PRACE GEOGRAFICZNE, zeszyt 126

Instytut Geografii i Gospodarki Przestrzennej UJ
Kraków 2011, 67–84

Zuzanna Bielec-Bąkowska, Grażyna Knozová, Mieczysław Leśniok, Dorota Matuszko, Katarzyna Piotrowicz

HIGH SUSPENDED DUST CONCENTRATIONS IN BRNO, SOSNOWIEC AND KRAKOW (THE YEAR 2009 AS AN EXAMPLE)

Abstract: The paper presents a description of synoptical and meteorological conditions on days with the highest suspended dust concentrations in three Central European cities (Brno, Sosnowiec and Krakow). The study was based on daily PM_{10} dust concentration records, selected weather data and calendars of types of synoptic situation (by T. Niedźwiedź and by the Czech Hydrometeorological Institute) for the year 2009. The highest PM_{10} concentrations were found to coincide with similar synoptic situations and weather conditions in all three cities. The fact that pollution norms were exceeded most frequently in Krakow, followed by Sosnowiec and Brno, suggests a local impact.

Key words: air pollution, air quality status, PM_{10}, Central Europe, urban areas, atmospheric circulation, anthropogenic factors
Słowa kluczowe: zanieczyszczenie powietrza, stan aerosanitarny, PM_{10}, Europa Środkowa, tereny zurbanizowane, cyrkulacja atmosferyczna, czynniki antropogeniczne

Introduction

In recent years, high concentrations of suspended dust and ground level ozone pollution were the most significant air pollution problems in European urban areas (Peters *et al*. 2000, Harrison 2004; Glorennec, Monroux 2007). The principal sources of dust in the air in urban areas include emissions from industrial sites (point emissions), residential areas (area emissions) and traffic (linear emissions). Reemission is also a considerable source of dust and is estimated at approximately 40–60% of total emissions. The formation of secondary gas particles around gas precursors (sulphur and nitrogen crystals, VOC) completes the list of significant gas pollution sources. Urban areas differ in their structures of PM_{10} dust pollution sources: the Upper Silesian conurbation receives most of this class of pollution from municipal sources (Fudała *et al.* 2007), while transport dominates in Brno (Skeřil *et al.* 2009). A review of dust emission trends in Central Europe suggests that after a drop in industrial emissions recorded in the 1990s (Adamec *et al.* 2006, *Raport...* 2010, Váňa *et al.* 2008), over the past decade there has been a clear increase in the total amount of dust suspended in the urban atmosphere (Bokwa 2007, Adamec 2008). This has been caused by increased numbers of cars and the related traffic emissions.

Emissions may be the decisive factor in the occurrence of pollution, but the actual concentration (immission) also depends on the conditions of the geographic environment, and especially on weather conditions (Bokwa 2010, Walczewski *et al.* 2000), including:

– wind causing the horizontal ventilation effect and removing pollution from the emission source;
– the intensity and extent of vertical mixing that is responsible for the vertical ventilation effect;
– precipitation that washes away dust from the atmosphere;
– the type of atmospheric stability; a stable stratification means a deterioration of ventilation conditions, while an instability improves it;
– air temperature, which has an indirect influence on air quality; the higher the temperature, the greater the free convection and vertical mixing effect; low temperatures in wintertime lead to a higher dust pollution from a greater consumption of heating fuels.

Local communities would benefit from air pollution forecasts and early warning systems, but the number of inputs (including weather conditions, land relief, type of development, etc.) required for running physical models (Burzyński 2002) makes forecasting high pollution concentrations exceedingly complex. To address this complexity a number of ways have been devised to predict air pollution and identify the possibility of air pollution alert and nearly each European country has its own air quality indicator. Examples include an indicator of meteorological conditions for pollution dispersion developed in Krakow (Feleksy-Bielak *et al.* 2004), the air quality (AQ) forecast method in use in the Upper Silesian conurbation, or the comprehensive air quality index (AQI) method based on a number of methods of data mining (*Indeks jakości powietrza AQI* 2010). It is, however, often necessary to compare air pollution regional data. Hence the need to devise universal indexes. One of these is the Common Air Quality Index (CAQI), which utilises various methods of assessing air pollution based on the "difference to target" method (Van den Elshout, Léger 2007).

The issues concerning the impact of synoptic situations and meteorological conditions on pollution concentrations has been dealt with in numerous works. The most important ones include:

– Łobocki *et al.* (2008), describing the results of modelling of the temperature field and wind velocity in Krakow during a PM_{10} smog episode,
– Leśniok and Caputa (2009) and Leśniok *et al.* (2010), in which the authors analyse the types of circulation favouring air pollution concentration or dispersion in the Silesian conurbation,

– Hrdličkova *et al.* (2008) concerning the forecasting of the mean daily PM_{10} concentration using the CALM autoregressive model.

The objective of this study was to describe and compare synoptic situations and weather conditions on days with particularly high suspended dust concentrations (PM_{10}) in three Central European urban areas: Brno, Sosnowiec and Krakow. The central research question is whether the maximum dust concentrations are essentially caused by local factors or by the types of air circulation. This study is of a preliminary nature and probes the topic at various spatial scales. Its results could be useful in modifying or refining methods of assessing air quality at local, regional and inter-regional scales.

Study area

Both of the Polish cities, i.e. Krakow and Sosnowiec, are located within the Silesia-Krakow Upland in the south of the country. The Krakow agglomeration and the Upper Silesian Industrial Region around Sosnowiec also rank among the areas most polluted by suspended dust in Central Europe. Indeed, a high concentration of various emission sources causes PM_{10} pollution allowed values to be quite frequently exceeded. Both cities also suffer from unfavourable ventilation conditions that contribute to poor air quality. In the Upper Silesia the primary adverse factor is the roughness of the built-up area, which hinders and modifies air flow, while Krakow is located within the River Wisla valley that is particularly prone to temperature inversions. Analyzing particularly high PM_{10} episodes which occurred in both these agglomerations a big coincidence in their timing can be noticed. It would suggest causes at a greater than local scale. This poses the obligatory question as to whether these factors are limited to the investigated region, or whether they also encompass a larger portion of Central Europe. A preliminary investigation of these factors can be performed through a comparative analysis of conditions that accompanied episodes of high dust concentration in the Silesia–Krakow region with a more distant urban area. The city of Brno in the Czech Republic was selected for this purpose; it is located to the south-east of the Moravian Gate at the boundary of the Czech Massif and the Western Carpathian Mountains, some 250 kilometres from the Silesian conurbation (Fig. 1).

The three urban areas differ in terms of size and geographic environment (Fig. 1). The largest of them, known as the Upper Silesian conurbation, is represented by Sosnowiec (Table 1). The city alone is the smallest of the three cities in terms of both its population (221 thousand; *Central Statistical Office* 2010) and area. The Krakow agglomeration is somewhat smaller than the Silesian conurbation (ca. 1.5 million) and is represented here by the city of Krakow with more than 750 thousand inhabitants. The Brno agglomeration is the smallest of the three (at 370 thousand) and also stands out with a more varied land relief than the other two and a sizable proportion of forests in the overall land use structure (28%) (Table 1). The three cities are located at a similar altitude above sea level, but differ in their climate because of the impact of dividing mountain ranges and land relief. Sosnowiec and Krakow have a typical transitional climate of the temperate zone, while Brno, with its more southern location and lower altitude, has smaller total precipitation.

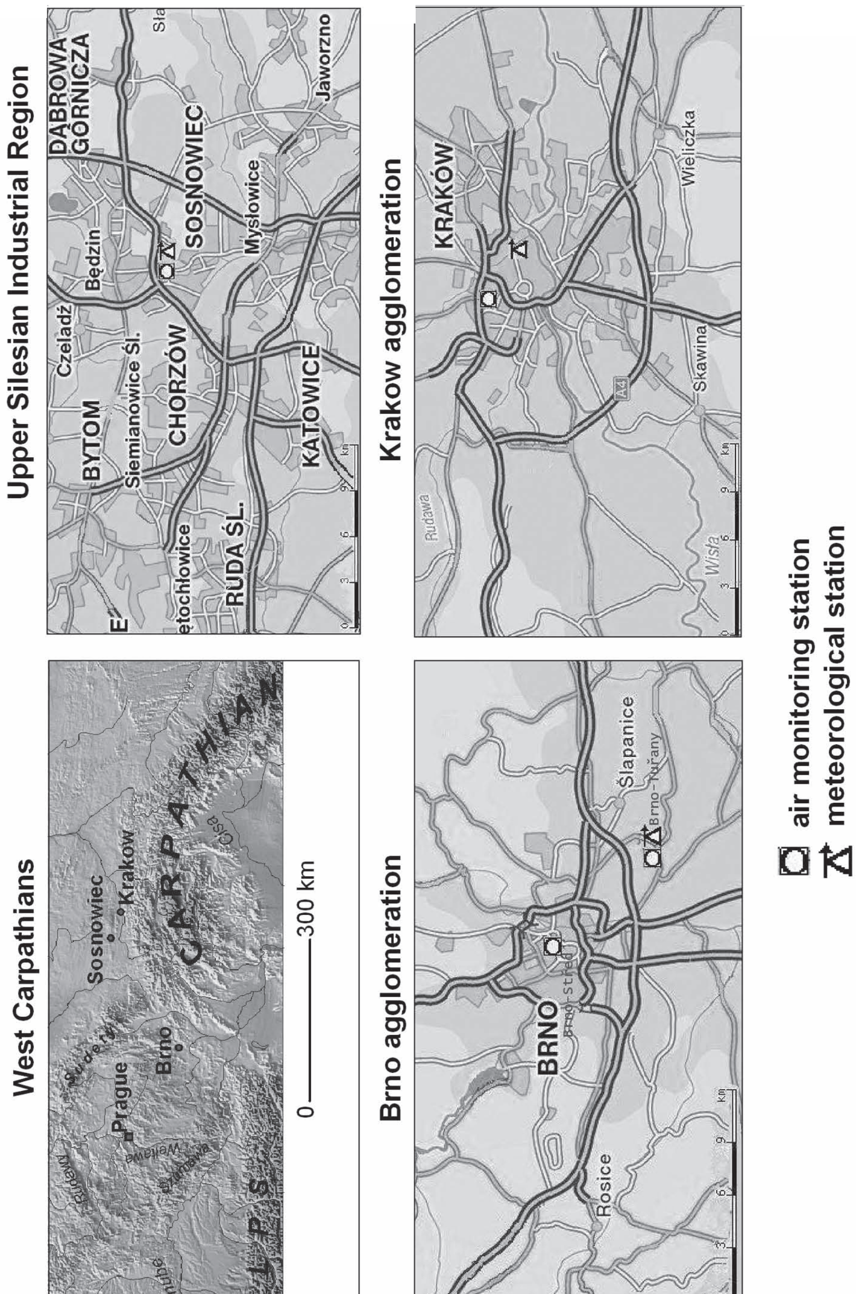

Fig. 1. Location of air monitoring and meteorological stations used in the study

Ryc. 1. Lokalizacja stacji monitoringu zanieczyszczeń powietrza i stacji meteorologicznych wykorzystanych w opracowaniu

Table 1. Chosen characteristics of the investigated urban areas
Tab. 1. Wybrane charakterystyki badanych obszarów miejskich

Parameters	Brno	Sosnowiec	Krakow
Population: city *agglomeration*	371 399 (2009)[1] *571 386 (2009)*[1]	221 259 (2009)[3] *2 226 300 (2006)*[4]	754 624 (2009)[3] *1 467 000 (2009)*[3]
Area [km^2]	230.2[1]	91.1[3]	326.8[3]
Forest [% of the area]	28.0[1]	21.6[3]	4.4[3]
Altitude [m a.s.l.]	190.0	250.0	220.0
Average annual air temperature [°C]	8.7[2]	8.6[5]	8.7[7]
Annual sum of precipitation [mm]	490.4[2]	721.0[6]	670.0[7]

[1] Czech Statistical Office (http://www.czso.cz)
[2] Average from 1961–1990, CHMI
[3] Central Statistical Office (http://www.stat.gov.pl/gus)
[4] Statistical Office in Katowice (http://www.stat.gov.pl/katow)
[5] Average from 1971–2000, Meteorological Station of the Department of Climatology, University of Silesia
[6] Absalon *et al.* (2001)
[7] Average from 1901–2000, Research Station of the Department of Climatology, Jagiellonian University.

Data and method

The study employed daily PM_{10} dust concentration records, selected weather data, atmospheric circulation typology and synoptic maps to search for a relationship between air pollution and meteorological conditions in 2009.

The data about PM_{10} came from automatic air monitoring stations in all three cities, and specifically from the Silesian University's (SU) station in Sosnowiec, a station of the National Air Quality Monitoring System (NAQMS) in Krakow-Krowodrza under the management of the Regional Environmental Protection Inspection and a station of the Automatic Immission Monitoring System in Brno-Stred managed by the Czech Hydrometeorological Institute (CHMI). All three stations use comparable methods of PM_{10} measurement. The average daily concentration values were calculated from hourly records. Concentrations of dust particles with the aerodynamic diameter of 10 µm or less (PM_{10}) are measured either with the weight fractioning method (*Raport...* 2010) or with the radiometric method (CHMI). Additionally, to estimate the role of the volume of pollution emissions and of weather conditions in the occurrence of high concentrations of suspended dust particles another Czech station in Brno-Turany was also included (Fig. 1). The latter station (also managed by CHMI) is located on the outskirts of Brno outside the direct impact of the city's largest emission sources.

The weather elements selected for the study included air temperature, relative humidity, insolation, total precipitation and wind speed. Their daily values were obtained from the weather stations of the Silesian University (Sosnowiec) and Jagiellonian University (Krakow) and from the CHMI stations (Brno). Two typologies of synoptic situations were used, including a calendar of synoptic situation types in the upper River Wisla basin by T. Niedźwiedź (2010) and the CHMI circulation type calendar (Brádka *et al.* 1961). Synoptic maps from the UK's MetOffice (National

Weather Service; www.metoffice.gov.uk) and the Deutscher Wetterdiest Offenbach (DWD; www.wetter3.de) were also used.

In the study only those days when PM_{10} concentration was greater than 50 $\mu g \cdot m^{-3}$ were considered. It is the threshold value of the average daily permissible concentration of suspended dust in the European Union, 200 $\mu g \cdot m^{-3}$ is the alert threshold, while the average permissible annual PM_{10} concentration is 40 $\mu g \cdot m^{-3}$ (http://ec.europa.eu/environment/air/quality/standards.htm). The next step was to find which synoptic situations were most frequently accompanied by high PM_{10} concentrations and a detailed synoptic analysis was performed for the days with the highest recorded concentrations.

High suspended dust concentrations at selected stations

Throughout 2009, the average annual concentration of suspended dust ranged from 27.7 $\mu g \cdot m^{-3}$ at Brno-Turany to 55.5 $\mu g \cdot m^{-3}$ in Krakow. However, on 162 days at least one of the three stations recorded average daily concentration of suspended dust higher than 50 $\mu g \cdot m^{-3}$ (163 days if the out-of-town Brno-Turany station is taken into account). Krakow had the largest number of days when the allowed values were exceeded with 148 days, followed by Sosnowiec with 108 days, Brno-Stred with just 57 and Brno-Turany with 28 days (Table 2). It is worth to mention that in winter

Table 2. Chosen characteristics of the suspended dust PM_{10} concentration at the selected stations in 2009

Tab. 2. Wybrane charakterystyki stężenia pyłu zawieszonego PM_{10} w powietrzu na wybranych stacjach w 2009 roku

Index		Brno-Turany	Brno-Stred	Sosnowiec	Krakow
Number of days without data		1	6	5	4
Concentration of PM_{10} $\mu g \cdot m^{-3}$	minimum	5.6	9.8	6.1	14.0
	average	27.7	35.8	48.3	55.5
	maximum	144.2	122.7	214.5	250.0
Number of days with concentration of PM_{10}>50 $\mu g \cdot m^{-3}$		28	57	108	148
Number of days with particular value of concentration of PM_{10}					
≤25 $\mu g \cdot m^{-3}$	≤50% of norm	206	94	79	61
25<x≤37.8	50<x≤75% of norm	94	138	106	94
37.5<x≤ 50.0	<75x≤100% of norm	36	70	67	58
>50.0	> norm	28	57	108	148
>100.0 $\mu g \cdot m^{-3}$	>100.0%	3	4	31	43
Share [%] of days with particular value of concentration of PM_{10}					
≤25 $\mu g \cdot m^{-3}$	50% of norm	56.6	26.2	21.9	16.9
25<x≤37.8	50<x≤75% of norm	25.8	38.4	29.4	26.0
37.5<x≤ 50.0	<75x≤100% of norm	9.9	19.5	18.6	16.1
>50.0	> norm	7.7	15.9	30.0	41.0
>100.0 $\mu g \cdot m^{-3}$	>100.0%	0.8	1.1	8.6	11.9

the PM_{10} concentration in Krakow remains permanently at 90 to 100 μg·m^{-3} and exceeds the permissible daily value on nearly every single day of the season.

The highest concentrations were recorded at the two Polish stations. In Krakow there were four days when the concentration exceeded 200 μg·m^{-3} and it peaked at 250 μg·m^{-3} on 13th January. Sosnowiec exceeded this alert threshold three times. In Brno the highest concentration was recorded at the out-of-town station (144 μg·m^{-3}) in contrast to the main station at Brno-Stred (122 μg·m^{-3}). When the concentrations on days within the threshold value exceeded are analysed, it is clear that the concentrations in Brno are quite low (at ≤75% of the norm on 82.4% of days at Brno-Turany and on 64.6% of days at Brno-Stred), while the Polish stations typically recorded values close to the allowed values or above it (>75% of the norm on 48.6% days in Sosnowiec and on 57.1% days in Krakow) (Table 2).

When looking at days when the permissible value was exceeded at least at one of the three urban stations (Brno-Stred, Sosnowiec and Krakow-Krowodrza), it was found that this occurred most frequently at two stations on the same day (45.1% of all days) and mostly involved Sosnowiec and Krakow (Table 3). The norm was exceeded at all three stations on 24.1% of days (on some of those days the Brno-Turany station also recorded excess concentrations). Because of the increased pollution emissions during the heating season, a majority of the high concentration days were recorded during the cold half of the year, from November to April, at 79.6% days (Table 3). The highest monthly scores were recorded in January (27 days) and in November and December (25 each). These three months combined accounted for 47.5% of all days

Table 3. Number of days in 2009 when the suspended dust (PM_{10}) concentration exceeded 50 μg·m^{-3} at least at one of the three urban stations: Brno-Stred, Sosnowiec and Krakow

Tab. 3. Liczba dni w 2009 roku, w których stężenie pyłu zawieszonego PM_{10} przekraczało 50 μg·m^{-3} przynajmniej na jednej ze stacji: Brno-Stred, Sosnowiec i Kraków

Month	Stations			Sum	Frequency [%]
	1 station	2 stations	3 stations		
January	3	12	12	27	16.7
February	3	11	3	17	10.5
March	9	6	2	17	10.5
April	7	4	7	18	11.1
May	1	-	-	1	0.6
June	-	-	-	-	-
July	-	2	-	2	1.2
August	5	-	-	5	3.1
September	6	6	1	13	8.0
October	3	6	3	12	7.4
November	7	12	6	25	15.3
December	6	14	5	25	15.4
Sum	50	73	39	162	100.0
%	30.9	45.1	24.1	100.0	-

with a concentration in excess of 50 μg·m^{-3}. Analysing the four days with the highest concentrations of suspended dust at each of the stations it was noticed that most of these cases occurred around the 10th January in the form of sequences of days with very high dust concentrations (Table 4). This would suggest that a synoptic situation prevailing during that period was particularly conducive to dust concentrations in the area.

Table 4. Four highest values of the suspended dust (PM_{10}) concentration at the particular stations in 2009

Tab. 4. Cztery najwyższe wartości stężenia pyłu zawieszonego PM_{10} na poszczególnych stacjach w roku 2009

Month	Day	Concentration of PM_{10} [μg·m^{-3}]	Number of stations at which concentration of PM_{10}>50μg·m^{-3}, when the considered number of station was:	
			3 stations	4 stations
Brno-Turany				
January	15	144.2	3	4
January	11	117.8	3	4
December	19	113.4	3	4
January	10	99.9	3	4
Brno-Stred				
January	11	116.9	3	4
January	15	120.3	3	4
January	10	122.7	3	4
January	14	103.6	3	4
Sosnowiec				
February	4	214.5	2	2
January	14	201.9	3	4
January	12	200.7	3	4
December	27	194.8	2	2
Krakow				
January	13	250.0	3	4
January	12	238.0	3	4
January	14	232.0	3	4
March	3	209.0	3	4

High dust concentrations vs. synoptic situations

The first step in the investigation of the relationship between high PM_{10} dust concentrations and synoptic situations involved an identification of synoptic situation types recorded on days with concentrations exceeding the allowed values. To accomplish this, frequencies of such days were compared with synoptic situation types using two classifications, i.e. by T. Niedźwiedź and by the CHMI. When compared to the former classification, it was found that there was a slightly higher number of days with concentrations above 50 µg·m^{-3} during anticyclonic situations (Table 5). This effect was the most pronounced in Brno, at 63.2–67.9% of all days considered, while in Sosnowiec and Krakow it was only slightly greater than 50% (at 55.6% and 51.4%, respectively). When the study included all days when at least one station recorded the value exceeding the allowed threshold, the anticyclonic pattern domination was only confirmed in relation to days with high concentrations at the three stations (at 69.2%). Five synoptic situations of the situation types recorded in 2009 stood out: Wa, Ka, Sc, SWc and Bc (Table 5). Other studies of the influence of synoptic situations on the long-term occurrence of high PM_{10} concentrations in the Upper Silesian Industrial Region, using the classification system by T. Niedźwiedź, did confirm a significant role of the Wa and Ka types, but attributed an even greater role to the SWa, Ca and Sa types (Leśniok, Caputa 2009).

Table 5. Number of days when the suspended dust (PM_{10}) concentration exceeded 50 µg·m^{-3} in each type of synoptic situations according to T. Niedźwiedź (2009)

Tab. 5. Liczba dni w 2009 roku ze stężeniem pyłu zawieszonego (PM_{10}) powyżej 50 µg·m^{-3} w poszczególnych typach sytuacji synoptycznych według klasyfikacji T. Niedźwiedzia

Synoptic situation	At individual stations				When during one day the norm was exceeded at			Sum
	Brno-Turany	Brno-Stred	Sosnowiec	Krakow	1 station	2 stations	3 stations	
Na	2	1	1	4	2	2	-	4
NEa	0	0	0	2	2	-	-	2
Ea	0	1	3	3	3	2	-	5
SEa	1	3	3	6	2	2	2	6
Sa	1	2	5	5	5	2	1	8
SWa	0	3	4	4	1	2	2	5
Wa	5	9	10	14	5	2	8	15
NWa	4	4	3	7	2	3	2	7
Ca	0	1	1	1	-	-	1	1
Ka	6	12	30	30	3	18	11	32
Nc	0	0	0	2	2	-	-	2
NEc	0	0	2	2	-	2	-	2
Ec	2	3	1	4	2	3	-	5
SEc	1	2	5	5	-	3	2	5
Sc	1	3	8	11	4	6	2	12
SWc	2	5	13	16	3	8	5	16
Wc	0	1	0	3	2	1	-	3
NWc	0	1	0	1	2	-	-	2
Cc	0	0	0	0	-	-	-	-
Bc	0	3	12	19	9	11	1	21
x	3	3	7	9	1	6	2	9
Sum	28	57	108	148	50	73	39	162
anticyclonic	19	36	60	76	25	33	27	85
%	67.9	63.2	55.6	51.4	50.0	45.2	69.2	52.5
cyclonic	6	18	41	63	24	34	10	68
%	21.4	31.6	38.0	42.6	48.0	46.6	25.6	42.0

Explanations: N – situations with an advection of air masses from the north, NE – from the northeast *etc.*, a – anticyclonic situation, c – cyclonic situation, Ca – central anticyclonic situation, lack of advection, centre of high pressure, Ka – anticyclonic wedge, Cc – central cyclonic situation, centre of low pressure, Bc – cyclonic trough, x – cols and situations which cannot be classified.

Objaśnienia: N – sytuacje z adwekcją mas powietrza z północy, NE – z północnego-wschodu *etc.*, a – sytuacja antycyklonalna, c – sytuacja cyklonalna, Ca – sytuacja centralna antycyklonalna, brak adwekcji, centrum wyżu, Ka – klin antycyklonalny, Cc – sytuacja centralna cyklonalna, centrum niżu, Bc – bruzda cyklonalna, x – sytuacje nie dające się zaklasyfikować.

According to the Czech classification, cyclonic situation types are the most significant. At the Brno stations these situations accounted for 57.1 and 59.6% days, while in Sosnowiec and Krakow they accounted for 71.3 and 73.0%. The four types that were the most frequent here included: Bp, Ec, SWc2 and Wcs (Table 6). The predominance of cyclonic situations is even clearer when looking at days when dust concentration exceeded the 50 μg·m^{-3} threshold in at least one of the three stations (Table 6). These results from 2009 are not confirmed by studies relying on

Table 6. Number of days in 2009 when the suspended dust (PM_{10}) concentration exceeded 50 μg·m^{-3} in each type of synoptic situations according to CHMI

Tab. 6. Liczba dni w 2009 roku ze stężeniem pyłu zawieszonego (PM_{10}) powyżej 50 μg·m^{-3} w poszczególnych typach sytuacji synoptycznych według klasyfikacji CHMI

Synoptic situation	At particular stations				When during one day the norm was exceeded at			Sum
	Brno-Turany	Brno-Stred	Sosnowiec	Krakow	1 station	2 stations	3 stations	
A	3	6	6	9	1	4	4	9
Ap1	3	4	7	8	-	5	3	8
Ap2	0	1	3	3	-	2	1	3
Ap4	1	1	0	1	-	1	-	1
B	0	0	4	5	1	4	-	5
Bp	4	9	20	21	5	9	9	23
Cv	0	0	0	1	1	-	-	1
Ea	0	1	0	1	-	1	-	1
Ec	4	6	7	11	4	7	2	13
Nc	2	3	3	5	2	3	1	6
NEa	2	2	2	3	2	1	1	4
NEc	0	0	2	5	3	2	-	5
NWc	2	3	7	12	5	4	3	12
Sa	0	0	0	1	1	-	-	1
SEa	0	0	0	2	2	-	-	2
SEc	1	2	1	4	3	2	-	5
SWa	3	6	4	6	2	1	4	7
SWc1	0	2	4	6	3	3	1	7
SWc2	1	3	7	12	5	4	3	12
SWc3	0	1	3	3	-	2	1	3
Vfz	0	1	8	9	1	7	1	9
Wa	0	1	6	6	-	5	1	6
Wal	0	1	3	0	4	-	-	4
Wc	0	0	2	3	3	1	-	4
Wcs	2	4	9	11	2	5	4	11
Sum	28	57	108	148	50	73	39	162
anticyclonic	12	23	31	40	12	20	14	46
%	42.9	40.4	28.7	27.0	24.0	27.4	35.9	28.4
cyclonic	16	34	77	108	38	53	25	116
%	57.1	59.6	71.3	73.0	76.0	72.6	64.1	71.6

Explanations: N – situations with an advection of air masses from the north, NE – from the northeast *etc.*, a – anticyclonic situation, c – cyclonic situation, 1, 2, 3, 4 – number type of the situation, A – central anticyclonic situation, centre of high pressure, Ap – travelling central anticyclonic situation, C – central cyclonic situation, centre of low pressure, Cv – elevated central cyclonic situation, B – cyclonic trough, Bp – travelling cyclonic trough, Wcs – west cyclonic situation with south way, Wal – west anticyclonic situation summer type, Vfz – enterway of frontal zone.

Objaśnienia: N – sytuacje z adwekcją mas powietrza z północy, NE – z północnego-wschodu *etc.*, a – sytuacja antycyklonalna, c – sytuacja cyklonalna, 1, 2, 3, 4 – numer typu sytuacji, A – sytuacja centralna antycyklonalna, centrum wyżu, Ap – sytuacja centralna antycyklonalna przemieszczająca się, C – sytuacja centralna cyklonalna, centrum niżu, Cv – sytuacja górna cyklonalna, B – bruzda cyklonalna, Bp – bruzda cyklonalna przemieszczająca się, Wcs – sytuacja zachodnia cyklonalna ukierunkowana południowo, Wal – sytuacja zachodnia antycyklonalna typu letniego, Vfz – wejście strefy frontalnej.

long data sequences. Indeed, the Czech classification system itself cites the central anticyclonic situation and anticyclonic situations with the eastern, southwestern and southern advection, as those most favourable for high PM_{10} concentrations (Blažek *et al.* 2008; Knozová, Hora 2010).

This difference between the results obtained using the two classification systems can be attributed to two causes. The first involves the slightly different assumptions made when designing the two systems while the second is linked to the area for which the classifications were originally designed. Nevertheless, the descriptions of selected synoptic situations favourable to the occurrence of the highest PM_{10} concentrations at the individual stations given below reveal significant similarities between the two areas. This would suggest that building a single classification for a region covering adjacent areas of Poland, the Czech Republic and Slovakia might be worth considering.

In 2009, there were 39 days when the PM_{10} concentration exceeded the allowed value at all three stations:

- 12 in January;
- 3 in February,
- 2 in March,
- 7 in April,
- 1 in September,
- 3 in October,
- 6 in November,
- 5 in December (Table 7).

Following the analysis of synoptic maps and the two classification systems of atmospheric circulation types, a conclusion can be drawn that the days considered mostly coincided with anticyclonic situations or situations with either southern or eastern advection. High concentrations would most frequently begin in Krakow, followed by Sosnowiec and finally Brno. This could be attributed to local conditions, and in particular the location of Krakow in the River Wisla valley. On 19 of these days, high concentrations (>50 $\mu g \cdot m^{-3}$) were also recorded at the Brno-Turany station.

In January, pollution values were not only the highest, but PM_{10} concentrations exceeding the allowed values were recorded on every day of the month except last four. Between January 4th and 27th, the allowed value was exceeded by a considerable amount at either two or three stations every day. During this period, anticyclonic situations dominated with a vast high pressure system over Central Europe. In February and March, concentrations exceeding the allowed values were much less frequently recorded, but the cyclonic influence markedly increased and the only day when a concentration exceeding the allowed values was recorded at all three stations coincided with a high pressure system over Central Europe. In Krakow and Sosnowiec high dust concentrations were also recorded in a SWc situation. April was also a month of note with high dust concentrations recorded at all three stations on seven consecutive days (3rd–9th April) at a time when a vast anticyclone system with the southern advection dominated over Europe. The unusually warm and sunny weather that lasted throughout this period was completely dry, initiating dust reemission from the drying ground (Knozová 2010). Another factor was the influx of polluted air from

Table 7. Number of days in selected months of 2009 when the suspended dust (PM_{10}) concentration exceeded 50 μg·m^{-3} at least at one of the three urban stations: Brno-Stred, Sosnowiec and Krakow (a detailed description was made for January, including also the Brno-Turany station)

Tab. 7. Liczba dni w wybranych miesiącach 2009 roku, w których stężenie pyłu zawieszonego PM_{10} przekraczało 50 μg·m^{-3} przynajmniej na jednej ze stacji: Brno-Stred, Sosnowiec i Kraków (bardziej szczegółowo potraktowano styczeń, uwzględniając również stację Brno-Turany)

Day	January				Month							
	Brno-Turany	Brno-Stred	Sosnowiec	Krakow	Jan.	Feb.	Mar.	Apr.	Sep.	Oct.	Nov.	Dec.
1	1	1	0	1	2	0	2	2	0	0	2	2
2	0	0	0	1	1	0	3	1	1	0	1	2
3	0	0	0	1	1	0	3	3	1	0	0	2
4	0	1	1	0	2	2	2	3	0	0	2	3
5	0	0	0	1	1	2	0	3	0	1	2	2
6	1	1	1	1	3	2	0	3	0	1	2	2
7	1	1	1	1	3	2	0	3	0	0	2	1
8	0	0	1	1	2	2	0	3	0	0	2	2
9	1	1	0	1	2	2	0	3	0	0	2	2
10	1	1	1	1	3	2	1	1	2	0	1	1
11	1	1	1	1	3	0	0	0	1	0	0	0
12	1	1	1	1	3	0	0	0	0	0	1	0
13	1	1	1	1	3	0	1	0	0	0	3	0
14	1	1	1	1	3	0	2	0	0	0	2	2
15	1	1	1	1	3	0	2	0	0	0	2	1
16	1	1	0	1	2	2	0	2	1	0	3	0
17	1	1	1	1	3	2	1	0	1	0	3	1
18	1	1	1	1	3	1	0	0	0	2	0	2
19	0	1	1	1	3	1	0	0	0	2	1	3
20	0	0	1	1	2	2	0	0	0	0	3	3
21	0	1	1	1	3	3	1	1	2	3	3	3
22	0	0	1	1	2	3	1	0	2	2	2	2
23	0	0	1	1	2	0	0	1	3	1	0	1
24	0	0	1	1	2	2	0	1	1	0	0	1
25	0	0	1	1	2	3	1	0	0	2	1	0
26	1	1	0	1	2	0	2	0	2	3	2	0
27	1	1	0	1	2	0	1	1	2	0	3	2
28	0	0	0	0	0	1	1	1	2	2	1	2
29	0	0	0	0	0	-	1	2	0	2	2	2
30	0	0	0	0	0	-	0	2	0	0	1	2
31	0	0	0	0	0	-	2	-	-	3	-	3
Number of days when concentration of PM_{10} >50 μg·m^{-3} at 3 stations					12	3	2	7	1	3	6	5

Explanations: 0 – concentration of PM_{10}≤50 μg·m^{-3}, 1 – concentration of PM_{10}>50 μg·m^{-3} at 1 station, 2 – concentration of PM_{10}>50 μg·m^{-3} at 2 stations, 3 – concentration of PM_{10}>50 μg·m^{-3} at 3 stations.

Objaśnienia: 0 – koncentracja PM_{10}≤50 μg·m^{-3}, 1 – koncentracja PM_{10}>50 μg·m^{-3} na jednej stacji, 2 – koncentracja PM_{10}>50 μg·m^{-3} na dwóch stacjach, 3 – koncentracja PM_{10}>50 μg·m^{-3} na trzech stacjach.

an eruption of Mt. Redoubt in Alaska on March 22nd over Europe. From then until the end of the summer season, occasions when dust pollution exceeded the allowed value were rare. High concentrations returned with a greater frequency in the last decade of September and in the second half of October, coinciding with anticyclone systems and the western and southern advection. In November, increased dust concentrations were recorded almost daily in Krakow and Sosnowiec. This happened again under anticyclonic conditions and/or the southern air advection. Pollution levels peaked during a six day spell when a strong and extensive high pressure system arrived from the south over Central Europe, and the three stations recorded values exceeding allowed. A similar situation repeated in December. Concentrations exceeded the allowed value most frequently in Krakow and Sosnowiec and this coincided with a wide range of synoptic situations, although often it was related to an advection from the south.

Highest suspended dust concentrations vs. weather conditions

When investigating the relationship between high suspended dust concentrations and weather conditions the latter were also analysed in terms of consistency across all the stations. Only four days were taken into account per station. These were the days when the highest suspended dust concentrations at each of them were recorded (Fig. 2). As it is provided in Table 4 most of the days analysed occured between 10th and 15th January. At Brno the values of PM_{10} concentration exceeded 100 µg·m^{-3}, which was more than values recorded on any other days of the year, with the exception of the records included in Table 4. In Sosnowiec and Krakow the highest concentrations recorded were about twice as high and all days with more than 200 µg·m^{-3} are listed in Table 4. It is worth to notice that on the same days the dust pollution allowed threshold (50 µg·m^{-3}) was exceeded at all the stations and these were typically the days with the highest PM_{10} concentrations at a given station. The Sosnowiec station was an exception as its highest PM_{10} concentrations were recorded on days when they stayed within the allowed range at Brno.

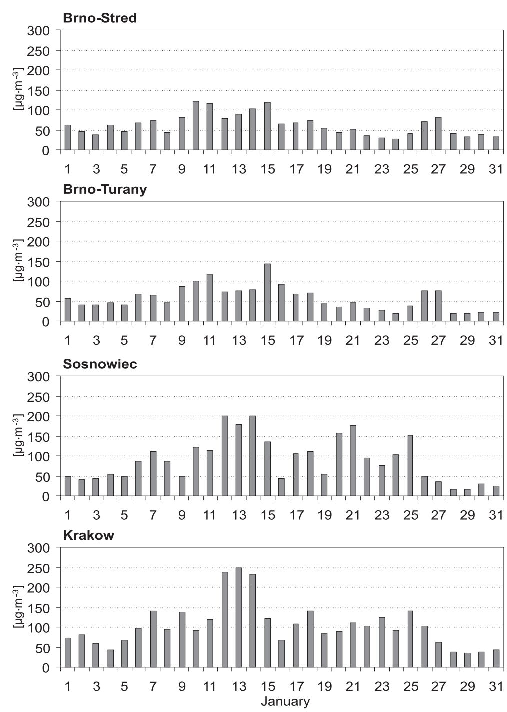

Fig. 2. Average daily concentration of suspended dust PM_{10} at the analyzed stations in January 2009

Ryc. 2. Średnie dobowe stężenie pyłu zawieszonego PM_{10} na analizowanych stacjach w styczniu 2009 roku

These high PM_{10} concentrations were linked to high-pressure systems that had influenced the weather over that part of Europe since the beginning of January. Between 10th and 15th January, a high pressure system centred on Central Europe caused an influx of old polar maritime air followed by polar continental air. During that period, all the stations recorded freezing weather types with a maximum temperature below 0°C and a minimum temperature between -5° and -15°C (Fig. 3). At Brno-Turany

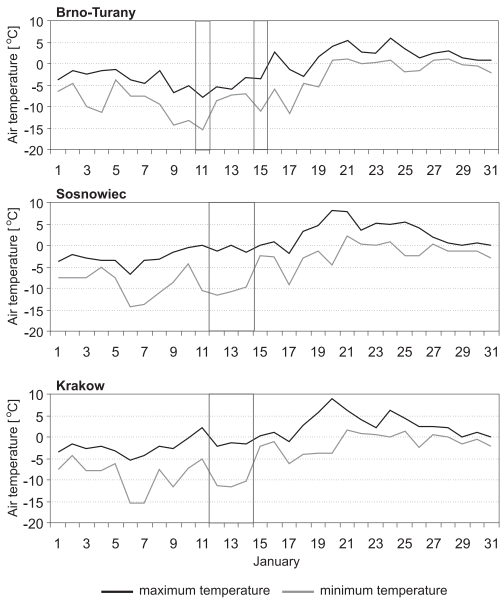

Fig. 3. Maximum and minimum air temperature at the analyzed stations in January 2009

Ryc. 3. Temperatura maksymalna i minimalna powietrza na analizowanych stacjach w styczniu 2009 roku

the weather was cloudy, while, apart from 14th January, it was sunny at Sosnowiec and Krakow. The pollutants there became more concentrated on account of a very weak wind (up to 2 m·s^{-1}), high air humidity (more than 70%) and a lack of precipitation (except the daily total of 0.7 mm at Sosnowiec on 14th January).

All of the other high concentration values recorded at the stations and listed in Table 4 occurred on different days. The first of these days was 4th February, when Sosnowiec recorded the highest concentration of the year at 214.5 μg·m^{-3}. The city was at the edge of a high pressure system centred on Russia that caused an influx of warm maritime polar air masses from the south west. The minimum temperature was below freezing on that day and the maximum temperature was 5°C. The cloud cover was complete, the relative humidity was 90%, but there was little wind and no precipitation. A high PM_{10} concentration was also recorded on 27th December, when a high pressure wedge was centred on the Black Sea and was accompanied by a maritime polar influx. For most of the day, the temperature remained below 0°C (down to -5.2°C), but it rose above that level and peaked in the early afternoon to 2.2°C. It was quite a sunny day with a high relative humidity (55–98%), very little wind and no precipitation. Similar conditions occurred in Krakow on 3rd March, and the dust concentration reached 209 μg·m^{-3}. On that day, Poland was at the edge of a weak high pressure system centred over the Ukraine with a system of atmospheric fronts travelling through the area investigated. Again, it was a frosty and cloudy day, humid, still, with fog and weak drizzle (0.3 mm in total). The last of the days was 19th December, when a considerable increase in dust concentration (more than 100 μg·m^{-3}) was recorded at Brno-Turany. Polar continental air was flowing from the south-east and a high pressure system was moving away towards the north east while a deep cyclone was building up over the Adriatic Sea. Similarly to the situation on 10th and 11th January, the weather was freezing, the cloud cover was continuous, and there was a weak wind and little snowfall (1.9 mm in total).

Certain patterns emerged from the comparison (Table 8). The weather conditions common to all stations included freezing temperatures for a part of or throughout the day and in most cases an overcast sky with a high humidity, and little wind, while

Table 8. Meteorological conditions during the days with exceptionally high suspended dust (PM_{10}) concentration at the analyzed stations in 2009

Tab. 8. Warunki meteorologiczne panujące podczas dni z wyjątkowo wysokim stężeniem pyłu zawieszonego PM_{10} na analizowanych stacjach w 2009 roku

Month	Day	Station	Weather type				
			Air temperature	Sky	Humidity	Precipitation	Wind
January	11–15	Brno-Turany	frost	cloudy	high	weak	moderate
		Sosnowiec	frost	sunny	moderate	weak	weak
		Krakow	frost	sunny	high	no precipitation	weak
December	19	Brno-Turany	frost	cloudy	high	weak	moderate
February	4	Sosnowiec	ground frost	cloudy	high	no precipitation	weak
December	27	Sosnowiec	ground frost	sunny	high	no precipitation	weak
March	3	Krakow	ground frost	cloudy	high (fog)	drizzle	calm

precipitation was either low or nonexistent. This type of weather typically occurred at the end of a period with a high pressure system that was on its way out.

Conclusions

The study was an attempt to analyse the synoptical and meteorological causes of particularly high suspended dust concentrations (PM_{10}) in three Central European urban areas (Brno, Sosnowiec and Krakow). The cities selected for the analyses differ in terms of their local geographical conditions, populations and degree of urbanisation. For this reason a degree of caution was exercised in making the comparison of concentrations and in interpreting the relationship with weather conditions. The assessment of the synoptic situations differed depending on whether it was performed using the classification system proposed by T. Niedźwiedź or by the Czech Hydrometeorological Institute. This called for an additional analysis of synoptic maps.

It was found that every case when the allowed value was considerably exceeded (up to and above 100 $\mu g \cdot m^{-3}$ in Brno and upwards of 200 $\mu g \cdot m^{-3}$ in Sosnowiec and Krakow) was accompanied by a similar synoptic situation and weather conditions, i.e. an anticyclonic situation with an advection from the south or east, frost or ground frost, the weather usually cloudy, with high humidity, a weak wind, without or with little precipitation.

It was observed that the highest PM_{10} dust concentrations occurred simultaneously at the three stations when Europe was under the influence of a vast and strong high pressure system, which suggests that they were caused by circulation factors operating at a scale greater than local. This is confirmed by the simultaneous occurrence of high suspended dust concentrations at the out-of-town station (Brno-Turany).

Mesoscale environmental conditions have an unquestionable influence on the occurrence of maximum pollution concentrations in each of the cities. A sequence was also found in the order in which the threshold value (PM_{10}>50 $\mu g \cdot m^{-3}$) was exceeded in each of them. These concentrations would always begin in Krakow, and were followed by Sosnowiec and Brno. Krakow is under a particularly clear influence of its location in the River Wisla valley making the city particularly sensitive and prone to high dust concentrations.

The research shows that there are similarities across the region in terms of weather conditions that are conducive to the occurrence of high dust concentrations. It seems that there is still a need for a more detailed verification of our results and checking whether they cover a larger area of Central Europe.

This study does not exhaust the subject of high PM_{10} dust concentration in Central European urban areas. It is just a methodological attempt intended to compare results and find out whether it might be possible to conduct joint Polish-Czech research into urban air quality. The analysis concluded that there was a need to develop a common calendar of atmospheric circulation types for the entire area taking into account circulation differences existing on both sides of the Carpathians and the Sudetes. There is also a need to refine the methods of forecasting alarm levels of pollution as well as to analyse the ways local authorities react to high concentrations of pollutants, e.g. imposing traffic restrictions.

Acknowledgment

This study was supported by a grant GAČR *Víceúrovňová analýza městského a příměstského klimatu na příkladu středně velkých měst* (*Multilevel analysis of the urban and suburban climate taking medium-sized towns as an example*) GA205/09/1297.

References

Absalon D., Jankowski A.T., Leśniok M., 2001, *Mapa Hydrograficzna M-34-63-A Katowice*, Główny Geodeta Kraju.

Adamec V., 2008, *Doprava, zdraví a životní prostředí*, Grada, Praha.

Adamec V., Hrubý O., Kurfürst J., Machálek P., Ostatnická J., Píša V., Pospíšilová J., Šolc J., 2006, *Kvalita ovzduší v Praze,* Ochrana Ovzduší, 12, 1–20.

Blažek, Z., Černikovský L., Krejčí B., Volná V., 2008, *Znečíštění ovzduší suspendovanými částicemi v oblasti ostravsko-karvinska*, Sborník prací Českého hydrometeorologického ústavu, 53.

Bokwa A., 2007, *Zanieczyszczenie powietrza*, [In:] D. Matuszko (ed.), *Klimat Krakowa w XX wieku*, IGiGP UJ, Kraków, 187–199.

Bokwa A., 2010, *Wieloletnie zmiany struktury mezoklimatu miasta na przykładzie Krakowa*, IGiGP UJ, Kraków.

Brádka J., Dřevikovský A., Gregor Z., Kolesár J., 1961, *Počasí na území Čech a Moravy v typických povětrnostních situacích*, HMÚ, Praha.

Burzyński J., 2002, *Przegląd zastosowań modelu CALMET/CALPUFF na obszarze województwa małopolskiego,* Wiadomości IMGW, 15(44), 3, 67–74.

Central Statistical Office, 2010, http://www.stat.gov.pl/gus.

Czech Statistical Office, 2010, http://www.czso.cz.

Feleksy-Bielak M., Tomaszewska A.M., Walczewski J., 2004, *Wskaźniki meteorologicznych warunków dyspersji zanieczyszczeń powietrza na stacji Kraków-Czyżyny dla lat 2000–2002*, Wiadomości IMGW, 27 (48), 1, 13–20.

Fudała J., Hławiczka S., Cenowski M., 2007, *Zmienność emisji zanieczyszczeń do powietrza atmosferycznego z terenu województwa śląskiego w latach 2001–2005 dla potrzeb analizy* *zmienności stężeń pyłu zawieszonego PM_{10}, dwutlenku siarki, dwutlenku azotu, tlenku węgla i ozonu*, [In:] J. Jamrocha (ed.), *Ocena jakości powietrza w województwie śląskim w latach 2002–2006*, WIOŚ, Katowice, 56–76.

Glorennec P., Monroux F., 2007, *Health impact assessment of PM_{10} exposure in the city of Caen, France*, Journal of Toxicology and Environmental Health, Part A, 70, 359–364.

Harrison R.M., 2004, *Key pollutants–airborne particles*, Science of the Total Environment, 334–335, 3–8.

Hrdličková Z., Michálek J., Kolář M., Veselý V., 2008, *Identification of Factors Affecting Air Pollution by Dust Aerosol PM_{10} in Brno City, Czech Republic*, Atmospheric Environment, 42 (37), 8661–8673.

Indeks jakości powietrza AQI, http://spjp.katowice.pios.gov.pl/aqi.aspx (z dnia 21.05.2010)

Knozová G., 2010, *Meteorologické příčiny zvýšených koncentrací znečištění ovzduší PM_{10} v Brně*, [In:] V. Kožnarová, S. Sulovska (eds.), *Bioklima 2010, Sborník příspěvků s mezinárodní konference*, Česká zemědělská univerzita v Praze, Praha, 151–159.

Knozová G., Hora P., 2010, *Vyhodnoceni meteorologických podmínek doprovázejících smogové epizody v České republice*, Meteorologické Zprávy, 63, 21–28.

Leśniok M.R., Caputa Z.A., 2009, *The role of atmospheric circulation in air pollution in Katowice Region (Sourthen Poland)*, International Journal Environment and Waste Management, 4, 1/2, 62–74.

Leśniok M., Małarzewski Ł., Niedźwiedź T., 2010, *Classification of circulation types for Southern Poland with an application to air pollution concentration in Upper Silesia*, Physics and Chemistry of the Earth, Parts A/B/C, 35 (9–12), 516–522.

Łobocki L., Kamiński J. W., Zdunek M., Strużewska J., 2008, *Modelowanie warunków meteorologicznych w eksperymencie „Kraków integrated methodology project – from toxic emissions to health effects“*, [In:] K. Kłysik, J. Wibig, K. Fortuniak (eds.), *Klimat i bioklimat miast*, Wydawnictwo Uniwersytetu Łódzkiego, Łódź, 279–287.

Niedźwiedź T., 2010, *Kalendarz typów cyrkulacji atmosfery dla Polski południowej*, Zbiór komputerowy, Uniwersytet Śląski, Katedra Klimatologii, Sosnowiec.

Peters A., Skorkovsky J., Kotesovec F., Brynda J., Spix C., Wichmann H. E., Heinrich J., 2000, *Associations between mortality and air pollution in Central Europe*, Environmental Health Perspectives, 108, 4, 283–287.

Raport o stanie środowiska w województwie małopolskim w 2009 roku, 2010, Biblioteka Monitoringu Środowiska, WIOŚ, Kraków.

Skeřil R., Elfenbein Z., Rožnovský J., 2009, *Pozaďové koncentrace částic na území města Brna*, [In:] R. Kostrhounová (ed.), *Ovzduší 2009*, Masarykova univerzita, Brno, 57–61.

Statistical Office in Katowice, 2010, http://www.stat.gov.pl/katow.

Van den Elshout S., Léger K., 2007, *Comparing Urban Air Quality Across Borders. A review of existing air quality indices and the proposal of a common alternative,* http://citeair.rec.org/downloads/Products/ComparingUrbanAirQualityAcrossBorders.pdf (21.05.2010).

Váňa M., Pekárek J., Čech J., Macoun J, Ostatnická J., Horálek J., Rychlík Š., 2008, *Trendy suspendovaných částic v ovzduší v České republice*, Ochrana ovzduší, 1, 26–30.

Walczewski J., Feleksy-Bielak M., Dębicka K., Śliwińska U., 2000, *Wskaźniki meteorologicznych warunków dyspersji zanieczyszczeń powietrza i ich zmienność w Krakowie w latach 1990-1999*, Wiadomości IMGW, 23, 3,13–27.

Wysokie stężenia pyłu zawieszonego w Brnie, Sosnowcu i Krakowie na przykładzie 2009 roku

Streszczenie

W opracowaniu przedstawiono charakterystykę warunków synoptycznych i meteorologicznych dni z najwyższym stężeniem pyłu zawieszonego PM_{10} w trzech aglomeracjach Europy Środkowej (w Brnie, Sosnowcu i Krakowie). Wykorzystano dane pochodzące z 2009 roku: średnie dobowe stężenia pyłu PM_{10}, dobowe wartości wybranych elementów meteorologicznych oraz kalendarze typów sytuacji synoptycznych T. Niedźwiedzia i Czeskiego Instytutu Hydrometeorologicznego. W wyniku przeprowadzonej analizy stwierdzono, że we wszystkich rozpatrywanych miastach najwyższym stężeniom pyłu PM_{10} towarzyszyły podobne sytuacje synoptyczne i warunki meteorologiczne. Zauważono, że przekroczenie normy zanieczyszczeń najczęściej i najwcześniej występuje w Krakowie, a następnie w Sosnowcu i Brnie, co świadczy o wpływie warunków lokalnych tych miast.

Zuzanna Bielec-Bąkowska
University of Silesia, Faculty of Earth Sciences
Department of Climatology
Będzińska 60, 41–200 Sosnowiec, Poland
zuzanna.bielec-bakowska@us.edu.pl

Grażyna Knozová
Czech Hydrometeorological Institute, Brno Regional Office
Kroftova 43, 616 67 Brno, Czech Republic
grazyna.knozova@chmi.cz

Meczysław Leśniok
University of Silesia, Faculty of Earth Sciences
Department of Climatology
Będzińska 60, 41–200 Sosnowiec, Poland
mieczyslaw.lesniok@us.edu.pl

Dorota Matuszko
Jagiellonian University
Institute of Geography and Spatial Management
Gronostajowa 7, 30–387 Krakow, Poland
d.matuszko@geo.uj.edu.pl

Katarzyna Piotrowicz
Jagiellonian University
Institute of Geography and Spatial Management
Gronostajowa 7, 30–387 Krakow, Poland
k.piotrowicz@geo.uj.edu.pl