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Kacper RAWICKI

VARIABILITY OF PARTICULATE MATTER CONCENTRATIONS IN POLAND IN THE WINTER 2012 / 2013

ZMIENNOŚĆ STĘŻENIA PYŁU ZAWIESZONEGO NA TERENIE POLSKI ZIMĄ NA PRZEŁOMIE 2012 I 2013 ROKU

Institute of Technology and Life Sciences, West Pomeranian Research Centre in Szczecin, Poland

Streszczenie. W okresie zimowym pogorszenie jakości powietrza na ogół związane jest z przekroczeniem norm przyjętych dla pyłu zawieszonego; epizody smogowe prawie zawsze są następstwem zwiększonej emisji spowodowanej spadkiem temperatury powietrza i występują w naszym kraju prawie każdej zimy. Oceniono w pracy zmienność imisji pyłu w powiązaniu z temperaturą powietrza w okresie kalendarzowej zimy – od grudnia 2012 r. do lutego 2013 r. w głównych miastach Polski. Analizą objęto godzinne i dobowe stężenia obu frakcji pyłu zawieszonego, PM10 i PM2,5 zarejestrowanych w 25 stacjach. Stężenie PM10 przekraczające dobową normę (50 μg · m^{-3}) stwierdzono w południowych rejonach kraju aż w 70% dni analizowanego sezonu zimowego, przy czym najwięcej w grudniu 2012 r. W tym miesiącu w większości stacji odnotowano także maksymalne dobowe wartości imisji. Wykazano, że zmienność warunków termicznych w analizowanym okresie miała statystycznie istotny wpływ na wielkość imisji pyłu PM2,5 i PM10 w powietrzu.

Key words: air temperature, correlation analysis, daily standard, PM2.5, PM10.
Słowa kluczowe: analiza korelacji, norma dobowa, PM2,5, PM10, temperatura powietrza.

INTRODUCTION

Despite gradual improvements in air quality, excessive values of particulate matter concentration, recorded particularly in urban stations, are still a problem in Poland (Majewski 2005). The problem of poor air quality is common both in small cities as well as large agglomerations in many European countries (Frans et al. 2008). Due to large amount of sources of emission – natural as well as anthropogenic, particulate matter can vary in terms of its physical properties (i.e. the size and density of particles) as well as chemical composition (Querol et al. 2004).

The most commonly monitored fractions of particulate matter are PM2.5 (diameter of particles below 2.5 μm) and PM10 (below 10 μm) (Directive… 2008). Smaller particles of particulate matter – PM2.5, can be transported large distance and their concentrations in air can linger up to several weeks. PM2.5 is a dangerous pathogenic agent and in comparison with PM10 it penetrates deeper into respiratory system and settles in alveoli. Both particulate matter fractions (PM2.5 and PM10) contain mutagenic and cytotoxic substances, and pose significant threat not only to human health but also life (Kozłowska et al. 2011).

Corresponding Author – Adres do korespondencji: MSc Kacper Rawicki, Institute of Technology and Life Sciences, West Pomeranian Research Centre in Szczecin, Czesława 9, 71-504 Szczecin, Poland, e-mail: k.rawicki@itp.edu.pl

Numerous papers show a marked increase in particulate matter pollution in winter seasons which coincides with increased heating processes resulting from the decrease in air temperature (Jóźwiak and Wróblewski 2002, Czarnecka and Kalbarczyk 2008). Apart from local and anthropogenic sources of emission, geographical conditions (i.e. land relief) and climatic conditions such as temperature, radiation, humidity, precipitation and air masses recirculation, have influence on the concentration on pollutants (Querol et al. 2004). Stationary combustion, the residential sector in particular, is among the main sources of PM10 initial emission in Poland (Czarnecka and Kalbarczyk 2008). Additionally, significant share of PM10 pollution results from an increased volume of vehicular traffic. Dusty and rarely cleaned cities as well as vehicular traffic cause increased secondary pollution of particulate matter (Majewski 2005; Lawrence et al. 2013).

The aim of the research was to determine variability of PM2.5 and PM 10 concentration in major Polish cities in relation to air temperature during the calendar winter period from December 2012 to February 2013.

MATERIALS AND METHODS

The research is based on data concerning daily PM2.5 and PM10 concentration as well as air temperature obtained from the automatic monitoring stations of the Voivodeship Inspectorate of Environmental Protection. The analysis of variability of particulate matter concentration was based on data obtained from 25 measuring stations all of which are located within city limits. Due to lack of records concerning air temperature in Białystok and Nowy Sącz, data from 23 stations listed in Table 1 were used in the research. All measuring stations automatically record PM10 concentrations, however only 12 of them additionally measure PM2.5 concentration.

The obtained values concerning concentration of particulate matter were compared with admissible values as specified in the Regulation of the Minister of Environment dated 24 August 2012 on levels of certain substances in air which specifies the standard level of admissible PM2.5 concentration as 25 $\mu g \cdot m^{-3}$ per year – to be obtained till 2015. However, the aforementioned Regulation does not specify the admissible daily concentration of PM2.5. The Regulation specifies the mean daily PM10 concentration as 50 $\mu g \cdot m^{-3}$ and allows for excess of this standard lasting up to 35 days in a year (Regulation of the Minister of Environment… 2012).

The effect of temperature on PM2.5 and PM10 concentrations was determined with the use of correlation analysis in STATISTICA software at the level of significance α=0.01. The correlated variables were mean daily concentrations of particulate matter ad mean daily air temperature.

RESULTS AND DISCUSSION

In the analysed period (December 2012 – February 2013) mean monthly PM2.5 concentration varied depending on location of the measuring station and ranged from 31 $\mu g \cdot m^{-3}$ to 79 $\mu g \cdot m^{-3}$. Monthly PM10 concentration of ranged from 27 $\mu g \cdot m^{-3}$ to 105 $\mu g \cdot m^{-3}$. The greatest variability of PM2.5 and PM10 concentration, expressed with standard deviation, was recorded in the southern part of Poland – Rybnik was characterized by the record high variability of PM10 concentration (over 113 μg · m^{-3}). High standard deviation (over 52 μg · m^{-3}) was also found for Kraków and Gliwice. Both fractions of particulate matter exhibited similar spatial distribution features – in the south of Poland mean concentration recorded in the analysed period were at least two times (PM2.5) or even three times (PM10) higher than concentrations recorded in the other parts of the country. In the south of Poland, the cities of the Upper Silesian Industry Region and additionally Jelenia Góra, Kraków and Żywiec were characterised by particularly high concentrations of both fractions of particulate matter, whereas the smallest concentration of both fractions was recorded in Szczecin.

The negative effect of high concentrations of particulate matter on human wellbeing and health is well-established by numerous research studies. The study on concentration of pollutants in air by Nidzgorska-Lencewicz and Mąkosza (2014) indicates the statistically significant relationship between high PM2.5 and PM10 concentrations and worsening of bioclimatic conditions. According to Tainio et al. (2010), high concentration of particulate matter recorded in Poland contributes to several thousand premature deaths a year. As can be seen from data presented in Fig. 1, maximum daily concentrations of particulate matter can be as high as over 300 μg · m^{-3} (PM2.5) and over 700 μg · m^{-3} (PM10) in the southern parts of Poland.

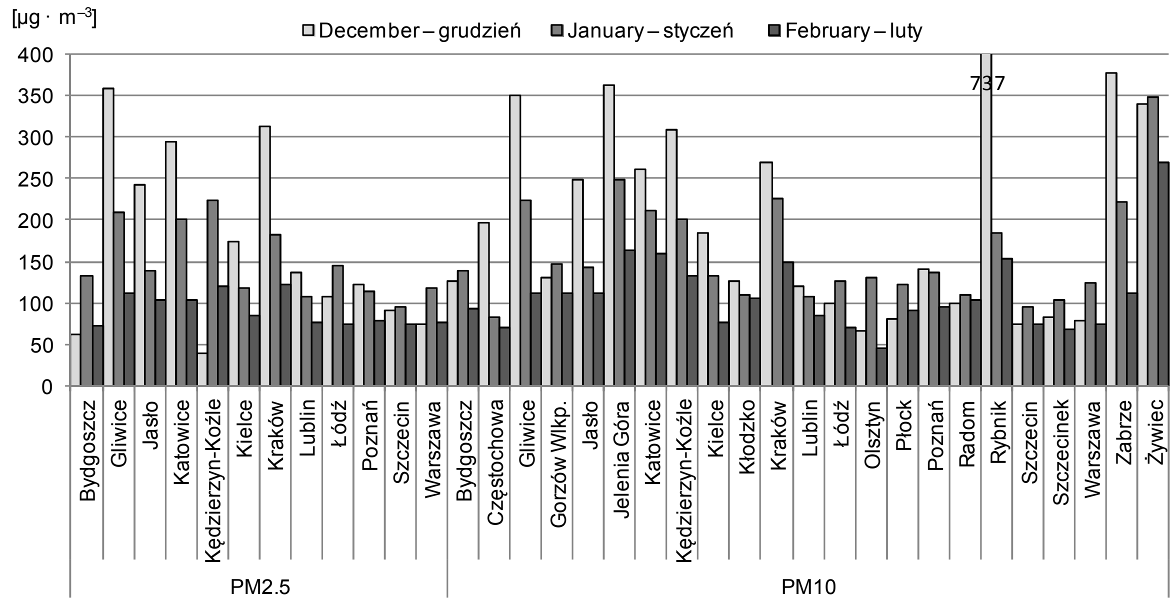

Fig. 1. The maximum daily concentration of particulate matter In the period from December 2012 to February 2013
Ryc. 1. Maksymalne dobowe stężenie pyłu zawieszonego w okresie od grudnia 2012 r. do lutego 2013 r.

The highest maximum daily concentration of PM2.5 and PM10 were recorded in December, particularly by the measuring stations located in Silesian Voivodeship. Daily PM2.5 concentration in Gliwice amounted to 358 μg · m^{-3}, and 294 μg · m^{-3} in Katowice. Slightly lower concentration of pollutants (314 μg · m^{-3}) was recorded in Lesser Poland Voivodeship – in Kraków. All-time high daily concentration of PM10 was recorded in Rybnik – 737 μg · m^{-3}.

High concentrations were also recorded in Gliwice – 350 μg · m^{-3} and Zabrze – 378 μg · m^{-3}. Maximum daily particulate matter concentrations recorded in cities located in the central and northern part of Poland were generally around three times smaller than that recorded in cities in the south of Poland – similarly to mean concentrations recorded during the analysed calendar winter.

The excess of daily standard of PM10 concentration (50 μg · m^{-3}) was observed in approximately 10% of days in the northern part of Poland and as much as 70% of days in the southern regions of the country (Fig. 2).

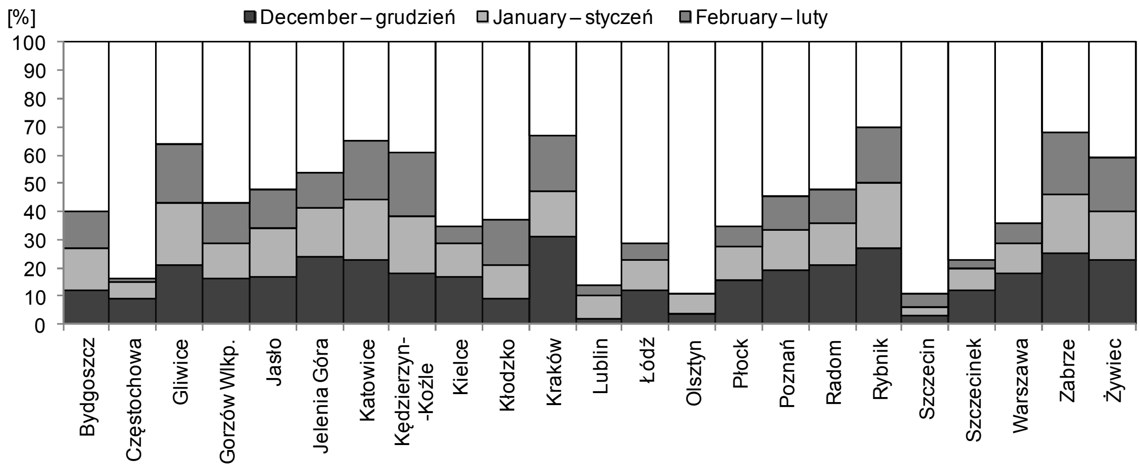

Fig. 2. Percentage of days with overnorm daily concentration of PM10 in period from December 2012 to February 2013
Ryc. 2. Procent dni z ponadnormatywnym dobowym stężeniem pyłu PM10 w okresie od grudnia 2012 r. do lutego 2013 r.

The highest number of days with an excess of standard PM10 concentration was recorded in December 2012. Excessive values were recorded on almost all days of December (28 days) in Kraków, and in Rybnik, Jelenia Góra and Zabrze on 22–24 days. Considering the maximum admissible number of days on which the standard concentration values can be exceeded (up to 35 days in a year) it transpires that in some cities the standard was already exceeded in the two months of the analysed calendar winter – January and February. In Gliwice, Katowice, Kędzierzyn-Koźle the daily standard was exceeded in 38 or 39 cases in the period of two months.

According to the Institute of Meteorology and Water Management IMGW (Biuletyn... 2013), in terms of temperature the winter of 2012 / 2013 was within normal limits in the most part of Poland, and only in Masurian Lake District the winter can be described as frosty. However, in most regions of the country the temperature below standard was recorded in December, whereas in the eastern regions of Poland in February the mean monthly temperature was by 2°C higher than in the period 1971–2000. According to data recorded by urban measuring stations included in the analysis, mean seasonal temperature (December – February) ranged from –3.9ºC in Zabrze to 0.5ºC in Poznań. Even though the analysed winter season was characterised by average thermal conditions, PM10 concentration was high in comparison with concentration recorded during winter periods characterised by extreme thermal conditions.

According to research by Czarnecka and Nidzgorska-Lencewicz (2011) in the winter of 2005 / 2006, which in the most part of Poland was characterised by temperature 5ºC lower than the average in the multi-year period, mean monthly PM10 concentration recorded in urban stations generally ranged from 50 µg · m^{-3} do 150 µg · m^{-3} – slightly exceeding the concentration recorded in the analysed winter period and exhibiting similar spatial variation.

In the winter of 2012 / 2013, PM2.5 and PM10 concentration recorded in all measuring stations indicate statistically significant relationship with variability of thermal conditions, and all correlation coefficients were significant at α = 0, 01 (Table 1).

Table 1. The statistical characteristics of particulate matter variability depending on the air temperature
Tabela 1. Charakterystyka statystyczna zmienności stężenia pyłu zawieszonego w zależności od temperatury powietrza

	The average seasonal air temperature Średnia sezonowa temperatura powietrza [°C]	PM2.5			PM10		
		the average seasonal concentration średnie stężenie sezonowe [µg · m^{-3}]	standard deviation odchylenie standardowe [µg · m^{-3}]	the correlation coefficient współczynnik korelacji	the average seasonal concentration średnie stężenie sezonowe [µg · m^{-3}]	standard deviation odchylenie standardowe [µg · m^{-3}]	the correlation coefficient współczynnik korelacji
Bydgoszcz	–1.1	37	24.6	–0.49	50	25.2	–0.51
Częstochowa	–2.3	●	●	●	33	27.4	–0.51
Gliwice	–1.3	74	52.8	–0.53	82	53.2	–0.49
Gorzów Wielkopolski	–3.6	●	●	●	57	34.2	–0.59
Jasło	–1.3	52	32.1	–0.61	54	48.5	–0.61
Jelenia Góra	–1.9	●	●	●	80	68.1	–0.60
Katowice	–1.6	69	47.9	–0.59	75	48.1	–0.56
Kędzierzyn-Koźle	–3.4	59	40.0	–0.41	68	53.7	–0.58
Kielce	–2.4	49	29.5	–0.53	47	32.4	–0.50
Kłodzko	–1.3	●	●	●	47	28.7	–0.64
Kraków	–1.7	79	52.3	–0.45	81	50.6	–0.46
Lublin	–3.4	39	22.9	–0.47	36	23.0	–0.42
Łódź	–2.9	46	24.8	–0.62	41	23.1	–0.56
Olsztyn	–3.4	●	●	●	33	17.8	–0.25
Płock	–2.7	●	●	●	44	21.2	–0.52
Poznań	0.5	44	27.6	–0.52	52	31.5	–0.52
Radom	–1.9	●	●	●	54	23.7	–0.60
Rybnik	–1.8	●	●	●	105	113.1	–0.50
Szczecin	0.4	31	22.5	–0.54	27	19.1	–0.49
Szczecinek	–2.0	●	●	●	39	19.0	–0.57
Warszawa	–1.7	43	19.2	–0.58	48	18.5	–0.47
Zabrze	–3.9	●	●	●	85	53.6	–0.41
Żywiec	–1.6	●	●	●	99	83.5	–0.53

● PM2.5 concentration not registered – Brak rejestracji stężeń PM2,5.

The increase in concentrations of particulate matter coincided with decrease in mean daily temperature – illustrated by dispersion charts for selected stations (Fig. 3).

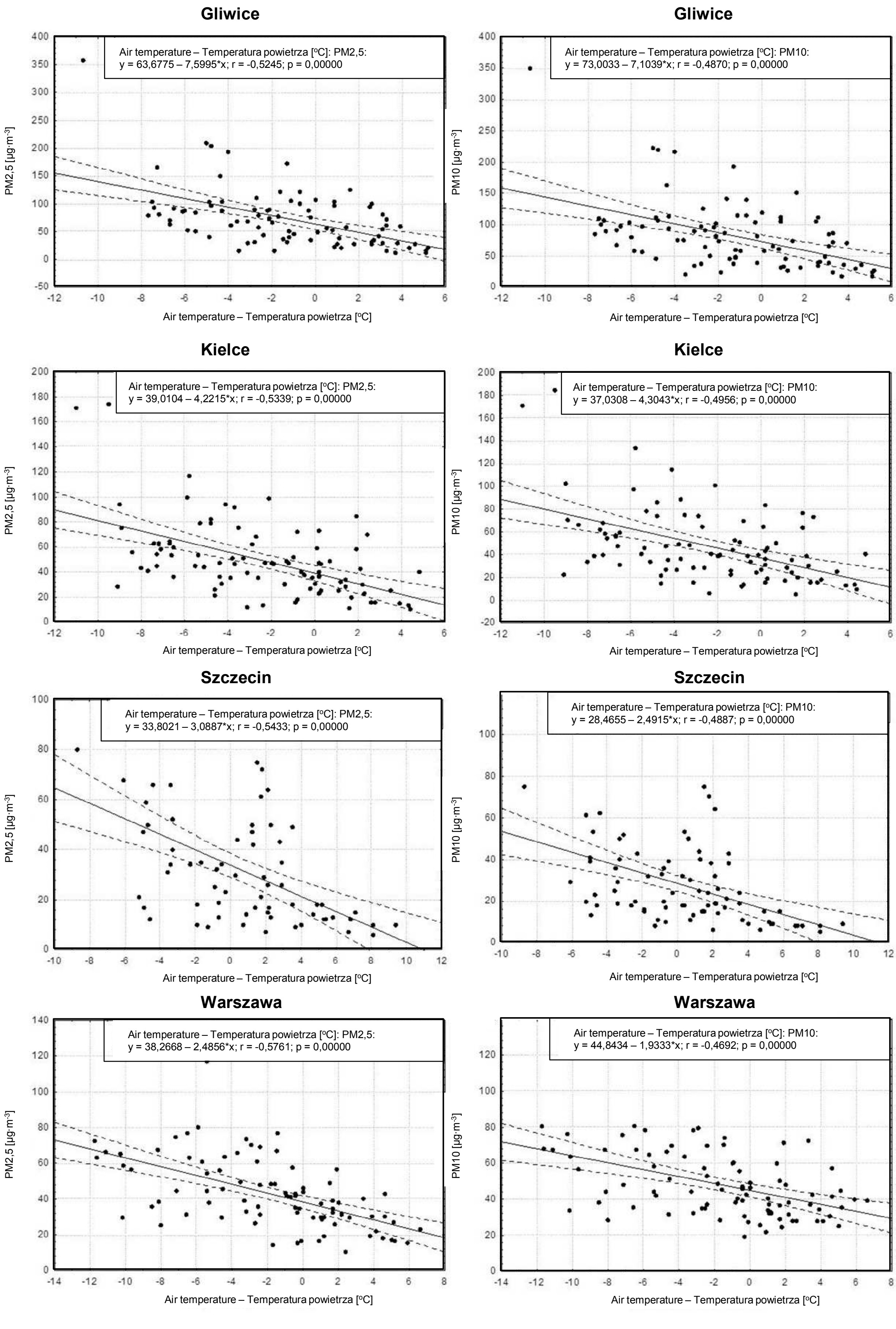

Fig. 3. The dispersion plots of the concentration of PM2.5 and PM10 air temperature
Ryc. 3. Wykresy rozrzutu zależności stężenia PM2,5 i PM10 od temperatury powietrza

The relationship between PM10 concentration and air temperature was expressed by correlation coefficients which in most stations ranged from –0.41 to –0.64. The relationship between PM2.5 concentration and temperature is less pronounced as the correlation coefficients ranged from –0.41 to –0.62. However, in some stations the influence of temperature was more pronounced in case of PM2.5 concentration than PM10 concentration – for example in Łódź or Szczecin. The strongest correlation between particulate matter concentration and air temperature was found in two mountainous basins in the Sudetes, in Jelenia Góra and Kłodzko as well as in Jasło and Radom.

The relationship between the increase in concentration of both fractions of particulate matter and decrease in temperature is strongly connected with domestic emission. Decrease in temperature in the conditions of anticyclonic weather brings about the increase of heating processes and consequently an increase of particulate matter emission resulting from the so-called low emission from local coal-burning heating plants and household furnaces fed with coal of poor quality. Importantly, local topographic conditions prevent pollution from spreading – for example Jelenia Góra, Kłodzko, Kraków. Numerous papers on the effect of air temperature on concentration and other meteorological elements on particulate matter show that the relationship is strong. According to the analysis of yearly PM10 measurements in urban background station by Grivas et al. (2004), daily PM10 concentration is higher in the winter season in comparison with other seasons in a year which is attributed to the use of traditional heating methods. Similarly, according to research conducted in the Netherlands by van der Wal and Janssen (2000), in the conditions of temperature decrease during winter season the concentration of PM10 can increase and be two times higher than that recorded in a year. Numerous authors point to the fact that PM10 concentration is to a greater extent determined by meteorological conditions than by changes in intensity of emission from natural and anthropogenic sources. Some research take into condsieration the influence of other meteorological elements on the variability of particulate matter concentration, namely Czarnecka and Kalbarczyk (2008) argue that in the Pomeranian region frequency of precipitation has a stronger influence on concentration of pollutants than air temperature.

RECAPITULATION

The analysis confirmed statistically significant effect of air temperature on variability and frequency of excessive particulate matter concentrations in the winter of 2012 / 2013 which was characterised by average conditions in terms of temperature. Even in the standard winter conditions, excessive PM10 concentration (50 μg · m^{-3}) was recorded all over the country – in the northern part on approximately 10 days of the calendar winter, whereas in the southern part the share reached 70% of the calendar winter period. The highest frequency of both the standard being exceeded and maximum daily particulate matter concentration was recorded in December 2012. The highest maximum daily PM10 concentration was recorded in Rybnik – 737 μg · m^{-3}, and for PM2.5 in Gliwice – 358 μg · m^{-3}.

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Abstract. Deterioration of air quality in winter is generally associated with exceeding the accepted norms for particulate matter, and smog episodes are almost always the consequence of increased emission caused by decrease in air temperature and occur almost every winter in Poland. The fundamental aim of this work was to evaluate the variability of dust immission in connection with air temperature during the calendar winter from December 2012 to February 2013 in major Polish cities. The analysis included hourly and daily concentrations of both fractions of particulate matter, PM10 and PM2.5 recorded at 25 stations. Concentrations

of PM10 which exceed the daily norm (50 µg · m^{-3}) were recorded in the southern parts of the country in 70% of the days of the analysed winter season – most in December 2012. In the same month the maximum daily values of concentration of pollutants were recorded in most of the stations. It has been shown that the variability of thermal conditions in the analysed period had a statistically significant effect on concentration of PM2.5 and PM10 in ambient air.