Preliminary analysis of variability in concentration of fine particulate matter - $PM_{1.0}$, $PM_{2.5}$ and PM_{10} in area of Poznań city

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Abstract. It is commonly known, that suspended particulate matter pose a threat to human life and health, negatively influence the flora, climate and also materials. Especially dangerous is the presence of high concentration of particulate matter in the area of cities, where density of population is high. The research aimed at determining the variability of suspended particulate matter concentration ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) in two different thermal seasons, in the area of Poznań city. As a part of carried out work we analyzed the variability of concentrations and also performed a preliminary analysis of their correlation. Measured concentrations of particulate matter were contained within following ranges: PM_{10} – 8.7-69.6 μg/m^3, $PM_{2.5}$ – 2.2-88.5 μg/m^3, $PM_{1.0}$ – 2.5-22.9 μg/m^3 in the winter season and 1.0-42.8 μg/m^3 (PM_{10}), 1.2-40.3 μg/m^3 ($PM_{2.5}$) and 2.7-10.4 ($PM_{1.0}$) in the summer season. Preliminary correlative analysis indicated interdependence between the temperature of air, the speed of wind and concentration of particulate matter in selected measurement points. The values of correlation coefficients between the air temperature, speed of wind and concentrations of particulate matter were respectively equal to: for PM_{10}: -0.59 and -0.55 (Jana Pawła II Street), -0.53 and -0.53 (Szymanowskiego Street), for $PM_{2.5}$: -0.60 and -0.53 (Jana Pawła II Street) and for $PM_{1.0}$ -0.40 and -0.59 (Jana Pawła II Street).

1 Introduction

The sources of the initial emission of particulate matter are mainly combustion processes in stationary sources, where the highest share in Poland (about 50%) is constituted by emission from combustion processes originating from outside of industry [7, 13]. Many studies indicate so-called low-stack-emission of particulate matter from communal and living sector as a main factor forming the quality of air in Poland in the winter season [11, 16]. An important source of particulate matter emission, especially in cities, is also road transport, which besides emitting particulate matter by combustion of fuel, also emits it by

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abrasion of vehicle elements (brake blocks, tires) and surface of roads. Another significant place, in the list of emission sources, is taken by secondary emission of particulate matter, this is uplifting particulate matter from the ground caused by moving vehicles [1, 9].

The level of contamination of the atmosphere depends highly on meteorological conditions, especially on the speed and direction of the wind, the temperature of air, relative humidity of air and solar irradiation [5]. Meteorological factors may as well increase as decrease the pollutants concentration, large wind speed favors 'rarefaction' of contamination in the air, and high humidity of air enables aggregation of particulate matter what increases the speed of its fall. Especially important kind of influence of meteorological conditions is observed in the presence of excessive concentrations of particulate matter contaminants. Depending on existing conditions they may magnify or minimize the smog effect [6, 13, 14]. Dense urban development may significantly influence processes of dispersion of pollutants in cities, it disrupts the process of air circulation, therefore, makes it more difficult to exchange air in an area of a city.

The aim of this work was analysis of variability of particulate matter concentrations: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} and preliminary assessment of the influence of the main meteorological parameters on particulate matter concentrations in Poznań.

2 Materials and methods

The research included two measurement campaigns in different thermal seasons: in the autumn-winter season (25.10-22.11.2016) and in the summer season (05.06-02.07.2017), at three measurement stations (Fig. 1.)

The collection of particulate matter - PM_{10} on Szymanowskiego Street during the first measurement campaign was done with usage of DERENDA PNS 16T-3.1 Automatic Sampling System (low-flow sequential impactor). During the second measurement campaign on Szymanowskiego Street and during two measurement campaigns on Polanka Street, the collection of samples was done with usage of LVS low-volume sequential impactor of a Umwelttechnik MCZ GmbH brand, (type MicroPNS LVS 16) which is characterized by a flow rate equal to 2.3 m^3/h. All of the impactors had a filter storage containing maximum 14 units. In the first case, as a supply material, Whatman QM-A quartz filters with a diameter of 150 mm and in the second case Whatman QM-A quartz filters with a diameter of 47 mm were used. In order to collect the suspended particulate matter - $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, in own research, impactors of a Harvard type (MS&T Area Samplers, Air Diagnostics and Engineering, Inc., Harrison, ME, USA) was used. The air flow was forced by ultra-quiet oil free vacuum pumps (Air Diagnostics and Engineering, air sampling pump, SP-280E model). As a supply material we used Whatman QM-A quartz filters with a diameter of 37 mm. The flow rate during the collection of samples was respectively equal to: for particles ≤ than 1.0 µm - 23 dm^3min^{-1}; for particles ≤ than 2.5 µm and for particles ≤ than 10 µm - 10 dm^3min^{-1}. The volume of pumped air was controlled with usage of Ataris type flow meter. The time of sample collection was equal to 24h.

Filters, as well before and after the exposure, were conditioned and weighed in a weighing room with constant humidity of 45 ± 5% and the temperature of air equal to 20 ± 2°C. We used analytical balances Xa 60/220 of the RADWAG company as the measurement equipment. The conditioning period was equal to a minimum 48 hours, and the second weighing took place after 24 hours.

The measurement of particulate matter was done with usage of gravimetric method in accordance PN-EN 12341 standard [15].

In order to examine interdependence between meteorological factors and concentration of suspended particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) correlation analysis was applied.

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Assumed statistical significance was equal to 0.05, and the number of measurement samples in both cases was equal to 28. Interdependence between concentrations of particulate matter and meteorological conditions was presented with usage of a correlation matrix.

Fig. 1. Locations of measurement points in Poznań: 1 – Szymanowskiego Street, 2 – Jana Pawła II Street, 3 – Polanka Street (map source: By Oskarro.© users of OpenStreetMap. Copyright https://commons.wikimedia.org/w/index.php?curid=16437602)

3 Results of the research and related discussion

Performed analysis of the data (Table 1) indicates that during the first measurement campaign were dominating the winds blowing from southwest direction with an average speed of 2 m/s. The average air temperature was equal to 5°C, and the average relative humidity of the air was considerably high and equal to 87%. During the second measurement campaign were dominating the winds blowing from the west direction with an average speed of 2 m/s. The average air temperature was equal to 19 °C and the relative humidity was 20% lower than in the autumn season and was equal to 70%.

Table 1. Descriptive statistics determined for main meteorological parameters during both measurement series (data source: WIOŚ Poznań [Provincial Inspector of Environmental Protection in Poznań]).

Statistics	Atmospheric pressure	Wind speed	Temperature	Humidity
	[hPa]	[m/s]	[°C]	[%]
Autumn-winter season n=28				
Minimum	992	0	-1	79
Maximum	1027	4	11	95
Average	1010	2	5	87
Median	1009	1	6	87

Standard deviation	9,46	0,91	3,79	4,35
Summer season, n=28				
Minimum	986	0	14	53
Maximum	1016	5	24	88
Average	1005	2	19	70
Median	1005,5	2	18	67,5
Standard deviation	6,56	1,07	2,23	9,52

Higher concentrations of particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) in the air were determined for the autumn-winter season (Table 2) for both of the measuring stations. The average concentration of PM_{10} in the autumn-winter season was higher at the station on Szymanowskiego Street (32.9 $\mu g/m^3$) than at the station on Jana Pawła II Street (25.4 $\mu g/m^3$), however, the concentration during the measurement session was comparable at both of the stations. At the station on Jana Pawła II Street the average concentration of PM_{10} in the summer season was 35% lower than during the first measurement session, in case of the station on Szymanowskiego Street, the concentration in the second measurement session was lower than the average concentration in the first measurement session (Figure 2a) by 55%. The concentrations of suspended particulate matter - $PM_{2.5}$ during the first measurement session were contained within the range of 2.2 – 39.9 $\mu g/m^3$ at the station on Jana Pawła II Street and at the station on Polanka Street concentration was contained within the range of 7.2 – 88.5 $\mu g/m^3$. The average concentration was respectively equal to 15.2 $\mu g/m^3$ for the station on Jana Pawła II Street and 30.8 $\mu g/m^3$ for the station on Polanka Street. The concentrations determined during the second measurement series were lower (Figure 2b) and were ranging from 1.2 to 40.3 $\mu g/m^3$ at the station on Jana Pawła II Street and from 7.2 to 17.1 $\mu g/m^3$ at the station on Polanka Street. The average concentration of $PM_{2.5}$ on Jana Pawła II Street, in the summer season, was 32% lower than in the winter season, and at the station on Polanka Street it was lower by 64%. The level of concentration of PM_{10} and $PM_{2.5}$ at both stations were similar to the concentration of PM_{10} observed in the same periods in previous years of measurements conducted by WIOŚ in cities of Wielkopolska, excluding Kalisz (in the city there are special conditions for dispersion of contaminants) [3, 4]. However, it should be noted, that the levels of concentration of particulate matter in the winter season, at all of the stations, were significantly higher than concentrations determined by WHO as safe for health and life of humans (PM_{10} – 20 $\mu g/m^3$, $PM_{2.5}$ – 10 $\mu g/m^3$) (**7**). Concentrations of $PM_{1.0}$ in the winter season were ranging within limits of 2.47 to 22.87 $\mu g/m^3$ and in the summer season they ranged between 2.72 and 10.35 $\mu g/m^3$. The average concentration in the winter season was equal to 8.50 $\mu g/m^3$ and was lower by 33% in the summer season and equal to 5.72 $\mu g/m^3$ (Table 2). In the graph presenting dependence between the concentration and the temperature (Figure 1 a, b) we might observe, that in the winter season, the lower was the air temperature the higher were concentrations of particulate matter - PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ (Figure 1a). The dependence presented above was more significant for concentrations of particulate matter at background stations (Szymanowskiego and Polanka Streets) than for the concentrations at traffic station (Jana Pawła II Street) The summer season presented no observable dependence between the concentrations of particulate matter and the temperature of air (Figure 2b).

Higher concentrations of particulate matter at the stations of the city background may be related to a phenomenon of low emission. The area of the station on Szymanowskiego Street mainly consists of single-family housing developments, and the area of the station on Polanka Street consists of multi-family housing developments which is heated by local boiler rooms. The methods of heating in the heating season, in this case, influences the quality of air. It should be noted that the average concentration of PM_{10} in the summer season at the station on Szymanowskiego Street (14.7 µg/m^3) was lower than at the station on Jana Pawła II Street (16.6 µg/m^3). This situation also confirms, that eliminating such factor as heating of buildings, influences quality of air in a specific area. The differences in concentrations of particulate matter $PM_{1.0}$ between seasons are not so significant as in the case of other two fractions (PM_{10}, $PM_{2.5}$). Measured concentrations of $PM_{1.0}$ in Poznań are comparable to concentrations measured in other cities of Poland, but at the same time are higher than in countries of Western Europe [8, 10, 17]. High concentrations of $PM_{1.0}$ in cities are related to the presence of many sources of emission in that areas, however, it should be noted, that high level of concentration of $PM_{1.0}$ is also identified at stations located in suburban and rural areas in Poland. It is probably related to the process of transporting $PM_{1.0}$ from other areas, which are sometimes very distant. The finest fraction of the particulate matter is characterized by a long time of presence in the atmosphere, therefore it is possible to be carried far away [12].

Table 2. Basic statistics for concentrations of particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) in the autumn-winter season (25.10-22.11.2016) and in the summer season (05.06-02.07.2017)

Statistics	**Concentration [µg/m^3]**	
	Autumn-winter season	**Summer season**
PM_{10} Szymanowskiego Street, n= 28		
Minimum	8,7	1,0
Maximum	69,6	22,6
Average	32,9	14,7
Median	34,5	15,7
Standard deviation	15,5	5,2
PM_{10} Jana Pawła II Street, n= 28		
Minimum	9,4	5,2
Maximum	68,6	42,8
Average	25,4	16,6
Median	21,5	15,1
Standard deviation	14,6	8,5
$PM_{2.5}$ Polanka Street, n= 28		
Minimum	7,2	7,2
Maximum	88,5	17,1
Average	30,8	11,0
Median	27,2	10,9
Standard deviation	19,1	2,5
$PM_{2.5}$ Jana Pawła II Street, n= 28		
Minimum	2,2	1,2
Maximum	39,9	40,3
Average	15,2	10,4
Median	12,9	8,7
Standard deviation	10,0	9,1
$PM_{1.0}$ Jana Pawła II Street, n= 28		
Minimum	2,5	2,7
Maximum	22,9	10,4
Average	8,5	5,7
Median	7,7	5,4
Standard deviation	5,3	1,9

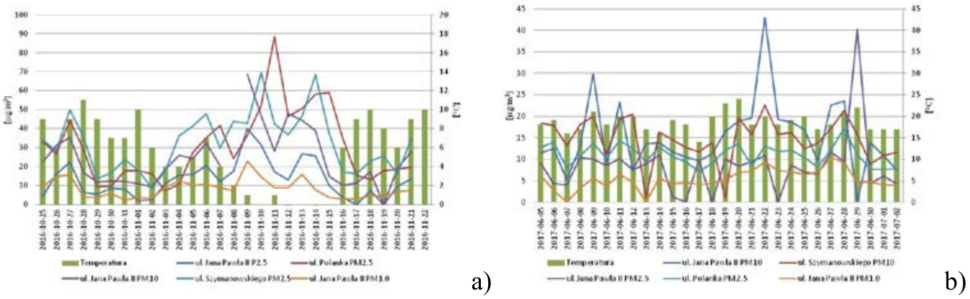

Fig. 2. Changes of the variability of particulate matter concentrations: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} and the temperature of air in Poznań, during two measurement series, in the autumn-winter (a) and summer (b) seasons

It is commonly known that suspended particulate matter is dependent on the temperature of air [1, 5, 9]. Basing on prepared correlation matrix, which elements were the coefficients of correlations for pairs of random variables described by a parameter of a line and a column of the matrix, in the winter season was determined statistically significant (with confidence level of $p<0.05$) negative correlations between the speed of wind, temperature and concentrations of particulate matter PM_{10} at the stations on Jana Pawła II Street (r=-0.55 and r=-0.59) and on Szymanowskiego Street (r=-0.53 and r=-0.53), $PM_{2.5}$ at the station on Jana Pawła II Street (r=-0.53 and r=-0.60) and $PM_{1.0}$ at the station on Jana Pawła II Street (r=-0.59 and r=-0.40) (Table 3). In case of concentrations of suspended particulate matter of $PM_{2.5}$ at the station on Polanka Street was also determined negative dependence between the concentration of particulate matter and the temperature of air (r=-0.64). In the summer season was determined reversed dependence in relation to the winter season, between the temperature of air and concentration of particulate matter. The positive correlation was established between the temperature of air and concentration of PM_{10} particulate matter at the station on Jana Pawła II Street (r=0.44) and particulate matter $PM_{2.5}$ (r=0.65) at the station on Polanka Street. In case of analysis of interdependence between concentrations of particulate matter and relative humidity of the air in summer season was determined negative dependence, for which the coefficients of correlation had following values: for PM_{10} particulate matter on Jana Pawła II Street r=-0.54, on Szymanowskiego Street r=-0.47, for $PM_{2.5}$ particulate matter at the station on Jana Pawła II Street r=-0.44, on Polanka Street r=-0.47.

Table 3. Acquired values of correlation coefficients between concentrations of particulate matter: PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ and the speed of wind, temperature and relative humidity in the autumn-winter and summer seasons

Variable	**Jana Pawła II Street PM_{10}**	**Szymanowskiego Street PM_{10}**	**Jana Pawła II Street $PM_{2.5}$**	**Polanka Street $PM_{2.5}$**	**Jana Pawła II Street $PM_{1.0}$**
Autumn-winter season					
Wind Speed, m/s	**-0,55**	**-0,53**	**-0,53**	-0,30	**-0,59**
Temperature, C	**-0,59**	**-0,53**	**-0,60**	**-0,64**	**-0,40**
Humidity, %	0,09	0,31	0,05	**0,46**	-0,04
Summer season					
Wind Speed, m/s	-0,23	-0,33	0,17	**-0,53**	0,06
Temperature, C	**0,44**	0,17	0,10	**0,65**	0,32
Humidity, %	**-0,54**	**-0,47**	**-0,44**	**-0,47**	-0,29

4 Summary

Measurements of concentration of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ done as a part of the research, confirm previous results of analyses performed in the city of Poznań [4] and indicate that there is a problem of high concentrations of suspended particulate matter in the autumn-winter season. Measured values were limited within ranges: from 8.7 to 69.6 $\mu g/m^3$ for PM_{10}, from 2.2 to 88.5 $\mu g/m^3$ for $PM_{2.5}$ and 2.5 to 22.9 $\mu g/m^3$ for $PM_{1.0}$. The analysis of correlation indicates that high concentrations of suspended particulate matter in the heating season may be dependent on the temperature of air (the lower the temperature, the higher concentrations of particulate matter) and stagnation conditions in the atmosphere (low values of the wind speed). The concentrations of particulate matter in Poznań, measured in the summer season, were lower and within ranges of 1.0 to 42.8 $\mu g/m^3$ for PM_{10}, 1.2-40.3 $\mu g/m^3$ for $PM_{2.5}$ and 2.7 to 10.4 $\mu g/m^3$ for $PM_{1.0}$. A significant negative dependence between concentrations of particulate matter and the temperature of air was determined. It can be concluded that the quality of air in this season is formed by the secondary uplift of particulate matter and the emission from transport, including abrasion of elements of vehicles and the surface of roads. In the summer season it is the road transport which constitutes the significant source of air contamination in cities of the Eastern Europe [2]. High temperatures of the air cause, that the factor, which is heating of the buildings, is eliminated. At the same time low relative humidity of the air favors uplifting of the particulate matter from surfaces of the roads, mainly by moving vehicles. This was confirmed by the fact of higher concentrations of particulate matter in the summer season at communication measurement station (Jana Pawła II Street) than at the background stations (Polanka and Szymanowskiego Streets)

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