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PM2.5 AIR POLLUTION IN WARSAW AGGLOMERATION, ASSESSMENT OF INHABITANTS EXPOSURE BASED ON AIR QUALITY INDEX (AQI)

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Abstract. Manual measurements of PM2.5 concentration are performed at two air quality monitoring stations located in the Warsaw agglomeration. At the first station, named MzWarszNiepodlKom, which is managed by the Voivodship Inspectorate of Environmental Protection in Warsaw, continuous measurements of PM2.5 concentration are carried out, whereas at the second station, MzWarszSGGW, belonging to the Division of Meteorology and Climatology at Warsaw University of Life Sciences, seasonal PM2.5 measurements are available. In this paper, preliminary results of the research on PM2.5 concentration at the considered stations for years 2004-2007 are presented. Estimation of PM2.5 fraction share in PM10 was also included in the contents of this paper. Using the methodology for air quality index determination (AQI), proposed by US EPA, the variability of classes of inhabitants exposure to the analysed particulate matter fraction was subject to considerations as well.

Keywords: air pollution, particulate matter PM2.5, Air Quality Index (AQI)

INTRODUCTION

Particulate matter is the most common air pollution, occurring even on areas without anthropogenic emission sources. Owing to its commonness, particulate matter is an excellent indicator of air quality. At present, a significant environmental problem concerns the content of particulate matter of high dispersion degree in the air, especially below 10 µm, which spreads most easily and remains longer in the air, penetrating quickly into living organisms. It needs to be stressed that particulate matter does not form a uniform group and that it involves compounds and substances of a various impact on environment and of a different chemical composition. Fine particles of diameter below 2.5 µm play a key role in global climate changes related with health threat problems. They also influence the natural energy balance of the Earth by absorbing or reflecting sunlight themselves and by changing the abilities of clouds to absorb or reflect sunlight (IPCC 2001, Maricq 2007).

Data published by the European Commission proved that the key role in health risk assessment, resulting from the exposure to air pollutants, is played by the concentration level of 2.5 µm grain particulate matter (PM2.5) (Commission staff... 2005). Epidemiological studies and other research confirm a significant relationship of finest matter fractions concentration with increase of health risk to inhabitants of urban-industrial agglomerations (Petrers *et al*. 2000, Englert 2004, Wiwanitkit 2008).

For several years now different research groups have gathered data on PM2.5 within Europe (Borbely-Kiss *et al*. 1999, Marcazzan *et al*. 2001, Querol 2001, Klejnowski *et al*. 2008). In many cases, the research on particulate matter air pollution results in similar or almost identical PM10 and PM2.5 concentration values (Alastuey *et al*. 2004). It means, that in research spots, the mass of particulate matter containing particles of aerodynamic diameter between 2.5 and 10 µm is small. Therefore, in air quality research it is vital to know the ratio of both fractions, which was expressed dividing PM2.5 by PM10 concentration. The average abovementioned ratio of these air pollutants concentration for urbanized areas ranges from 0.5 to 0.8 (Elvingson 2006).

In Poland, research on PM2.5 particulate matter began in mid 1990's (Pastuszka 1997). Systematic PM2.5 particulate matter measurements have been carried out for several years by the Voivodship Inspectorate of Environmental Protection in Malopolska Voividship, at the Institute of Environmental Engineering of the Polish Academy of Sciences (IEE PAS) in Zabrze, together with the Voivodship Inspectorate of Environmental Protection both in Katowice and in Lublin, and also at the Wrocław University of Technology. Recently, not until 2004, the monitoring of PM2.5 in Warsaw has been executed by the Voivodship Inspectorate of Environmental Protection and by the Division of Meteorology and Climatology at Warsaw University of Life Sciences.

The subject of a wide discussion has focused on the establishment of the normative value for PM2.5 particulate matter, because research results indicate that there is, at present, no safe concentration level for this kind of fine matter. On 21st May 2008 the European Parliament introduced finally the Directive 2008/50/WE on air quality and pure air for Europe. In that document, a vital position is taken by particulate matter as well as by measurements of its concentration, its impact on human health, the possibilities of its concentration decrease and hazard mitigation. A particular significance is assigned to PM2.5 and to measurements of its concentration. According to the Directive 2008/50/WE, the allowable mean yearly PM2.5 concentration was determined as equal to 25 μg m^{-3} (Directive 2008/50/WE- appendix XIV, section D). At the same time, WHO recommends a maximum of 10 μg m^{-3} (WHO 2005).

MATERIAL AND METHODS

The place of particulate matter concentration measurements was the air quality monitoring station Ursynow-SGGW in Warsaw (MzWarszSGGW), functioning within the regional air quality monitoring network in Mazowieckie Voivodship. The sampling point is representative for a general urban background in the area of city districts exposed to traffic emission, urban emission, and industrial emission. At MzWarszSGGW station the measurements of particulate matter concentration have been carried out since 1st January 2002 by a medium-volume dust sampler of MVS6D type made by ATMOSERVICE. The sampler is equipped with two separate heads – the first is adjusted to PM10 sampling at the flow rate set to 2.3 $m^3 h^{-1}$ (according to norm No. 12341) and the second handles PM2.5 sample collection (according to norm No. EN14907) also at the flow rate set to 2.3 $m^3 h^{-1}$. The matter collected by the filters undergoes quantitative analysis, involving its mass measurements, by weighting the filters before their installation in the dust sampler and after their sampling cycle. Proper particulate matter concentration measurements require the elimination of the influence of particles vapour absorption and for this reason the filters are kept and weighted always in constant, standard conditions. The calculation of PM10 and PM2.5 concentration values involves dividing the particulate matter mass held by the filter by the air volume which flowed through the filter This methodology of PM10 concentration measurement is consistent with the reference methodology. The results achieved using this methodology may be directly referred to the contemporarily introduced criteria concerning ambient air quality (Journal of Laws 2008, No. 47, pos. 281-concerns PM10).

The analysis carried out in this paper used mean daily PM10 and PM2.5 concentration values recorded at MzWarszSGGW station and also data on PM10 and PM2.5 concentration recorded at the automatic air quality monitoring station MzWarszNiepodlKom (station directly influenced by heavy traffic in the centre of Warsaw - so called “transportation” station). The data recorded by this station were made available by the Voivodship Inspectorate of Environmental Protection in Warsaw. All measurement data used in this paper concern the period of 2004-2007.

One of commonly used methods for informing the society about a threat level, concerning the exposure to pollution, is so called air quality index. In different countries the way of expressing this index varies, and in many cases it has relationships with normative levels (i.e. it forms a percentage of an allowable limit).

In this paper, for better illustration of PM2.5 air pollution problem, the American index AQI was used (EPA 1998, EPA 2006). The air quality index is based on criteria for substances concentration in the air and this index is defined by human health threat scale. In so called human health threat assessment, the AQI determination, resulting from daily PM2.5 concentration values, is divided into the following intervals: 0-15.4 μg m^{-3} meaning good air quality, 15.5-40.4 μg m^{-3} – which stands for medium air quality, and 40.5-65.4 μg m^{-3} – the unhealthy interval for sensitive human groups, 65.5-150.4 μg m^{-3} – unhealthy, 150.5-250.4 μg m^{-3} – very unhealthy and higher than 250.4 μg m^{-3} – dangerous.

The aim of this paper was, first of all, specification of the four-year period PM2.5 measurement results at the air quality monitoring stations in Warsaw agglomeration and, secondly, estimation of PM 2.5 concentration share in PM10 concentration. Using the methodology of air quality index determination (AQI) proposed by US EPA, the variability of classes of inhabitants exposure to the discussed particulate matter fraction influence was also presented.

RESEARCH RESULTS

Basic statistics of measurement series for the period 2004-2007 at the stations MzWarszNiepolKom and MzWarszSGGW are presented in Tables 1 and 2.

Daily PM2.5 concentration values, measured at the two monitoring stations in Warsaw agglomeration (for the period 2004-2007), ranged from 1.9 to 179.8 μg m^{-3} at the MzWarszSGGW station and from 4.0 to 183 μg m^{-3} at the MzWarszNiepodlKom station. Mean values of PM2.5 daily concentration for individual years at the MzWarzNiepodlKom station ranged from 25.6 to 38.8 μg m^{-3} (which corresponds, respectively, to 102.4% and 155.2 % of the yearly allowable limit, equal to 25 μg m^{-3}). Mean concentration values at the MzWarszSGGW station ranged from 22.2 to 31.3 μg m^{-3} (which corresponds, respectively, to 88% and 125% of the yearly allowable limit). Higher concentration values in the winter season occurred at the MzWarszSGGW station in the years 2005-2006. This confirms a different emission pattern in the winter season, which results in 1.5 times higher average winter concentration values than summer concentration values, and also points at an influence of climatic conditions on a wider variability range of concentration values for individual winter seasons of the research period. Concentration levels of PM2.5 in 2006 were significantly influenced by urban emissions during the first quarter of that year, which was the period of extremely low air temperatures occurrence. In that period, daily PM2.5 concentration values ranged from 90 to 179.8 μg m^{-3}. At the MzWarszNiepodlKom station, mean concentration values for the winter and the summer periods were at a similar level. The observed variability of yearly concentration values, recorded at the analysed stations for the period 2004-2007, did not show any decreasing trend. The reasons for this fact come from the impact of the climatic situation (extending periods without precipitation or longer periods of low air temperature occurrence) and this fact is also justified by the increase in urban emission rates, related with the rise in vehicles number in Poland, especially of vehicles imported as second-hand from other EU countries. A decrease in average yearly concentration values was observed in 2006. The reasons for that PM2.5 concentration decrease were found in the course of meteorological conditions.

Frequent occurrence of low air pressure sequences and accompanying fronts, inflow of polar-marine air, increase in wind velocity and the occurrence of precipitation contributed to the improvement of pollution spread conditions and, in consequence, the PM2.5 concentration values, registered at the stations, decreased.

Table 1. Statistics of PM2.5 concentration for the years 2004-2007 at MzWarszNiepodlKom station

Parameters	2004	2005	2006	2007
Minimum value ($\mu g\ m^{-3}$)	7,0	12,0	8,0	4,0
Maximum value ($\mu g\ m^{-3}$)	125,0	85,0	183,0	57,0
Mean value ($\mu g\ m^{-3}$)	33,4	34,2	38,8	25,6
Mean value ($\mu g\ m^{-3}$) in winter period	33,1	33,0	38,8	22,4
Mean value ($\mu g\ m^{-3}$) in summer period	33,7	37,8	-	30,2
Standard deviation ($\mu g\ m^{-3}$)	15,4	14,3	32,1	11,2
Percentile 25 ($\mu g\ m^{-3}$)	23,0	24,8	20,5	17,0
Median ($\mu g\ m^{-3}$)	30,0	30,5	30,0	24,0
Percentile 75 ($\mu g\ m^{-3}$)	41,0	41,3	44,0	34,0
Percentile 98 ($\mu g\ m^{-3}$)	72,0	71,8	143,0	50,1
AEI* ($\mu g\ m^{-3}$)			35,5	32,9
Number of 24h measurements	325	112	87	247
PM2.5 share in PM10 (%)	65,5	67,9	70,5	59,8

– no data

* Average Exposure Indicator – AEI, expressed as mean yearly concentration, calculated basing on three values: the first value is the mean concentration of the current year and two other values are the mean concentrations of two preceding years (Directive 2008/50/WE).

Table 2. Statistics of PM2.5 concentration for the years 2004-2007 at MzWarszSGGW station

Parameters	2004	2005	2006	2007
Minimum value (μg m^{-3})	5,7	1,9	3,6	3,8
Maximum value(μg m^{-3})	40,1	116,7	179,8	64,5
Mean value (μg m^{-3})	22,4	31,3	26,6	22,4
Mean value (μg m^{-3}) in winter period	22,4	38,7	35,4	22,1
Mean value (μg m^{-3})in summer period	–	23,9	19,8	22,8
Standard deviation (μg m^{-3})	10,7	26,2	30,4	14,1
Percentile 25 (μg m^{-3})	15,0	15,5	11,3	12,2
Median (μg m^{-3})	20,6	21,2	18,9	21
Percentile 75 (μg m^{-3})	28,3	34,2	29,0	29,1
Percentile 98 (μg m^{-3})	38,9	92,8	116,5	63,5
Number of 24h measurements	9	50	46	52

A vital aspect of the PM2.5 threat assessment and of forecasting the effects of implementing the new Directive of the European Parliament and the Council, dated 21st May 2008 (2008/50/WE), is the estimation of PM2.5 fraction share in a wide, country-scale monitored PM10. This estimation enables simultaneous measurement of both fractions which is carried out at MzWarszNiepodlKom station. For the years 2004-2007 the share of PM2.5 in PM10 ranged from 59.8% (2007) to 70.5% (2000) and did not differ from the average values observed in European agglomerations (Tab. 1). For comparison, Table 4 presents the percentage share of PM2.5 in PM10 for measurement series collected in other cities of Poland.

One of commonly used methods for informing the society about a threat level, concerning the exposure to pollution, is so called air quality index. In this paper, for better illustration of PM2.5 and PM10 pollution problem scale, the American indicator AQI was used (EPA 1998, EPA 2006). In Figures 1 and 2, the air quality index (AQI) for PM2.5 at the considered stations is shown for the whole period of 2004-2007, and Table 4 presents AQI values for individual years of the research period for comparison purposes. The results of four-year measurement series at the MzWarszNiepodlKom station indicate that for 78.3% of the considered period duration there occurred a good or a medium air quality. In the considered four-year period, the optimum air-sanitary conditions with regard to PM2.5 pollution dominated in 2007, whereas a good and a medium air quality took place for 89.8% of that year, and only for 10.1% of that year there were unhealthy conditions for sensitive human groups. The unhealthy conditions occurred in years 2004, 2005 and 2006. The very unhealthy conditions were observed only in 2006 (Tab. 4).

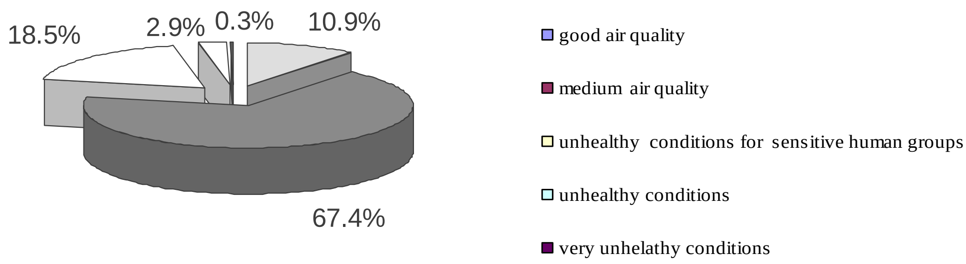

Fig. 1. Air Quality Index for PM2.5 for the years 2004-2007, MzWarszNiepodlKom station

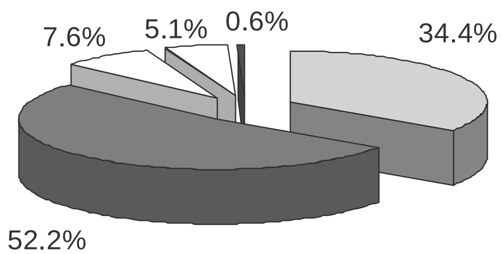

Fig. 2. Air Quality Index for PM2.5 for the years 2004-2007, MzWarszSGGW station

At MzWarszSGGW station, there was good and medium air quality for the greater part of the considered period (86.6%). The optimum air-sanitary conditions with regard to PM2.5 pollution dominated at MzWarsz SGGW station in 2007, similarly to MzWarszNiepodlKom station, while good and medium air quality took place for 88.5% of that year duration, and only for 11.5% of that year duration there were unhealthy conditions for sensitive human groups. The unhealthy conditions occurred only in the winter period of 2006.

Considering the above presented research results and CAFE data (CAFE 2004) regarding the average life expectancy decrease resulting from exposure of the examined region inhabitants to PM2.5, it can be concluded that the area of Warsaw agglomeration is subject to negative health stress, originating from high PM2.5 concentration values within the class which indicates unhealthy conditions. Therefore, a wide range of research on spatial variability of PM2.5 concentration should be brought into effect, and the issue of human groups sensitive to PM2.5 exposure level ought to be tackled, aiming at elaboration of a wise strategy for the exposure level reduction.

Table 3. PM2.5 share in PM10 at selected stations in Poland (Klejnowski *et al.* 2006, Klejnowski *et al.* 2008)

Year	Station	PM2.5/PM10 ratio (%)	Number of measurements
2005	Częstochowa	66	222
2004	Zabrze	69	123
2006	Zabrze	68	265
2007	Zabrze	70	267
2007	Katowice	70	160

Table 4. Air Quality Index for PM2.5 – comparison for the years 2004-2007

AQI	MzWarszNiepodlKom				MzWarszSGGW			
	2004	2005	2006	2007	2004	2005	2006	2007
good air quality	5,5	3,6	11,5	21,1	33,3	22,0	39,1	42,3
medium air quality (moderate)	67,7	70,5	58,6	68,8	66,7	56,0	52,2	46,2
unhealthy conditions for sensitive human groups	23,7	21,4	19,5	10,1	–	10,0	2,2	11,5
unhealthy conditions	3,1	4,5	8,0	–	–	12,0	4,3	–
very unhealthy conditions	–	–	2,3	–	–	–	2,2	–
dangerous conditions	–	–	–	–	–	–	–	–

SUMMARY AND CONCLUSIONS

The research results presented in this paper originate from the first PM2.5 concentration measurement series performed within the Warsaw agglomeration. Too low number of PM2.5 concentration values measurements (caused by numerous faults in the dust sampler at MzWarszNiepodlKom station and, as well, resulting from only seasonal measurements of PM2.5 concentration at MzWarszSGGW station) did not allow to draw broader conclusions at this stage of the research. However, on the basis of already gathered data, it can be concluded that there will be a vital problem for the Warsaw agglomeration to keep the target levels of PM2.5 concentration recommended by the Directive of the European Parliament and the Council (2008/50/WE) dated 21st May 2008. PM 2.5 concentration level, with regard to PM primary emission structure and considering the precursors of solid particles, does not favour the possibility of fast air quality improvement with respect to PM2.5.

Confronting the achieved mean yearly PM2.5 concentration values for the period 2004-2007 with the allowable PM2.5 concentration limit (Directive 2008/50/ WE), it was found that the yearly allowable limit was exceeded within the range from 102.4% to 155.2% at the MzWarszNiepolKom station. At the MzWarszSGGW station, mean PM 2.5 concentration values ranged from 88% to 125% of the yearly allowable limit.

The prevailing factor causing the occurrence of high PM 2.5 concentration values within the research area is the influence of emission from low sources of combustion and emissions from public transport.

The share of PM2.5 in PM10 is similar to its mean value observed in other European agglomerations and is equal to 65.9%. The assessment of Warsaw inhabitants exposure to air pollution, expressed as an AQI index, indicates the risk for sensitive human groups to be under the influence of high concentration levels of PM2.5 (unhealthy or very unhealthy conditions), which, simultaneously with the exposure to other environmental stresses, may take a negative health effect. This situation requires an action to be undertaken for environmental and health education and also for the creation of health threat notification system, involving information on the reasons of health threat and on the ways of mitigation of their consequences.

Contemporary knowledge concerning the negative influence of fine matter particles on various environmental zones and, in particular, on living organisms, and also the maintenance of a relatively high PM10 concentration level in Warsaw agglomeration (Majewski 2007, Majewski and Przewoźniczuk 2009), point at the need to widely extend the PM2.5 concentration measurements in the Warsaw agglomeration. Wider research on PM2.5 concentration will facilitate acquisition of better knowledge on the development of this air pollution type within the research area, and it will also simplify the elaboration of future effective policy for the possible reduction of those pollutants emission which influence PM2.5 concentration levels.

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ZANIECZYSZCZENIE POWIETRZA PYŁEM PM2.5 W AGLOMERACJI WARSZAWSKIEJ, OCENA POZIOMU NARAŻENIA MIESZKAŃCÓW NA BAZIE INDEKSU AQI

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Streszczenie. W aglomeracji warszawskiej na dwóch stacjach pomiarowych jakości powietrza prowadzone są manualne pomiary stężenia pyłu PM2.5. Na stacji MzWarszNiepodlKom, należącej do WIOŚ w Warszawie – pomiary ciągłe i na stacji MzWarszSGGW, należącej do Zakładu Meteorologii i Klimatologii SGGW – pomiary okresowe. W pracy przedstawiono wstępne wyniki badań stężenia pyłu PM2.5 na wymienionych stacjach, z lat 2004-2007. Przedstawiono również ocenę udziału frakcji PM2.5 w pyle PM10. Wykorzystując proponowaną przez US EPA metodykę określania indeksu jakości powietrza AQI, przedstawiono także, zmienność klas narażenia mieszkańców na oddziaływanie omawianej frakcji pyłu.

Słowa kluczowe: zanieczyszczenia powietrza, pył zawieszony PM2.5, Indeks Jakości Powietrza (AQI)