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Oryginal Research

Trace Metals Concentration in Size-Fractioned Urban Air Particulate Matter in Łódź, Poland. I. Seasonal and Site Fluctuations

M. Krzemińska-Flowers[1], H. Bem[1]*, H. Górecka[2]

[1]Institute of Applied Radiation Chemistry, Faculty of Chemistry, Technical University of Łódź,
ul. Żwirki 36, 90-924 Łódź, Poland
[2]Institute of Inorganic Technology and Mineral Fertilizers, Faculty of Chemistry, Technical University of Wrocław,
Wyb. Wyspiańskiego 27, 50-370 Wrocław, Poland.

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Abstract

Urban airborne particulate matter (APM) was collected non-simultaneously at three sampling sites in Łódź, Poland in summer and winter using an Andersen 8-stage impactor. The sampling sites are characterized by different contributions of coal combustion, traffic intensity and soil resuspension factors to total APM. The concentration of several trace elements (TEs): Ag, As, Ca, Cd, Co, Cr, Hg, Mn, Ni, Pb, Sb, Th, U, V and Zn in particulate matter collected on nitrocellulose filters were determined by means of ICP-MS. The obtained aerosol concentrations of TEs were compared to their abundance in fly ash from local high-level and low-level emission sources.

Keywords: urban air particulate matter; trace elements; size-fractioned aerosol; vehicle emissions; combustion emissions

Introduction

Heavy metals present in the atmosphere in trace amounts may pose a serious risk to human health in urban populations. The potential hazard of several toxic elements such as As, Cd, Cr, Hg and Pb is well known [1]. Therefore, WHO gives guidelines for some trace metals [2], which can be present in urban air well above natural background levels as the result of anthropogenic processes. The measurements of metal concentration in total suspended particles (TSP), PM_{10} or $PM_{2.5}$ give some indication of the general levels of pollution, but provide no information on size distribution of the pollutants. From a toxicological point of view, the most important particles are those with a diameter <10 μm (PM_{10}), so-called respirable fraction, which penetrate the human respiratory system deeply. It is well established that fine particles (smaller than 2.5 μm) penetrate the pulmonary region and tend to deposit in alveoli [2] causing adverse health effects leading to pulmonary and respiratory diseases [1].

Trace elements (TEs) are released into the atmosphere both from natural and anthropogenic sources, namely: resuspended surface dust, combustion of fossil fuels and traffic. Trace elements from high temperature sources tend to concentrate during combustion in particles of a diameter below 3 μm. Combustion of fossil fuels and emissions from gasoline fueled road vehicles are the principal anthropogenic source of Cu, Ni and Zn in the urban air particulate matter [3]. In some cities industry (e.g. smelters, foundries) produces high trace element emissions. Long range transport of pollutants is also of great importance. For these reasons the examination of heavy metals

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*Corresponding author; e-mail: henrybem@p.lodz.pl and trace elements concentration size distribution is a useful tool for the characterization and apportionment of the sources of urban airborne particulate matter [4-6].

The Łódź region of Poland is recognized as the area with the highest level of air pollution in Poland. This is a result of the fact that in a relatively small area of 400 km^2 with a dense population (over 1 million inhabitants), there are three big power plants and several smaller local power plants with insufficient fly ash removal systems. Main power and heating plants in Łódź (Fig. 1) produce 26 mln GJ of energy per year, using 1.35 mln Mg of coal [7]. However, recent estimations show great importance of so-called low emissions from household heating and traffic [8]. Individual heating devices or local heating plants are still utilized by 70% of inhabitants of the city center, whereas for the whole city of Łódź this percentage is lower – 20–25% [7]. These low-level emission facilities use about 300,000 Mg of coal per year; however, because of lack of sufficient fly ash removal devices they are responsible for dust emissions even 3 times higher than three main power plants together [7]. During recent years the emission of particulate matter in the city of Łódź have slowly decreased and mean annual concentrations of PM do not presently exceed maximum permitted value of 50 μg/m^3 for TSP, but daily concentration values of 125 μg/m^3 for PM$_{10}$ are still sometimes exceeded [9].

Although there are several known studies on TE contamination for other Polish towns [10-14], research on the size distribution of trace elements and aerosol source apportionment has not yet been published for the Łódź area of Poland. The pilot study results concerning the concentration levels of several elements in the total suspended particles (TSP) in Łódź have already been published [15]. Present research focused on size distribution of trace metals in ambient particulate matter. The comparison of the results obtained for three sites in the city in diverse periods of the year allows appraisal of the input of different pollution sources in the city.

Experimental Procedure

Sampling Area

The samples were taken in diverse periods in the years 2001–2003 non-simultaneously at three measuring points to analyze the influence of traffic intensity and other sources on ambient air pollution. The first measurement place, Kilinskiego Street is in the town center and is characterized by dense buildings, narrow streets and heavy traffic. Also, many of the old apartment houses are not connected to the city's central heating system and have their own coal-fired boilers. The APM sampler was situated 2 m above ground level, 5 m from the nearest busy street intersection, with intense car, bus and tram traffic. The second sampling point, Wroblewskiego Street (Institute of Applied Radiation Chemistry, Technical University of Łódź) is placed outside the city center and is less exposed to heavy traffic and local combustion, but is close to one of the biggest power plants in Łódź. The sampler was situated 1 m above ground level, 30 m from nearest busy street (car, bus, heavy duty vehicle and tram traffic), 500 m from EC2 power plant. The third point, Szkolna Street, is located in a suburban area, not exposed to vehicular traffic, but with elevated local combustion during winter period. The APM sampler was placed 1 m above ground level, 50 m from local street with car and bus traffic, 30 m from small local road. The localization of the sampling points and main power plants (EC) is shown in Fig. 1.

Sample Collection

Each sampling lasted from 10 days to 2 weeks to minimize the influence of short-term weather condition changes. The samples were collected in three selected sampling sites using Eight-Stage Cascade Impactor Series 20-800 Mark II (Andersen Instruments) on nitrocellulose filtration media substrates (Millipore HAWP). For the average air flow rate of 70 dm^3/h, the fractions of the following 50% cutoff aerodynamic equivalent diameters (AED) were separated: over 9.0 μm, 7.7 μm, 6.0 μm, 3.9 μm, 3.0 μm, 1.8 μm, 1.0 μm and 0.4 μm. A final filter collects all particles smaller than

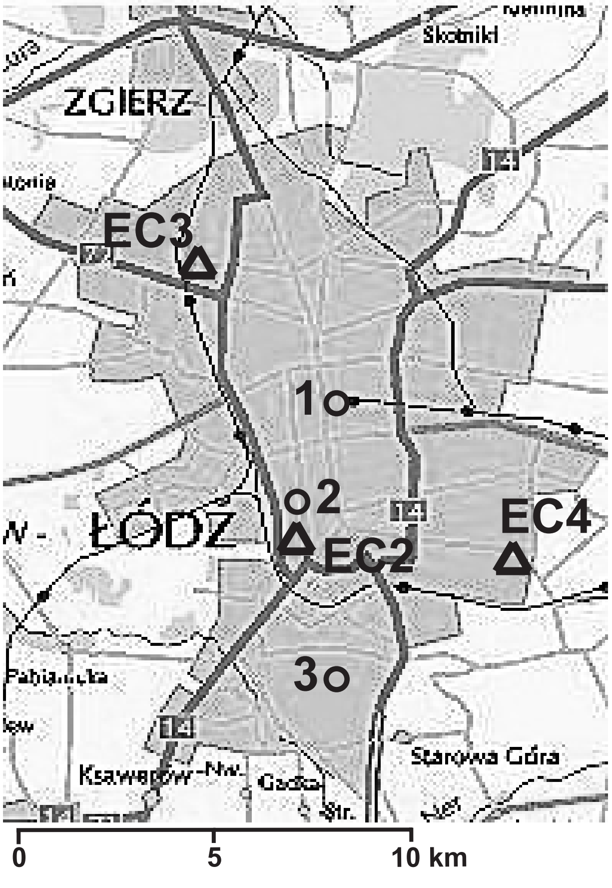

Fig. 1. Location of sampling points (circles): 1 – Kilinskiego St., 2 – Wroblewskiego St., 3 – Szkolna St. Position of three main power plants in Łódź is indicated with triangles.

0.4 μm. Nitrocellulose filters were dried to constant mass and weighed (Sartorius Precision Balance CP2252-OCE) before and after aerosol sampling. The load of collected APM in fractioned samples varied from 40 to 2 mg. Filters with collected dust were analyzed for concentration of several trace elements by means of ICP-MS.

Multielemental Analysis

The analysis of trace element concentration was performed by means of induced coupled plasma mass spectrometry ICP-MS (the analytical system UltraMass 700, VARIAN, Australia). Mass spectrometry detection allows high sensitivity measurements with a very low detection limit. The nitrocellulose substrates with collected urban aerosol were mineralized with spectrally pure nitric and hydrochloric acid in the proportion of *aqua regia*, under pressure of 100 atm in microwave apparatus (MILESTONE – Italy).

Quality Assurance

The calibration of the measurement method was ensured using standard solutions of high purity (ICP class) by Johnson-Matthey. Quality assurance of the ICP analysis procedure was carried out by measurement of the standard reference material – Fine Fly Ash (CTA–FFA–1, Institute of Nuclear Chemistry and Technology, Warsaw, Poland) in the same conditions as the samples. The discrepancy between measured values and those certified for most of the analyzed TE did not exceed 10% (except As and Zn for which the disagreement reached respectively 15 and 22%).

Results

Fractioned APM samples were collected over a long period of time (~2 weeks), which allowed for minimizing short-term weather pattern influence on measured mean TE concentration.

In all of the three sampling sites the concentration of air particulate matter in the fine particles region (< 2μm) were higher during the winter period, which indicated higher contribution of the fuel combustion sources. The increased input of the coarse fraction during the summer months can be explained by higher contribution of surface soil resuspension to total AMP concentration. Typical aerosol mass distribution curve is presented in Fig. 2. Fraction contributions F_i are calculated from the following equation:

$$F_i = m_i / \sum_{i=1}^{9} m_i$$

where m_i denotes gravimetrically determined mass of the i-th fraction.

Tables 1–6 show the values of weight concentration [ppm] of 15 TEs in fly ashes escaping from power plants and originating from other coal-burning sources (low emissions) compared with their concentration in relevant ambient aerosol fractions: PM_3 and PM_{10}, respectively, for three locations and both sampling seasons. For ease of data presentation and further calculations, the results of TE concentrations obtained for 9 size fractions were grouped into PM_3 (the sum for first 5 separated fractions: from 0.4 μm to 3.0 μm 50% cutoff AED) and PM_{10} (the sum for all 9 fractions). This simplification is justified in light of discussed observed trace elements distribution and visible differences between fine and coarse aerosol composition (below; compare Fig. 3) as well as observed emission profiles for power plants equipped with electrostatic precipitators [16].

Discussion

According to the data presented in Tables 1-6, generally three types of concentration size distribution tenden-

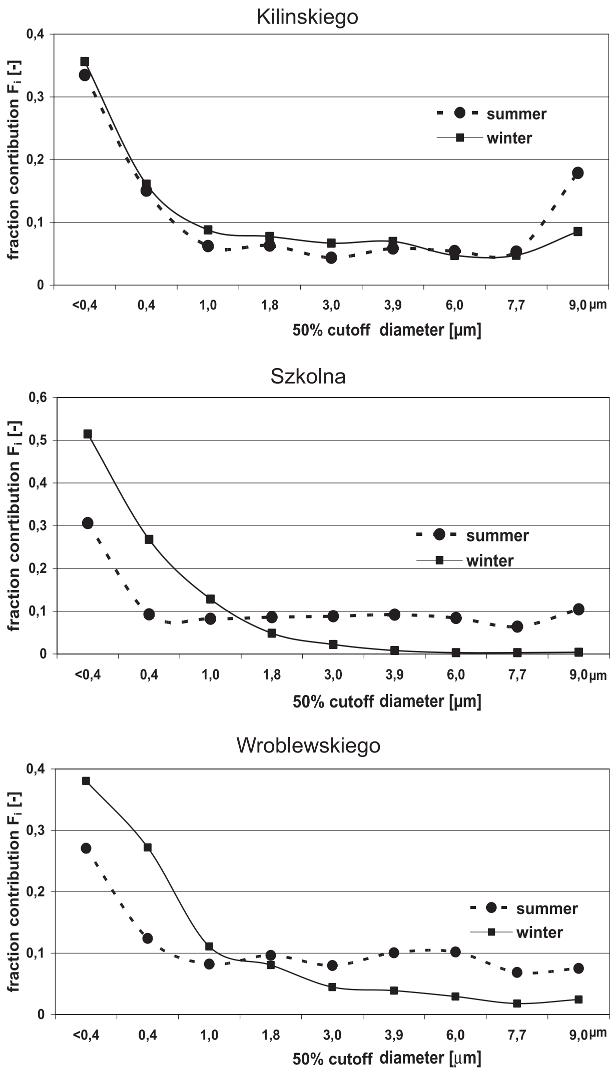

Fig. 2. Aerosol mass size distributions.

Table 1. Air concentration $C_{Air, PM3}$ of 15 TEs [ng/m^3]. Trace element weight concentrations [ppm] in fly ash escaping from power plants (C_{EFA}) compared with their concentration C_{PM3} in relevant ambient aerosol fraction PM_3 from Kilinskiego sampling site.

	$C_{Air, PM3}$ [ng/m^3]		C_{PM3} [ppm]		C_{EFA} [ppm]	C_{PM3}/C_{EFA}		Winter to Summer C_{PM3} ratio
	Winter	Summer	Winter	Summer		Winter	Summer	
Ag	0.714	0.326	44.5	18.6	24.9	1.79	0.75	2.39
As	0.666	0.462	41.5	26.4	24.3	1.71	1.09	1.57
Ca	203	1440	12700	82300	19300	0.66	4.27	0.15
Cd	0.364	0.780	22.7	44.5	4.59	4.94	9.70	0.51
Co	0.094	0.157	5.88	8.96	35.3	0.17	0.25	0.66
Cr	3.27	2.64	204	150	210	0.97	0.71	1.35
Hg	0.0729	0.0501	4.55	2.86	1.51	3.01	1.89	1.59
Mn	3.85	6.71	240	383	706	0.34	0.54	0.63
Ni	2.43	1.24	151	70.9	155	0.97	0.46	2.13
Pb	11.3	21.6	704	1235	365	1.93	3.38	0.57
Sb	1.22	3.42	75.8	195	10.4	7.25	18.71	0.39
Th	0.0086	0.0409	0.536	2.34	15.2	0.04	0.15	0.23
U	0.0193	0.0216	1.20	1.24	7.70	0.16	0.16	0.97
V	0.810	0.921	50.5	52.6	242	0.21	0.22	0.96
Zn	58.1	54.5	3620	3120	2090	1.73	1.49	1.16

Table 2. Air concentration $C_{Air, PM10}$ of 15 TEs [ng/m^3]. Trace element weight concentrations [ppm] in fly ash originating from low emissions coal-burning sources (C_{TFA}) compared with their concentration C_{PM10} in relevant ambient aerosol fraction PM_{10} from Kilinskiego sampling site.

	$C_{Air, PM10}$ [ng/m^3]		C_{PM10} [ppm]		C_{TFA} [ppm]	C_{PM10}/C_{TFA}		Winter to Summer C_{PM10} ratio
	Winter	Summer	Winter	Summer		Winter	Summer	
Ag	1.98	0.451	48.0	16.9	3.2	15.01	5.27	2.85
As	0.817	0.534	38.2	20.0	16.6	2.30	1.20	1.91
Ca	333	2160	15600	81000	12100	1.29	6.69	0.19
Cd	0.365	0.806	17.1	30.2	1.72	9.94	17.58	0.57
Co	0.143	0.271	6.67	10.1	22.7	0.29	0.45	0.66
Cr	5.45	4.99	254	186	91.5	2.79	2.04	1.37
Hg	0.0871	0.0613	4.07	2.29	0.118	34.48	19.43	1.77
Mn	5.82	11.1	272	417	1128	0.24	0.37	0.65
Ni	6.64	2.15	310	80.3	71.6	4.33	1.12	3.86
Pb	12.2	23.6	568	884	128	4.44	6.91	0.64
Sb	1.43	3.97	67.1	148	5.47	12.25	27.15	0.45
Th	0.0172	0.0827	0.804	3.09	12.6	0.06	0.24	0.26
U	0.0288	0.0333	1.35	1.25	4.27	0.32	0.29	1.08
V	1.49	0.968	69.8	36.2	109	0.64	0.33	1.93
Zn	69.4	66.5	3240	2490	380	8.54	6.55	1.30

Table 3. Air concentration $C_{Air, PM3}$ of 15 TEs [ng/m^3]. Trace element weight concentrations [ppm] in fly ash escaping from power plants (C_{EFA}) compared with their concentration C_{PM3} in relevant ambient aerosol fraction PM_3 from Szkolna sampling site.

	$C_{Air, PM3}$ [ng/m^3]		C_{PM3} [ppm]		C_{EFA} [ppm]	C_{PM3}/C_{EFA}		Winter to Summer C_{PM3} ratio
	Winter	Summer	Winter	Summer		Winter	Summer	
Ag	1.52	0.313	135	18.3	24.9	5.42	0.73	7.39
As	0.173	0.154	15.4	9.16	24.3	0.63	0.38	1.68
Ca	1810	279	161000	16400	19300	8.36	0.85	9.85
Cd	0.948	0.209	84.3	12.2	4.59	18.37	2.66	6.90
Co	0.227	0.0838	20.2	4.90	35.3	0.57	0.14	4.12
Cr	3.76	2.61	334	153	210	1.58	0.72	2.19
Hg	0.0760	0.0325	6.77	1.90	1.51	4.47	1.26	3.56
Mn	3.83	3.03	341	177	706	0.48	0.25	1.92
Ni	10.8	3.30	962	192	155	6.20	1.24	4.99
Pb	18.1	4.99	1614	291	365	4.42	0.80	5.53
Sb	2.44	0.639	217	37.4	10.4	20.76	3.58	5.80
Th	0.0560	0.0253	4.98	1.48	15.2	0.33	0.10	3.37
U	0.0192	0.0203	1.71	1.19	7.70	0.22	0.15	1.44
V	1.63	1.20	144	70.0	242	0.60	0.29	2.07
Zn	58.6	22.9	5220	1340	2090	2.50	0.64	3.90

Table 4. Air concentration $C_{Air, PM10}$ of 15 TEs [ng/m^3]. Trace element weight concentrations [ppm] in fly ash originating from low emission coal-burning sources (C_{TFA}) compared with their concentration C_{PM10} in relevant ambient aerosol fraction PM_{10} from Szkolna sampling site.

	$C_{Air, PM10}$ [ng/m^3]		C_{PM10} [ppm]		C_{TFA} [ppm]	C_{PM10}/C_{TFA}		Winter to Summer C_{PM10} ratio
	Winter	Summer	Winter	Summer		Winter	Summer	
Ag	2.26	0.559	163	24.5	3.2	51.2	7.65	6.70
As	0.512	0.190	37.2	8.70	16.6	2.24	0.52	4.28
Ca	1970	514	143000	22600	12100	11.8	1.87	6.34
Cd	1.00	0.212	73.0	9.31	1.72	42.5	5.43	7.84
Co	0.296	0.140	21.5	6.13	22.7	0.95	0.27	3.51
Cr	7.35	4.33	534	190	91.5	5.84	2.08	2.81
Hg	0.0948	0.0587	6.89	2.57	0.118	58.4	21.8	2.68
Mn	5.27	4.30	382	189	1128	0.34	0.17	2.03
Ni	12.9	4.65	939	204	71.6	13.1	2.85	4.60
Pb	19.3	5.49	1404	240	128	11.0	1.88	5.83
Sb	2.65	0.742	192	32.5	5.47	35.2	5.94	5.92
Th	0.130	0.0509	9.45	2.23	12.6	0.75	0.18	4.24
U	0.0271	0.0308	1.97	1.35	4.27	0.46	0.32	1.46
V	2.22	1.84	161	80.8	109	1.48	0.74	2.00
Zn	73.4	36.2	5330	1590	379	14.0	4.17	3.36

Table 5. Air concentration $C_{Air, PM3}$ of 15 TEs [ng/m^3]. Trace element weight concentrations [ppm] in fly ash escaping from power plants (C_{EFA}) compared with their concentration C_{PM3} in relevant ambient aerosol fraction PM_3 from Wroblewskiego sampling site.

	$C_{Air, PM3}$ [ng/m^3]		C_{PM3} [ppm]		C_{EFA} [ppm]	C_{PM3}/C_{EFA}		Winter to Summer C_{PM3} ratio
	Winter	Summer	Winter	Summer		Winter	Summer	
Ag	0.684	0.286	23.5	88.5	24.9	0.94	3.55	0.27
As	0.596	0.229	20.5	128	24.3	0.84	5.28	0.16
Ca	385	77.6	13200	34600	19300	0.69	1.80	0.38
Cd	0.688	0.165	23.7	97.0	4.59	5.16	21.1	0.24
Co	0.148	0.100	5.11	30.9	35.3	0.14	0.87	0.17
Cr	4.32	3.21	148	984	210	0.71	4.67	0.15
Hg	1.31	0.0130	45.0	4.34	1.51	29.8	2.87	10.4
Mn	10.4	2.16	358	814	706	0.51	1.15	0.44
Ni	1.96	3.16	67.5	1090	155	0.43	7.01	0.06
Pb	25.6	3.39	880	1720	365	2.41	4.70	0.51
Sb	3.67	0.865	126	414	10.4	12.1	39.7	0.30
Th	$2 \cdot 10^{-5}$*	0.0102	0.0050*	2.91	15.2	0.00	0.19	0.00
U	0.107	0.0161	3.69	4.15	7.70	0.48	0.54	0.89
V	0.431	1.81	14.8	638	242	0.06	2.63	0.02
Zn	78.6	16.1	2700	6250	2090	1.30	2.99	0.43

Table 6. Air concentration $C_{Air, PM10}$ of 15 TEs [ng/m^3]. Trace element weight concentrations [ppm] in fly ash originating from low emissions coal-burning sources (C_{TFA}) compared with their concentration C_{PM10} in relevant ambient aerosol fraction PM_{10} from Wroblewskiego sampling site.

	$C_{Air, PM10}$ [ng/m^3]		C_{PM10} [ppm]		C_{TFA} [ppm]	C_{PM10}/C_{TFA}		Winter to Summer C_{PM10} ratio
	Winter	Summer	Winter	Summer		Winter	Summer	
Ag	0.916	0.496	24.4	81.6	3.20	7.62	25.5	0.30
As	0.606	0.268	15.9	88.3	16.6	0.96	5.32	0.18
Ca	667	213	17800	43600	12100	1.47	3.60	0.41
Cd	0.713	0.167	19.0	63.6	1.72	11.1	37.1	0.30
Co	0.233	0.179	6.20	30.4	22.7	0.27	1.34	0.20
Cr	7.24	5.58	193	933	91.5	2.11	10.21	0.21
Hg	2.20	0.028	58.6	4.81	0.118	496	40.7	12.2
Mn	14.6	3.53	390	709	1130	0.35	0.63	0.55
Ni	4.16	7.10	111	1210	71.6	1.55	16.9	0.09
Pb	26.9	3.77	716	1170	128	5.60	9.13	0.61
Sb	4.16	1.00	111	289	5.47	20.2	52.9	0.38
Th	$2 \cdot 10^{-5}$*	0.0223	0.0050*	3.43	12.6	0.00	0.27	0.00
U	0.136	0.0219	3.62	3.46	4.27	0.85	0.81	1.05
V	0.431	2.28	11.5	476	109	0.10	4.35	0.02
Zn	90.00	25.6	2390	5280	380	6.30	13.9	0.45

* lower limit of detection

cies were observed for particular elements in all locations and for both sampling periods.

For the first group of important elements: Cd, Pb, Sb, V and Zn, air concentration strongly decreased with the increase of particle diameter (Fig. 3a). The second group of TEs: Ag, As, Co, Cr, Mn and Ni, does not show any significant concentration pattern for the whole range of diameter, or display a slight increase for the finest fractions smaller than 1 µm (Fig. 3b). For U and Th the increase of the concentration for coarse particles above 5 µm was observed (Fig 3c). Some interesting observations can also be made regarding the ratio of trace elements concentration in given air PM fraction (C_{PM}) and abundance in particles originating from coal burning: escaping (C_{EFA}) and total fly ash (C_{TFA}).

First, there is a group of elements (Ag, Cd, Cr, Hg, Ni, Pb, Sb and Zn) for which the ratios C_{PM3}/C_{EFA} and C_{PM10}/C_{TFA} are >> 1, which suggests that those TEs originate also from other sources except for coal burning. For this group of elements the weight concentrations are within the range of values observed for $PM_{2.5}$ collected at a site strongly influenced by vehicular traffic (ground-based, roadside or intersection) in California [18] (compare Table 7). Besides, the winter-to-summer ratios of C_{PM} (both for PM_3 and PM_{10}) for those elements at Kilinskiego and Wroblewskiego sites (i.e. sites with constant, relatively heavy traffic, including passenger cars, buses, trams and heavy duty trucks) are below 1 (besides Ag at Kilinskiego and Hg at the latter site). This fact can indicate both a generally higher, in percentage terms, influence of vehicular traffic on particulate matter emission (due to lower emissions from coal burning sources because of no heat production), or better air mixing and transport of traffic-related particles in dry, summer weather.

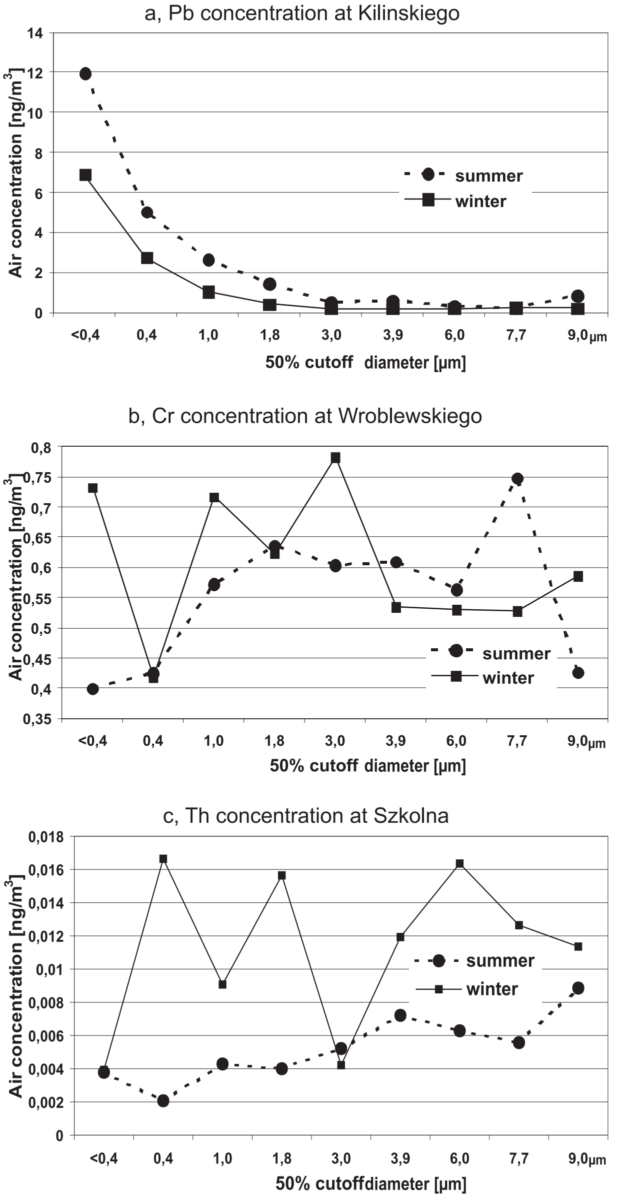

Fig. 3. Typical TE concentration distributions.

The second group of elements, namely As, Co, Mn, Th, U and V, for which the ratios C_{PM3}/C_{EFA} and C_{PM10}/C_{TFA} are ~ 1, which may suggest that they originate mainly from coal burning (in winter) or resuspension of upper soil layer (in summer). As it is known from escaping fly ash size distribution study, 80% of particles emitted from power plants are smaller than 3 µm [16], therefore coal combustion in big power plants is supposed to influence mainly PM_3 ambient aerosol fractions. The fine fraction of aerosol is also supposed to contain particles originating from long range transport of pollutants from, e.g., Belchatow Power Plant. On the other hand, particles emitted from coal burning devices unequipped with dust removal facilities cover a wider range of diameters, up to above 100 µm [16], affecting TSP ambient concentration. The elements for which the C_{PM3}/C_{EFA} ratios are ~ 1 can be treated as power plant coal combustion indicators; however, the assumption should be confirmed by winter-to-summer concentration ratios higher than 1. The two conditions are fulfilled for As, Cr, Ni, Zn for PM_3 weight concentration at Kilinskiego site. For Wroblewskiego sampling site, the winter C_{PM3}/C_{EFA} ratios for Ag, As, Ca, Cr and Zn are close to 1; however, they are not accompanied by winter-to-summer concentration ratios higher than 1. The site is located in close proximity to one of the big power plants in Łódź. The particles emitted from the power plant are thrown with hot stack gases to a height of 200–500 m and are known to settle down within several kilometres from their source of origin [22]; therefore, they should not be observed in the closest vicinity of the plant. On the other hand, the mercury concentration at Wroblewskiego site belonged to the highest observed values in the study. Mercury is emitted from combustion process partly as a vapour, and is supposed to attach rapidly to aerosol particles while cooling down and mixing the flue gases with ambient air [22, 23]. High concentrations of Hg in particulate matter collected at Wroblewskiego site, and its high winter-to-summer concentration ratios indicates the input of coal burning in the adjacent power plant.

The elemental concentration ratio C_{PM3}/C_{EFA} ~ 1 indicates the strong input of fly ash from local coal burning devices (low emission) into PM_{10} weight concentrations of discussed elements, confirmed additionally by winter-to-summer concentration ratios higher than 1, as can be observed for As and V at the Kilinskiego site.

At Szkolna sampling site, which is located in the suburbs, near a small road with low traffic intensity, the winter-to-summer ratios of C_{PM} are > 1 for all measured elements, which proves the greater input connected with increased coal burning during winter season (both medium-distance transport from power plants as well as from local low emission sources).

Conclusions

The long-term air sampling period (10–14 days) necessary for fractioned ambient particulate matter collection allows for the integration of diurnal and weather-influenced fluctuations of trace metal concentrations in the urban atmosphere. This is important for a reliable appraisal of the inhabitant's exposure to the inhalation of toxic elements with suspended fine particles.

The city of Łódź is still contingent upon coal burning as a source of electricity and heat and includes three large power plants within city limits, as well as not fully developed public heat supply system, resulting in uncontrolled low-lewel emissions from home stoves and heaters. Therefore, the concentration of the majority of measured TEs in Łódź during both summer and winter periods can be connected with emissions from coal burning for energy purposes and heating (the latter during cold months only).

The second most important source: vehicular traffic influences mainly the aerosol composition in the centre of the city, predominantly in the fine particulate matter range. According to environmental monitoring and modelling data [9], the mean 24-hr concentration of PM_{10} resulting from vehicular traffic ranges from 1 μg for most of the city area up to 2 μg in the centre of the city and around main highway junctions.

The predominant part of the trace elements from both high-level emissions (coal combustion in EC) and traffic sources is concentrated in a fine fraction of aerosols with particle diameter below 1 μm, which are the most dangerous from an epidemiological point of view.

However, the concentrations of important TEs observed for PM_{10} in Lodz are comparable to those determined in another large Polish city, Kraków [13], or even lower than the reported values for size fractioned particulate matter for other industrial and urban areas in the world [6, 17, 24, 25].

Table 7. TE concentration [ppm] in particulate matter originating from different pollution sources. PPP – coal-fired public power plant, LE – low emission sources, VT – location influenced by vehicular traffic, DPM – diesel particulate matter, S – sandy soils, data in parenthesis regarding urban or near highways locations.

	PPP		LE [16]	VT[18]	DPM[19]	S[17]
	Łódź [16]	Konin[17]				
Ag	24.91	-	3.20	100 ÷ 300	750	0.03 ÷ 0.1
As	24.33	20	16.60	20 ÷ 230	-	0.5 ÷ 15 (38 – 118)
Ca	19266	-	12100	60 ÷ 10990	22300	2.7%
Cd	4.591	5	1.720	60 ÷ 910	500	0.01 ÷ 0.24 (0.08 ÷ 61)
Co	35.30	13	22.70	0 ÷ 10	1310	0.1 ÷12
Cr	210.9	36	91.5	10 ÷ 140	6800	2 ÷ 60
Hg	1.512	-	0.118	10 ÷ 290	-	0.02 ÷ 0.16
Mn	706.5	2420	1130	30 ÷ 100	2000	15 ÷1500
Ni	155.3	-	71.6	20 ÷ 220	4450	1 ÷52
Pb	365.4	26	128.0	190 ÷ 3640	860	8.5 ÷ 23.5 (165 ÷ 2115)
Sb	10.45	0.8	5.47	90 ÷ 290	1340	0.3 ÷1.8
Th	15.2	10	12.6	-	-	4.0*
U	7.70	1.8	4.27	10 ÷ 70	-	1.4*
V	242.5	31.5	109.5	60 ÷ 270	820	10 – 37
Zn	2087	37	380	1000 ÷ 2660	3540	7 ÷ 150 (100 ÷ 14500)

* mean value for soils in Łódź [20]

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