

CONCENTRATIONS OF  $PM_{2.5}$ ,  $PM_{2.5-10}$  AND PM-RELATED  
ELEMENTS AT TWO HEIGHTS IN AN URBAN BACKGROUND  
AREA IN ZABRZE (POLAND)

WIOLETTA ROGULA-KOZŁOWSKA, BARBARA BŁASZCZAK,  
KRZYSZTOF KLEJNOWSKI

Institute of Environmental Engineering PAS, 41-819 Zabrze  
M. Skłodowskiej-Curie str. 34

\*Corresponding author's e-mail: wioletta@ipis.zabrze.pl

**Keywords:** Particulate Matter,  $PM_{2.5}$ ,  $PM_{2.5-10}$ , fine dust, coarse dust, chemical composition, heavy metals, elements, virtual impactor, cascade impactor, energy dispersive X-ray fluorescence, EDXRF, spectrometer, urban background, spatial distribution, secondary emission, enrichment factor.

**Abstract:** Concentrations and elemental composition of fine ( $PM_{2.5}$ ) and coarse ( $PM_{2.5-10}$ ) ambient particles, at two sampling points located at the same urban background sites, were investigated. The points were 20 m distant from each other and at various heights (2 and 6 m) above the ground. A dichotomous sampler, equipped with a virtual impactor, and a cascade impactor were used to sample the dust. An X-ray fluorescence spectrometer was used in the elemental analyses. The investigations revealed heterogeneity of the spatial distribution and the elemental composition of suspended dust at the investigated urban background site. Coarse dust, whose concentration at 2.0 m above the ground was affected by secondary emission from roads, soil and other local low-level sources in some periods, appeared more heterogeneous.

## INTRODUCTION

The need to measure ambient concentrations of particulate matter (PM) is due to the effects PM exerts on health, climate, and ecosystems. It arises from the necessity of identification of sources of PM and evaluation of effects of measures undertaken to limit ambient dust concentrations [6, 12, 13, 23, 62, 67]. In Europe, ambient PM is monitored by air quality monitoring stations (e.g. the *European Monitoring and Evaluation Programme* network, EMEP), which work within various domestic [1, 52] and international [6, 9, 13] projects. However, data on PM from various sites can be hardly compared or analyzed together because of different location criteria for the stations of their origin, limited size of the data sets [39], and, what is the most important, because of differences in PM samplers applied at different sites [24]. The domestic and international guidelines recommend the gravimetric method [5, 11, 45, 46, 62] as a standard for determination of the  $PM_{2.5}$  and  $PM_{10}$  concentrations. However, the EU directives allow EU member countries to apply any method unless its consistency with the standard method cannot be proved.

Meteorological conditions [20, 32, 51, 52, 69], seasonal variability, and long-range transport of air pollutants [38, 52], but also the local conditions, affect strongly PM concentrations at a sampling site. Even very weak local sources may alter the regional representativeness of a sample [63]. The assumption of uniformity of  $PM_{2.5}$ ,  $PM_{10}$  or  $PM_{2.5-10}$  concentrations within particular urban area is usually forced by sparseness of measuring points (often a single measuring point within an area), but the actual dust concentrations in summer may vary from point to point even by 69% [23]. Addressing the issue, Wilson *et al.* (2005) [67] review works concerning hazards from atmospheric aerosol which compare PM concentrations in different points of an urban area. On the one hand, they cite works that assume and base on the uniformity of the PM concentrations in an area, on the other hand, they cite works proving spatial variability of concentrations of all PM fractions. Concluding, they recommend an individual approach to every area.

Spatial distribution of  $PM_{2.5}$  concentrations is relatively uniform. Higher concentrations may occur close to the sources. The  $PM_{2.5-10}$  concentrations are much more diversified. For example,  $PM_4$  concentration at about 3 m above the ground may be lower by only 12% than at 1 m, while this difference is 35% for total PM [36]. The criterion of 1.5–4.0 m (or up to 8.0 m in special circumstances) above the ground for the height at which the sampling head of a dust sampler should be installed is clearly defined by the 2008/50/EC Directive [11]. In the context of [36], such optionality (1.5—8 m) allows methodology for measurement of concentrations of ambient dust, and consequently of the related elements, to have itself a serious effect on comparability of results. The goal of this work was to investigate concentrations and elemental composition of  $PM_{2.5}$  and  $PM_{2.5-10}$  at two, allowed by the 2008/50/EC Directive [11], heights (2 and 6m) at the same urban background site.

## METHOD

The site selected for the experiment was an urban background area [11] in Zabrze. The PM concentrations at this site are representative of the concentrations in those living quarters of Upper Silesian cities that are affected by industrial and vehicular emissions.

At the first stage of the experiment, at two sites, horizontally distant by 20 m, samples of PM were taken with two simultaneously working samplers. The two samplers were: a sequential two-channel Ruprecht & Patashnik Dichotomous Partisol®-Plus Model 2025 (Partisol) [31] and a three-stage Dekati® $PM_{10}$  cascade impactor (Dekati) [29]. The sampling head of Partisol was located 2.0 m above the ground, the sampling head of Dekati—6.0 m. Dekati was located on the roof of the Institute building (Figure 1). On every sampling day, at 12:00 midnight (Table 1), both samplers started simultaneously and were working for 48 hours – Dekati continuously, Partisol automatically changed its substrate filter after 24 hours.

This allowed for collection of sufficient amount of PM on each Dekati stage and prevented the filters in Partisol from overloading. Measurements of PM concentrations were accompanied by measurements of basic meteorological parameters (Table 1, the Regional Inspectorate for Environmental Protection automatic station, located 20 m from Partisol and 40 m from the Institute building – Figure 1).

Table 1. Average 48h weather conditions and concentrations of fine ( $PM_{2.5}$ ) and coarse ( $PM_{2.5-10}$ ) dust at two heights (2 and 6 m) in Zabrze in 26.04–03.07.2008

Period	Height	T [°C] <sup>a)</sup>	P [hPa] <sup>b)</sup>	V [m·s <sup>-1</sup> ] <sup>c)</sup>	RH [%] <sup>d)</sup>	Pr. [mm] <sup>e)</sup>	$PM_{2.5}$ [ $\mu\text{g}\cdot\text{m}^{-3}$ ]	$PM_{2.5-10}$ [ $\mu\text{g}\cdot\text{m}^{-3}$ ]	$PM_{10}$ [ $\mu\text{g}\cdot\text{m}^{-3}$ ]
26 - 27.04.2008	6 m <sup>f)</sup>	9.5	992	0.75	69.5	0	39.2	4.1	43.3
	2 m <sup>g)</sup>						48.8	12.7	61.5
29 - 30.04.2008	6 m	11.05	973	1.15	65.5	0	30.0	7.0	37.0
	2 m						32.3	41.9	74.2
07 - 08.05.2008	6 m	10.45	986	0.9	67	0	27.8	6.1	33.9
	2 m						29.1	17.8	46.9
14 - 15.05.2008	6 m	14	979.5	0.55	56.5	0	31.9	9.2	41.1
	2 m						22.5	17.0	39.5
28 - 29.05.2008	6 m	14.6	985	1.7	52.5	0	26.4	5.6	32.0
	2 m						13.5	18.2	31.7
04 - 05.06.2008	6 m	15.55	980	1.4	73	3.9	17.1	5.2	22.3
	2 m						17.3	14.0	31.3
11 - 12.06.2008	6 m	15.4	979	0.6	92	4.4	18.9	5.7	24.6
	2 m						19.4	14.0	33.4
18 - 19.06.2008	6 m	16.25	982.5	0.7	65.5	0	26.6	6.5	33.1
	2 m						25.7	14.6	40.3
25 - 26.06.2008	6 m	19.05	983	0.6	75.5	1.5	22.8	7.0	29.8
	2 m						21.9	15.6	37.5
02 - 03.07.2008	6 m	21.4	980	0.5	43.5	0	30.6	9.0	39.6
	2 m						25.9	20.1	46.0

<sup>a)</sup> weather conditions for the site were taken from the RIEP Internet site; they were used to compute two-day averages of meteorological data (arithmetical means for two days)

<sup>a)</sup> T – air temperature; <sup>b)</sup> P – atmospheric pressure; <sup>c)</sup> V – wind speed at 14 m above the ground level; <sup>d)</sup> RH – relative humidity of air; <sup>e)</sup> Pr. – precipitation, <sup>f)</sup> sampled with Dekati, <sup>g)</sup> sampled with Partisol

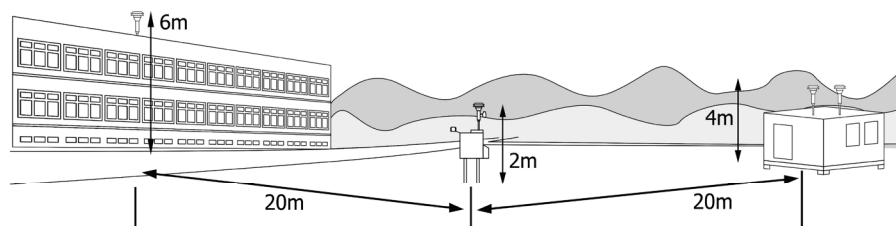


Figure 1. Arrangement of the samplers at the measuring site in Zabrze: Dekati, Partisol, and TEOMs (6, 2, 4 m above the ground, respectively)

The experiment was carried out in spring and summer, between 26 April and 3 July, because in winter very high municipal emission obscures contributions of other sources (e.g. vehicular) in the area [44, 53].

For both,  $PM_{2.5}$  and  $PM_{2.5-10}$ , 48h concentrations were determined from masses of collected dust and volumes of air passed through the samplers. The masses were de-

terminated gravimetrically, according to [45, 46]. The substrates were conditioned for 48 hours in the weighing room (air humidity  $45 \pm 5\%$ , air temperature  $20 \pm 2^\circ\text{C}$ ) before weighing. Each substrate was weighed twice with a 24 h period between the weighings, before and after exposure, on a Mettler Toledo microbalance (resolution  $2 \mu\text{g}$ ). A clean substrate was rejected if its two weights differed more than  $10 \mu\text{g}$ . Before chemical analyses, substrates were stored in tight containers in a refrigerator.

All samples were analyzed for their elemental composition by using energy dispersive X-ray fluorescence (EDXRF). PANalytical Epsilon 5, used in the analyses, was equipped with a water-cooled X-ray tube (Gadolinium anode, working range 25–100 kV,  $150 \mu\text{m}$  thick Be side window), system of nine secondary targets (Al, Ti, Fe, Ge, Zr, Mo, Ag,  $\text{Ce}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ ), Ge(Li) detector (resolution of 140 eV, energy range 0.7–100 keV,  $30 \text{ mm}^2$  active area,  $8 \mu\text{m}$  thick Be window).

Measurements were done in vacuum, each analysis lasted for 4800 s (the whole runtime of the analytical program using secondary targets: Al, Ti, Fe, Ge, Zr and  $\text{Al}_2\text{O}_3$ ). The concentrations of particular analytes were determined by comparing the results with calibration curves. The curves were determined by applying the Micromatter Inc. thin layer standards, the factors correcting the inter-elemental effects were referred to.

The limits of detection and recoveries of the standard (NIST 2873) for the procedure are presented in Table 2.

Table 2. Limits of detection and recoveries of the standard for the EDXRF procedure for determination of content of elements in suspended dust collected on Teflon filters

Element	Limit of detection		Recovery, %
	$\text{ng}\cdot\text{cm}^2$	$\text{ng}\cdot\text{m}^3$ *	
S	1.5	0.7	96
Cl	1.3	0.6	-
Ca	1.2	0.6	86
Ti	0.8	0.4	99
Cr	0.9	0.4	103
Fe	0.7	0.3	102
Ni	0.6	0.3	88
Zn	0.9	0.4	112
As	11.6	5.8	84
Br	0.4	0.2	-
Cd	4.5	2.2	-
Pb	0.3	0.1	116

\* flow rate  $21.6 \text{ m}^3$

## RESULTS

### **Mass concentrations of $PM_{2.5}$ and $PM_{2.5-10}$**

In Table 1, 48 h concentrations of  $PM_{2.5}$  and  $PM_{2.5-10}$  are presented. Concentrations were measured with the use of two samplers, Partisol and Dekati, at the same urban background site in Zabrze, at two different heights: 2.0 m (Partisol) and 6.0 m (Dekati) above the ground. Dekati allows for simultaneous measurement of concentrations of  $PM_{1,}$

PM<sub>1-2.5</sub>, and PM<sub>2.5-10</sub>. The Dekati-measured PM<sub>2.5</sub> concentration is the sum of the concentrations of dust collected on the Dekati afterfilter and its third stage (PM<sub>1</sub>+PM<sub>1-2.5</sub>). The average concentrations of PM<sub>2.5</sub> in the measuring period (26.04–03.07.2008) were 26  $\mu\text{g}\cdot\text{m}^{-3}$  at 2.0 m and 27  $\mu\text{g}\cdot\text{m}^{-3}$  at 6.0 m. The minimum PM<sub>2.5</sub> concentrations, 14  $\mu\text{g}\cdot\text{m}^{-3}$  at 2.0 m and 17  $\mu\text{g}\cdot\text{m}^{-3}$  at 6.0 m, occurred on 28–29.05 and 04–05.06, respectively (Table 1). The maxima, 49  $\mu\text{g}\cdot\text{m}^{-3}$  at 2.0 m and 39  $\mu\text{g}\cdot\text{m}^{-3}$  at 6.0 m, occurred on 26–27.04. Also on 26–27.04, the lowest PM<sub>2.5-10</sub> concentrations, 13  $\mu\text{g}\cdot\text{m}^{-3}$  at 2.0 m and 4  $\mu\text{g}\cdot\text{m}^{-3}$  at 6.0 m, occurred. The maximum PM<sub>2.5</sub> concentrations are much higher than the other PM<sub>2.5</sub> concentrations.

The concentrations of PM<sub>2.5-10</sub>, like those of PM<sub>2.5</sub>, fell into a very wide interval. The average PM<sub>2.5-10</sub> concentration at 2.0 m was 19  $\mu\text{g}\cdot\text{m}^{-3}$ , almost three times the average concentration at 6.0 m (7  $\mu\text{g}\cdot\text{m}^{-3}$ , Table 1). The maximum PM<sub>2.5-10</sub> concentration at 6.0 m, 9  $\mu\text{g}\cdot\text{m}^{-3}$ , occurred twice: on 14-15.05 and 02–03.07; the one at 2.0 m, four times greater (42  $\mu\text{g}\cdot\text{m}^{-3}$ ), occurred on 29–30.04.

Several independent factors shape concentrations of air pollutants. The most effective are emission, meteorological conditions, and geographical location [33, 49, 52]. Nevertheless, in the period 26.04–03.07.2008, neither fine nor coarse dust concentrations were significantly correlated with the meteorological parameters (Table 3).

Table 3. Pearson linear correlation coefficients for sets of 48h average concentrations determined gravimetrically (PARTISOL/DEKATI) and automatically (TEOM) and Pearson linear correlation coefficients for meteorological parameters and concentrations of PM<sub>2.5</sub> and PM<sub>2.5-10</sub> in 26.04–03.07.2008

	Partisol	Dekati	TEOM <sup>a)</sup>	T [°C] <sup>b)</sup>	P [hPa] <sup>c)</sup>	V [m/s] <sup>d)</sup>	RH [%] <sup>e)</sup>	Pr. [mm] <sup>f)</sup>
PM <sub>2.5</sub>								
Partisol <sup>g)</sup>	1	0.78	0.90	-0.41	0.40	-0.25	-0.51	-0.81
Dekati <sup>h)</sup>	-	1	0.74	-0.55	0.42	-0.33	0.01	-0.43
TEOM <sup>i)</sup>	-	-	1	-	-	-	-	-
PM <sub>2.5-10</sub>								
Partisol	1	0.28	-	0.51	-0.54	-0.47	-0.54	-0.33
Dekati	-	1	-	-0.23	-0.66	0.23	-0.22	-0.32
TEOM	-	-	1	-	-	-	-	-
PM <sub>10</sub>								
Partisol	1	-	0.51	-	-	-	-	-
Dekati	-	1	0.79	-	-	-	-	-
TEOM	-	-	1	-	-	-	-	-

<sup>a)</sup> TEOM for PM<sub>2.5</sub> measurements was operated by the authors of the paper; TEOM for PM<sub>10</sub> measurements was operated by the Regional Inspectorate for Environmental Protection;

<sup>b)</sup> T – air temperature; <sup>c)</sup> P – atmospheric pressure; <sup>d)</sup> V – wind speed at 14 m above the ground level; <sup>e)</sup> RH – relative humidity of air; <sup>f)</sup> Pr. – precipitation, <sup>g)</sup> sampled at 2m, <sup>h)</sup> sampled at 6m, <sup>i)</sup> sampled at 4m

Possibly, the insufficiency of data prevented the credible statistical analysis. Relatively strong linear correlations were found between precipitation and PM<sub>2.5</sub> concentrations (Pearson correlation coefficient  $r = -0.81$ ), and between atmospheric pressure and PM<sub>2.5-10</sub> concentrations ( $r = -0.66$ ). The lack of correlations between the concentrations and majority of meteorological parameters may also be due to domination of local dust sources [49].

The 48h concentrations of  $PM_{2.5}$  at both heights were fairly well correlated ( $r = 0.78$  – Table 3). However, the differences between them were significant (even  $13 \mu\text{g}\cdot\text{m}^{-3}$ ) on 28–29.05 (Table 1). Except for the first three pairs, where the concentrations differed by at most  $10 \mu\text{g}\cdot\text{m}^{-3}$  on 26–27.04, the concentrations at 6.0 m were higher than or (like on 04–05.06 and 11–12.06) equal to the concentrations at 2.0 m (Table 1).

The differences between  $PM_{2.5-10}$  concentrations at 2.0 m and 6.0 m were between  $7.8 \mu\text{g}\cdot\text{m}^{-3}$  (14–15.05) and  $34.9 \mu\text{g}\cdot\text{m}^{-3}$  (29–30.04). Their average,  $12 \mu\text{g}\cdot\text{m}^{-3}$ , is three times higher than the average difference between the  $PM_{2.5}$  concentrations. The Pearson coefficient ( $r = 0.28$ , Table 3) proves a lack of correlation between  $PM_{2.5-10}$  concentrations at the two heights. The spatial variability of  $PM_{2.5-10}$  concentration is considerable in the area.

The results from Partisol and Decati were also checked for their linear correlation with the results from automatic monitors of  $PM_{10}$  and  $PM_{2.5}$  (TEOMs). The TEOM station was located about 20 m from Partisol and 40 m from Decati. The TEOM measuring  $PM_{2.5}$  was operated by the authors, whereas the TEOM measuring  $PM_{10}$  was operated by the Regional Inspectorate for Environmental Protection (RIEP) in Katowice [68]. The sampling heads of the two TEOMs were at 4 m above the ground level.

The  $PM_{2.5}$  concentrations from Partisol were better correlated with the  $PM_{2.5}$  concentrations from TEOM ( $r = 0.67$ ) than the concentrations from Dekati. There was no significant correlation between the results from Partisol and TEOM for  $PM_{2.5-10}$ ; the linear correlation coefficient for  $PM_{2.5-10}$  concentrations from Dekati and TEOM was  $r = 0.79$  (Table 3). It means that in the period 26.04–03.07.2008 the height of sampling head had a great effect on measurement of concentration of dust, especially coarse dust. Obviously, the Partisol head, 2.0 m above the ground, collected secondary dust.

The Decati and TEOM heads were located at heights excluding or strongly limiting effects of secondary  $PM_{2.5-10}$  emission. This explains as well the good linear correlation of the  $PM_{2.5-10}$  concentrations from Dekati and TEOM as the Partisol-Dekati and the Partisol-TEOM differences in these concentrations. Because secondary emission adds almost exclusively to coarse particles [57] the difference in heights of sampling heads did not affect significantly the  $PM_{2.5}$  concentrations.

The better correlation between  $PM_{2.5}$  concentrations from Partisol and TEOM is probably due to identity of their sampling heads (US EPA [61], air flow rate  $1 \text{ m}^3\cdot\text{h}^{-1}$ ). Concentrations from longer periods covering uniformly winter (slight effect of secondary emission on  $PM_{2.5-10}$  concentrations) and summer are in high linear correlation as well when measured with Partisol and Decati as with Partisol and TEOM for both  $PM_{2.5}$  and  $PM_{2.5-10}$  [30].

The results from the period 2007–2008 from the investigated site are presented in Table 4.

Partisol was used to measure 24 h concentrations in uneven months of 2007 and the whole year 2008. In 2007–2008 Dekati started every third day and measured 48 h concentrations. The  $PM_{2.5}$  concentrations from 04–07.2008 (this study) are lower than the yearly average concentrations, the  $PM_{2.5-10}$  concentrations from 04–07.2008 are higher than the averages from 2007 and 2008 (Table 4).

In general, the  $PM_{2.5-10}$  concentrations show seasonal fluctuations. They assume higher values in spring (greater part of 04–07.2008) and winter, lower in summer and autumn [17]. High yearly  $PM_{2.5}$  concentrations are caused by high concentrations in winter (heating season) – not only in the south of Poland (Zabrze) but also in other European

Table 4. Mass concentrations of PM<sub>2.5</sub> and PM<sub>2.5-10</sub> at selected sites in Europe and the world

Country	Location, measuring period	PM <sub>2.5</sub> [μg·m <sup>-3</sup> ]	PM <sub>2.5-10</sub> [μg·m <sup>-3</sup> ]
Poland, Upper Silesia	Zabrze (urban background, PARTISOL); IV-VII 2008 <sup>a)</sup>	27	19
	Zabrze (urban background, DEKATI); IV-VII 2008 <sup>a)</sup>	26	7
	Zabrze (urban background, PARTISOL); 2007 ( <i>n</i> = 181) <sup>b)</sup>	33.1	10
	Zabrze (urban background, PARTISOL); 2008 ( <i>n</i> = 354) <sup>b)</sup>	40.5	9
	Zabrze (urban background, DEKATI); 2007 ( <i>n</i> = 106) <sup>b)</sup>	38.5	5
	Zabrze (urban background, DEKATI); 2008 ( <i>n</i> = 81) <sup>b)</sup>	42.7	5
	Zabrze(urban background station);smog episode (01.2006) <sup>c)</sup>	187.30	25.19
Finland	Helsinki (urban background); 23 VIII – 23 IX 2002 <sup>d)</sup>	11.5	6.82
Spain	Tarragona (urban background); 2001 <sup>e)</sup>	21.8	15.6
	Huelva (urban background); 2001 <sup>e)</sup>	19.3	18.2
	Alcobendas (urban background); 2001 <sup>e)</sup>	24.9	7.3
	Llodio (urban background); 2001r. <sup>e)</sup>	23.9	7.8
	Madrid (urban background); 1999 – 2000 <sup>e)</sup>	34.1	13.6
Netherlands	Arnhem (background); VIII – IX 1994 <sup>g)</sup>	35.0	26.8
Scotland	Fort William (suburban station); 2007 <sup>h)</sup>	10	4
Swiss	Zurich-Kaserne (city center, yard); IV 1998r. – III 1999r. <sup>i)</sup>	20	6.3
	Basilea (suburb); IV 1998r. – III 1999 <sup>o)</sup>	18.9	6.7
Turkey	Erzurum; II 2005r. – II 2006r. <sup>j)</sup>	12.67	17.96
	Erzurum; heating season <sup>j)</sup>	19	17
	Erzurum; non-heating season <sup>j)</sup>	6	19
Southern Wales	Port Talbot (industrial station); 26 IV – 25 V 2001 <sup>k)</sup>	83.61	54.73
	Cardiff (urban station); 22 I – 06 III 2001 <sup>k)</sup>	89.87	26.31
Hungary	Budapest (urban background); 12 – 17 IV 1999 <sup>l)</sup>	30	35
Hungary	Budapest (city centre, park); 19 IV – 13 V 1999 <sup>l)</sup>	28	41
Italy	Milan (urban station); winter 1997/1998 <sup>m)</sup>	70	40
	Milan (urban station); summer 1998 <sup>m)</sup>	51	23
Mexico	Mexico city (urban area, various sources); III 2006 <sup>n)</sup>	50	37.7
Brazil	Rio de Janeiro; X 1998r. – IX 1999 <sup>o)</sup>	17.1	25.7
Australia	Brisbane; II – IV 2003r. <sup>p)</sup>	4.5	7.3
	Melbourne (Australia); II – IV 2003 <sup>p)</sup>	5.9	8.3
	Sydney (Australia); II – IV 2003 <sup>p)</sup>	5.5	8.3
Southern Africa	Qualabothja (urban area); winter 1997 <sup>q)</sup>	115.46	11.95
Bangladesh	Dhaka (living quarter, moderate traffic); I – IV 2006 <sup>r)</sup>	63.6	10.1
	Dhaka (urban-rural area); I – IV 2006r. <sup>r)</sup>	57.1	4.9
China	Guangzhou (city center, dense traffic); 02 VIII – 10 IX 2004 <sup>s)</sup>	103.35	41.17
India	Kolkata (agglomeration); winter 2002 <sup>o)</sup>	178.57	125.47
Lebanon	Beirut (living and commercial area); III – VIII 2004 <sup>u)</sup>	33.50	54.03
	Beirut (living and commercial area); II 2004r. – I 2005 <sup>u)</sup>	34.36	64.96
Taiwan	Taichung Harbor (spring– III, IV, V) <sup>v)</sup>	49.3	37.0
	Taichung Harbor (summer – VI, VII, VIII) <sup>v)</sup>	46.4	26.6
	Taichung Harbor (autumn – IX, X, XI) <sup>v)</sup>	43.0	26.2
	Taichung Harbor (winter – XII, I) <sup>v)</sup>	49.5	36.0
Vietnam	Ho Chi Minh (urban station) <sup>w)</sup>	32	16

<sup>a)</sup> [this study]; <sup>b)</sup> [investigation conducted in IEE PAS]; <sup>c)</sup> [44]; <sup>d)</sup> [58]; <sup>e)</sup> [48]; <sup>f)</sup> [47]; <sup>g)</sup> [26]; <sup>h)</sup> [1]; <sup>i)</sup> [26]; <sup>j)</sup> [3]; <sup>k)</sup> [38]; <sup>l)</sup> [57]; <sup>m)</sup> [34]; <sup>n)</sup> [40]; <sup>o)</sup> [35]; <sup>p)</sup> [22]; <sup>q)</sup> [14]; <sup>r)</sup> [55]; <sup>s)</sup> [64]; <sup>t)</sup> [10]; <sup>u)</sup> [56]; <sup>v)</sup> [17]; <sup>w)</sup> [16]



(e.g. Italy) and world (The Republic of South Africa, Turkey, Taiwan, India) urbanized areas (Table 4). Accidentally, intensive combustion of fossil fuels in heating season, yielding rapidly peaking emission of fine dust from low-level domestic sources, together with specific weather conditions, cause smog episodes similar to the one that occurred in Zabrze in January 2006 (Table 4).

$PM_{2.5}$  concentrations at urban background sites in Finland, Scotland, Switzerland, the Netherlands, Brazil or Llodio in Spain are lower than in Zabrze. But in many areas in Europe (Barcelona in Spain, Arnhem in The Netherlands, Hungary, Italy, Southern Wales), North America (Mexico), Africa (The Republic of South Africa), Asia (Bangladesh, China, Lebanon, Taiwan, Vietnam),  $PM_{2.5}$  concentrations are significantly higher (Table 4).

Only at few sites listed in Table 4  $PM_{2.5-10}$  concentrations are lower than the concentrations at 6.0 m above the ground in Zabrze (Helsinki, Fort William, Zurich-Kaserne, Basel). Majority of the  $PM_{2.5-10}$  concentrations from almost the whole world are higher than the concentrations in Zabrze in the considered period (Tables 1, 4). The difference between yearly average  $PM_{2.5-10}$  concentration in Zabrze (in 2007 and 2008, especially measured at 6.0 m with Dekati) and the concentrations in other regions is yet more distinctive (Table 4). It means great, much greater than in other sites listed in Table 4, contribution of  $PM_{2.5}$  to PM in Zabrze. Exceptionally high carbon content indicates anthropogenic origin of fine ambient dust in Zabrze [43].

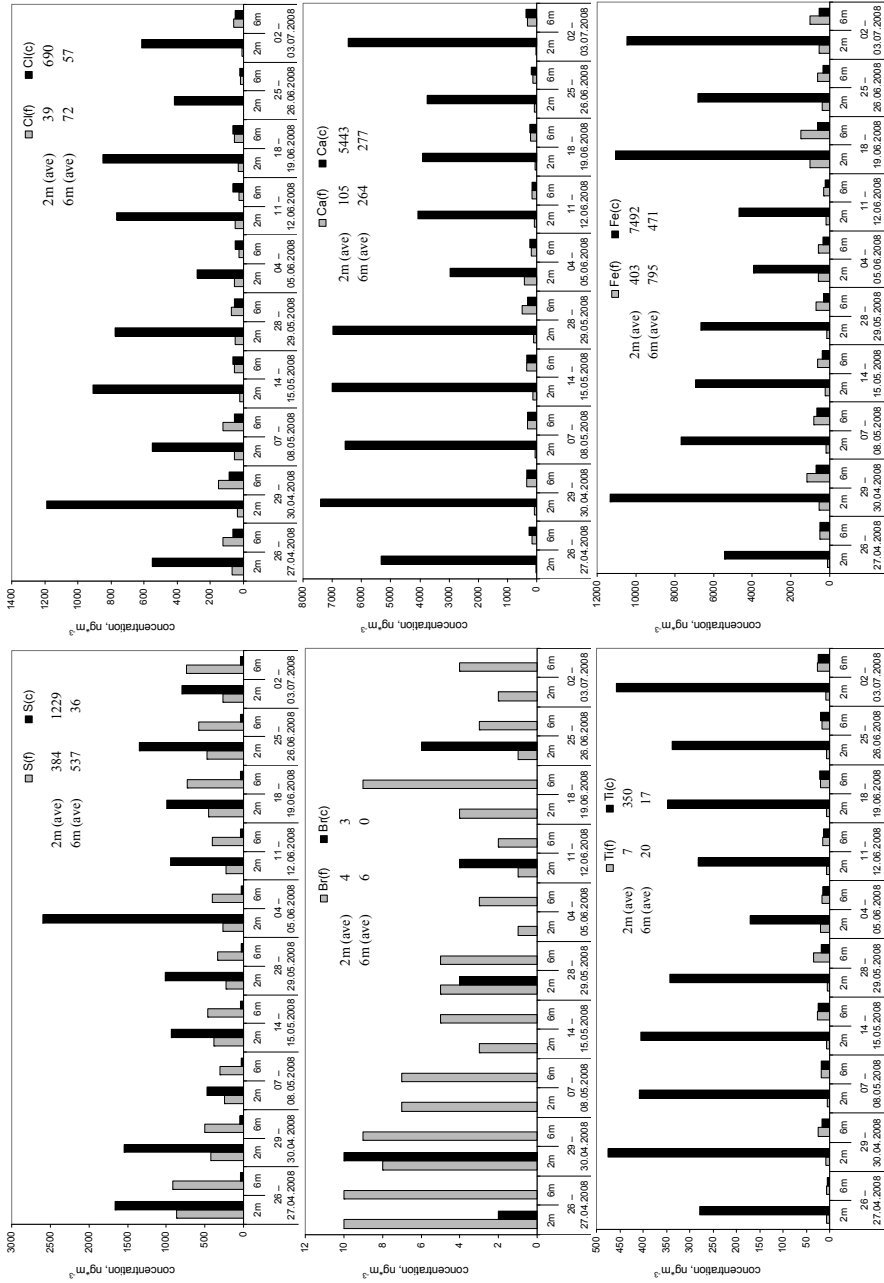
The differences in the concentrations, especially of  $PM_{2.5-10}$ , occur for relatively little differing heights above the ground (4 m). Although the results, received at two distant by 20 m points with two different samplers within a short period of time, do not allow for quantitative determination of the effect of height of a head location on the measurements, it is obvious that the effect is significant to monitoring of air quality, especially for  $PM_{10}$ . The differences between yearly means of daily concentrations, of both  $PM_{2.5}$  and  $PM_{2.5-10}$  at the two points are small (Table 4). It means that the big differences, observed in 04–07.2008 (especially for  $PM_{2.5-10}$ ), are neither due to the distance nor to the construction of the samplers but to the different heights of the heads location. It also means that this height difference is not probable to cause so big a difference in yearly concentrations as to occur exceeding of the standard at one height and not at the other, but the episodes of elevated  $PM_{2.5-10}$  concentrations, such as described in this study, may cause violation of the standard for 24 h  $PM_{10}$  concentrations ( $50 \mu\text{g}\cdot\text{m}^{-3}$ , [11]) at only one height.

In 26.04–03.07.2008, concentrations of  $PM_{10}$  exceeded the standard on 26–27.04 and 29–30.04 with the values  $62 \mu\text{g}\cdot\text{m}^{-3}$  and  $74 \mu\text{g}\cdot\text{m}^{-3}$ , respectively, but it was indicated only by Partisol, 2.0 m above the ground. In such a short period the standard for  $PM_{10}$  was exceeded twice, therefore, the risk of exceeding the standard more often than 35 times in a year is high. The fact is significant because people inhale air from the height of 2.0 m above the ground level. Coarse dust occurring in such high concentrations may adversely affect human health [12, 15, 28, 41, 54].

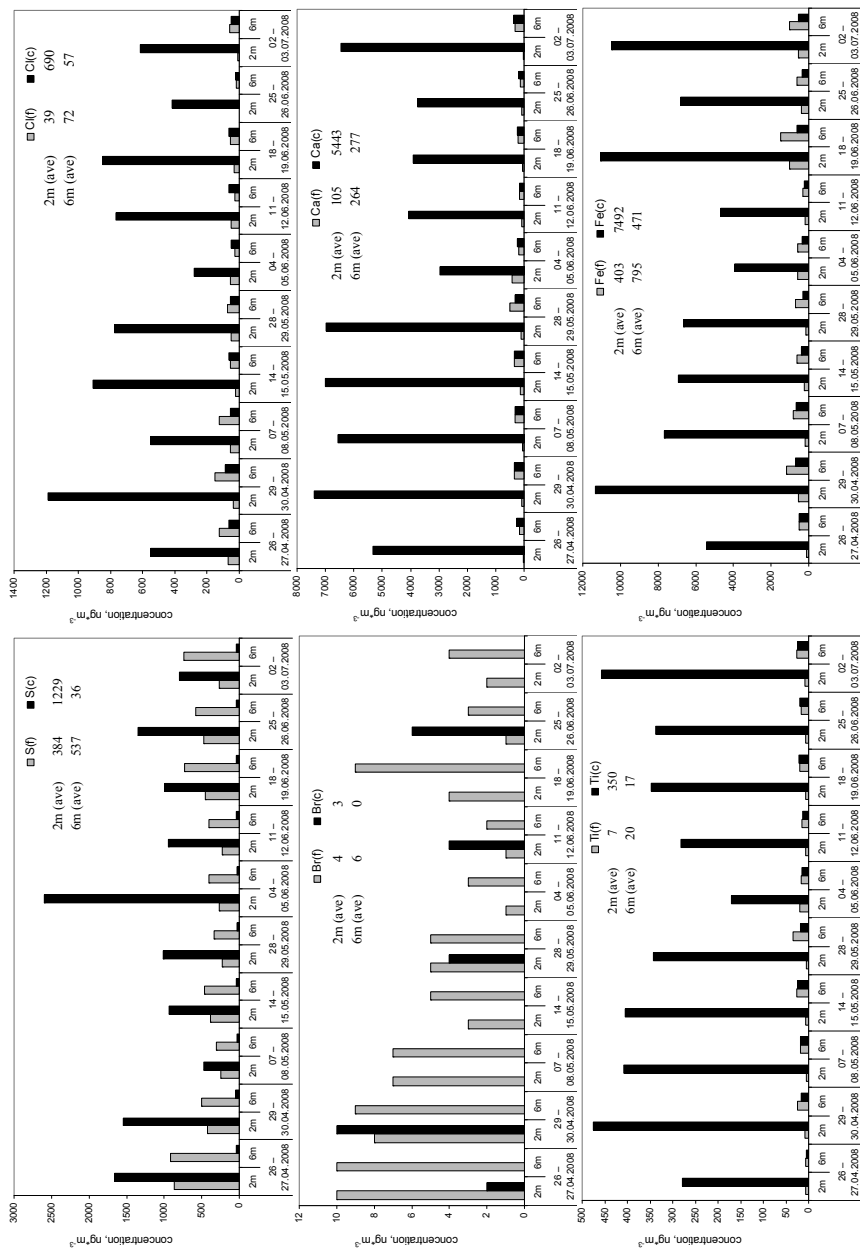
#### ***Elemental composition of $PM_{2.5}$ and $PM_{2.5-10}$***

Because of different origins and times of persistence in the atmosphere [21],  $PM_{2.5}$  and  $PM_{2.5-10}$  significantly differ in the elemental composition (Figure 2).





Symbols: (f) – fine dust ( $PM_{2.5}$ ); (c) – coarse dust ( $PM_{2.5-10}$ ); 2m – sampled with Partiso; 6m – sampled with Dekati; (AVE) – average value



Symbols: (f) – fine dust ( $\text{PM}_{2.5}$ ); (c) – coarse dust ( $\text{PM}_{2.5-10}$ ); 2m – sampled with Partisol; 6m – sampled with Dekati; (AVE) – average value  
 Figure 2. Average 48h concentrations ( $\text{ng}\cdot\text{m}^{-3}$ ) of elements related to  $\text{PM}_{2.5}$  and  $\text{PM}_{2.5-10}$  sampled at two heights (2 and 6m) in Zabrze in 26.04–03.07.2008

Among the PM<sub>2.5</sub>-related elements, at 2.0 m above the ground (Partisol-measured), iron had the greatest average 48h ambient concentration ( $C_{av} = 402.6 \text{ ng}\cdot\text{m}^{-3}$ ); next were sulfur ( $C_{av} = 383.8 \text{ }\mu\text{g}\cdot\text{m}^{-3}$ ) and calcium ( $C_{av} = 105.0 \text{ ng}\cdot\text{m}^{-3}$ ). The average concentrations of the rest of the elements were lower than  $100 \text{ ng}\cdot\text{m}^{-3}$  – the concentrations of nickel ( $C_{av} = 0.6 \text{ ng}\cdot\text{m}^{-3}$ ), cadmium ( $C_{av} = 1.9 \text{ ng}\cdot\text{m}^{-3}$ ), and arsenic ( $C_{av} = 2.7 \text{ ng}\cdot\text{m}^{-3}$ ) were lowest. All the elements, except bromine and cadmium, were almost entirely contained in PM<sub>2.5-10</sub>. The ambient concentrations of some (especially crustal) PM<sub>2.5-10</sub>-related elements were drastically higher than the concentrations of the PM<sub>2.5</sub>-related ones: average concentration of PM<sub>2.5-10</sub>-related calcium was  $5442.5 \text{ ng}\cdot\text{m}^{-3}$  while the concentration of calcium from PM<sub>2.5</sub> was  $105.0 \text{ ng}\cdot\text{m}^{-3}$  (Figure 2). It was  $7491.8 \text{ ng}\cdot\text{m}^{-3}$  and  $402.6 \text{ ng}\cdot\text{m}^{-3}$ , respectively, for iron.

The opposite is true of dust sampled at 6.0 m above the ground (Dekati) except for calcium, the greater amount of each element was accumulated in PM<sub>2.5</sub>. Among the PM<sub>2.5</sub>-related elements, iron ( $C_{av} = 794.5 \text{ ng}\cdot\text{m}^{-3}$ ), sulfur ( $C_{av} = 537.4 \text{ ng}\cdot\text{m}^{-3}$ ), calcium ( $C_{av} = 263.7 \text{ ng}\cdot\text{m}^{-3}$ ), and zinc ( $C_{av} = 106.4 \text{ ng}\cdot\text{m}^{-3}$ ) had the greatest ambient concentrations; among the PM<sub>2.5-10</sub>-related elements, iron ( $C_{av} = 471.0 \text{ }\mu\text{g}\cdot\text{m}^{-3}$ ) and calcium ( $C_{av} = 276.6 \text{ ng}\cdot\text{m}^{-3}$ ). Except for chlorine and sulfur ( $C_{av} = 56.9 \text{ ng}\cdot\text{m}^{-3}$  and  $C_{av} = 36.1 \text{ ng}\cdot\text{m}^{-3}$ , respectively), the rest of the 48h ambient concentrations of the PM-related elements were not greater than  $30 \text{ ng}\cdot\text{m}^{-3}$ .

Except for arsenic and cadmium, whose average ambient concentrations at both heights were close, the concentrations of almost all PM<sub>2.5</sub>-related elements were about two times greater at 6.0 m than at 2.0 m. Instead, the concentrations of PM<sub>2.5-10</sub>-related elements at 2.0 m were several times greater than at 6.0 m. Because the head of Dekati was placed 4 m higher than the head of Partisol, it suggests the effect of a low-level emission source [42].

Among the PM<sub>2.5</sub>-related non-metals, sulfur had the greatest ambient concentrations; among the PM<sub>2.5-10</sub>-related non-metals it was chlorine. Greater part of PM-related sulfur at 2.0 m was in PM<sub>2.5</sub> (Figure 2). Some authors maintain that sulfur in ambient fine dust originates mainly from combustion of fossil fuels [7] and photochemical reactions in the atmosphere [7, 42]. High ambient concentrations of PM<sub>2.5</sub>-related sulfur at the two heights are due to the origin of PM<sub>2.5</sub> from these sources.

PM-related chlorine may originate from various sources but in an urban area it is mostly anthropogenic. High ambient concentrations of PM<sub>2.5</sub>-related chlorine are probably due to combustion of, among others, coal and wastes. Exceptionally high, much higher than the PM<sub>2.5</sub>-related, concentrations of PM<sub>2.5-10</sub>-related sulfur and chlorine at 2.0 m may reflect the effect of re-suspended road dust. Chlorine, together with many other elements, in PM<sub>10</sub> may originate from the abrasion of car breaks [18].

Among crustal elements, calcium, titanium, and iron [2], iron had the highest ambient concentrations. Most of iron in PM at 2.0 m was in PM<sub>2.5-10</sub> (Figure 2). Similar results, about 3.5 times higher the PM<sub>2.5-10</sub>-related than the PM<sub>2.5</sub>-related iron concentrations, are reported by [16]. At 6.0 m, iron occurred rather in PM<sub>2.5</sub>.

Iron is one of the most abundant elements in the Earth crust, therefore, high iron content of PM may prove the mineral origin of a great part of the investigated PM [2]. On the other hand, many stationary sources and industrial processes emit great amounts of iron [19, 50]. It may give an explanation for the presence of iron in PM<sub>2.5</sub>, especially at 6.0 m above the ground, beyond any effects of secondary emission. High ambient concen-

trations of calcium and titanium are commonly attributed to the propagation of mineral dust and, in the case of calcium, of abrasive dust from road surface and soil dust [42]. It agrees with the high  $PM_{2.5-10}$ -related calcium and titanium concentrations at 2.0 m, higher than the concentrations of calcium and titanium from  $PM_{2.5}$  and from both PM fractions at 6.0 m.

Except for arsenic and cadmium, the concentrations of  $PM_{2.5}$ -related heavy metals were higher at 6.0 than at 2.0 m (Figure 2). Like sulfur, they may indicate high contribution of combustion of fossil fuels and energy production-related sources [42]. Moreover, almost all heavy metals listed in Figure 2 are related to  $PM_{2.5}$  from combustion of gasoline and diesel oil in cars [65].

Like the other elements, the  $PM_{2.5-10}$ -related heavy metals had higher, often several times, concentrations at 2.0 m. It confirms the earlier assumption that PM from roads has great contribution to coarse dust in the considered period.

To discriminate between crustal (natural) and anthropogenic elements in PM, the element enrichment factors ( $EF$ ) in  $PM_{2.5}$  and  $PM_{2.5-10}$  were analyzed [8, 37, 50]. The enrichment factor  $EF_x$  for an element  $x$  is defined as:

$$EF_x = \frac{(C_x / C_{ref})_{PMi}}{(C_x / C_{ref})_{crust}} \quad (1)$$

where  $PM_i$  is  $PM_{2.5}$  or  $PM_{2.5-10}$ ,  $C_x$  and  $C_{ref}$  designate concentrations of the element  $x$  and the reference element,  $(C_x / C_{ref})_{PMi}$  and  $(C_x / C_{ref})_{crust}$  are proportions of these concentrations in  $PM_i$  and in the Earth crust, respectively. The observed concentrations  $C_x$  were referred to the concentration  $C_{Ti}$  of titanium, a marker element for the Earth crust. Consequently,  $EF_{Ti} = 1$ .

The data on the chemical composition of the upper continental crust were taken from the literature [66].  $EF_x$  close to 1 means crustal origin of the element  $x$ ; high  $EF_x$  means other (generally anthropogenic) origin of  $x$  [4, 27, 37]. Because the elemental composition of the local Earth's surface differs from the averaged composition of the upper continental crust the anthropogenic origin was attributed to the elements  $x$  with  $EF_x > 10$ .

$EF_s$ , computed for twelve elements in  $PM_{2.5}$  and  $PM_{2.5-10}$ , are presented in Table 5.

All the elements in Table 5 may be divided into two groups. The first group comprises the elements with low  $EF$  ( $EF \leq 10$ ), falling between  $EF_{Ca} = 1.4$  and  $EF_{Fe} = 5.7$  (Ca and Fe  $PM_{2.5}$ -related, Partisol-measured), i.e. elements with the probable natural origin (soil dust). Because of low  $EF$ , the crustal origin might be attributed to  $PM_{2.5-10}$ -related sulfur from Dekati and to  $PM_{2.5-10}$ -related chlorine and chromium from Partisol. However, despite their low  $EF$ s their other important source may be fly ash [60].

The second group comprises the elements having high  $EF$ s both in  $PM_{2.5}$  and in  $PM_{2.5-10}$ . It comprises Cd, Br, Pb, Zn, As with very high  $EF$ s, and S, Cl, Cr, Ni with lower ones. All heavy metals, except Cr and Ni, have  $EF$ s greater than 100. Therefore, because of high  $EF$ s, these elements are of anthropogenic origin in both  $PM_{2.5}$  and  $PM_{2.5-10}$ . They probably come from combustion of hard coal for heating, combustion of wastes, high-temperature industrial processes [49, 64], vehicular sources (car exhaust, re-suspended road dust, particles from abrasion of tires and breaks, particles from other parts of cars) [25, 44, 59].

The value of  $EF_x$  depends on the dust fraction the element  $x$  is related to and the location of a sampler (Table 5).

Table 5. Enrichment factors for selected elements in PM<sub>2.5</sub> (f) and PM<sub>2.5-10</sub> (c) sampled at two heights (2 and 6m) in Zabrze

Element	S(f) <sup>a)</sup>	S(c) <sup>b)</sup>	Cl(f)	Cl(c)	Br(f)	Br(c)	
2m <sup>c)</sup>	Mean	194.8	14.0	29.2	9.6	1337.7	14.0
	Range	43.5÷472.1	3.8÷49.7	0.8÷57.6	6.0÷13.3	97.4÷3246.9	0.0÷40.9
6m <sup>d)</sup>	Mean	115.2	8.3	22.1	19.9	714.2	0.0
	Range	31.5÷427.1	5.0÷24.9	5.8÷87.0	5.4÷61.4	278.3÷2783.0	0.0
Element	Ca(f)	Ca(c)	Ti(f)	Ti(c)	Fe(f)	Fe(c)	
2m	Mean	1.4	1.7	1.0	1.0	5.7	2.2
	Range	0.5÷2.3	1.2÷2.2	1.0	1.0	1.7÷17.4	1.7÷3.2
6m	Mean	1.4	2.0	1.0	1.0	4.4	3.3
	Range	0.9÷2.4	1.1÷5.5	1.0	1.0	2.1÷8.0	1.7÷10.1
Element	Cr(f)	Cr(c)	Ni(f)	Ni(c)	Zn(f)	Zn(c)	
2m	Mean	46.9	10.3	18.7	2.6	566.6	89.7
	Range	4.5÷77.9	6.2÷15.5	0.0÷55.9	0.0÷7.8	110.9÷1043.0	34.2÷172.5
6m	Mean	21.8	14.3	14.1	5.6	367.9	121.4
	Range	7.6÷56.3	0.0÷89.1	4.8÷47.9	0.0÷33.5	162.7÷1019.0	0.0÷383.6
Element	As(f)	As(c)	Cd(f)	Cd(c)	Pb(f)	Pb(c)	
2m	Mean	594.8	154.7	9829.8	336.8	1079.2	124.0
	Range	0.0÷1558.5	18.2÷419.3	0.0÷25465.7	0.0÷3216.7	210.9÷2230.7	42.3÷203.8
6m	Mean	262.0	0.0	3626.0	648.2	616.3	193.0
	Range	0.0÷1558.5	0.0	0.0÷13096.6	0.0÷3395.4	237.7÷1702.6	42.3÷623.4

<sup>a)</sup> (f)-fine dust (PM<sub>2.5</sub>), <sup>b)</sup> (f)-coarse dust (PM<sub>2.5-10</sub>), <sup>c)</sup> sampled with Partisol, <sup>d)</sup> sampled with Dekati

All the elements, except Ca, have *EF*s higher, often several times, in PM<sub>2.5</sub> than in PM<sub>2.5-10</sub>. It suggests the anthropogenic origin of fine dust at both heights and agrees with other studies on urban PM [26, 34, 48]. The contribution of natural sources to the emission of PM<sub>2.5</sub> is small. Moreover, the differences between *EF*<sub>x</sub> in PM<sub>2.5</sub> and *EF*<sub>x</sub> in PM<sub>2.5-10</sub> are much smaller in the first than in the second group.

*EF*s of the elements of natural origin were similar at both heights, although almost all slightly higher at 6.0 m (except S in PM<sub>2.5-10</sub> and Fe in PM<sub>2.5</sub>). *EF*s of majority of anthropogenic elements in PM<sub>2.5</sub> were greater at 2.0 m; *EF*s of majority of anthropogenic elements in PM<sub>2.5-10</sub> —at 6.0 m.

The analysis of *EF*s provides a good confirmation of high spatial variability of the elemental composition of both PM fractions. The effect of re-suspended road dust, a mixture of combustion [59] and non-combustion [25, 59, 65] particles from vehicular sources on concentrations of, especially coarse dust-associated, elements at the lower height is clear. However, the presence of heavy metals in coarse dust may also be due to the pollution from soil or other components of the environment [57]. Road traffic and movements of air raise deposited pollutants back into the atmosphere [19, 44]. The road dust particles are permanently made to move by passing cars and the finer particles stay suspended in the air [60]. The ambient elements from road dust may be accumulated as well in fine as in coarse dust.

Road dust is a considerable source of suspended dust and the associated elements, including heavy metals, within many urban areas [19, 59]. The emission from low-level

sources (car exhaust and road dust) may cause great spatial differentiation of concentrations and elemental composition of ambient dust. However, the contribution of road dust to ambient dust depends on a season of a year and meteorological conditions [7]. In the periods of heavy rain or snow, the differences in concentration and elemental composition of coarse dust may not be as great as presented here or they may be even negligible.

## CONCLUSION

The ambient concentrations and elemental composition of  $PM_{2.5}$  and  $PM_{2.5-10}$  at the urban background site in Zabrze in spring and summer strongly depend on the height above the ground level, those of the  $PM_{2.5}$  to a lesser and those of the  $PM_{2.5-10}$  to a greater extent.

The small difference of 4 m between heights of location of the two sampling heads caused considerable differences in the measured concentrations and elemental composition of ambient dust. Such differences may affect interpretation of results of monitoring air for  $PM_{10}$  in urban background areas, such as Zabrze. The small difference in heights of head locations may not be significant to measurement of yearly concentrations (long term and/or continuous measurements). However, if an experiment is a measuring campaign to catch short-term phenomena or differences between several areas (in spring/summer), then the type of a sampler and the height of a sampling head location are of great importance. It may apply to majority of urban areas in Poland.

The low contributions of the fine dust and the associated elements to suspended dust in 26.04–03.07.2008 at 2.0 m is not specific of the site but illustrates the effects of resuspension of road and soil dust in summer. In Polish cities, such as Zabrze, unlike in most other European cities, dust and sand are not routinely removed from the streets nor are the streets water-sprayed in summer.

*The work was financed from the 2009 statutory funds.*

## REFERENCES

- [1] AEA.: Measurement of  $PM_{10}$  and  $PM_{2.5}$  in Scotland with Gravimetric Samplers. Report to The Scottish Government, 12 June 2009.
- [2] Arditoglou A., C. Samara: *Levels of total suspended particulate matter and major trace elements in Kosovo: a source identification and apportionment study*, Chemosphere, **59**, 669–678 (2005).
- [3] Bayraktar H., F. Turalioğlu, G. Tuncel: *Average mass concentrations of TSP,  $PM_{10}$  and  $PM_{2.5}$  in Erzurum urban atmosphere, Turkey*, Stochastic Environmental Research and Risk Assessment, **24**, 57–65 (2010).
- [4] Birmili W., A. Allen, F. Bary, R. Harrison: *Trace metal concentrations and water solubility in size-fractionated atmospheric particles and influence of road traffic*, Environmental Science & Technology, **14**(4), 1144–1153 (2006).
- [5] Bulpitt S., M. Price: *The composition of  $PM_{10}$  as collected by a conventional TEOM, a modified TEOM and a Partisol gravimetric monitor at a kerbside site in the North East of England*, Environmental Monitoring and Assessment, **121**, 479–489 (2006).
- [6] CAFE Working Group on Particulate Matter: *Second position paper on particulate matter*, December 20<sup>th</sup> 2004.
- [7] Chen J.-L., C.-T. Lee, S.-Y. Chang, C.C.K. Chou: *The elemental contents and fractal dimensions of  $PM_{2.5}$  in Taipei City*, Aerosol and Air Quality Research, **1**(1), 9–20 (2001).
- [8] Cong Z., S. Kang, X. Liu, G. Wang: *Elemental composition of aerosol in the Nam Co region, Tibetan Plateau, during summer monsoon season*, Atmospheric Environment, **41**, 1180–1187 (2007).
- [9] COST 633. *Final Report. Particulate Matter – Properties Related to Health Effects*, 2 May 2009.
- [10] Das M., S.K. Maiti, U. Mukhopadhyay: *Distribution of  $PM_{2.5}$  and  $PM_{2.5-10}$  in  $PM_{10}$  fraction in ambient*

- air due to vehicular pollution in Kolkata megacity, *Environmental Monitoring and Assessment*, **122**, 111–123 (2006).
- [11] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.
- [12] Dockery D.W., A. Pope: *Epidemiology of acute health effects: summary of time-series studies*, [w:] Wilson R., J.D. Spengler (eds): *Particles in our air: concentration and health effects*. Harvard University Press, Cambridge 1996, 123–147.
- [13] EMEP. Transboundary Particulate Matter in Europe, Status report 4/2009.
- [14] Engelbrecht J.P., L. Swanepoel, J.C. Chow, J.G. Watson, R.T. Egami:  *$PM_{2.5}$  and  $PM_{10}$  concentrations from the Qalabotjha low-smoke fuels macro-scale experiment in South Africa*, *Environmental Monitoring and Assessment*, **69**, 1–15 (2001).
- [15] Englert N.: *Fine particles and human health – a review of epidemiological studies*, *Toxicology Letters*, **149**, 235–242 (2004).
- [16] Fang G.-C., Y.-S. Wu, S.-H. Huang, J.-Y. Rau: *Review of atmospheric metallic elements in Asia during 2000 – 2004*, *Atmospheric Environment*, **39**, 3003–3013 (2005).
- [17] Fang G.-C., Y.-S. Wu, J.-B. Lin, C.-K. Lin, J.-Y. Rau, S.-H. Huang: *Characterization of atmospheric particulate and metallic elements at Taichung Harbour near Taiwan Strait during 2004-2005*, *Chemosphere*, **63**, 1912–1923 (2006).
- [18] Garg B.D., S.H. Cadle, P.A. Mulawa, P.J. Groblicki: *Brake wear particulate matter emissions*, *Environmental Science & Technology*, **34(21)**, 4463–4469 (2000).
- [19] Gaudry A., M. Moskura, C. Mariet, S. Ayrault, F. Denayer, N. Bernard: *Inorganic pollution in  $PM_{10}$  particles collected over three French sites under various influences: rural conditions, traffic and industry*, *Water, Air & Soil Pollution*, **193**, 91–106 (2008).
- [20] Glavas S.D., P. Nikolakis, D. Ambatzoglou, N. Mihalopoulos: *Factors affecting the seasonal variation of mass and ionic composition of  $PM_{2.5}$  at a central mediterranean coastal site*, *Atmospheric Environment*, **42**, 5365–5373 (2008).
- [21] Han J.S., K.J. Moon, B.J. Kong, S.J. Lee, J.E. Kim, Y.J. Kim: *Seasonal variation of chemical composition in fine particles at Gosan, Korea*, *Environmental Monitoring and Assessment*, **107**, 221–237 (2005).
- [22] Hawas O., E. Stelcer, D. Cohen, D. Button, L. Denison, N. Wong, A. Chan, R. Simpson, E. Christensen, G. Golding, M. Hodge, J. Kirkwood, R. Mitchell, D. Wainwright, F. Ardern: *Elemental composition of fine particles in four major Australian cities*, *Clean Air Society of Australia and New Zealand*, Newcastle, N.S.W. (2003).
- [23] Hinds W.C.: *Aerosol technology. Properties, behaviour, and measurement of airborne particles*. Second Edition. John Wiley & Sons, Inc. New York 1998.
- [24] Hitzenberger R., A. Berner, Z. Galambos, W. Maenhaut, J. Cafmeyer, J. Schwarz, K. Müller, G. Spindler, W. Wiegand, K. Acker, R. Hillamo, T. Mäkelä: *Intercomparison of methods to measure the mass concentration of the atmospheric aerosol during INTERCOMP2000 – influence of instrumentation and size cuts*, *Atmospheric Environment*, **38**, 6467–6476 (2004).
- [25] Hjortenkranz D., B. Bergbäck, A. Häggerud: *New metal emission patterns in road traffic environments*, *Environmental Monitoring and Assessment*, **117**, 85–98 (2006).
- [26] Hueglin C., R. Gehrig, U. Baltensperger, M. Gysel, C. Monn, H. Vonmont (2005): *Chemical characterization of  $PM_{2.5}$ ,  $PM_{10}$  and coarse particles at urban, near-city and rural sites in Switzerland*, *Atmospheric Environment*, **39**, 637–651 (2005).
- [27] Jasan R.C., R.R. Plá, R. Invernizzi, M. Dos Santos: *Characterization of atmospheric aerosol in Buenos Aires, Argentina*, *Journal of Radioanalytical and Nuclear Chemistry*, **281**, 101–105 (2009).
- [28] Kappos A.D., P. Bruckmann, T. Eikmamm, N. Engler, U. Heinrich, P. Höpfe, E. Koch, G.H.M. Krause, W.G. Kreyling, K. Rauchfuss, P. Rombout, V. Schulz-Klemp, W.R. Thiel, H.-E. Wichmann: *Health effects of particles in ambient air*, *International Journal of Hygiene and Environmental Health*, **207(4)**, 399–407 (2004).
- [29] Klejnowski K., A. Krasa, W. Rogula: *Seasonal variability of concentrations of total suspended particles (TSP) as well as  $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$  modes in Zabrze, Poland*, *Archives of Environmental Protection*, **33(3)**, 15–29 (2007).
- [30] Klejnowski K., J. Błaszczyk: *Porównanie wyników pomiarów stężeń pyłu  $PM_{2.5}$  i  $PM_{10}$  mierzonych metodą gravimetryczną i z wykorzystaniem miernika automatycznego*, [w:] *Ochrona powietrza w teorii i praktyce*, tom 2, Zabrze 2008, 1–12.
- [31] Klejnowski K., W. Rogula-Kozłowska, A. Krasa: *Structure of Atmospheric Aerosol in the Upper Silesian Agglomeration (Poland) – Contribution of  $PM_{2.5}$  to  $PM_{10}$  in Zabrze, Katowice and Częstochowa in 2005-2007*, *Archives of Environmental Protection*, **35(2)** (2009).



- [32] Kocak M., N. Mihalopoulos, N. Kubilay: *Chemical composition of the fine and coarse fraction of aerosols in the northeastern Mediterranean*, Atmospheric Environment, **41**, 7351–7368 (2007).
- [33] Lu H.C.: *The statistical characters of  $PM_{10}$  concentration in Taiwan area*, Atmospheric Environment, **36**, 491–502 (2002).
- [34] Marcazzan G.M., S. Vaccaro, G. Valli, R. Vecchi: *Characterisation of  $PM_{10}$  and  $PM_{2.5}$  particulate matter in the ambient air of Milan (Italy)*, Atmospheric Environment, **35**, 4639–4650 (2001).
- [35] Mariani R.L., W.Z. de Mello: *Short communication.  $PM_{2.5-10}$ ,  $PM_{2.5}$  and associated water-soluble inorganic species at a coastal urban site in the metropolitan region of Rio de Janeiro. Short communication*, Atmospheric Environment, **41**, 2887–2892 (2007).
- [36] Micallef A., C.N. Deuchar, J.J. Colls: *Indoor and outdoor measurements of vertical concentration profiles of airborne particulate matter*, The Science of the Total Environment, **215**, 209–16 (1998) 209–216.
- [37] Morata D., M. Polvé, A. Valdés, M. Belmar, M.I. Dinator, M. Silva, M.A. Leiva, T. Aigouy, J.R. Morales: *Characterisation of aerosol from Santiago, Chile: an integrated PIXE-SEM-EDX study*, Environmental Geology, **56**, 81–95 (2008).
- [38] Moreno T., T.P. Jones, R.J. Richards: *Characterisation of aerosol particulate matter from urban and industrial environments: examples from Cardiff and Port Talbot, South Wales, UK*, Science of the Total Environment, **334–335**, 337–346 (2004).
- [39] Moreno T., X. Querol, A. Alastuey, F. Ballester, W. Gibbons: *Airborne particulate matter and premature deaths in urban Europe: the new WHO guidelines and the challenge ahead as illustrated by Spain*, European Journal of Epidemiology, **22**, 1–5 (2007).
- [40] Mugica V., E. Ortiz, L. Molina, A. De Vizcaya-Ruiz, A. Nebot, R. Quintana, J. Aguilar, E. Alcántara: *PM composition and source reconciliation in Mexico City*, Atmospheric Environment, **43**, 5068–5074 (2009).
- [41] Ovadnevaitė J., K. Kvietkus, J. Šakalys: *Evaluation of the Impact of Long-range Transport and Aerosol Concentration Temporal Variations at the Eastern Coast of the Baltic Sea*, Environmental Monitoring and Assessment, **132**, 365–375 (2007).
- [42] Pakkanen T.A., V.-M. Kerminen, K. Loukkola, R.E. Hillamo, P. Aarnio, T. Koskentalo, W. Maenhaut: *Size distributions of mass and chemical components in street-level and rooftop  $PM_1$  particles in Helsinki*, Atmospheric Environment, **37** 1673–1690 (2003).
- [43] Pastuszka J.S., A. Awaróś, E. Talik, U. Paw: *Optical and chemical characteristics of the atmospheric aerosol in four towns in southern Poland*, The Science of the Total Environment, **309**, 237–251 (2003).
- [44] Pastuszka J.S., W. Rogula-Kozłowska, E. Zajusz-Zubek: *Characterization of  $PM_{10}$  and  $PM_{2.5}$  and associated heavy metals at the crossroads and urban background site in Zabrze, Upper Silesia, Poland, during the smog episodes*, Environmental Monitoring and Assessment (in press).
- [45] PN-EN 12341:2006a: *Air quality – Determination of the  $PM_{10}$  fraction of suspended particulate matter – Reference method and field test procedure to demonstrate equivalence of measurement methods*.
- [46] PN-EN 14907:2006b: *Ambient air quality – Standard gravimetric measurement method for the determination of the  $PM_{2.5}$  mass fraction of suspended particulate matter*.
- [47] Querol X., A. Alastuey, S. Rodriguez, F. Plana, C.R. Ruiz, N. Cots, G. Massagué, O. Puig:  *$PM_{10}$  and  $PM_{2.5}$  source apportionment in the Barcelona Metropolitan area, Catalonia, Spain*, Atmospheric Environment, **35**, 6407–6419 (2001).
- [48] Querol X., A. Alastuey, M.M. Viana, S. Rodriguez, B. Artiñano, P. Salvador, S. Garcia do Santos, R. Fernandez Patier, C.R. Ruiz, J. de la Rosa, A. Sanchez de la Campa, M. Menendez, J.I. Gil: *Speciation and origin of  $PM_{10}$  and  $PM_{2.5}$  in Spain*, Aerosol Science, **35**, 1151–1172 (2004).
- [49] Ragosta M., R. Caggiano, M. Macchiato, S. Sabia, S. Trippetta: *Trace elements in daily collected aerosol: Level characterization and source identification in a four-year study*, Atmospheric Research, **89**, 206–217 (2008).
- [50] Rajšić, S., Z. Mijić, M. Tasić, M. Radenković, J. Joksić: *Evaluation of the levels and sources of trace elements in urban particulate matter*, Environmental Chemistry Letters, **6**, 95–100 (2008).
- [51] Rampazzo G., M. Masiol, F. Visin, B. Pavoni: *Gaseous and  $PM_{10}$ -Bound Pollutants Monitored in Three Sites with Differing Environmental Conditions in the Venice Area (Italy)*, Water, Air & Soil Pollution, **195**, 161–176 (2008).
- [52] Ravindra K., M. Stranger, R. Van Grieken: *Chemical characterization and multivariate analysis of atmospheric  $PM_{2.5}$  particles*, Journal of Atmospheric Chemistry, **59**, 199–218 (2008).
- [53] Rogula-Kozłowska W. (2009): *Charakterystyka aerozolu pyłowego ze źródeł komunikacyjnych*, praca doktorska.
- [54] Rössli M., G. Theis, N. Künzli, J. Staehelin, P. Mathys, L. Oglesby, M. Camenzind, C. Braun-Fahrlander: *Temporal and spatial variation of the chemical composition of  $PM_{10}$  at urban and rural sites in Basel area, Switzerland*, Atmospheric Environment, **35**, 3701–3713 (2001).

- [55] Salam A., T. Hossain, M.N.A. Siddique, A.M. Shafiqul Alam: *Characteristics of atmospheric trace gases, particulate matter, and heavy metal pollution in Dhaka, Bangladesh*, Air Quality, Atmosphere & Health, **1**, 101–109 (2008).
- [56] Saliba N.A., H. Kouyoumdjian, M. Roumié: *Effect of local and long-range transport emissions on the elemental composition of  $PM_{10-2.5}$  and  $PM_{2.5}$  in Beirut*, Atmospheric Environment, **41**, 6497–6509 (2007).
- [57] Salma I., W. Meanhaut, G. Záray: *Comparative study of elemental mass size distributions in urban atmospheric aerosol*, Aerosol Science, **33**, 339–356 (2002).
- [58] Sillanpää M., S. Saarikoski, R. Hillamo, A. Pennanen, U. Makkonen, Z. Spolnik, R. Van Grieken, T. Koskentalo, R.O. Salonen: *Chemical composition, mass size distribution and source analysis of long-range transported wildfire smokes in Helsinki*, Science of the Total Environment, **350**, 119–135 (2005).
- [59] Sternbeck J., Å. Sjödin, K. Andréasson: *Metal emissions from road traffic and the influence of resuspension – results from two tunnel studies*, Atmospheric Environment, **36**, 4735–4744 (2002).
- [60] Teixeira E.C., L. Meira, E.R.R. de Santana, F. Wiegand: *Chemical composition of  $PM_{10}$  and  $PM_{2.5}$  and seasonal variation in South Brazil*, Water, Air & Soil Pollution, **199**, 261–275 (2009).
- [61] US EPA: *National ambient air quality standards for particulate matter*, final rule. 40 CFR Part 50. Federal Register, Vol. 62, No. 138, July 18, 1997.
- [62] US EPA. *Policy Assessment for the Review of the Particulate Matter National Ambient Air Quality Standards*, June 2006.
- [63] VanCuren T.: *Spatial Factors Influencing Winter Primary Particle Sampling and Interpretation*, Journal of Air & Waste Management, **45**, 3–15 (1999).
- [64] Wang X., X. Bi, G. Sheng, J. Fu: *Chemical composition and sources of  $PM_{10}$  and  $PM_{2.5}$  aerosols in Guangzhou, China*, Environmental Monitoring and Assessment, **119**, 425–439 (2006).
- [65] Weckwerth K.G.: *Verification of traffic emitted aerosol components in the ambient air of Cologne, Germany*, Atmospheric Environment, **35**, 5525–5536 (2001).
- [66] Wedepohl K.H.: *The composition of the continental crust*, Geochimica et Cosmochimica Acta, **59(7)**, 1217–1232 (1995).
- [67] Wilson J.G., S. Kingham, J. Pearce, A.P. Sturman: *A Review of Intraurban Variations in Particulate Air Pollution: Implications for Epidemiological Research*, Atmospheric Environment, **39**, 6444–6462 (2005).
- [68] [www.katowice.pios.gov.pl](http://www.katowice.pios.gov.pl), strona internetowa WIOŚ w Katowicach.
- [69] Zoras S., A.G. Triantafyllou, D. Deligiorgi: *Atmospheric stability and  $PM_{10}$  concentrations at far distance from elevated point sources in complex terrain: Worst-case episode study*, Journal of Environmental Management, **80**, 295–302 (2006).

Received: November 15, 2010; accepted: April 4, 2011.

#### STĘŻENIA $PM_{2.5}$ , $PM_{2.5-10}$ I PIERWIĄTKÓW ZWIĄZANYCH Z PM NA DWÓCH WYSOKOŚCIACH W OBSZARZE TŁA MIEJSKIEGO W ZABRZU

Celem pracy było zbadanie stężeń i składu pierwiastkowego pyłu drobnego ( $PM_{2.5}$ ) i grubego ( $PM_{2.5-10}$ ) w dwóch punktach wybranych w obszarze tła miejskiego w Zabrze. Punkty były w zlokalizowane w odległości 20 m od siebie na różnych wysokościach (2 i 6 m). Do pobierania próbek pyłu wykorzystano dwukanałowy pobornik z impaktorem wirtualnym i impaktor kaskadowy. Badania składu pierwiastkowego przeprowadzono wykorzystując spektrometr fluorescencji rentgenowskiej. Badania wykazały heterogeniczność w rozkładzie przestrzennym i składzie pierwiastkowym pyłu zawieszonego w punkcie tła miejskiego. Wniosek ten dotyczy przede wszystkim frakcji cząstek grubych, których, jak wykazano w pracy, imisję w pewnych okresach, na wysokości 2 m, kształtuje wtórna emisja pyłu drogowego, glebowego i inne lokalne „niskopoziomowe” źródła pyłu.