JEE Journal of Ecological Engineering
Volume 21, Issue 1, January 2020, pages 97–104
https://doi.org/10.12911/22998993/113074

Received: 2019.09.05
Revised: 2019.10.15
Accepted: 2019.11.30
Available online: 2019.12.20

The Effect of Meteorological Conditions on Air Pollution in Siedlce

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ABSTRACT
The objective of the work was to determine the influence of selected meteorological elements on the concentration of PM10 and PM2.5 in the air as well as arsenic, cadmium, lead and benzoapirene contents in PM10. The work is based on the data collected by the automatic measurement station located on ul. Konarskiego, Siedlce, in 2013–2017. ANOVA demonstrated that the heavy metal content throughout the year was significantly influenced by the month of the year. The lowest concentration of arsenic was recorded from May to August, and cadmium from January to March as well as from October to December. Similarly to cadmium, the lead content was the highest in the winter months (from October to March). The analysis of correlation revealed that air pollution was predominantly affected by air temperature, wind speed and air humidity. The relationship between the air temperature and pollutant content was negative. As the temperature increased, arsenic, cadmium, lead, benzoapirene and the PM10 contents declined. It was found that an increase in wind speed contributed to a significant decline in the concentration of PM10 and PM2.5. Moreover, wind speed affected the heavy metal content. Relative air humidity influenced the metal concentration from November to May, whereas an increase in wind speed contributed to a significant decline in the concentration of only PM10 in the period from January to November.

Keywords: particular matter PM2.5 and PM10, heavy metals, meteorological conditions, correlation

INTRODUCTION AND WORK OBJECTIVE

Sources of air pollution include anthropogenic – that is human-related – activities as well as natural processes. The pollution sources can be divided into organised and non-organised sources according to types of emitted pollutants (Nadziakiewicz 2005). The organised sources of emission introduce pollutants into the air during the production processes (Juda-Rezler 2010). The non-organised sources include landfill sites and spoil heaps which emit particulate matter and poisonous gases such as ammonia (Czarnecka and Koźmiński 2006, Czarnecka and Kalbarczyk 2008, Janka 2014). Scientists as well as programs to protect the environment, atmosphere and health are interested in identifying the mechanisms of the air pollution dispersal with particulate matter and heavy metals as well as its effect on the environment and human health. Rogula et al. (2007) as well as Hofman and Wachowski (2010) claim that exhaust fumes contain many substances known as 'carcinogens', the most dangerous ones, including polycyclic aromatic hydrocarbons, particulates and heavy metals. The atmospheric air is a perfect carrier in which gaseous pollutants and particulates disperse rapidly (Sówka 2011, Kołwzan 2011). The meteorological conditions markedly contribute to the removal of harmful particles from the air as they e.g.: wash away pollutants and initiate chemical reactions, (Czarnecka Kalbarczyk 2008, Majewski et al. 2009). The most frequent changes in the meteorological conditions occur in the ground layer. On the one hand, the layer is characterised by permanence of turbulent fluxes, on the other, one of its characteristics is substantial gradients of meteorological elements (temperature, wind, humidity) (Garratt 1992, Majewski et al. 2009, Zhao et al. 2010). The concentration of pollutants − smog − forms and persists under windless conditions when thermal inversions occur.

In particular, the phenomenon can be observed in winter in the temperate climate (Kożuchowski and Żmudzka 2001). The meteorological conditions determine the concentration of particulate matter and heavy metals in the atmosphere. Due to a complicated character of the relationship between the meteorological factors and particulate pollution, it is very difficult to unequivocally determine the effect of individual meteorological elements on the concentration of particulate matter and other pollutants.

The objective of the work was to determine the effect of the selected meteorological elements on the concentration in the air of PM10 and PM2.5 as well as the heavy metals contained in PM10.

STUDY AREA

The research was conducted in Siedlce (φ°=52°10′03″N; λ°=22°17′24″E; H_sm a.s.l. = 150 m) which is a town located in the eastern part of Poland, Mazovian Voivodeship, about 100 km east of Warsaw and 60 km west of the Polish-Belarusian border, in the centre of the Siedlecka Upland mesoregion.

The residential and service-related areas are typical of Siedlce. In turn, the production and service-related areas are located at the edges of the town and they include two industrial zones, that is the Northern and Southern Industrial Districts.

MATERIALS AND METHODS

The work draws on the measurements of PM10 and PM2.5 as well as arsenic, cadmium, lead and benzo(e)pyrene concentration contained in PM10. The measurements were taken at the automated measurement station located on ul. Konarskiego, Siedlce, in 2013–2017 (Fig. 1). The data is available online at the website of the Environmental Protection Inspectorate and through the application of General Environmental Protection Inspectorate. The data is updated hourly and used to calculate the average daily values for the purposes of comparison to the permissible levels.

The second data set included the results of observations obtained from the Siedlce Meteorological Station, such as average daily air temperature, relative air humidity and daily values of wind speed and direction from 2013 to 2017. The wind direction frequencies in all the months (all the directions) are graphically presented as a compass rose.

The statistical analysis of daily PM10 and PM2.5 as well as arsenic, cadmium, lead and benzo(e)pyrene concentrations contained in PM10 was performed. One-way ANOVA was used in order to analyse the differences between the concentrations of individual pollutants in months, with arsenic, cadmium, lead, benzo(e) pyrene, PM2.5 and PM10 concentrations used as dependent variables and months used as an independent variable. The comparison of means was

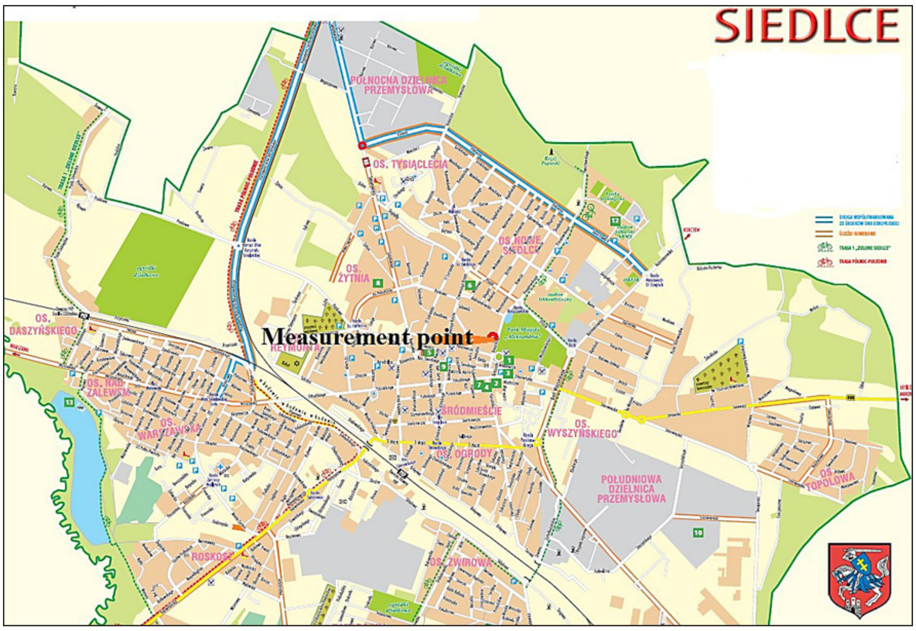

Fig. 1. Location of the measurement point

achieved using Tukey test at p≤0.05. Moreover, the range of monthly variation in pollutants was analysed based on minimum and maximum values as well as standard deviations. The relationships between the meteorological elements and pollutant contents were analysed by means of a linear correlation analysis at p≤0.05.

RESULTS AND DISCUSSION

The average yearly air temperature in Siedlce in the study years ranged from 7.2°C in 2013 to 9.1°C in 2015. July was the warmest month as the average temperature in this month reached 19.4°C. January was the coldest month, its average air temperature amounting to -2.6°C (Fig. 2).

The highest average yearly wind speed values in the study years were recorded in 2016, being the lowest in 2014. They amounted to 10.3 and 9.7 m/s, respectively. The lowest average monthly values of this parameter (8 m/s) were recorded from June to August. In turn, the average wind speed values exceeding 10 m/s occurred in the cold season (from November to April) (Fig. 3).

In 2013–2017, the prevailing wind direction in Siedlce was the west-south-west (WSW). The frequency of this wind direction in December and January was, 17% and 15%, respectively. In February, July and November, it was 14%, whereas in September and August, it amounted to, 13% and 12%, respectively. In March, the prevailing wind direction was south-west (SW − 11%) and west-north-west (WNW − 11%). May experienced the wind blowing most frequently from the north-north-east direction (NNE − 10%), and for October the east-south-east (ESE − 12%) and south-west direction (SW − 12%) were the most frequent (Fig. 4).

The average arsenic concentration during the year was significantly affected by the month, the highest value was recorded in January and February (1.44 and 1.26, respectively). Significantly lower values were recorded in March and April (0.98 and 0.83, respectively) and during the September-December period, they ranged from 0.51 (September) to 0.96 (December). The lowest and least varied arsenic concentrations were recorded from May to August (Fig. 5).

The cadmium content was the most varied and the highest during the January-March as well as October-December periods. In April and September, the cadmium content was statistically the

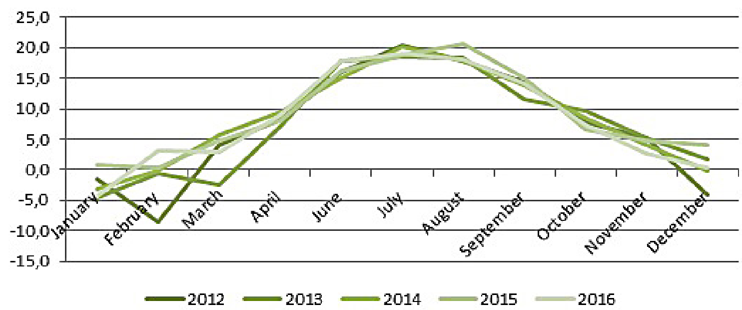

Fig. 2. Average monthly air temperature (°C) in Siedlce from 2013 to 2017

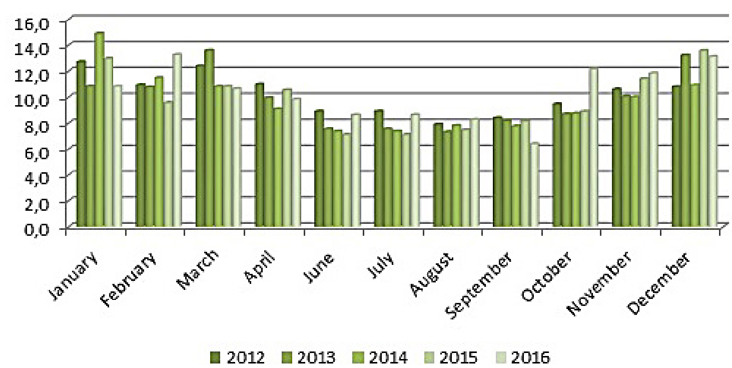

Fig. 3. Average monthly wind speed (m/s) in Siedlce from 2013 to 2017

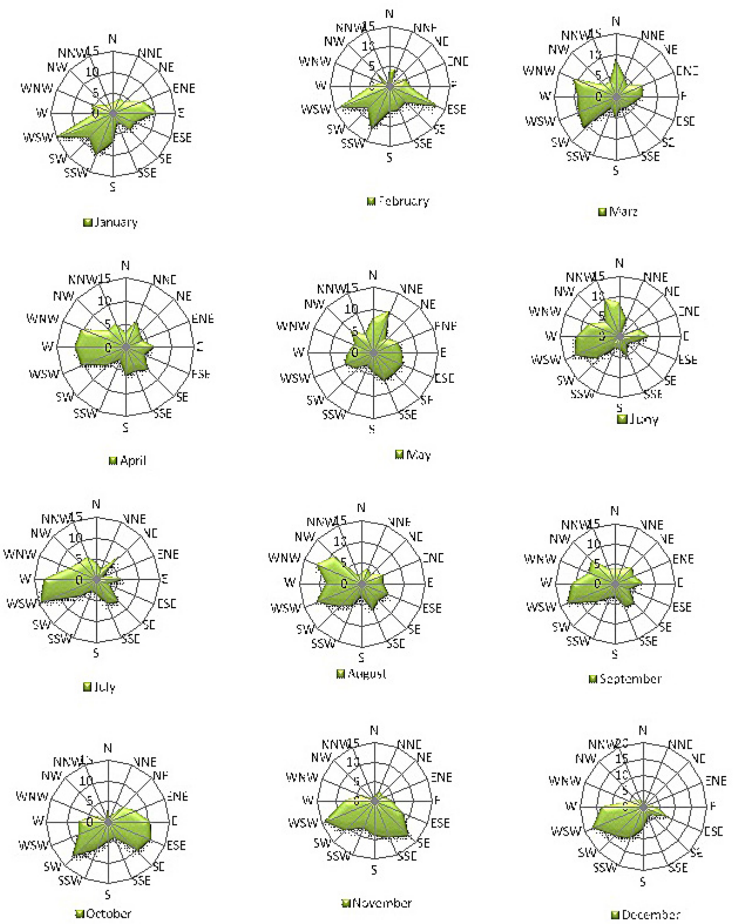

Fig.4. Frequency (%) of individual wind directions in Siedlce from 2013 to 2017

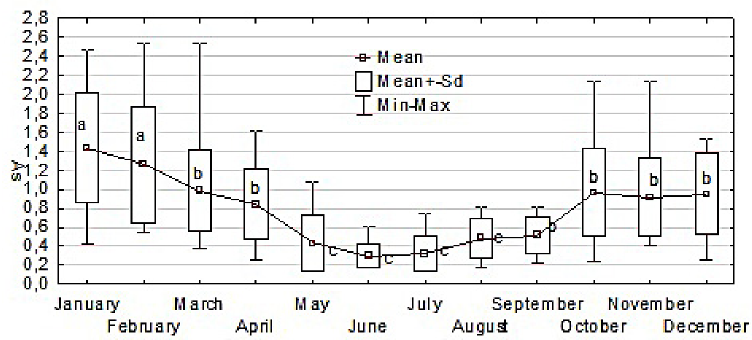

Fig. 5. Basic statistics of the arsenic concentration in the air in Siedlce from 2013 to 2017

same and amounted to 0.32 and 0.27, respectively. This type of pollution was the lowest in the summer months, that is from May to August, as its amount did not exceed 0.17. Additionally, the variation in the cadmium content was the lowest in this period (Fig. 6).

Similarly to cadmium, the lead content was the highest and statistically the same during the winter months (from October to March); it ranged from 0.016 in January to 0.012 in March. From April to September, the Pb content was significantly lower − from 0.009 in April to 0.002 in July. The highest daily variation in the lead content was recorded in October, November and December (Fig. 7).

The highest variation in the benzo(e)pyrene concentration was recorded in February and March, being slightly lower in January and April, and the lowest from May to August. The statistical analysis demonstrated that the benzo(e)pyrene content was the highest in February (14.1) and March (11.9), significantly lower levels were

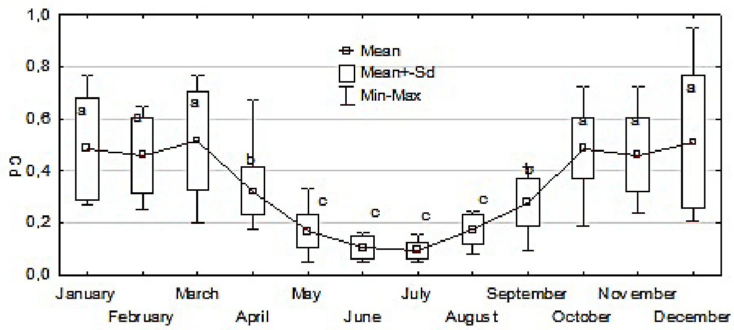

Fig. 6. Basic statistics of the cadmium concentration in the air in Siedlce from 2013 to 2017

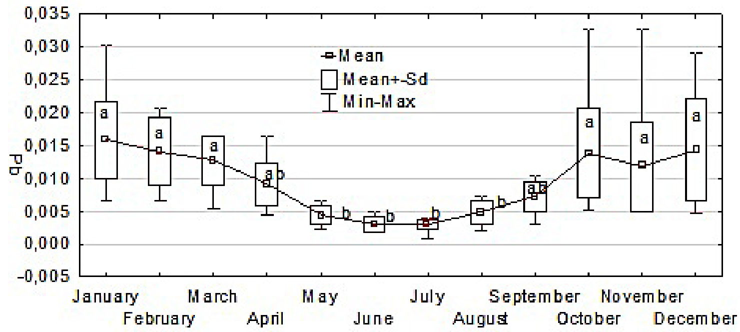

Fig. 7. Basic statistics of the lead concentration in the air in Siedlce from 2013 to 2017

recorded in April (4.68), October (4.67), November (5.30), and December (6.09). The lowest values of this parameter were observed in June, July and August when they ranged from 0.26 to 0.09 (Fig. 8)

The PM2.5 content was the highest in February (41); similar values of this parameter were recorded in January, November and December. In these months, the PM2.5 content varied the most. In the period from May to August, the amount of PM2.5 was similar and significantly lower compared with the remaining months (Fig. 9).

Similarly to the remaining pollutants, the PM10 concentration was significantly higher during the winter months compared with the summer period (May-August). Moreover, the PM10 content in April (29.7) and September (24.74) differed insignificantly from the values recorded in the remaining months (Fig. 10).

The correlation analysis demonstrated that the air pollution in all the months was primarily affected by the air temperature. The relationship was usually negative in the winter months and positive during the summer period. The strongest associations were recorded in June and July for PM10, in June, July and August for PM2.5, in August and November for benzo(e)pyrene, in April for lead, in May for cadmium and in February for arsenic (Table 1–6). Similar relationships were reported by Prządka et al. (2012) under the

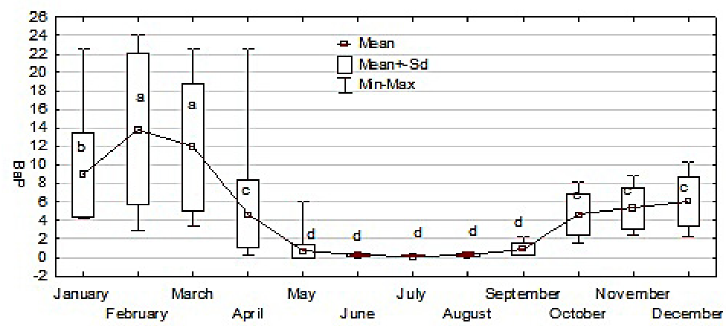

Fig. 8. Basic statistics of benzo(e)pyrene concentration in the air in Siedlce from 2013 to 2017

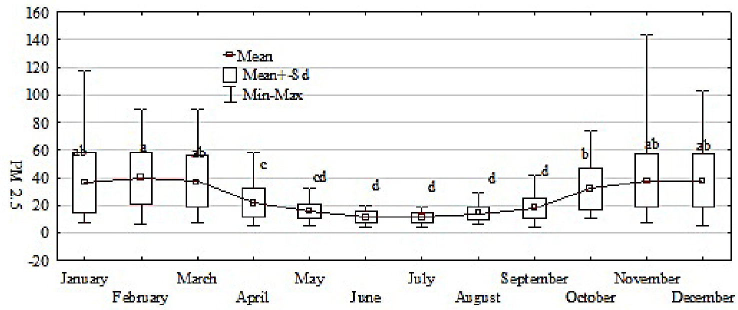

Fig. 9. Basic statistics of PM2.5 concentration in the air in Siedlce from 2013 to 2017

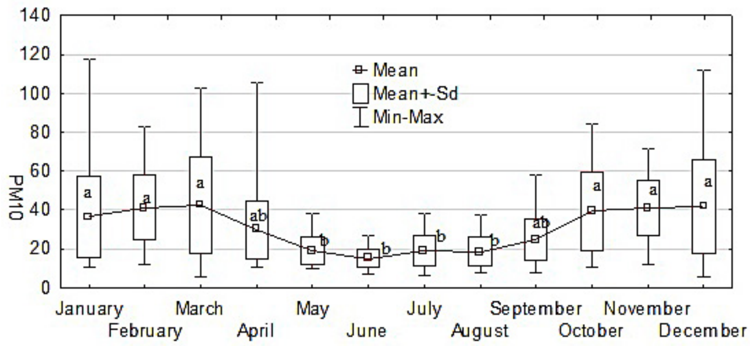

Fig. 10. Basic statistics of PM10 concentration in the air in Siedlce from 2013 to 2017

extra-urban conditions of north-eastern Poland. The research they conducted revealed that the concentration of PM10 and heavy metals it contained was season-related and predominantly affected by the air temperature.

An increase in wind speed was found to significantly contribute to a decline in the PM10 and PM2.5 concentrations in the air in all the months (excluding May and June for PM10). Moreover, wind speed influenced the heavy metal content (excluding arsenic) in most months. Drzeniecka-Osiadacz and Netzel (2010) found an increased PM10 concentration in Wrocław from June 2008 to May 2009 during days characterised by low temperatures, marked anticyclonic weather frequency, low wind speeds, and the mixed layer limited by thermal inversions. Wind speed and direction may contribute to an increase or decline in the pollution level of a city/town. Here, the positive role of local winds, such as breeze or

Table 1. Correlation coefficients between meteorological elements and PM10

	Air temperature	Wind speed	Air humidity	Wind direction
January	-0.227*	-0.583*	0.546*	0.057
February	-0.127	-0.616*	0.475*	-0.160
March	0.113	-0.577*	0.108	0.104
April	0.183	-0.258*	-0.148	-0.201
May	0.315*	-0.153	0.166	-0.015
June	0.623*	-0.042	0.274*	-0.186
July	0.740*	-0.214*	0.222*	-0.536*
August	0.571*	-0.292*	0.175	-0.510*
September	0.451*	-0.242*	0.329*	-0.103
October	-0.221*	-0.227*	0.210*	-0.185
November	-0.282*	-0.391*	-0.082	-0.177
December	-0.412*	-0.690*	0.207*	-0.204*

* -significant at $p \leq 0.05$.

Table 2. Correlation coefficients between meteorological elements and PM2.5

	Air temperature	Wind speed	Air humidity	Wind direction
January	-0.288*	-0.655*	0.246*	-0.025
February	-0.028	-0.695*	0.309*	-0.157
March	0.019	-0.654*	-0.109	0.080
April	0.122	-0.404*	0.080	-0.199
May	0.095	-0.341*	0.032	-0.074
June	0.506*	-0.218*	0.257*	-0.132
July	0.645*	-0.390*	0.193	-0.348*
August	0.545*	-0.465*	-0.239*	-0.372*
September	0.369*	-0.316*	-0.004	0.128
October	-0.224*	-0.401*	-0.053	-0.004
November	-0.397*	-0.515*	0.088	-0.112
December	-0.427*	-0.652*	0.309*	-0.154

* -significant at $p \leq 0.05$.

Table 3. Correlation coefficients between meteorological elements and the BPA content

	Air temperature	Wind speed	Air humidity	Wind direction
January	-0.148	-0.390*	0.016	0.062
February	-0.200	-0.42*6	0.303*	0.029
March	-0.046	-0.28*7	0.091	0.108
April	-0.205	-0.102	-0.104	-0.129
May	0.299*	-0.096	0.195	-0.035
June	0.492*	-0.252*	0.193	0.215*
July	-0.087	-0.321*	-0.180	0.159
August	0.448*	0.142	-0.251*	-0.207
September	-0.321*	0.065	0.221	0.232*
October	-0.355*	0.048	0.402*	-0.111
November	-0.467*	-0.263*	0.175	-0.169
December	-0.384*	-0.357*	0.129	-0.107

* -significant at p≤0.05.

Table 4. Correlation coefficients between meteorological elements and the Pb content

	Air temperature	Wind speed	Air humidity	Wind direction
January	-0.141	-0.119	0.036	0.016
January	-0.445*	-0.330*	-0.109	-0.087
February	0.093	-0.151	-0.172	0.068
March	0.070	-0.203	-0.052	-0.182
April	-0.379*	-0.109	-0.099	0.073
May	0.012	-0.312*	0.230*	-0.150
June	0.211*	-0.175	0.015	-0.191
July	0.277*	-0.171	0.363*	0.219*
August	0.311*	0.017	0.069	-0.041
September	-0.019	-0.251*	-0.100	0.095
October	-0.215*	-0.327*	-0.075	-0.160
November	-0.002	-0.304*	0.139	-0.060

* -significant at p≤0.05.

foehn, emerges. Breeze circulation removes clean air from suburban areas during the day, and the polluted air is transferred outside the city/town in the night. In turn, foehns play a significant purifying role in mountainous valleys (Griffin 2007).

Relative air humidity affected the concentration of pollutants, too. The strongest association was recorded in January and February for PM10, and in January, February and December for PM2.5. An increase in humidity was followed by a significant rise in the concentration of benzo(e) pyren in February and October, lead in July, cadmium in August, as well as arsenic in January and August. Wind direction was the least influential factor affecting the concentration of the analysed pollutants in the air. The strongest relationships were recorded in the warm season (excluding cadmium).

CONCLUSIONS

1. The average yearly air temperature in Siedlce in the study years was 8.0°C. July was the warmest month, whereas January was the coldest. The highest wind speed (>12 m/s) was recorded in January and December. The prevailing wind direction was west-south-west (WSW).
2. The concentration of the analysed pollutants was affected by months of the year. During the cold season, the air was more polluted than in the warm season. In the winter months, the air content of heavy metals and particulates was more varied compared with the summer months.
3. The concentration of PM10 and PM2.5 was significantly correlated mainly with air temperature and wind direction. In contrast, relative

Table 5. Correlation coefficients between meteorological elements and the Cd content

	Air temperature	Wind speed	Air humidity	Wind direction
January	0.077	-0.237*	0.179	0.081
February	-0.333*	-0.486*	0.081	-0.080
March	0.155	-0.075	-0.248*	0.036
April	0.016	-0.298*	-0.002	-0.239*
May	0.317*	-0.062	-0.140	0.220*
June	0.206	-0.040	-0.249*	-0.038
July	0.249*	-0.407*	-0.154	-0.171
August	0.223*	-0.109	0.397*	0.244*
September	-0.229*	0.022	0.060	-0.095
October	-0.102	-0.345*	-0.080	-0.063
November	-0.108	-0.275*	0.046	-0.299*
December	0.017	-0.242*	-0.011	-0.378*

Table 6. Correlation coefficients between meteorological elements and the As content

	Air temperature	Wind speed	Air humidity	Wind direction
January	0.031	-0.114	0.251*	-0.100
February	-0.386*	-0.170	-0.176	-0.161
March	0.095	-0.212	0.096	0.063
April	-0.134	-0.126	-0.100	-0.323*
May	-0.134	-0.126	-0.100	-0.323*
June	0.120	-0.111	-0.104	0.047
July	0.041	-0.292*	0.109	-0.104
August	0.270*	-0.127	0.241*	0.214*
September	0.124	-0.074	0.079	0.051
October	0.124	-0.074	0.079	0.051
November	-0.085	-0.244	-0.064	-0.117
December	0.183	-0.138	0.060	-0.111

air humidity was the most strongly negatively correlated with the concentration of particular matter in the winter and summer months, respectively.
4. The air content of the analysed heavy metals (excluding arsenic) was predominantly determined by air temperature and wind speed.
5. Relative air humidity had the strongest negative effect on the air content of benzo(e)pyrene in October, lead in July, cadmium in August and arsenic in January and August. Wind direction had the greatest influence on the arsenic content in April, May and August.

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