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Circulation Conditions Determining High PM_{10} Concentrations in the Sącz Basin (Poland)

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1. Introduction

Increasing amounts of hazardous pollutants are present in the air. This is due to the progressive growth of industry, including the automotive industry, and to burning of solid fuels for heating purposes in individual households. Particularly harmful are fine suspended particles, and among these PM_{10}, with a diameter below 10 μm. Particles of such small size easily penetrate the upper respiratory tract and lungs, causing dyspnoea and cough and exacerbating allergic symptoms. However, health effects can be much more serious if toxic substances are absorbed on the surface of the particles (Degórska, 2016; American Meteorological Society, 2014; Pascal et al. 2013; Jacobson, 2002).

Most scientific studies dealing with air pollution focus on identifying emission sources and the volume of emissions in urban and industrial agglomerations (Pasela et al. 2017; Whiteman et al., 2014; Russo et al. 2014; Trivedi et al. 2014; Wang et al. 2014). The authors of some studies have attempted to determine the effect of meteorological conditions on the level of pollution concentrations (Kalbarczyk et al. 2018; Czarnecka & Niedzgorska-Lencewicz 2017; Palarz 2014; Bokwa 2012; Majewski et al. 2018; Majewski & Przewoźniczuk 2009b; Walczewski 2009; Malek et al. 2006; Kukkonen et al. 2005).

Malek et al. (2006) described the meteorological determinants of one of the largest smog episodes in the United States. The authors noted that a high concentration of $PM_{2.5}$ (fine particulates with a diameter below 2.5 μm) in a relatively small metropolis with about 100,000 inhabitants was caused by adverse meteorological conditions impeding the dispersion of air pollutants and by the unfavourable location of the town in concave terrain.

The problem of air pollution in upland and mountainous areas of southern Poland and determination of the influence of meteorological and circulation conditions on PM_{10} concentrations has been the subject of numerous scientific works (Tomaszewska 2010; Bokwa 2012, Palarz 2014). Walczewski (2009) and Hajto & Rozwoda (2010), based on the example of cities located in basins, have shown that certain characteristic types of synoptic conditions, especially those accompanied by temperature inversions, may adversely affect the sanitary state of the air. Palarz (2014) and Palarz & Celiński-Mysław (2017) have demonstrated that the location of a city in concave terrain is particularly conducive to stagnation of cold air and the formation of cold pools, as well as the appearance of inversion layers that interfere with mixing of the air. They observed the highest concentrations of pollutants during night-time periods accompanied by thermal inversions associated with specific circulation types.

In many cities in Poland, PM_{10} concentrations very often exceed the limit values (Adamek & Ziernicka 2017, Pasela et al. 2017, Majewski & Przewoźniczuk 2009a). This also applies to Nowy Sącz, which is located on the flat bottom of the Sącz Basin. According to the WHO report, Nowy Sącz ranked 14th in 2016 and 10th in 2017 among the most polluted cities in the European Union (WHO report 2017).

A review of existing works shows that in addition to monitoring of air pollution and inventory of sources of emissions of harmful substances to the atmosphere, it is very important to recognize the weather conditions that are conducive to the concentration of air pollutants in a given location. This knowledge is particularly important in predicting the occurrence of high concentrations. This prompted the authors of the present study to analyse the dependence of the level of particulate matter in the air of the Sącz Basin on circulation conditions. The main objective of the research was to examine the influence of the type of atmospheric circulation on the PM_{10} concentrations in particular seasons of the year.

2. Study area, materials and methods

The Sącz Basin is located in the south-eastern part of the Lesser Poland Voivodeship and constitutes a large concave landform with a bottom situated at an altitude of 280-300 m above sea level (Kondracki, 2002). The area of the basin is about 300 km^2, of which its flat bottom occupies about 80 km^2. The bottom of the basin was formed by the rivers Dunajec, Poprad and Kamienica Nawojowska, which belong to the Upper Vistula River Basin. The Sącz Basin is surrounded by the elevations of the Rożnów Foothills to the north, the Low Beskids to the east, Beskid Sądecki to the south, and the Island Beskids to the west. The surrounding areas rise to a height of several hundred metres above the bottom of the basin. Nowy Sącz is located in the centre of the flat bottom of the valley. It is the third most populous city in the Lesser Poland Voivodeship and has the fifth largest area (Fig. 1).

The study used average daily PM_{10} concentrations measured from December 2006 to November 2016 at the air monitoring reference station in Nowy Sącz, belonging to the Regional Inspectorate for Environmental Protection in Krakow. The monitoring station is located on Nadbrzeżna Street on the flat bottom of the Sącz Basin at 305 m above sea level, with geographic coordinates 20°42'52"E 49°37'09"N. The station is surrounded by dispersed buildings, and the results of measurements performed at the station represent the background of air pollution in the built-up area of the Sącz Basin.

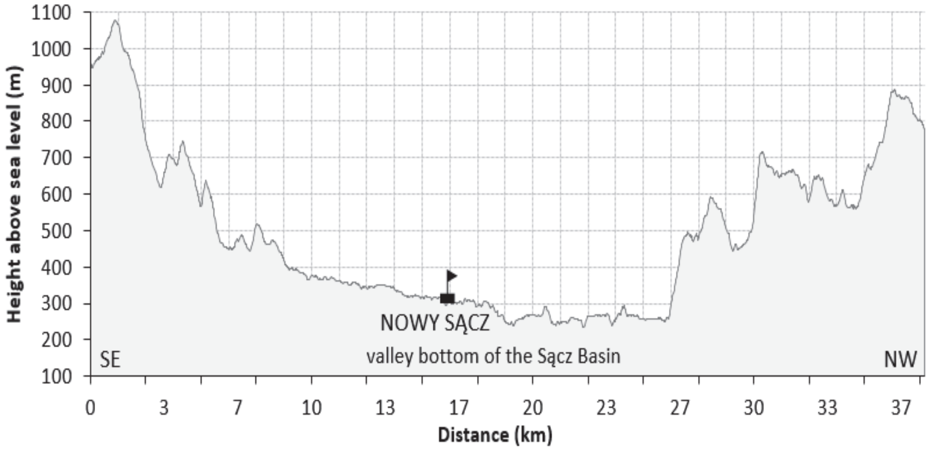

Fig. 1. Location of the air monitoring station in the SE-NW profile of the Sącz Basin

A calendar of atmospheric circulation types for southern Poland, developed by Niedźwiedź (2017), was also used in the research. It distinguishes 21 types of atmospheric circulation depending on the pressure system and the direction of incoming of air masses (Table 1).

PM_{10} concentration limits were adopted in accordance with the Regulation of the Minister of the Environment of 24 August 2012 on the levels of certain substances in the air (Journal of Laws (Dz.U.) 2012, item 1031).

Table 1. Circulation types for southern Poland (Niedźwiedź 2017)

Type	Anticyclonic conditions (a)	Type	Cyclonic conditions (c)
Na	North	*Nc*	North
NEa	North-east	*NEc*	North-east
Ea	East	*Ec*	East
SEa	South-east	*SEc*	South-east
Sa	South	*Sc*	South
SWa	South-west	*SWc*	South-west
Wa	West	*Wc*	West
NWa	North-west	*NWc*	North-west
Ca	Central anticyclonic	*Cc*	Central cyclonic
Ka	Anticyclonic wedge or ridge of high pressure	*Bc*	Trough of low pressure
*X**	Unclassified conditions	*X**	Unclassified conditions

* Note – type X is unclassified, so it was included in both anticyclonic and cyclonic conditions

Table 2. Acceptable PM_{10} concentrations according to the Regulation of the Minister of the Environment of 24 August 2012 on the levels of certain substances in the air Dz.U.(2012)[1] and the WHO (2005)[2]

Averaging period of measurement results	Acceptable concentration ($\mu g \cdot m^{-3}$)[1,2]	Acceptable frequency of exceedances[1]	Information level ($\mu g \cdot m^{-3}$)[1]	Alarm level ($\mu g \cdot m^{-3}$)[1]
24 hours	50	35 times/year	200	300

Note: [2] The WHO standard does not specify the acceptable frequency of exceedances of the acceptable level, information level or alarm level

The collected data on average daily PM_{10} concentrations were used to calculate seasonal mean values for spring, summer, autumn and winter for the period from December 2006 to November 2016. Based on the limit value for 24-hour average PM_{10} concentration (50 $\mu g \cdot m^{-3}$), the frequency of its exceedances (%) was calculated in the analysed time intervals, as well as the frequency of exceedances of the information level (200 $\mu g \cdot m^{-3}$) and alarm level (300 $\mu g \cdot m^{-3}$) (Table 2).

In the last stage of the research, for each of the 21 atmospheric circulation types, the mean, maximum and minimum PM_{10} concentrations were calculated for the analysed time intervals, and then the mean values were plotted against the frequency of these types in each season.

3. Results

In the decade from 2006 to 2016, air pollution in Nowy Sącz exceeded acceptable levels of pollutant concentrations (Journal of Laws of 2012, item 1031, WHO 2006) on 34% of days of the year. The average daily PM_{10} concentration was 85 $\mu g \cdot m^{-3}$ for winter, 45 $\mu g \cdot m^{-3}$ for spring, 25 $\mu g \cdot m^{-3}$ for summer, and 49 $\mu g \cdot m^{-3}$ for autumn. The highest PM_{10} concentrations were recorded in the winter of 2010/2011 (Fig. 2). Pronounced seasonal variation in concentrations was observed over the course of the year. The particulate concentration increased in the colder half of the year and decreased in the warmer half.

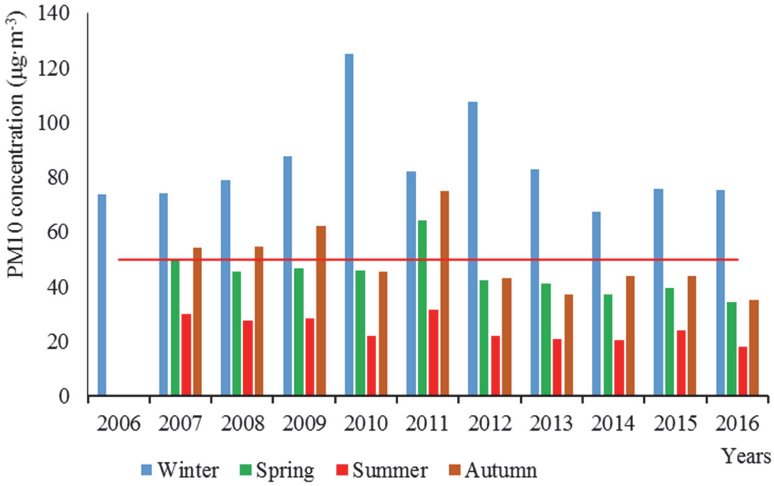

Fig. 2. Mean daily PM_{10} concentrations ($\mu g \cdot m^{-3}$) in seasons of successive years of the research period (horizontal line indicates the acceptable daily concentration)

The most days when standards were exceeded were recorded in the coldest months of the year (Tables 3 and 4). The frequency (%) of exceedances of the PM_{10} limit values was 69% for winter, 36% for the autumn, 30% for spring, and only 2% for summer (Table 3).

Exceedances of the information level and the alarm level occurred almost exclusively in the winter months, i.e. in December, January and February (Tab. 4). The most exceedances the limit values were found in 2011-162 days (47%), while the acceptable annual number is 35 days (9.6%). The acceptable, information and alarm levels were most frequently exceeded in 2009, 2010 and 2012, and in February 2012 the information level was exceeded on as many as 30% of days.

Table 3. Frequency of days (%) in which the acceptable concentration of PM_{10} was exceeded in Nowy Sącz (2006-2016)

Frequency	Winter			Spring			Summer			Autumn		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Mean	69.5	66.7	69.4	58.1	30.4	1.4	0.7	0.7	3.9	13.3	41.9	53.3
Max	93.5	90.3	85.7	87.1	56.7	6.5	6.7	6.5	22.6	43.3	74.2	90.0
Min	51.6	41.9	35.7	38.7	10.0	0.0	0.0	0.0	0.0	0.0	12.9	30.0
Mean for season	68.5			30.0			1.8			36.2		
Mean for year	33.9											

Atmospheric circulation is one of the basic processes shaping weather conditions. As this is a highly variable process in time, there is a need for research aimed at determining how variation in the degree of air pollution depends on the prevailing type of synoptic conditions. In the Sącz Basin, weather conditions are highly variable, which is linked to the movement of pressure systems, as well as the very frequent and active incoming air masses from various directions. In the analysed multi-annual period from 2006 to 2016, anticyclonic types were predominant, occurring on 53% of days in the year. Among these, the most frequent were high-pressure stagnation systems (anticyclonic wedge *Ka*), with a frequency from 11% in autumn to 13% in summer. Low-pressure conditions appeared on 46% of days of the year, and the most common type of circulation was the low-pressure trough *Bc* – 12%. Advections from the west (*Wc* and *Wa*) and from the south-west (*SWc* and *SWa*) and north-west (*NWc* and *NWa*) sectors, which are most typical of the climate of southern Poland, were somewhat less common.

Table 4. Frequency of days (%) in which the acceptable (A), information (B) and alarm (C) levels of PM_{10} concentration was exceeded in Nowy Sącz (2006-2016)

Month	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
January	-	19-0-0	58-0-0	76-7-14	75-7-14	63-7-0	45-13-0	61-10-0	70-0-0	52-0-0	81-3-0
February	-	66-0-0	55-7-0	82-7-0	82-7-0	86-0-0	53-30-0	62-0-0	64-0-0	83-0-0	34-0-0
March	-	53-0-3	45-0-0	64-0-0	64-0-0	83-3-0	57-0-0	57-0-0	43-0-0	72-0-0	40-0-0
April	-	33-0-0	40-0-0	20-0-0	20-0-0	55-0-0	10-0-0	23-0-0	17-0-0	10-0-0	10-0-0
May	-	0-0-0	0-0-0	0-0-0	0-0-0	6- 0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0
Jun	-	0-0-0	0-0-0	0-0-0	0-0-0	7-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0
July	-	6-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0
August	-	6-0-0	0-0-0	0-0-0	0-0-0	23-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0
September	-	14-0-0	20-0-0	4-0-0	4-0-0	43-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0
October	-	58-0-0	74-0-0	67-0-0	67-0-0	58-0-0	36-0-0	33-0-0	23-0-0	29-0-0	0-0-0
November	-	43-3-0	47-3-0	34-0-0	34-0-0	87-3-0	60-0-0	31-0-0	40-0-0	53-0- 0	40-0-0
December	70-0-0	61-6-6	48-6-0-	70-10-0	70-0-0	52-3-0	87-6-0	61-0-0	68-0-0	90-0-0	-
Mean for year	-	30-1-1	32-1-0-	35-2-1	35-2-1	47-1-0	29-4-0	27-1-0	27-0-0	33-0-0	-

Legend: *(A-B-C): A – acceptable level, B –information level, C – alarm level
Objaśnienia:* (A-B-C): A – poziom dopuszczalny, B – poziom informowania, C – poziom alarmowy

Table 5. Extreme values of PM_{10} concentrations ($\mu g \cdot m^{-3}$) for each type of atmospheric circulation (2006-2016)

Type	Spring		Summer		Autumn		Winter	
	Max	Min	Max	Min	Max	Min	Max	Min
Na	96	14	25	11	85	9	80	15
NEa	115	11	36	7	68	14	99	17
Ea	152	11	59	12	93	13	378	14
SEa	172	18	75	19	150	19	388	25
Sa	118	21	71	19	211	18	174	22
SWa	193	21	45	11	236	15	296	19
Wa	119	16	48	11	185	13	328	14
NWa	127	17	44	7	179	8	220	10
Ca	127	18	41	16	138	13	278	55
Ka	152	16	57	10	210	13	425	30
Nc	132	8	34	8	52	6	71	13
NEc	88	6	39	6	40	6	135	25
Ec	158	10	43	10	70	8	141	28
SEc	378	17	53	17	138	11	251	22
Sc	84	12	65	12	108	11	176	16
SWc	150	10	47	10	105	10	225	16
Wc	162	10	35	10	163	9	193	7
NWc	89	9	32	9	81	6	105	10
Cc	43	8	10	8	13	13	77	36
Bc	132	8	72	8	134	11	236	10
X	150	13	36	13	103	21	189	28

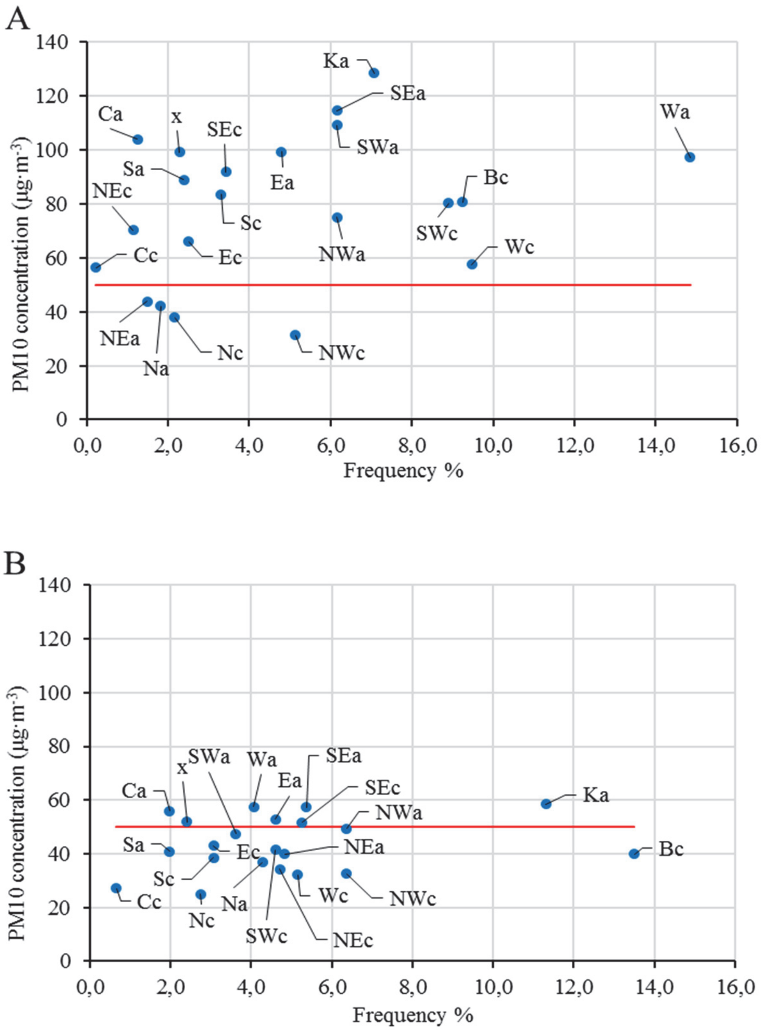

Fig. 3a. Mean concentration of PM_{10} and frequency of circulation type during: (A) winter and (B) spring, in Nowy Sącz (2006-2016) (horizontal line indicates the acceptable daily concentration)

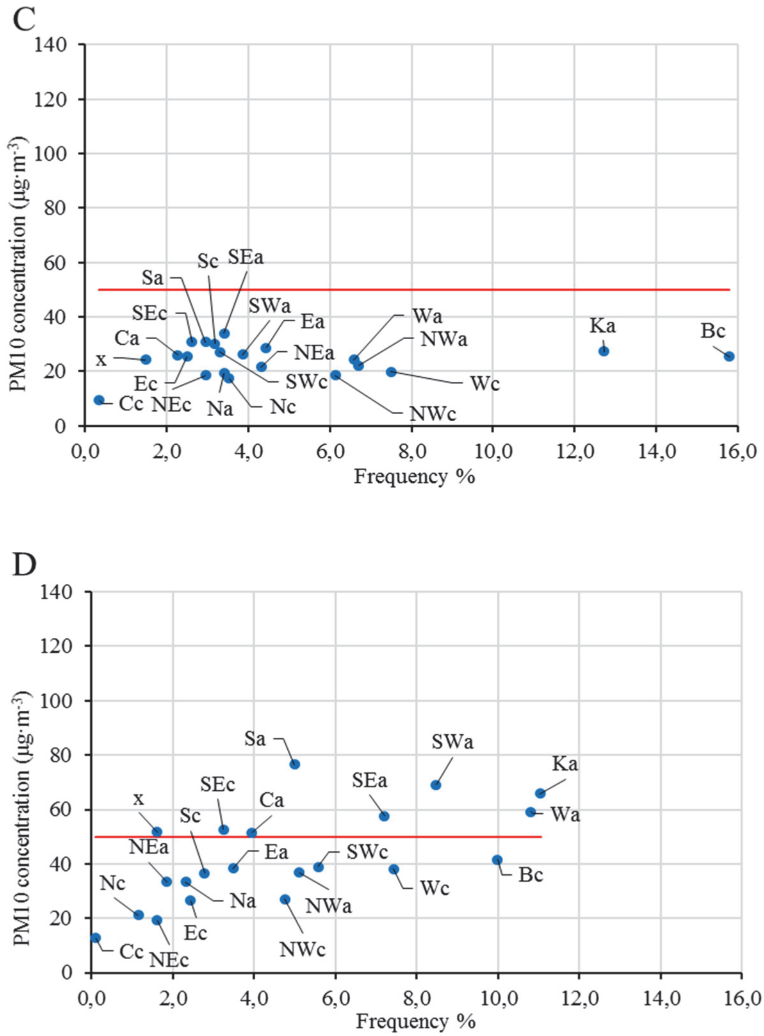

Fig. 3b. Mean concentration of PM_{10} and frequency of circulation type during: (C) summer and (D) autumn in Nowy Sącz (2006-2016) (horizontal line indicates the acceptable daily concentration)

Irrespective of the season, the highest PM_{10} concentrations were found in non-directional anticyclonic types (*Ka* and *Ca*) as well as in the case of advections of air masses from southern directions (*SEa*, *Sa* and *SWa*). The highest PM_{10} concentrations were observed in winter, on average 128 $\mu g \cdot m^{-3}$ for *Ka*, 115 $\mu g \cdot m^{-3}$ for *SEa*, and 109 $\mu g \cdot m^{-3}$ for *SWa*. In non-directional *Ka* conditions in December 2007, PM_{10} concentrations exceeded the alarm level (300 $\mu g \cdot m^{-3}$) twice, reaching a maximum value of 425 $\mu g \cdot m^{-3}$ (Tables 4 and 5).

The lowest PM_{10} concentrations throughout the year accompanied low pressure systems, especially in the case of advections of air from northern directions (*NWc*, *Nc* and *NEc*) and the non-directional type *Cc*. In cyclonic conditions, concentrations of particulate matter exceeding the limit value were noted mainly in winter, and less often in autumn and spring. High PM_{10} concentrations were associated with non-directional conditions (*Bc* and *X*) and with advections of air from southern directions (*SEc*, *Sc* and *SWc*).

The lowest PM_{10} concentrations in all types of atmospheric circulation were noted in the summer months and very rarely exceeded the limit values (Tables 3 and 5, Fig. 2, 3a and 3b).

4. Discussion

The analysis confirmed the existence of a relationship between the type of atmospheric circulation and the PM_{10} concentration in Nowy Sącz. The results coincide with those reported by numerous authors who have analysed various aspects of the influence of atmospheric circulation on the concentration of air pollution (Adamek & Ziernicka, 2018, Leśniok et al., 2010, Russo et al., 2014, Bokwa, 2012, Niedźwiedź & Olecki, 1994). In Nowy Sącz, which represents the built-up area of the Sącz Basin, the average seasonal PM_{10} concentrations were higher than in urban areas located in the lowland part of Poland (Kalbarczyk et al. 2018, Adamek & Ziernicka-Wojtaszek, 2018, Czrnecka & Nidzgorska-Lencewicz 2017). Bokwa (2012) showed that in Krakow, which has equally unfavourable ventilation conditions as Nowy Sącz, high PM_{10} concentrations were associated with incoming air masses from southern sectors in high-pressure conditions (*SEa*, *Sa* and *SWa*) and with the presence of an anticyclonic wedge (*Ka*). The author explained the reasons for the increase in the concentration of air pollution during advections from the southern sector. In directional and non-directional low-pressure conditions, warmer air flows in from lower latitudes, which promotes thermal inversion. In the valleys of the Beskid Mountains, the frequency of atmospheric calm in the winter months ranges from 18% to 21% (Wiszniewski 1971, Lorenc 2005). Miczyński (1990) emphasized that in the Sącz Basin PM_{10} concentrations exceeding 300 $\mu g \cdot m^{-3}$, i.e. the alarm level, most often occurred in conditions of atmospheric calm and at wind speeds below 2.0 $m \cdot s^{-1}$. The location of Nowy Sącz in a basin and the prevalence of days with anticyclonic weather are conducive to the formation of temperature inversion and thus greater concentrations of pollutants. Miczyński (1990) stressed that the dense build-up of Nowy Sącz and the intensity of vehicular traffic combined with the limited ventilation of the city additionally augment the concentration of particulate air pollutants. In the present study, the highest exceedances of limit values were observed in high pressure conditions, which is consistent with the observations of Miczyński (1990), Niedźwiedź & Olecki (1994), Palarz & Celiński-Mysław (2017) and other authors. Skowera & Wojkowski (2009) found that in the Upper Vistula River Basin, the most common circulation types in autumn and winter were non-directional high-pressure circulation (*Ka* and *Ca*) and advections from the east (*Ea*), south (*Sa*) and west (*Wa*). The authors observed the greatest negative air temperature deviations from the long-term average in these situations. The low temperatures resulted in higher levels of solid fuel combustion for heating purposes, mainly by individual households, which increased emissions to the atmosphere.

Circulatory conditions and the city's location at the bottom of the Sącz Basin are the main factors shaping the sanitary condition of the air in Nowy Sącz. However, the very high particulate concentrations in the Sącz Basin are due primarily to high emissions from industrial pollution and low-stack emissions. In Nowy Sącz, emissions of particulates from fuel combustion ranged from 215 Mg in 2008 to 77 Mg in 2016 (GUS, 2008-2017), which was confirmed by the high concentrations recorded at the air monitoring station.

5. Conclusions

In Nowy Sącz, located at the bottom of the Sącz Basin, the permissible 24-hour PM_{10} concentration was exceeded on average on 124 times per year in 2006-2016. The acceptable frequency of exceedances is 35 days per year (DZ.U. 2012, poz. 1031), so this limit was exceeded by over 89 days, which was significantly higher than in other parts of Poland.

The highest PM_{10} concentrations exceeding the limit value were observed in winter and autumn in anticyclonic non-directional conditions (*Ka* and *Ca*) and during advections of air masses from southern directions (*SEa*, *Sa* and *SWa*). These conditions most often determined the weather in southern Poland.

Significantly lower PM_{10} concentrations accompanied low-pressure weather. During cyclonic weather, the highest concentrations exceeding limit values were observed in autumn and winter and were linked to the appearance of non-directional conditions (*Bc* and *X*) or advections of air from southern directions (*SEc*, *Sc* and *SWc*).

The analyses indicate that recognition of circulation conditions determining levels of particulate concentrations in the air can be very useful in the predicting the occurrence of high PM_{10} concentrations in the Sącz Basin.

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Abstract

The aim of the study was to investigate the level of atmospheric particulate matter in the Sącz Basin depending on circulation conditions. The study used average daily PM_{10} concentrations measured from December 2006 to November 2016 at the air monitoring reference station in Nowy Sącz, belonging to the Regional Inspectorate for Environmental Protection in Krakow. A calendar of circulation types for southern Poland was used as well.

The collected data on average daily PM_{10} concentrations were used to calculate seasonal mean values for spring, summer, autumn and winter for the period from December 2006 to November 2016. Based on the limit value for 24-hour average PM_{10} concentration (50 $\mu g \cdot m^{-3}$), the frequency of its exceedances (%) was calculated in the analysed time intervals, as well as the frequency of exceedances of the information level (200 $\mu g \cdot m^{-3}$) and alarm level (300 $\mu g \cdot m^{-3}$). Then, particulate concentrations were analysed with respect to types of synoptic conditions. For this purpose, average PM_{10} concentrations in different types of synoptic conditions and the frequency of these types in each season were calculated.

In the decade from 2006 to 2016, the highest PM_{10} concentrations in Nowy Sącz were observed in the winter and the lowest in the summer. The average daily PM_{10} concentration was 85 $\mu g \cdot m^{-3}$ for winter, 45 $\mu g \cdot m^{-3}$ for spring, 25 $\mu g \cdot m^{-3}$ for summer, and 49 $\mu g \cdot m^{-3}$ for autumn. The most days in which the acceptable PM_{10} values were exceeded were recorded in December, January and February (66.7-69.5%). The acceptable, information and alarm levels were most frequently exceeded in 2009, 2010 and 2012, and in February 2012 the information level was exceeded on as many as 30% of days.

The research showed a relationship between the PM_{10} level and the type of accompanying atmospheric circulation. The highest exceedances of the acceptable values were nearly always observed in certain characteristic circulation conditions. Irrespective of the season, the highest PM_{10} concentrations were found in anticyclonic non-directional types (*Ka* and *Ca*) and in the case of advections of air masses from the southern sector (*SEa*, *Sa* and *SWa*). The highest PM_{10} concentrations were observed in winter, on average 128 $\mu g \cdot m^{-3}$ for *Ka*, 115 $\mu g \cdot m^{-3}$ for *SEa* and 109 $\mu g \cdot m^{-3}$ for *SWa*.

Lower concentrations accompanied low-pressure systems. In cyclonic conditions, the highest concentrations of particulate matter exceeding the acceptable level were recorded especially in autumn and winter. They were mainly associated with non-directional types (*Bc*, *Cc* and *X*).

Keywords:
PM_{10}, level of particulate matter, types of atmospheric circulation, Sącz Basin.

Cyrkulacyjne uwarunkowania występowania wysokich stężeń pyłu PM_{10} w Kotlinie Sądeckiej (Poland)

Streszczenie

Celem pracy było zbadanie poziomu stopnia zapylenia powietrza atmosferycznego w Kotlinie Sądeckiej w zależności od uwarunkowań cyrkulacyjnych. W badaniach wykorzystano średnie dobowe stężenia pyłu zawieszonego PM_{10} pomierzone w okresie od grudnia 2006 roku do listopada 2016 roku na stacji referencyjnej monitoringu powietrza w Nowym Sączu należącej do Wojewódzkiego Inspektoratu Ochrony Środowiska w Krakowie. Wykorzystano również kalendarz typów cyrkulacji dla obszaru Polski Południowej.

Zebrane dane o średnim dobowym stężeniu pyłu PM_{10} posłużyły do obliczeń wartości średnich sezonowych dla wiosny, lata, jesieni i zimy za okres od grudnia 2006 roku do listopada 2016 roku. Na podstawie dopuszczalnej wartości średniego dobowego (24-godzinnego) stężenia pyłu PM_{10} (50 $\mu g \cdot m^{-3}$) obliczono w analizowanych przedziałach czasowych częstość jego przekroczeń (%), a także częstość przekroczeń poziomu informowania (200 $\mu g \cdot m^{-3}$) i poziomu alarmowego (300 $\mu g \cdot m^{-3}$).

Następnie stężenia pyłu przeanalizowano na tle sytuacji synoptycznych. W tym celu obliczono średnie wartości stężeń pyłu PM_{10} w poszczególnych typach sytuacji synoptycznych oraz częstości występowania tych typów w analizowanych sezonach kalendarzowych.

W badanym dziesięcioleciu 2006-2016 najwyższe wartości stężeń pyłu PM_{10} obserwowano w Nowym Sączu w sezonie zimowym, a najniższe latem. Średnie dobowe stężenie pyłu PM_{10} wyniosło dla sezonu zimowego 85 $\mu g \cdot m^{-3}$, wiosennego 45 $\mu g \cdot m^{-3}$, letniego 25 $\mu g \cdot m^{-3}$, a jesiennego 49 $\mu g \cdot m^{-3}$. Najwięcej dni, w których wystąpiło przekroczenie wartości dopuszczalnych pyłu PM_{10} zanotowano w grudniu, styczniu i lutym (66,7-69,5%). Przekroczenia poziomów dopuszczalnych, informowania i alarmowych najczęściej obserwowano w latach 2009, 2010 i 2012, a w lutym 2012 roku aż w 30% dni przekroczone były poziomy informowania.

Przeprowadzone badania wykazały zależność pomiędzy stopniem zapylenia pyłem PM_{10} a występującym typem cyrkulacji atmosferycznej. Najwyższe przekroczenia wartości dopuszczalnych prawie zawsze były obserwowane tylko w pewnych charakterystycznych warunkach cyrkulacyjnych. Niezależnie od pory roku, najwyższe poziomy stężeń pyłu PM_{10} stwierdzono w sytuacjach antycyklonalnych bezadwekcyjnych (*Ka* i *Ca*) oraz przy adwekcjach mas powietrza z sektora południowego (*SEa, Sa* i *SWa*). W sezonach zimowych obserwowano najwyższe wartości stężeń PM_{10}, średnio 128 $\mu g \cdot m^{-3}$ dla *Ka*, 115 $\mu g \cdot m^{-3}$ dla *SEa* i 109 $\mu g \cdot m^{-3}$ dla *SWa*.

Niższe stężenia towarzyszyły pogodzie niżowej. Podczas pogody cyklonalnej najwyższe zarejestrowane stężenia pyłu przekraczające dopuszczalny poziom, występowały szczególnie jesienią i zimą. Były one związane przede wszystkim z sytuacjami bezadwekcyjnymi (*Bc, Cc,* i *X*).

Słowa kluczowe:
PM_{10}, stopień zapylenia, typy cyrkulacji atmosferycznej, Kotlina Sądecka