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The Effect of Meteorological Conditions on PM_{10} and $PM_{2.5}$ Pollution of the Air

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1. Introduction and work's aim

Air pollutants include solid, liquid or gaseous substances of foreign origin, or naturally occurring in the atmosphere when their level exceeds the limit value. Pollutants entering the atmosphere may be generated during production processes, combustion, transport or the municipal sector and households (Nadziakiewicz 2005). The sources release into the atmosphere mainly nitrogen oxides, carbon oxides, particulate matter, sulphur dioxide and carbon dioxide (Juda-Rezler 2006). Other pollution sources which change the natural composition of the air include landfill sites and dumps which release into the air particulates as well as poisonous gasses, particularly ammonia (Czarnecka & Kalbarczyk 2008). Typical air pollutants include particulate matter whose particles have different size, origin and form in which they occur. The term 'particulate matter' (PM) is applied when referring to the dispersed aerosol phase, and it denotes a mixture of solid and liquid particles dispersed in the air (WHO 2006, EEA, 2014). There are two major categories of particular matter whose measurement is part of air quality monitoring in the urban environment both in Poland and Europe: PM_{10} and $PM_{2.5}$. PM10 includes fine particles whose aerodynamic diameter does not exceed 10 μm. $PM_{2.5}$ is made up of very fine particles with the diameter of no more than 2.5 μm. The particles consist of e.g.: sulphur, heavy metals, toxic dioxins and polycyclic hydrocarbons as well as aromatic hydrocarbons and allergens (Malec & Borowski 2016). As particles are capable of remaining in the atmosphere over a time, they may negatively influence human health, the biosphere or other environment elements (Malec & Borowski 2016, Sówka et al. 2016). PM_{10} has a substantial adsorbing surface which holds back harmful substances causing respiratory diseases. Particles of $PM_{2.5}$ are more harmful because they penetrate the deepest located, smallest bronchioles which are a component of the non-ciliated part of the respiratory tract, and directly enter the bloodstream. (Cembrzyńska et al. 2012). Many studies have confirmed a correlation between particulate matter concentration and morbidity and mortality rate (Power et al. 2011, Weuve et al. 2012, Wilker et al. 2015, Gruszecka-Kosowska 2018). PM harmfulness is not so much associated with their abrupt emission as the prevalence of conditions which favour dispersal of the particles (Drzeniecka-Osiadacz & Netzel 2010), the following meteorological conditions being decisive: air temperature, wind speed and direction, air humidity and solar radiation intensity (Gioda et al., 2013, Kim et al. 2015, Oleniacz et al. 2016 a, b). Accordingly, EU directives (in particular Directive 2008/50/WE) detail the permissible levels of particular matter in the air, and encourage the development of a PM monitoring system and of action plans. It is important to get to know the mechanisms leading to pollutant accumulation and dispersal, also at a local scale. A stage of such analyses may include determination of the effect of selected meteorological elements on the concentration of particulate matter in the air. Thus, it was attempted to determine the influence of air temperature, wind speed and direction, as well as air humidity on the concentration of PM_{10} and $PM_{2.5}$ in Siedlce.

2. Materials and methods

24-hour results of measurements of PM_{10} and $PM_{2.5}$ and of meteorological observations in Siedlce ($\varphi°=52°10'03''$N; $\lambda°=22°17'24''$E; H_sm a.s.l.=150 m) taken in 2012-2016 were analysed.The data, collected by an automated measurement station situated in Konarskiego Street, Siedlce, (Fig. 1) was sourced from the website of the Environmental Protection Inspectorate (www.gios. gov.pl). Siedlce is located in the east of Poland, in the central part of the Mesoregion Wysoczyna Siedlecka, Mazovian Voivodeship. The urban landscape of Siedlce includes residential and commercial areas. The residential areas are built to blocks of flats as well as single-family housing, and are intermingled with service-related spots. Areas developed with production and commercial facilities are located at the outskirts of the town. Despite lack of formal administrative division of the town's area, Siedlce can be divided into structural units. There are seven residential districts characterised by a certain degree of individuality: Nowe Siedlce (located in the north-east, with predominantly single-family houses), Piaski Zamiejskie (western part of the town, with single-family single-storey houses), Roskosz (southern part of the town, with both single-family houses and blocks of flats), Sekuła (southern part of the town with residential buildings), Stara Wieś (eastern part of the town with mixed types of housing), Śródmieście (the town's centre where there are many shops and shopping centres, measurement point in Konarskiego Street), Taradajki (south-eastern part of the town dominated by single-family houses), and two industrial districts: Północna Dzielnica

Przemysłowa (Northern Industrial District) and Południowa Dzielnica Przemysłowa (Southern Industrial District).

Fig. 1. Measurement point location (www.siedlce.pl)

The first stage included calculation of the number of days with a certain index of air quality based on 24-h concentrations of particulate matter. According to guidelines of the Chief Inspectorate for Environmental Protection, the Index of Air Quality includes six classes (http://powietrze.gios.gov.pl/ pjp/archives) (Table 1).

Table 1. Air quality index

	Very good	Good	Moderate	Satisfactory	Poor	Very poor
PM_{10} [µg/m^3]	0-21	21-61	61-101	101-141	141-201	> 201
$PM_{2.5}$ [µg/m^3]	0-13	13-37	37-61	61-85	85-121	> 121

The next step included analysis of excessive 24-h concentrations of PM_{10} and $PM_{2.5}$. The standard value, as set by WHO, was the 24-h concentration of 50 µg/m^3 for PM_{10} and 25 µg/m^3 for $PM_{2.5}$. Also, there was determined the number of days in individual months of the 5-year period when the concentration of particular matter exceeded the standard, in addition to minimum and maximum values of the concentration as well as the coefficient of variation.

Analysis of correlation and path analysis developed by Wright (1923) were used in order to analyse the effect of the following meteorological factors: air temperature, wind speed and direction, and air humidity on above-standard concentration of PM_{10} and $PM_{2.5}$.

Path analysis rests on a stepwise linear analysis of regression of standardised variables, which makes it possible to compare the extent of direct influence of individual causative variables on a casual (dependent) variable. Moreover, it allows assessment of the direct effect of causative variables resulting from their interrelations. The causative variables were as follows: X_1 – air temperature, X_2 – wind direction, X_3 – wind speed, X_4 – air humidity. The dependent variables (Y) included excessive concentration of PM_{10} and $PM_{2.5}$. For the sake of calculations, wind direction was expressed on an angular scale.

The first step of the analysis involved calculation of correlation matrix between variables, and multiple stepwise regression for variables standardised according to the equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon_i \quad (1)$$

where:
Y, X_1, X_2, X_3, X_4 – standardised variables.

Standardisation was carried out based on the following formulae:

$$Y = \frac{Y_i - \bar{Y}}{S_y}; X_{1,2,3,4} = \frac{X_i - \bar{X}}{S_x} \quad (2)$$

where:
Y_i – 24-h value of excessive concentration of PM_{10} or $PM_{2.5}$,
$\bar{y}$ – average 24-h concentration of particulate matter,
S_y – standard deviation of the concentration of particulate matter,
X_i – values of meteorological components,
$\bar{x}$ – average values of meteorological components,
S_x – standard deviation of meteorological components.

Partial coefficients of regression β_i are path coefficients which express the direct effect of each causative variable on the dependent variable. The relationship between the path coefficient p_i and regression coefficient is as follows: $p_j = \beta_i$. Indirect effects of each causative variable on variation in the concentration of particulate matter through the remaining independent variables were calculated as a sum of the products of correlation coefficients between the variables and relevant values of path coefficient, as shown below:

$$\sum p_j \cdot r_{ij} \quad (3)$$

where:
p_i – path coefficient,
r_{ij} – correlation coefficient.

The sum of the direct effect and indirect effect for each element of the equation is equal to the Pearson's coefficient of linear correlation, that is the overall effect of a given variable:

$$r_{yj} = p_j + \sum p_j \cdot r_{ij} \quad (4)$$

For explanations see formula (3).

3. Results

Table 2 presents the number of days with individual air quality indices for PM_{10} and $PM_{2.5}$. In the study years, the highest was the number of days with good air quality, in terms of both PM_{10} and $PM_{2.5}$. Over 32 and 21% of days were characterised by very good air quality, respectively for PM10 and $PM_{2.5}$. It should be noted that, as far as PM_{10} was concerned, the greatest was the number of days with very good air quality in the last two study years, that is 129 days in 2015 and 140 days in 2016. Poor and very poor air quality, due to the concentration of PM_{10} of over 141 $\mu g/m^3$, and of $PM_{2.5}$ of over 85 $\mu g/m^3$, was only occasional (in 2012 only).

Table 2. Annual number of days with individual types of air quality index for PM_{10} and $PM_{2.5}$ in the years 2012-2016

Year	Air quality index					
	very good	good	moderate	satisfactory	poor	very poor
	PM_{10}					
2012	91	233	27	10	3	2
2013	114	218	30	3		
2014	117	218	27	3		
2015	129	203	28	5		
2016	140	208	16	2		
Total	591	1080	128	23	3	2

Table 2. cont.

Year	Air quality index					
	very good	good	moderate	satisfactory	poor	very poor
	$PM_{2.5}$					
2012	59	226	50	18	10	3
2013	68	214	61	18	4	
2014	84	191	72	13	4	
2015	104	183	57	19	1	1
2016	80	211	54	15	7	
Total	395	1025	294	83	26	4

Over the five-year period, in all the study months the greatest were the numbers of days with good and very good air quality, in terms of PM_{10}. Moderate and satisfactory air quality was observed in the autumn and winter months (from October to April), it being poor or very poor in February only. The concentration of $PM_{2.5}$ present in the air was low enough to classify the majority of days (in each month) as characterised by good or very good air quality. Poor quality was observed during the winter period, from November to March, it being very poor in February only (Table 3).

Table 3. Monthly number of days with individual types of air quality index for PM_{10} and $PM_{2.5}$ in the years 2012-2016

Month	Air quality index					
	very good	good	moderate	satisfactory	poor	very poor
	PM_{10}					
January	30	102	15	4		
February	17	84	30	7	3	2
March	29	91	28	7		
April	40	105	4	1		
May	73	83				
June	103	48				
July	73	82				
August	73	83				
September	59	91				
October	30	108	18			
November	25	105	16	3		
December	39	98	17	1		

Table 3. cont.

Month	Air quality index					
	very good	good	moderate	satisfactory	poor	very poor
	$PM_{2.5}$					
January	13	82	36	13	6	
February	9	64	40	21	6	3
March	13	83	42	12	5	
April	20	113	18	1		
May	54	101				
June	95	55				
July	86	69				
August	50	104	1			
September	31	114	6			
October	9	82	48	9		
November	7	68	44	13	3	1
December	8	90	59	14	6	

An above-standard PM_{10} concentration (>50 μg/m^3) in the study period was observed from January to March and from October to December (heating season). The greatest number of days with exceedences was found in February (10% of days) and March (33% days). Also, PM_{10} content in these months had the highest variation, the respective values being 47.4 and 29.1% (Table 4).

Table 4. Minimum (μg/m^3), maximum (μg/m^3) values and the coefficient of variation (%) of exceedence for PM_{10} in individual months in the years 2012-2016

Month	Min.	Max.	Coefficient of variation	Number of days when standards were exceeded	Percentage of number of days in the study period when exceedences were observed
January	50.8	125.7	28.2	31	20
February	50.9	252.1	47.4	56	40
March	50.3	139.1	29.1	51	33
October	50.5	83.9	16.0	34	22
November	50.5	129.3	27.1	35	23
December	50.2	111.6	21.5	27	17

Correlation analysis revealed that the concentration of PM_{10} was significantly related to air temperature in February and March, wind speed in February and December, air humidity in February, and wind direction in November (Table 5). Path analysis indicated that an above-standard concentration of PM_{10} in January was affected by wind direction and wind speed although the effect was statistically insignificant. In February, the highest significant direct effect on PM_{10} content was associated with air temperature and wind speed. The value of the direct effect of temperature is indicative of the fact that as air temperature increased by 1 degree Celsius, PM_{10} content declined by an average of 0.466 µg/m^3 whereas a 1 m/s increase in wind speed was followed by a decline in PM10 content of 0.257 µg/m^3, on average. The remaining parameters, that is wind direction and air humidity had only a slight effect on the examined parameter. The greatest indirect effect causing an increase in PM_{10} content was associated with air humanity (-0.148), the effect being primarily due to a direct influence of air temperature (-0.222).

Table 5. Correlation coefficients as well as direct and indirect effects of the influence of meteorological elements on PM_{10} content

Causative variable	Direct effect	Indirect effect	Correlation coefficient
January			
Wind direction(X_2)	0.218		-0.066
Indirect effect through X_3		0.0071	
Wind speed (X_3)	-0.247		-0.253
Indirect effect through X_2		-0.0063	
February			
Air temperature(X_1) –	-0.466*		-0.541*
Indirect effect through X_2		0.022	
Indirect effect through X_3		-0.024	
Indirect effect through X_4		-0.073	
Wind direction (X_2)	0.125	-0.035	0.091
Indirect effect through X_1		-0.080	
Indirect effect through X_3		0.0715	
Indirect effect through X_4		-0.0263	
Wind speed (X_3)	-0.257*	-0.047	-0.305*
Indirect effect through X_1		-0.043	
Indirect effect through X_2		-0.035	
Indirect effect through X_4		0.031	

Table 5. cont.

Causative variable	Direct effect	Indirect effect	Correlation coefficient
February			
Air humidity (X_4)	-0.153	-0.148	-0.301*
Indirect effect through X_1		-0.222	
Indirect effect through X_2		0.022	
Indirect effect through X_3		0.052	
March			
Air temperature (X_1)	0.139		-0.459*
Indirect effect through X_3		-0.0636	
Wind speed (X_3)	-0.447*		
Indirect effect through X_1		0.0185	
October			
Air temperature (X_1)	-0.595*		-0.476*
Indirect effect through X_2		0.119	
Wind direction (X_2)	-0.447*		0.073
Indirect effect through X_1		0.0185	
November			
Air temperature (X_1) –	0.195		-0.176
Indirect effect through X_2		0.0285	
Indirect effect through X_3		-0.010	
Wind direction (X_2)	0.349*		-0.343*
Indirect effect through X_1		0.016	
Indirect effect through X_3		-0.009	
Wind speed (X_3)	-0.215		-0.239
Indirect effect through X_1		-0.0094	
Indirect effect through X_2		-0.015	
December			
Wind speed	-0.481*		-0.481*

A similar small indirect impact on PM_{10} content was determined for air temperature, wind direction and wind speed. An increased concentration of PM_{10} in March was also directly related to wind speed and air temperature. A 1 m/s increase in wind speed was followed by a 0.447 $\mu g/m^3$ decline in PM_{10} content. Indirectly, a higher influence on PM_{10} was exerted by air temperature than wind speed. PM_{10} content in October was directly and significantly influenced by air temperature and wind direction. A 1 degree increase in temperature was followed by a 0.595 $\mu g/m^3$ decline in PM_{10} concentration whereas a 1 degree change in wind direction contributed to a 0.447 μg/m³ decline in the concentration of PM_{10}. Indirectly, the effect of temperature was greater compared with wind direction. In November, there was observed a direct effect of air temperature, wind direction and wind speed resulting in an excessive concentration of PM_{10}, it being significant for wind direction only. The greatest indirect influence was associated with air temperature, it being the result of the effect of wind direction. In December, there was observed only direct effect of wind speed on above-standard PM_{10} content in the air. A 1 m/s increase in wind speed was followed by a 0.481 μg/m³ decline in the concentration of PM_{10} (Table 5).

An excessive concentration of $PM_{2.5}$ in the five-year period was observed in January, February, March, September, October, November and December. The greatest number of days with above-standard $PM_{2.5}$ contents was recorded in February (as much as 76% days), October (68%), January (63%) and March (61%), the smaller number of such days being in September (Table 6). Correlation analysis demonstrated a significant relationship of above-standard $PM_{2.5}$ content with air temperature in January, February, October and November, wind speed in February, March, September, October, November and December, and a air humidity in February and March. Wind direction had a significant effect on an excessive concentration of $PM_{2.5}$ in September only (Table 7).

Table 6. Minimum (μg/m³), maximum (μg/m³) values and the coefficient of variation (%) of exceedence for $PM_{2,5}$ in individual months in the years 2012-2016

Month	Min.	Max.	Coefficient of variation	Number of days with above-standard concentration	Percentage of days when exceedence was recorded in the study period
January	25.2	117.4	42	98	63
February	25.5	151.1	49	107	76
March	25.2	95.6	38	94	61
September	25.3	53.3	20	35	23
October	25.1	78.1	29	105	68
November	25.2	144.1	42	113	75
December	25.2	102.7	37	120	77

Path analysis demonstrated that $PM_{2.5}$ content in January was directly affected by wind speed and air temperature but only the effect of wind speed was significant. A 1 m/s increase in wind speed was followed by a decline in $PM_{2.5}$ concentration of about 0.5 μg/m³. Air temperature had a more pronounced indirect effect on the discussed parameter than wind speed (Table 7). In February, an above-standard $PM_{2.5}$ concentration was directly influenced by air temperature, wind speed and air humidity. An increase in temperature and a decline in wind speed were followed by a significant decline in the concentration of $PM_{2.5}$. Air humidity had the greatest indirect influence on the examined parameter, the effect being affected by air temperature. Wind speed and air humidity negatively and significantly influenced the variation in $PM_{2.5}$ concentration in March whereas in April the variation of over 25 μg/m^3 was directly and negatively affected by air temperature, the relationship being statistically insignificant. The variation in the concentration of $PM_{2.5}$ in September was directly affected by air temperature, wind direction, wind speed and air humidity. The effect was negative, which means that an increase in the value of these parameters was followed by a decline in $PM_{2.5}$ content in the air. The greatest indirect influence was associated with air temperature (totalling 0.376). The effect was predominantly due to an indirect impact through air humidity and temperature. The overall indirect effect of wind speed was 0.215 and it followed mainly from an indirect influence through wind direction. In October and November, the variation in $PM_{2.5}$ content was directly and negatively affected by air temperature, wind speed and air humidity, the impact of only wind speed being statistically significant. The greatest indirect impact was due to air temperature in October and air humidity in November. The impact in October was related to air humidity and in November to wind speed. Similarly to PM10, variation in $PM_{2.5}$ content in December was directly influenced by wind speed only, the influence being significant. A 1 m/s increase in wind speed was followed by a 0.486 μg/m^3 decline in the concentration of $PM_{2.5}$ (Table 7).

Table 7. Correlation coefficients as well as direct and indirect effects of the influence of meteorological elements on $PM_{2.5}$ content

Causative variable	Direct effect	Indirect effect	Correlation coefficient
January			
Air temperature(X1) –	-0.146		-0.252*
Indirect effect through X_3		-0.106	
Wind speed (X3)	-0.520*		-0.550*
Indirect effect through X_3		-0.0298	
February			
Air temperature (X_1) –	-0.366*		-0.518*
Indirect effect through X_3		-0.102	
Indirect effect through X_4		-0.049	

Table 7. cont.

Causative variable	Direct effect	Indirect effect	Correlation coefficient
February			
Wind speed (X_3)	0.390*		-0.477*
Indirect effect through X_1		-0.096	
Indirect effect through X_4		0.0089	
Air humidity (X_4)	-0.114		-0.242*
Indirect effect through X_1		-0.158	
Indirect effect through X_3		0.030	
March			
Wind direction (X2)	0.097		0.085
Indirect effect through X_3		-0.0219	
Indirect effect through X_4		0.0099	
Wind speed (X_3)	-0.492*		-0.488*
Indirect effect through X_2		0.0043	
Indirect effect through X_4		-0.0009	
Air humidity (X4)	-0.237*		-0.243*
Indirect effect through X_2		-0.0041	
Indirect effect through X_3		-0.0019	
September			
Air temperature (X1)	-0.338*		-0.282
Indirect effect through X_2		0.110	
Indirect effect through X_3		0.093	
Indirect effect through X_4		0.173	
Wind direction (X2)	-0.697*		-0.348*
Indirect effect through X_1		-0.053	
Indirect effect through X_3		0.129	
Indirect effect through X_4		-0.106	
Wind speed (X_3)	-0.500*		-0.010*
Indirect effect through X_1		0.063	
Indirect effect through X_2		0.180	
Indirect effect through X_4		-0.0280	
Air humidity (X4)	-0.277*		-0.167
Indirect effect through X_1		0.210	
Indirect effect through X_2		-0.268	
Indirect effect through X_3		0.050	

Table 7. cont.

Causative variable	Direct effect	Indirect effect	Correlation coefficient
October			
Air temperature (X_1)	-0.170		-0.227*
Indirect effect through X_3		-0.0193	
Indirect effect through X_4		-0.0378	
Wind speed (X_3)	-0.361*		-0.339*
Indirect effect through X_1		-0.0193	
Indirect effect through X_4		0.0091	
Air humidity (X4)	-0.159		-0.127
Indirect effect through X_1		-0.040	
Indirect effect through X_3		0.072	
November			
Air temperature (X_1)	-0.159		-0.185*
Indirect effect through X_3		-0.060	
Indirect effect through X_4		0.0342	
Wind speed (X_3)	-0.364*		-0.337*
Indirect effect through X_1		-0.026	
Indirect effect through X_4		0.053	
Air humidity (X4)	-0.128		0.064
Indirect effect through X_1		0.042	
Indirect effect through X_3		0.150	
December			
Wind speed	-0.487*		-0.487*

4. Discussion

The air quality in Siedlce is affected by pollutants released by industrial facilities, vehicles and household combustion devices. Due to low industrialisation of the town, the main source of pollutants is residential heating with coal.

Due to a complex nature of the relationship between meteorological factors and PM pollution, it is very difficult to clearly determine the effect of individual meteorological elements on PM concentration (Olofson et al. 2009, Weber et al. 2013). In Siedlce, above-standard concentration of PM_{10} and $PM_{2.5}$ was usually directly affected by wind direction and speed although the influence was sometimes insignificant. As wind speed increased (particularly in the winter months), particulate matter concentration declined, which might have been caused by more rapid dispersal of the pollutants. Such a relationship has been reported by Oleniacz et al. (2016a) who confirmed that wind speed in Kraków exceeding 2 m/s contributed to a dispersal of pollution concentration. Similar findings were also reported by Czarnecka and Kalbarczyk (2008) who confirmed a ventilatory role of wind in the Pomerania area, in particular in February and March. No or little wind makes it impossible to effectively ventilate a town area (Cichoń and Hławiczka 2010, Błedowska et al. 2012, Kalbarczyk and Kalbarczyk 2007, Nowicka et al. 2004). Also Drzeniecka-Osiadacz and Netzel 2010 have pointed to a decisive effect of wind speed and direction on PM dispersal. On the basis of regression analysis, the authors confirmed a statistically significant relationship between the average 24-h concentration of PM_{10} and wind speed. Moreover, the authors have emphasised the fact that PM concentration is affected by the range and duration of temperature inversion which is an obstacle to vertical air mixing in the atmosphere. This phenomenon may explain the indirect effect of temperature (through wind speed and direction) in the study reported here on PM concentration in February, March and November. Directly, wind direction affected PM_{10} content in January and $PM_{2.5}$ concentration in October and November. In those months, the most frequent wind direction was WSW and it carried pollutants from single-family housing districts. Similar relationships for Trójmiasto (Tricity) were reported by Czarnecka and Nidzgorska-Lencewicz (2015) who confirmed that wind directions caused inflow emissions from outside of the agglomeration. In the study reported here, a direct effect of air temperature on PM dispersion was confirmed for the winter season, which is associated with intensive heating of buildings, that is the process of solid fuel combustion (particularly hard coal). This relationships is also confirmed by the fact that no above-standard concentrations of PM were recorded outside of the heating season in Siedlce. Similarly to other urban areas located in Poland and Europe, Siedlce struggles to maintain standards of air quality during the winter season. Multi-location research conducted in five European countries (Poland, Czech Republic, Bulgaria, Romania, Slovak Republic) has demonstrated that the concentration of PM_{10} and $PM_{2.5}$ in winter was, on average, twice as high as during the summer, which was mainly due to hard coal being used as fuel for heating in the municipal sector (Houthuijsat al. 2001).

The influence of individual meteorological elements on air quality is a complex process associated with vertical gradients of temperature, wind and humidity in the layer of the atmosphere which is closest to the ground (Majewski et al. 2009, Zhao et al. 2010), which was also confirmed in the present work. Depending on pollution type and study month, above-standard PM concentrations were usually affected by several meteorological elements, all analysed variables entering equations of path analysis in several cases. Similar findings were reported by Ćwiek and Majewski (2015) who, using stepwise regression equations, confirmed a simultaneous effect of several elements, including wind speed, atmospheric pressure, air temperature, relative humidity and horizontal visibility, on the concentration of air pollutants.

5. Summary

The effect of meteorological variables on pollutant content in the air is frequently analysed by means of the regression function. However, unlike path analysis, the method does not account for all the relationships between the variables. Path analysis made it possible to assess the direct and indirect effect of four meteorological elements on above-standard concentration of particulate matter in the Siedlce agglomeration. Throughout most of the year, air quality in Siedlce was good, it being satisfactory, poor and very poor in winter (from October to March) only. What is more, path analysis demonstrated that variation in pollutants is directly affected by wind speed and direction as well as air temperature. Increased PM concentrations were recorded mainly on days when wind speed dropped and air temperature was low. The value of the direct effect of temperature is indicative of the fact that as air temperature increased by 1 degree Celsius, PM_{10} content declined by an average of 0.466 $\mu g/m^3$ whereas a 1 m/s increase in wind speed was followed by a decline in PM10 content of 0.257 $\mu g/m^3$, on average. The indirect effect of the examined meteorological elements on PM dispersion varied and was predominantly influenced by the study month.

Further research into the dispersion of pollution in urban agglomerations is recommended as well as action to be taken to improve air quality, such as urban planning which considers location of buildings in terms of optimum air circulation. The action, although not commensurable with the effects of elimination of pollution sources, will definitely improve the inhabitants' quality of life.

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Abstract

The work is based on results of hourly measurements of the particles PM_{10} and $PM_{2.5}$ as well as 24-h measurements of meteorological elements in Siedlce. Analysis spanned the years 2012-2016. Based on the Polish Index of Air Quality developed by the Chief Inspectorate of Environmental Protection (GIOŚ), there were determined numbers of days in six air quality classes. Analysis of the effect of meteorological conditions on particulate matter content in the air was based on 24-h concentrations of PM_{10} and $PM_{2.5}$ exceeding the standard value of 50 $\mu g/m^3$ for PM_{10} and 25 $\mu g/m^3$ for $PM_{2.5}$. Variation in the excessive concentrations in weather conditions described by means of air temperature, air humidity, wind direction and speed was assessed by means of Wright path analysis. Satisfactory, poor and very poor air quality was recorded in winter only. Path analysis revealed that variation in pollution is affected by wind speed and direction as well as air temperature. Increased concentrations of particulate matter were found mainly on days with low wind speed and low air temperature.

Key words:
PM_{10}, $PM_{2.5}$, path analysis, meteorological conditions

Wpływ warunków meteorologicznych na zanieczyszczenie powietrza pyłem zawieszonym PM10 i PM2,5

Streszczenie

W pracy wykorzystano wyniki pomiarów godzinnych stężeń pyłów PM10 i PM2,5 oraz dobowych pomiarów elementów meteorologicznych w Siedlcach. Analizą objęto lata 2012-2016. Na podstawie Polskiego Indeksu Jakości Powietrza opracowanego przez Główny Inspektorat Ochrony Środowiska (GIOŚ) określono liczbę dni w sześciu przedziałach klas jakości powietrza. Analizę wpływu warunków meteorologicznych na zawartość w powietrzu pyłów oparto na stężeniach dobowych PM10 i PM2,5 przekraczających normę: 50 $\mu g/m^3$ dla PM10 i 25 $\mu g/m^3$ dla PM2,5. Zmienność ponadnormatywnych stężeń w warunkach pogodowych opisanych temperaturą powietrza, wilgotnością powietrza, kierunkiem i prędkością wiatru oceniono przy zastosowaniu analizy ścieżek Wrighta. Dostateczną, złą i bardzo złą jakość powietrza notowano jedynie w zimnej porze roku. Analiza ścieżek wykazała, że zróżnicowanie zanieczyszczeń zależy od prędkości i kierunku wiatru oraz temperatury powietrza. Podwyższone stężenia pyłów zawieszonych notowano głównie w dniach z małą prędkością wiatru i niską temperaturą.

Słowa kluczowe:
PM10, PM2,5, analiza ścieżek, warunki meteorologiczne