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THE INFLUENCE OF THE SYNOPTIC SITUATIONS ON THE CONCENTRATION OF HEAVY METALS IN PRECIPITATION WATER AND THE EXTENT OF THEIR DEPOSITION AT ŁAZY IN THE CARPATHIAN FOOTHILLS

Abstract: Atmospheric pollution diffuses and returns to the earth's surface in a variety of forms. Weather conditions greatly influence the spread of pollution. The purpose of this paper is to identify the influence of the synoptic situation on the concentration and load of heavy metals advecting with precipitation. In the period stretching from 1 April 1994 to 31 March 1995, daily precipitation totals were collected at the Łazy Weather Station in the Wieliczka Foothills and the concentration of heavy metals (zinc, lead, cadmium, copper and manganese) measured. The relevant synoptic situation was determined for each day on which rainfall has occurred. A comparison of mean metal concentration and deposition with the synoptic situation shows the influence of barimetric situations (cyclonal and anticyclonal) on the concentration and load of heavy metals in precipitation. The extent of deposition of heavy metals is heavily dependent on synoptic situations with passing frontal systems.

1. Preface

Depending on their location and distance from large urban-industrial agglomerations, rural areas are at risk from various kinds of pollution. These are commonly gas, dust and aerosol pollution. Deposition results from both locally-sourced pollution (which comes from both rainout and dry fallout) and externally-sourced pollution (mostly rainout) (Legge, Krupa, 1986). The relative importance of local and distant emissions varies with time, weather conditions and the magnitude and quality of emitted substances (Turzański, 1991). After being emitted into the atmosphere substances diffuse and return to the earth's surface as a result of:

– falling with precipitation (wet deposition) as a result of rainout and washout;
– gravity-driven sedimentation of large particles (fall out);
– absorption of gas pollution and aerosols by the ground (Garland, 1978; Hryniewicz, Przybylska, 1993a).

2. Area of study

A survey of the concentration and extent of pollution advecting with precipitation was carried out at Łazy, an agricultural area in the Wieliczka Foothills near the town of Bochnia. This is an area potentially under danger from incoming pollution from both local and distant emission sources (Fig. 1). To the west lies the Upper Silesia Industrial Region to the north-west - Cracow and the steel works at Nowa Huta, to the north, the gypsum plants at Pińczów and the chalk and cement works around Kielce - Sitkówka and Małogoszcz. From the north-east comes pollution sourced in areas of sulphur extraction and refining around Grzybów, Staszów and Tarnobrzeg, and also from the Połaniec generating station. To the east, in Tarnów, is a nitrate production plant. To the south there are no large pollution sources. Pollution also sometimes comes from the Moravian Gate region to the south-west (more exactly west-south-west), which hosts the coke production and steelmills of Ostrava-Karvina in the Czech Republic.

3. Research aims, range and methods

The goal of the research is to determine the concentration of heavy metals in atmospheric precipitation and the degree of their deposition during particular synoptic

Fig. 1. The location of the Łazy Research Centre in relation to the main sources of atmospheric pollution in south-eastern Poland.

Ryc. 1. Położenie Stacji Naukowej w Łazach w stosunku do głównych źródeł zanieczyszczenia atmosfery w południowo-wschodniej Polsce.

conditions. Rainfall samples were taken at Łazy at 6.00 GMT every day, when precipitation had occurred. All forms of deposition were measured, i.e. both rainborne wet deposition and dry deposition occurring in the period prior to precipitation. Water samples were taken with the aid of three teflon-coated aluminium cones of inlet area of 1000 cm^2 each. This method ensured an adequate quantity of water even after small falls of precipitation. In the laboratory the water was poured into polypropylene test-tubes and treated with ultraclean HNO_3 to pH 2. In such water samples the concentration of heavy metals (zinc, lead, cadmium, copper and manganese) was determined using flame and non-flame atomic absorption on a Varian 20 spectrometer. The accuracy of the measurement was checked by using NRC (SLRS-3) reference samples. In falls of more than 1 mm it was possible to carry out the whole range of analyses, while when there was less than 1mm of rainfall analysis was limited. From 1 April 1994 to 30 March 1995 the heavy metal concentration in 146 samples was measured (Tab. 1).

Calculated average concentrations are weighted values. Weights are daily precipitation totals. The main meteorological elements influencing the behaviour of pollution in the environment are the direction and velocity of wind, the type of barometric situation, the quantity of precipitation and the degree of stratification of

Tab. 1. Number of samples and precipitation totals in particular types of synoptic situation at Łazy between 1 April 1994 and 31 March 1995.

Tab. 1. Liczba badanych przypadków i sumy opadów atmosferycznych w poszczególnych typach sytuacji synoptycznych w Łazach w okresie od 1 kwietnia 1994 do 31 marca 1995 r.

Type of synoptic situation Typ sytuacji synoptycznej	Number of precipitation events Liczba przypadków opadowych	Precipitation in all situations Opady przy wszystkich sytuacjach		Precipitation in anti-cyclonic situations Opady przy sytuacjach antycyklonalnych		Precipitation in cyclonic situations Opady przy sytuacjach cyklonalnych	
		mm	%	mm	%	mm	%
N	10	45.1	6.4	6.9	0.98	38.2	5.41
NE	7	38.1	5.4	14.2	2.01	23.9	3.39
E	5	15.6	2.2	5.3	0.75	10.3	1.46
SE	3	36.6	5.2	none	none	36.6	5.19
S	3	15.2	2.2	none	none	15.2	2.15
SW	21	53.3	7.6	15.0	2.13	38.3	5.43
W	36	113.7	16.1	45.6	6.46	68.1	9.65
NW	15	61.2	8.7	6.9	0.98	54.3	7.70
Bc+Cc	33	268.6	38.1	none	none	268.6	38.07
Ka+Ca	11	28.8	4.1	28.8	4.08	none	none
X	2	29.3	4.2	none	none	none	none
Total	146	705.5	100.0	122.7	17.39	553.5	78.45

the atmosphere (including temperature inversion). In the mesosynoptic scale the most important elements of atmospheric circulation directly influencing the weather of a given area are the direction of air masses advection and the type of barometric system (Niedźwiedź, 1981).

For every daily rainfall total the type of synoptic situation during which precipitation occurred was determined. This was done on the basis of the calendar drawn up and made available by Prof. T. Niedźwiedź (manuscript). The average concentration and deposition of heavy metals for rainfall connected with the advection of air masses from particular directions were calculated. There is a difference between falls occurring during cyclonic (low pressure) and anti-cyclonic (high pressure) conditions.

All the types of synoptic situation are presented below; subscript 'c' indicates cyclonic conditions, while subscript 'a' implies anticyclonic conditions (Niedźwiedź, 1981):

- Na, Nc - situations with air-masses advection from the north,
- NEa,NEc - situations with air-masses advection from the north-east,
- Ea, Ec - situations with air-masses advection from the east,
- SEa, SEc - situations with air masses advection from south-east,
- Sa, Sc - situations with air-masses advection from the south,
- SWa, Swc - situations with air-masses advection from the south-west,
- Wa,Wc - situations with air-masses advection from the west,
- NWa, NWc - situations with air-masses advection from the north-west.
- Ca - central anticyclonic situation, no advection, high pressure centre over south Poland or Slovakia,
- Ka - high-pressure wedge, sometimes several undistinct centres or unclearly defined area of high pressure, axis of the ridge of high pressure,
- Ca - central cyclonic situation, low pressure centre over south Poland or Slovakia,
- Bc - low-pressure trough, unclearly defined area of low pressure or axis of the low-pressure trough with different directions of advection and frontal systems separating different air-masses.
- X - undefined situations and pressure cols.

In the analysis material gained from rainfall connected with situations Ca (1 case) and Cc (2 cases) were treated together with the related situations Ka and Bc. In the case of advection of air masses from four directions - NE, E, SE and S - the quantity of precipitation samples received is too small and thus in these cases we must be careful in interpreting resultant data.

4. Results

4.1 Concentrations of metals in rainfall

The average concentration of heavy metals in precipitation was: for zinc 67.0, manganese 11.9, lead 8.9, copper 5.4 and cadmium 0.8 (all figures in µg dm^{-3}). In

Fig. 2. Average concentration of heavy metals in precipitation water in various kinds of barometric situation.

Ryc. 2. Średnia koncentracja metali ciężkich w wodach opadowych w różnych rodzajach układu barycznego.

industrial areas heavy metal concentrations are several times higher, e.g. in Głogów copperfield in south-western Poland they amount to zinc 960, copper 426, lead 255 and cadmium 2.4 (all figures in μg dm^{-3}) (Hryniewicz, Przybylska, 1993b). In Upper Silesia and its environs, respective concentrations are zinc 297, copper 5, lead 13 and cadmium 1 (Leśniok, 1993).

In precipitation connected with with anticyclonic barometric conditions a concentration of heavy metals 1.7-2.4 times higher on average than for precipitation linked with cyclonic conditions was observed (Fig. 2). This was the case for all metals.

With regard to the large industial concentrations in the area lying to the west and north-west of Łazy (Upper Silesia, Olkusz and Cracow), the highest pollution levels might be expected in precipitation advecting from those directions. Analysis of metal concentrations with respect to the direction of incoming air mass, independent of the barometric conditions, shows the truth of this only for cadmium and lead (Fig. 3). This draws attention to the fact that in stable high pressure systems (Ka and Ca) the concentration of metals was high, generally several times higher than was the case for rain falling during low atmospheric pressure conditions (Bc and Cc).

The distribution of metal concentrations in rainfall arriving from particular directions broken into the cyclonic and anti-cyclonic situations shows a complex array of factors shaping the level of pollution in rainfall (Fig. 4). The greatest concentration of heavy metals in rainfall occurred in anti-cyclonic situations advecting from the north, north-west and east. In the case of lead, zinc and cadmium the greatest concentration occurring in rainfall from those directions shows the origin of these contaminants in Cracow, the Nowa Huta steelworks and Olkusz. The case of copper is different. Its greatest presence is in precipitation advecting from the east. Here it should be noted that the highest concentrations do not advect from the west. This is probably a result of upwind wash out of pollution and the tendency to rain out at the sampling site.

A comparison of heavy metal concentrations occurring in anti-cyclonic situations with those in cyclonic situations emanating from the same cardinal direction shows the role of the barometric situation in shaping the chemistry of precipitation. Heavy metal concentrations are generally higher in falls occurring in high-pressure systems. It is worth underlining that the greatest disproportion (the ratio of concentration of surveyed elements in anticyclonic and cyclonic situations) occurs in those directions where the distance between the emission sources and Łazy is the least. This is most obvious in the case of zinc, cadmium and lead in falls originating to the NW and N. The lowest concentration was noted in precipitation coming from the S and SE. Here it should be noted that - as shown in another paper (Ciszewski, Żelazny, 1995c) - the concentration of pollution in precipitation water can change dramatically during one event. In almost one in two cases the highest concentration of heavy metals occurs not in the first hour of precipitation (so-called ‘normal type’), but rather in the following hours. The classification of the synoptic situation herein and the recording of only one barometric situation for a particular day oversimplifies the real picture, which has very complicated dynamics. Despite the analysis of 97% of cases of rainfall during the time in question, their number is too small to create a sufficiently large databank.

4.2 Deposition

The annual load of the five surveyed heavy metals deposited on the area under research amounted to 60, 584 μg m^{-2}. The most heavily-deposited was zinc (72.8%),

Fig. 3. Average concentration of heavy metals in precipitation water with regard to direction of advecting air masses (in μg dm^{-3}).

Ryc. 3. Średnia koncentracja metali ciężkich w wodach opadowych w zależności od kierunku napływu mas powietrza (w μg dm^{-3}).

much less manganese (11.9%), lead (8.9%), copper (5.4%) and, the least, cadmium (0.8%) (Fig. 5). Deposition of heavy metals in industrial regions was considerably greater. In Głogów copperfield it amounted to 897,800 μg m^{-2} (Hryniewicz, Przybylska, 1993b), while in Cracow it was 108,200 μg m^{-2} (Grodzińska, 1995).

Analysis of pollution deposited with precipitation, which occurred in cyclonic and anti-cyclonic barometric conditions shows that cases connected with cyclonic situations accounts for 60% of deposits in the area (Fig. 6). This is a consequence of the quantity of precipitation connected with low-pressure systems, which account for 78% of the total (Tab. 1). The large precipitation totals advecting from the west (despite relatively low metal concentrations) means that metal deposits received from that direction are substantial and in the case of cadmium and copper, the most substantial (Fig. 7). It should be stressed that the largest load of metals (Zn, Mn, Pb - the greatest deposition) is received in situations classed as cyclonic troughs (Bc) or central cyclonic situations (Cc), which are connected with rainfall arriving with frontal systems.

In the case of zinc, manganese, copper and lead, the synoptic situation, which is characterised by changed directions of air masses (Bc, Cc, Ca, Ka) leads to more metals being deposited than precipitation recorded during synoptic conditions connected with particular directions. This results from significantly greater rainfall occurring during such conditions. Such precipitation accounts for 42% of annual total.

The pattern of pollution deposited separated according to its advection in low and high-pressure systems shows the even greater role that precipitation advecting with frontal systems (Bc) plays. It is a rule

Fig. 4. Average concentration of heavy metals in precipitation water with regard to direction of advecting air masses in cyclonic (c) and anticyclonic (a) synoptic situations (in μg dm^{-3}).

Ryc. 4. Średnia koncentracja metali ciężkich w wodach opadowych w zależności od kierunku napływu mas powietrza w cyklonalnej (c) i antycyklonalnej (a) sytuacji synoptycznej (w μg dm^{-3}).

Fig. 5. Relative size of deposition of the heavy metals at Łazy in the period from 1 April 1994 to 31 March 1995.

Ryc. 5. Względna wielkość depozycji badanych metali w Łazach w okresie od 1 kwietnia 1994 do 31 marca 1995 r.

Fig. 6. Relative size of deposition of the heavy metals at Łazy in various kinds of barometric conditions between 1 April 1994 and 31 March 1995.

Ryc. 6. Względna wielkość depozycji badanych metali ciężkich w Łazach w różnych rodzajach układu barycznego w okresie od 1 kwietnia 1994 do 31 marca 1995 r.

that during the events occurring during barimetric depressions the most pollution was deposited (from 36% for cadmium to 48% for zinc) in synoptic conditions Bc and Cc. This is a consequence of the large amount of rainfall during such synoptic situations (38.1%). In high-pressure conditions deposition of metals was greatest with westerlies; in the case of lead amounting to over half (52%) of the total load (Fig. 8). Precipitation connected with high-pressure situations Ka and Ca, and thus not assigned to a direction, held relatively little pollution, despite several-times-higher concentrations of heavy metals occurring in precipitation. This is a result of the low precipitation total (4.08%) connected with these synoptic situations. The lowest levels of pollution come from the south, east and south-east.

5. Conclusion

A comparison of deposition and concentration of heavy metals with values noted in the literature allows us to say that the area under survey has a mild degree of atmospheric pollution (Ciszewski, Żelazny, 1995a and b; Jeffries, Snyder, 1981, Grodzińska et al. 1995; Hryniewicz, Przybylska 1993b; Leśniok 1996; Turzański 1991; Turzański, Bik, 1993).

The concentration of heavy metals in rainwater depends above all on the type of barometric system. Anticyclonic conditions lead to a higher concentration than cyclonic conditions. The influence of direction of the incoming air mass on the metal concentration is not limited to a single aspect. In anticyclonic conditions rain with a high metal concentration comes generally from the north and north-west. For cyclonic situations it is hard to work out any kind of rule. Concentrations are different for different metals.

The amount received is undoubtedly connected with the magnitude of precipitation. More metal fallout is received from the west than from other directions. The largest load of metals is however caused by cyclonic trough situations, of changed direction of incoming air masses but high precipitation totals. The central cyclonic situation (Ca) and cyclonic ridge (Ka) do not account for such a role due to the insignificant amounts of rainfall.

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Fig. 7. Relative size of deposition of the heavy metals at Łazy with regard to direction of advecting air mass independent of the synoptic situation between 1 April 1994 and 31 March 1995.

Ryc. 7. Względna wielkość depozycji metali ciężkich w Łazach w zależności od kierunku napływu mas powietrza, niezależnie od sytuacji synoptycznej, w okresie od 1 kwietnia 1994 do 31 marca 1995 r.

References

Ciszewski D., Żelazny M. (1995a): *Koncentracja makro i mikrojonów w wodach opadach atmosferycznych w Łazach na Pogórzu Karpackim* [in:] L. Kaszowski (ed.), *Dynamika i antropogeniczne przeobrażenia środowiska przyrodniczego progu Karpat między Rabą a Uszwicą*, Instytut Geografii UJ.

Ciszewski D., Żelazny M. (1995b): *Ładunki zanieczyszczeń w wodach opadowych w Łazach na Pogórzu Wielickim* [in:] L. Kaszowski (ed.), *Dynamika i antropogeniczne przeobrażenia środowiska przyrodniczego progu Karpat między Rabą a Uszwicą*, Instytut Geografii UJ.

Ciszewski D., Żelazny M. (1995c): *Koncentracja makro i mikrojonów w poszczególnych fazach opadów atmosferycznych w Łazach na Pogórzu Karpackim* [in:] L. Kaszowski (ed.), *Dynamika i antropogeniczne przeobrażenia środowiska przyrodniczego progu Karpat między Rabą a Uszwicą*, Instytut Geografii UJ.

Garland J. A. (1978): *Dry and wet removal of sulphur from the atmosphere*, Atmospheric Environment, 12.

Grodzińska K. (ed.) (1995): *Zakwaszenie i skład chemiczny opadów atmosferycznych w województwie krakowskim w okresie II 1994-I 1995*, manuscript.

Hryniewicz R., Przybylska G. (1993a): *Actual and predicted air pollution and deposition rates of pollutants in north - eastern Poland*, Ekologia Polska, 41, 1-2.

Hryniewicz R., Przybylska G. (1993b): *Zanieczyszczenie opadów atmosferycznych w Polsce* [in:] I. Dynowska (ed.), *Przemiany stosunków wodnych w Polsce w wyniku procesów naturalnych i antropogenicznych*, Kraków.

Jeffries D. S., Snyder W. R. (1981): *Atmospheric deposition of heavy metals in central Ontario*, Water, Air and Soil Pollution, 15.

Legge A. H., Krupa S. V. (1986): *Air pollutants and their effect on the terrestrial ecosystem*. Advances in Environmental Science and Technology, 18., Wiley, New York, Chichester, Brisbane, Toronto, Singapore.

Leśniok M. (1996): *Zanieczyszczenie wód opadowych w obrębie Wyżyny Śląsko-Krakowskiej*, Prace Nauk. Uniw. Śl., 1591.

Niedźwiedź T. (1981): *Sytuacje synoptyczne i ich wpływ na zróżnicowanie przestrzenne wybranych elementów klimatu w dorzeczu górnej Wisły*, Rozprawy hab., 58, UJ.

Turzański K. P. (1991): *Zanieczyszczenie wód opadowych południowej Polski, Kwaśne deszcze i ich monitoring*, Sozologia i Sozotechnika, 34.

Fig. 8. Relative size of deposits of the heavy metals at Łazy with regard to direction of advecting air mass separated into cyclonic and anticyclonic situations between 1 April 1994 and 31 March 1995.

Ryc. 8. Względna wielkość depozycji metali ciężkich w Łazach w zależności od kierunku napływu mas powietrza, oddzielnie w sytuacjach cyklonalnych i antycyklonalnych, w okresie od 1 kwietnia 1994 do 31 marca 1995 r.

Turzański K. P., Bik A. (1993): *Pollution of the atmospheric precipitation in the area of the water reservior in Dobczyce*, Ekologia Polska, 41, 3-4.

Wpływ sytuacji synoptycznych na koncentrację metali ciężkich w wodach opadowych i wielkość ich depozycji w Łazach na Pogórzu Karpackim

Streszczenie

Zanieczyszczenia emitowane do atmosfery ulegają rozpraszaniu i powracają na powierzchnię ziemi w różnej postaci. Warunki meteorologiczne istotnie wpływają na rozprzestrzenianie zanieczyszczeń. Celem pracy jest określenie wpływu sytuacji synoptycznych na koncentrację i ładunek metali ciężkich dostarczanych na powierzchnię terenu wraz z wodami opadowymi. Na stacji meteorologicznej w Łazach na Pogórzu Wielickim w okresie od 1 kwietnia 1994 do 31 marca 1995 r. pobierano wody opadowe (sumy dobowe), w których mierzono stężenia metali ciężkich (cynk, ołów, kadm, miedź i mangan). Dla każdej dobowej sumy opadu atmosferycznego ustalono typ sytuacji synoptycznej, przy której wystąpił opad. Porównanie średnich wielkości koncentracji i depozycji metali w różnych sytuacjach synoptycznych wskazuje na istotny wpływ rodzaju układu barycznego (cyklonalnego, antycyklonalnego) na zawartość metali ciężkich w wodzie opadowej. Wielkość depozycji metali ciężkich zależy w dużym stopniu od sytuacji synoptycznej (Bc i Cc), która charakteryzuje się zmienną adwekcją mas powietrza, w związku z przemieszczaniem się frontów atmosferycznych.