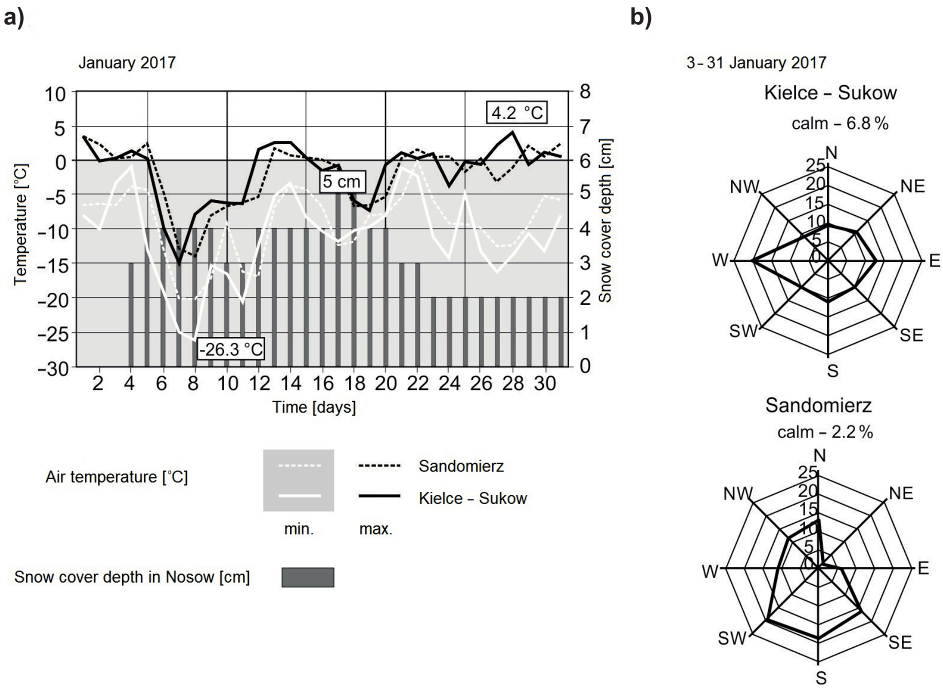

Fig. 2. Meteorological conditions: a) air temperature, b) wind direction – own elaboration

The mean arithmetic pH value of the analysed snow samples was 7.38 (with variation in the range from 6.31 to 10.18) – Table 1. All the snow samples had slightly increased and increased pH values according to the classification by Jansen et al. [12]; those which were increased (pH > 6.5) constituted almost 80 % of the snow samples. Specific Electrical conductivity (*SEC*) of the samples was ranging from 2.56 to 10.7 mS · m^{-1}, with an average of 4.15 mS · m^{-1} (Table 2). Its values were varying from slightly increased to very much increased according to the classification by Jansen et al. [12].

Table 2

Basic statistics of physicochemical properties and concentration of principal ions and metals in the snow cover in the study area (n = 18)

Characteristic		Mean	Minimum	Maximum	Coefficient of variability [%]	Skewness	Kurtosis
pH	[-]	7.38	6.31	10.18	17.29	1.18	–0.14
SEC	[$\mu S \cdot m^{-1}$]	4.15	2.56	10.70	54.90	2.12	4.69
Ca^{2+}	[$mg \cdot dm^{-3}$]	4.00	0.90	12.61	79.04	1.54	1.92
SO_4^{2-}		3.63	2.01	7.41	37.46	1.37	2.38
Fe	[$\mu g \cdot dm^{-3}$]	62.50	35.12	157.13	41.38	2.86	9.98
Zn		57.14	8.90	133.34	61.45	0.21	–0.68
Mn		15.51	0.77	45.48	73.13	0.94	1.12
Al		8.10	1.25	21.65	58.65	1.14	2.20
Cu		1.72	0.64	7.54	88.46	3.30	12.42
Cr		0.56	0.23	1.14	38.55	1.45	2.34
Ni		0.37	0.00	1.17	102.34	0.94	–0.56
Cd		0.11	0.00	0.29	88.52	0.65	–0.80
Pb		0.06	0.00	0.14	87.68	0.33	–1.44
Co		0.06	0.00	0.28	118.45	2.21	6.21

Among the ions found in the snow samples, the highest concentrations were found for: calcium cation Ca^{2+} (mean concentration: 4.00 mg · dm^{-3}) and sulphate anion SO_4^{2-} (mean concentration: 3.63 mg · dm^{-3}). The coefficient of variation of the physicochemical properties of the snow cover and the concentration of the analysed compounds was ranging from 17 to 118 %. The latter value refers to cobalt whose concentrations were ranging from 0.06 to 0.28 μg · dm^{-3}. The concentrations of nickel, copper and lead were also characterized by a large dispersion of values. Except for zinc whose concentrations had almost a symmetric distribution, the other analysed characteristics of the physicochemical properties and chemical composition of the snow cover were characterised by a right-skewed distribution, as evidenced by the positive values of coefficient of skewness. The distribution of copper, iron and cobalt was the most asymmetrical. In the case of copper and cobalt concentrations, it was observed that their maximum measured values were several times higher than the mean ones. The samples characterised by the highest values were collected near the ironworks in Ostrowiec Swietokrzyski. The pH values and concentrations of zinc, nickel, cadmium and lead were characterised by platykurtic distribution (negative value of kurtosis). The other analysed characteristics had leptokurtic distribution (positive values of kurtosis), i.e. their values were more concentrated around the mean than in the case of normal distribution. This especially concerned the concentrations of copper and iron (Table 3).

The strongest positive correlation was found between Fe and Cr as well as Fe and Ni concentrations. The concentrations of Fe and Ni also correlated positively with pH and *SEC* (the Ni concentrations correlated with the concentrations of calcium and sulphate

Table 3

Spearman's rank correlation among heavy metal concentrations and physicochemical properties and concentrations of selected ions in the snow samples collected in the study area on 31th Jan. 2017 (only statistically significant at the level of $p < 0.05$)

Characteristic	Fe	Zn	Mn	Al	Cu	Cr	Ni	Cd	Pb	Co
Fe										
Zn	–0.50									
Mn	–0.60	0.59								
Al										
Cu										
Cr	0.77									
Ni	0.56	–0.61	–0.52							
Cd										
Pb		0.50					–0.48			
Co										
pH	0.47		–0.56				0.80			
SEC	0.65	–0.61	–0.61				0.74			
Ca^{2+}		–0.63					0.71		–0.52	
SO_4^{2-}				–0.51			0.65			

ion as well), which suggests that the size of their deposition was determined by the proximity of the emission source, i.e. the ironworks. In the case of Zn, Mn and Pb concentrations, there were negative correlations with pH, *SEC*, calcium ion concentrations as well as Fe and Ni concentrations. The Zn concentrations were statistically significantly and positively correlated with the Mn and Pb concentrations.

Concentrations of selected heavy metals were analysed in the two cross-section profiles, i.e. the parallel (W-E) and the meridional (N-S) ones intersecting at the central point constituted by the ironworks CELSA "Huta Ostrowiec" (Fig. 3).

In the case of Fe and Ni concentrations, their increase was clearly visible in the immediate vicinity of the industrial plant. In the case of Fe, the concentrations of this metal in the samples collected in the southern part of the study area were about 50 $\mu g \cdot dm^{-3}$ and increased to 157.13 $\mu g \cdot dm^{-3}$ in its central part. In the same profile, the concentrations of Ni and Al increased from 0.15 $\mu g \cdot dm^{-3}$ to 1.16 $\mu g \cdot dm^{-3}$ and from 3.15 $\mu g \cdot dm^{-3}$ to 21.64 $\mu g \cdot dm^{-3}$, respectively. The increase in the Cr concentrations was visible between the steelworks and the city centre, as well as in the area south of the steelworks. The spatial distribution of Pb, Cd, Co and Zn concentrations did not show any clear relationship with either the steelworks area or the city centre. The high concentrations of Pb, Cd and Zn were observed, among others, in the snow sample collected about 6 km north of the ironworks (sample no. 14, Fig. 2).

Cluster analysis carried out using the Ward's method (Manhattan distance) allowed for separating three sets of sites. The first group A included sites located in the immediate vicinity of the ironworks and to the south of it. This group had 7 sampling sites (Fig. 4) characterised by the highest concentrations of Fe (mean value: 79.16 $\mu g \cdot dm^{-3}$),

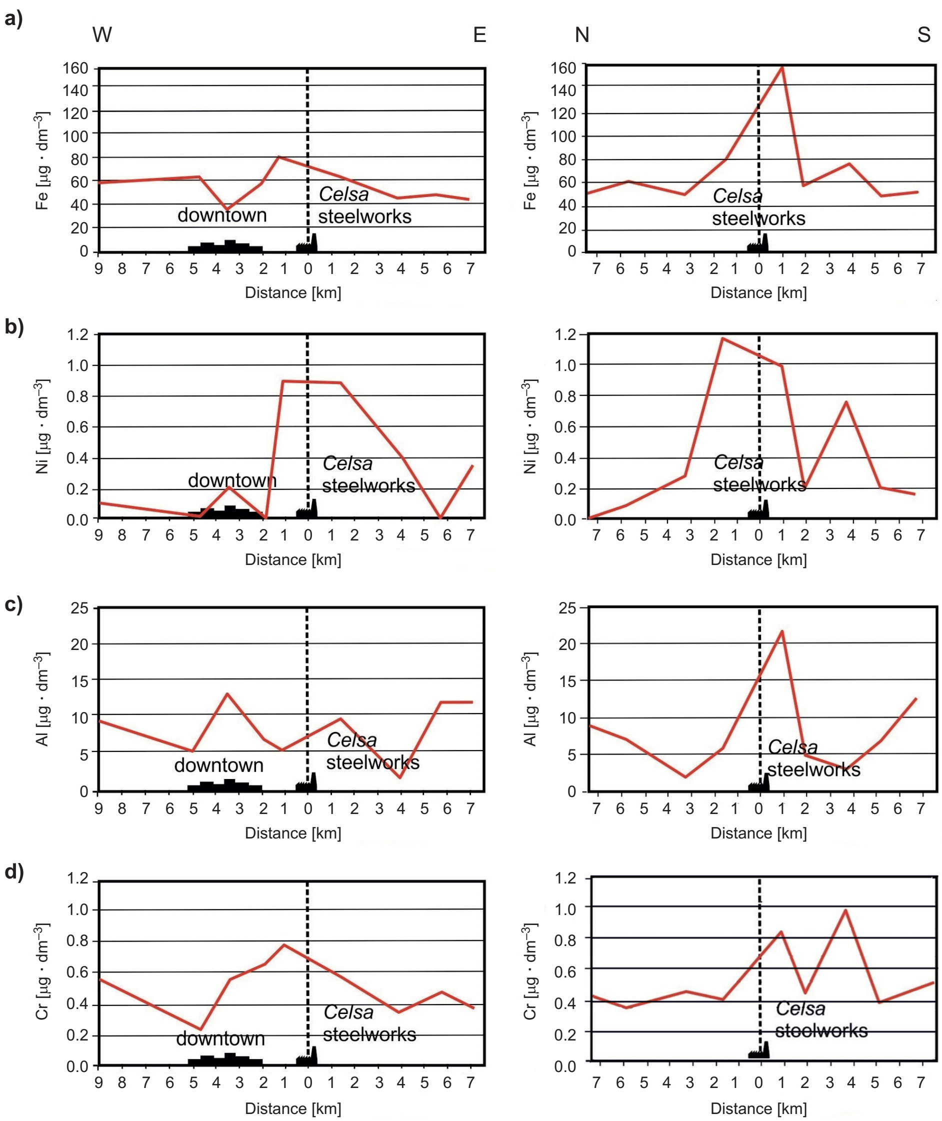

Fig. 3. N-S and W-E cross-section profiles of selected heavy metal concentrations in the snow samples collected near Ostrowiec Swietokrzyski and the ironworks CELSA "Huta Ostrowiec": a) Fe, b) Ni, c) Al, d) Cr

Al (9.18 $\mu g \cdot dm^{-3}$), Ni (0.71 $\mu g \cdot dm^{-3}$) and Cr (0.70 $\mu g \cdot dm^{-3}$). This area should be considered as particularly vulnerable to pollutant emissions from the heating as well as metallurgical sectors. Similar studies conducted in Quebec and devoted to pressure from the petrochemical industry and copper metallurgy [4] showed similar concentrations of Al, nearly halved lower concentrations of Zn and much lower (95 times) concentrations of Cu. The concentrations of Pb, Cd and Co were in Quebec, however, several hundred

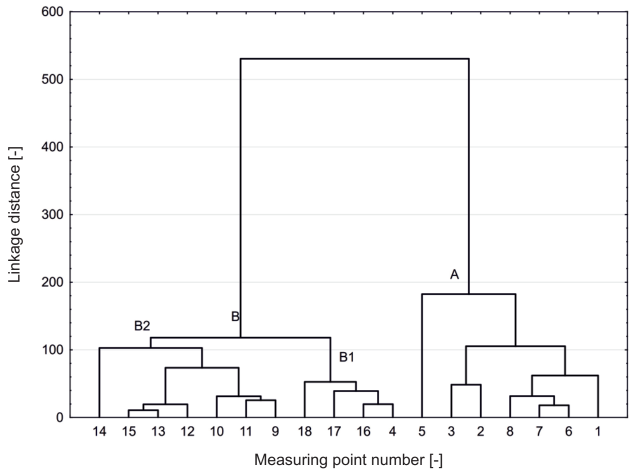

Fig. 4. Agglomeration of snow samples by the Ward's method (Manhattan distance) [own elaboration using the Statistica 13 Program]

times higher than those recorded near Ostrowiec Swietokrzyski. The group B included the remaining 11 sites located mainly to the west, north and east of the ironworks and apart from the reduced concentrations of Fe, Al, Ni and Cr – was characterised by the higher Mn concentrations (18.60 µg · dm^{-3}) than in the group A. The studies on the snow chemistry in the Italian Po Valley urban agglomeration (Ferrara and Codigoro) [3] showed similar concentrations of Mn (about 14 µg · dm^{-3}), several times higher concentrations of Fe (4 times), Zn (3 times), Cu (10 times) and Al (33 times) than those reported for the areas near Ostrowiec Swietokrzyski. At a further stage of analysis, the group B was divided into the subgroup B1 characterised by the increased concentrations of Pb (0.08 µg · dm^{-3}), Co (0.08 µg · dm^{-3}) and Cu (3.33 µg · dm^{-3}) (the subgroup included sites located mainly in the western part) and the subgroup B2 with the increased concentrations of Cd (0.13 µg · dm^{-3}) and Zn (92.12 µg · dm^{-3}), which included sites located to the north and east of Ostrowiec Swietokrzyski and the ironworks.

Based on the analysis of distribution of concentrations and the location of sampling sites, it may be assumed that the dominant source of pollution within these groups were road transportation and deposition of pollutants transferred from local and regional sources. Similar studies conducted in the American Cincinnati [13] showed the concentrations of Pb, Cu and Cd lower than in the study area. Only the Zn concentrations were almost 3 times higher. The Zn, Cu, Pb and Cd concentrations in the snow samples collected in the study area were much lower than those recorded in Innsbruck [1]. Near Ostrowiec Swietokrzyski, the mean concentrations of zinc, copper, cadmium and lead were 2.6, 11.7, 27.3 and 266.6 lower than in Innsbruck, respectively. The studies on the snow samples collected in Ostrava [2] allowed for making a comparison for Cu, Pb and Fe concentrations. Their concentrations were significantly more diverse.

The concentrations of Fe were halved lower, but those of Pb and Cu were several hundred times higher (Pb 113 times, Cu 1649 times) than in Ostrava. In Chile [5], where the impact of Santiago and Chillan urbanisation on snow properties in the Andean Cerro Colorado and Nevados de Chillan was studied, the increased concentrations of heavy metals were observed in the former one. The concentrations of Cu, which were 30 times higher than in Ostrowiec Swietorkzyski, were influenced by the copper mine at Los Bronces, located 40 km north-west from the Cerro Colorado. The concentrations of Cd, Cr and Ni were comparable, while those of Zn were almost half as low. The concentrations of Pb were, in turn, several hundred times higher.

Table 4

Results of statistical testing using non-parametric Mann-Whitney U test

A : B	Sum of ranks		U	Z	P	Valid *n*	
	A	B				A	B
Pb	43	128	15	–2.08	0.04	7	11
Cd	66	105	38	0.00	1.00	7	11
Cr	88	83	17	1.90	0.06	7	11
Co	66	105	38	0.00	1.00	7	11
Cu	68	103	37	0.09	0.93	7	11
Mn	43	128	15	–2.08	0.04	7	11
Ni	96	75	9	2.63	0.01	7	11
Zn	28	143	0	–3.44	0.00	7	11
Al	71	100	34	0.36	0.72	7	11
Fe	93	78	12	2.35	0.02	7	11

B1 : B2	Sum of ranks		U	Z	P	Valid *n*	
	B1	B2				B1	B2
Pb	27	39	11	0.47	0.64	4	7
Cd	17	49	7	–1.23	0.22	4	7
Cr	27	39	11	0.47	0.64	4	7
Co	38	28	0	2.55	0.01	4	7
Cu	37	29	1	2.36	0.02	4	7
Mn	16	50	6	–1.42	0.16	4	7
Ni	25	41	13	0.09	0.92	4	7
Zn	11	55	1	–2.36	0.02	4	7
Al	26	40	12	0.28	0.78	4	7
Fe	29	37	9	0.85	0.40	4	7

The statistical analysis carried out using the Mann-Whitney U test showed statistically significant differences in the Pb, Mn, Ni Zn and Fe concentrations in both groups A and B. In the case of sites located in the central part of the study area (group A), this was related to the emission and deposition of pollutants from the combined heat and power plant and the ironworks. The increased Fe, Al, Ni and Cr values may be related to the use of iron ore-extender additives in technological processes [14]. After getting into the atmosphere, they can be then deposited to the top soil levels, which is noticeable to a depth of 50 cm and a distance of up to 4 km from the emission source [15]. In the western and south-western part (group B1), the presence of metals (Pb, Cu, Co) occurring along communication routes, with road transportation predominance, was found. In the B2 group with sites located in the north-eastern part, behind a large forest surface limiting the dispersion of pollutants, the increased concentrations of Cd and Zn were found. The source of these heavy metals may be both local and regional centres emitting pollutants which are then transferred with air masses coming from the western and south-western directions, prevailing in the study period.

Conclusions

Based on the obtained results, it should be stated that there is a significant impact of the functioning industry on the study area environment. The applied methods showed their effectiveness in identifying the potential sources of pollution and their spatial extent. The industrial profile of the city, related to the iron industry – the ironworks CELSA "Huta Ostrowiec" along with the combined municipal heat and power plant, has the biggest impact on the air quality in Ostrowiec Swietokrzyski. Additional factors that reduce the air quality are local road transportation as well as local and regional deposition of pollutants from the atmosphere. The spatial pattern of deposition of pollutants in the snow cover near Ostrowiec Swietokrzyski is clearly noticeable. The agglomeration and statistical testing procedure allowed for indicating the areas differing in the size of deposition, with the highest concentrations of heavy metals in the snow cover, i.e. Fe, Al, Ni and Cr in the immediate vicinity of the ironworks and the combined heat and power plant. The spatial distribution of the Pb, Co and Cu concentrations with the highest values recorded in the samples collected in the vicinity of the national road no. 9 indicates road transportation as an emission source of these pollutants. In the case of Cd and Zn, the highest concentrations were recorded in sites located in the north-eastern part of the study area. It should be emphasised that these sites are located in the areas adjacent to forests along their leeward sides. Such a distribution indicates an increase in the importance of barriers in the form of dense forest complexes in limiting the spread of pollutants.

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ANALIZA ZANIECZYSZCZEŃ ŚNIEGU W UPRZEMYSŁOWIONEJ STREFIE MIEJSKIEJ W REJONIE OSTROWCA ŚWIĘTOKRZYSKIEGO

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Abstrakt: W stopionych próbkach śniegu, pobranych w rejonie huty żelaza w Ostrowcu Świętokrzyskim oznaczono właściwości fizyczno-chemiczne i skład chemiczny za zawartość metali ciężkich (Pb, Cd, Co, Cr, Cu, Mn, Ni, Zn, Al, Fe) oraz głównych kationów i anionów. Zakład przemysłowy stanowił centralny punkt badań terenowych, pozostałe punkty poboru prób śniegu zlokalizowano wzdłuż osi północ–południe i wschód–zachód. Łącznie w dniu 31.01.2017 r. pobrano 18 próbek. W tym czasie pokrywa śnieżna zalegała w otoczeniu zakładu już ponad cztery tygodnie, co pozwoliło na depozycję zanieczyszczeń, w tym pyłów hutniczych zawierających m.in. metale ciężkie. Stężenia rozpuszczonych form metali analizowano za pomocą spektrometru ICP-MS-TOF. Najwyższą zawartość odnotowano dla żelaza (średnia 62,50 $\mu g \cdot dm^{-3}$), cynku (57,14 $\mu g \cdot dm^{-3}$), manganu (15,51 $\mu g \cdot dm^{-3}$), glinu (8,10 $\mu g \cdot dm^{-3}$) oraz miedzi (1,72 $\mu g \cdot dm^{-3}$). Stężenia ołowiu, kadmu, chromu, kobaltu i niklu nie przekroczyły 1 $\mu g \cdot dm^{-3}$. Wyniki analiz, jak i przestrzenny rozkład stężeń niektórych metali w pobranych próbkach śniegu, wskazują na wyraźne oddziaływanie emisji zanieczyszczeń powietrza przez hutę żelaza w Ostrowcu Świętokrzyskim na otoczenie.

Słowa kluczowe: chemizm opadów, antropopresja, pokrywa śnieżna