Environ Monit Assess (2017) 189:381
DOI 10.1007/s10661-017-6094-0

Associations between air pollution in the industrial and suburban parts of Ostrava city and their use

Vitezslav Jirik · Barbara Brezna · Ondrej Machaczka · Sabina Honkysova · Hana Miturova · Vladimir Janout

Received: 18 November 2016 / Accepted: 20 June 2017

Abstract Selecting the locations and numbers of air quality monitoring stations is challenging as these are expensive to operate. Representative concentrations of pollutants in certain areas are usually determined by measuring. If there are significant correlations with concentrations of other pollutants or with other monitoring sites, however, concentrations could also be computed, partly reducing the costs. The aim of this study is to provide an overview of such possible relationships using data on concentrations of ambient air pollutants obtained in different areas of a larger city. Presented are associations between industrial (IP) and suburban parts (SP) as well as correlations between concentrations of various pollutants at the same site. Results of air pollutant monitoring come from Ostrava, an industrial city in Central Europe with a population of over 300,000. The study showed that certain pollutants were strongly correlated, especially particulate matter (r = 0.940) and ozone (r = 0.923) between the IP and SP. Statistically significant correlations were also found between different pollutants at the same site. The highest correlations were between PM_{10} and NO_2 (r_{IP} = 0.728; r_{SP} = 0.734), NO_2 and benzo(a)pyrene (r_{IP} = 0.787; r_{SP} = 0.697), and NO_2 and ozone (r_{IP} = −0.706; r_{SP} = −0.686). This could contribute to more cost-effective solutions for air pollution monitoring in cities and their surroundings by using computational models based on the correlations, optimization of the network of monitoring stations, and the best selection of measuring devices.

Keywords Air monitoring · Industrial part · Suburban part · Pollutant association

Introduction

Under the European legislation, EU members are obliged to carry out an ambient air quality assessment by stationary monitoring in all zones and agglomerations where the emission limits are not adhered to, or by preliminary measurement and modeling in other cases (Directive 2008/50/EC). Frequently, it is rather difficult to decide on the optimal number and placement of monitoring stations to provide a representative overview of pollutant concentrations in areas of interest, in terms of both selecting suitable places and financial costs required for running such stations (Spangl et al. 2007). In many cases, however, there is no need for continuous assessment using a dense network of stations because of temporal and spatial correlations between certain pollutants (Mücke et al. 2014; Blanchard et al. 2014; Schipa et al. 2009). These associations

V. Jirik (✉) · B. Brezna · O. Machaczka · S. Honkysova · V. Janout
Faculty of Medicine, Department of Epidemiology and Public Health, University of Ostrava, Syllabova 19, 703 00 Ostrava, Czech Republic
e-mail: vitezslav.jirik@osu.cz

H. Miturova
Institute of Public Health in Ostrava, Partyzanske nam. 7, 702 00 Ostrava, Czech Republic

Published online: 06 July 2017

can be found for a particular pollutant measured at different stations as well as for various pollutants monitored at the same site. Thus, pollutant concentrations may be calculated while reducing the expenditure on equipment and number of sampling points (Barbulescu and Barbes 2014). Another example of taking advantage of these relationships is verification or validation of model calculations using computer software. Concentrations of some pollutants are, usually with good accuracy, predicted applying various dispersion models (Dėdelė and Miškinytė 2015; Duyzer et al. 2015). For example, concentrations of nitrogen oxides and particulate matter 2.5 ($PM_{2.5}$) are often and successfully modeled by level of surrounding traffic sections (Beckerman 2008; Wu 2015).

Air pollutant concentrations in suburban parts of cities are also normally obtained with dispersion models. Less frequently, they are an object of measurement, unlike city centers. Since unverified modeling results might provide incorrect information, measured data are still considered to be more reliable. Therefore, it is recommended to first take measurements in industrial and suburban parts of cities, as was the case with this study carried out in Ostrava, Czech Republic over an entire year. Ostrava is an industrial city with a population of more than 300,000. The town center and surrounding areas are characterized by high levels of air pollution due to significant pollution sources and geographical conditions. The whole region (Upper Silesian Basin) is regarded as the most polluted area in the Czech Republic and probably in the whole Central Europe (Rossner et al. 2012; Jirik et al. 2016). For our purposes, that is, monitoring network optimization and verification of model calculations, the following pollutants were measured: particulate matter (PM_{10}), benzo(a)pyrene [B(a)P], nitrogen dioxide (NO_2), ozone (O_3), and benzene.

The objective was to prove that there are associations between concentration levels detected for the same pollutants in both industrial and suburban parts of the city as well as between concentration levels of different pollutants at the same monitoring site (in either the industrial or suburban area). The results may contribute to the optimization of the existing network of measuring stations and equipment needed. Statistically significant relationships between pollutant concentrations would mean more efficient measuring and verification of model calculations and reduction of equipment costs. As a result, some stations may only need to be operated for a limited period of time or even canceled.

Materials and methods

Equipment

The study was conducted with a PM_{10} high-volume air sampler (Hi-Q Environmental Products Company, USA), the APOA-370 ambient ozone monitor (Horiba, Japan), APNA-370 ambient NOx monitor (Horiba, Japan), a volatile organic compound sampler (Horiba, Japan), thermal desorber (Supelco, USA), gas chromatography-mass spectrometry system (Thermo Fisher Scientific, USA), and high-pressure liquid chromatography system (Waters, USA).

Software

Data obtained from monitoring stations were processed with the Stata statistical software, release 9 (StataCorp, USA) and MS Excel spreadsheet (Microsoft, USA). Figures were created using MS Excel and IrfanView.

Study settings

For the measurements, two boroughs of the city of Ostrava were selected, namely Přívoz, a residential area directly influenced by industrial sources (hereinafter referred to as IP—industrial part), and Polanka nad Odrou (SP—suburban part), as shown in Fig. 1.

In the area of IP, there are significant emission sources such as the metal and coke industry, heat plants, and automobile transportation. The SP is not directly affected by major industrial sources. In the past, it used to be a separate agricultural village (animal and crop farming). The SP is situated on the upwind side, that is, in the main southwest wind direction. The secondary prevailing wind direction is from the north and north-northeast where numerous distant sources of industrial emission are located such as a heat plant at a distance of 11.4 km (Fig. 1). Transport emissions were assumed to be at an average level. Both city parts are fully supplied with gas, but solid fuel boilers are still used for local heating in some households.

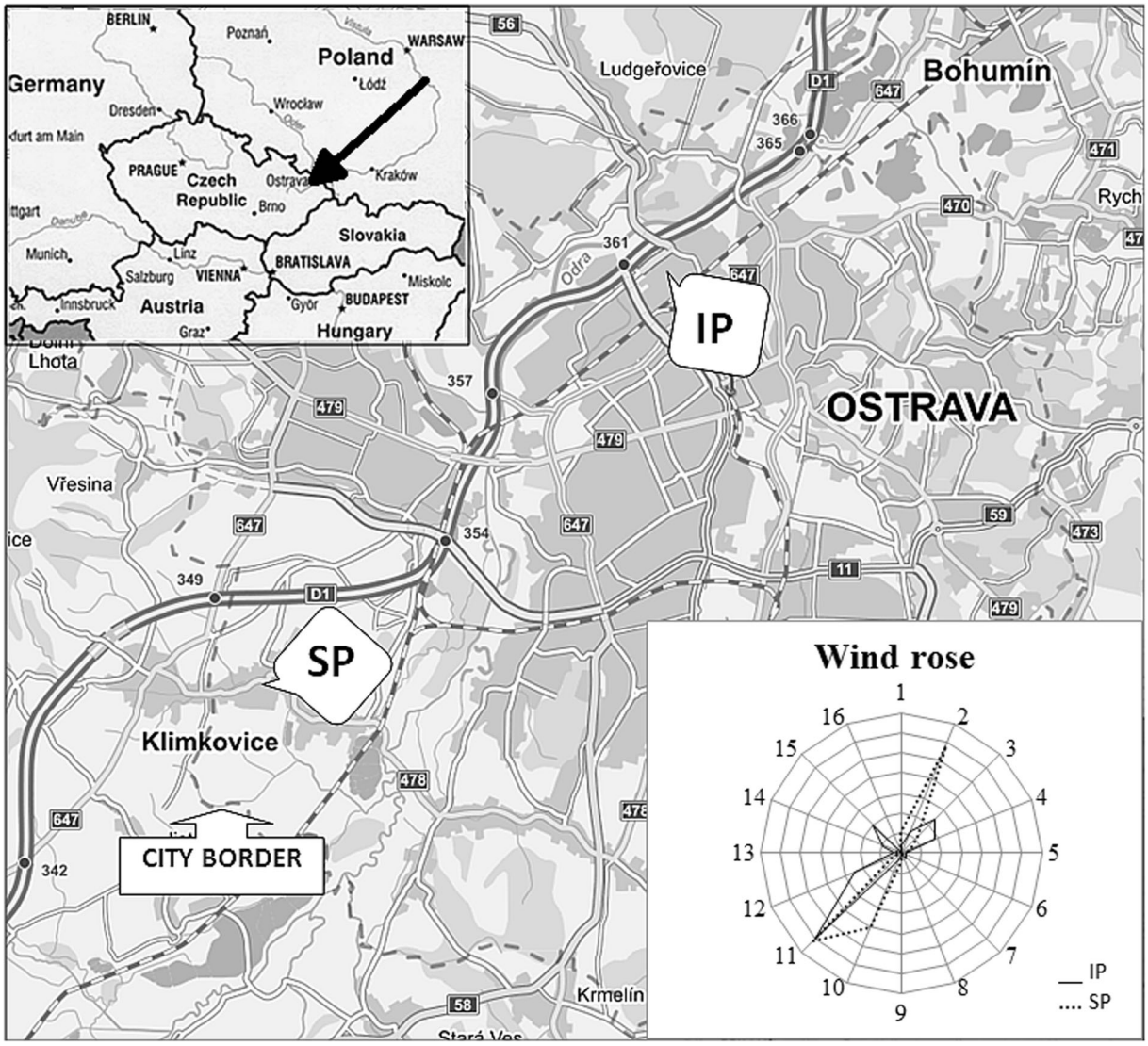

Fig. 1 Monitored sites of SP and IP where the measuring stations were placed; wind rose for SP and IP during 1 year; the position of the Czech Republic and Ostrava city in Central Europe

Methods

Stationary monitoring stations for measuring air pollution in all the above locations were operated in accordance with Directive 2008/50/EC. Pollutant monitoring was conducted in various modes over one calendar year.

Ozone and NO_2 were measured continuously by automated analyzers and 24-h mean concentrations were evaluated daily. Twenty-four-hour concentrations of benzene, PM_{10}, and B(a)P were recorded on every six.

Samples of PM_{10} were collected using fiber filters, weighed (according to EN 12341:1998), and extracted with dichloromethane. Benzo(a)pyrene was determined by the US EPA TO-13A method using high-pressure liquid chromatography with fluorescence detection (according to EUR 14988 EN). The determination of benzene in ambient air was based on the US EPA TO-2 method, with capture of the analyte in a carbon molecular sieve being followed by thermal desorption and gas chromatography-mass spectrometry (EN 14662-2:2005). Nitrogen dioxide was determined using an automated analyzer by chemiluminescence (EN 14211:2012) and O_3 was specified using the automatic analyzer on the principle of UV absorption (EN 14625:2005). For the obtained air pollutant concentrations in the SP and IP, correlation and regression analysis was performed (Zalel et al. 2014).

Table 1 Comparison of pollutant concentration measurements in the SP and IP

Pollutant	PM_{10} (μg.m^3)		B(a)P (ng.m^3)		NO_2 (μg.m^3)		O_3 (μg.m^3)		Benz (μg.m^3)	
Concentration	SP	IP	SP	IP	SP	IP	SP	IP	SP	IP
N	60	60	60	60	344	344	290	290	58	58
C_p	39	44	6.2	7.8	19.1	29.4	47.0	43.9	2.6	4.6
Me	33	37	4.7	6.2	17.0	27.6	48.6	45.2	2.2	3.6
Min	11	12	0.2	0.4	2.0	6.8	3.0	5.2	0.6	0.6
Max	224	203	41.6	35.5	60.5	76.6	114.4	114.6	6.7	16.8

N number of paired data, C_p annual arithmetic mean, *Me* annual median, *Min* minimum daily mean concentration, *Max* maximum daily mean concentration

The results were subjected to exploratory statistical analysis, and data distribution was investigated; finally, logarithmic transformation was applied to the data. The monitored pollutant concentrations showed a logarithmic distribution rather than a normal distribution. Therefore, logarithmic regression was applied using the following equations:

$$ln\ C_{SP} = k \cdot ln\ C_{IP} + j \quad (1)$$

$$ln\ C_m = b \cdot ln\ C_n + a \quad (2)$$

Results and discussion

Relationships between pollutant concentrations at suburban and industrial sites of Ostrava city

Comparisons of pollutant concentration measurements in the SP and IP are shown in Tables 1 and 2. Figure 2a–e shows concentration correlations for particular pollutants in the above areas. The inner chart illustrates the correlation of the concentration logarithm for pollutants at monitored sites of SP and IP, where along the vertical

Table 2 Statistical analysis of pollutant concentrations in the SP and IP

ln statistics	PM_{10}	B(a)P	NO_2	O_3	Benzene
C_p ratio (SP/IP)	0.879	0.790	0.649	1.070	0.579
Me ratio (SP/IP)	0.892	0.758	0.617	1.075	0.611
r	0.940	0.717	0.679	0.923	0.169
p (r)	<0.001	<0.001	<0.001	<0.001	0.205
j	0.097	−1.264	0.121	0.173	0.521
p (j)	0.557	0.030	0.444	0.048	0.005
j_{min} (95% CI)	−0.232	−2.400	−0.190	0.001	0.168
j_{max} (95% CI)	0.425	−0.129	0.433	0.346	0.874
k	0.936	0.823	0.818	0.970	0.154
p (k)	<0.001	<0.001	<0.001	<0.001	0.205
k_{min} (95% CI)	0.846	0.613	0.724	0.923	−0.086
k_{max} (95% CI)	1.025	1.034	0.912	1.017	0.393

Ratios of concentrations are calculated by using unrounded values

C_p *ratio (SP/IP)* ratio of annual arithmetic means of pollutant concentrations at SP and IP site, *Me ratio (SP/IP)* ratio of annual medians of pollutant concentrations at SP and IP site, *r* correlation coefficient, *j* regression coefficient (y-intercept), *k* regression coefficient (slope), *p (r)* statistical significance of the correlation coefficient r, *p (j)* statistical significance of the regression coefficient j, *p (j)* statistical significance of the regression coefficient j, *p (k)* statistical significance of the regression coefficient k, j_{max}-j_{min} *(95% CI)* 95% confidence interval of the y-intercept, k_{max}-k_{min} *(95% CI)* 95% confidence interval of the slope k

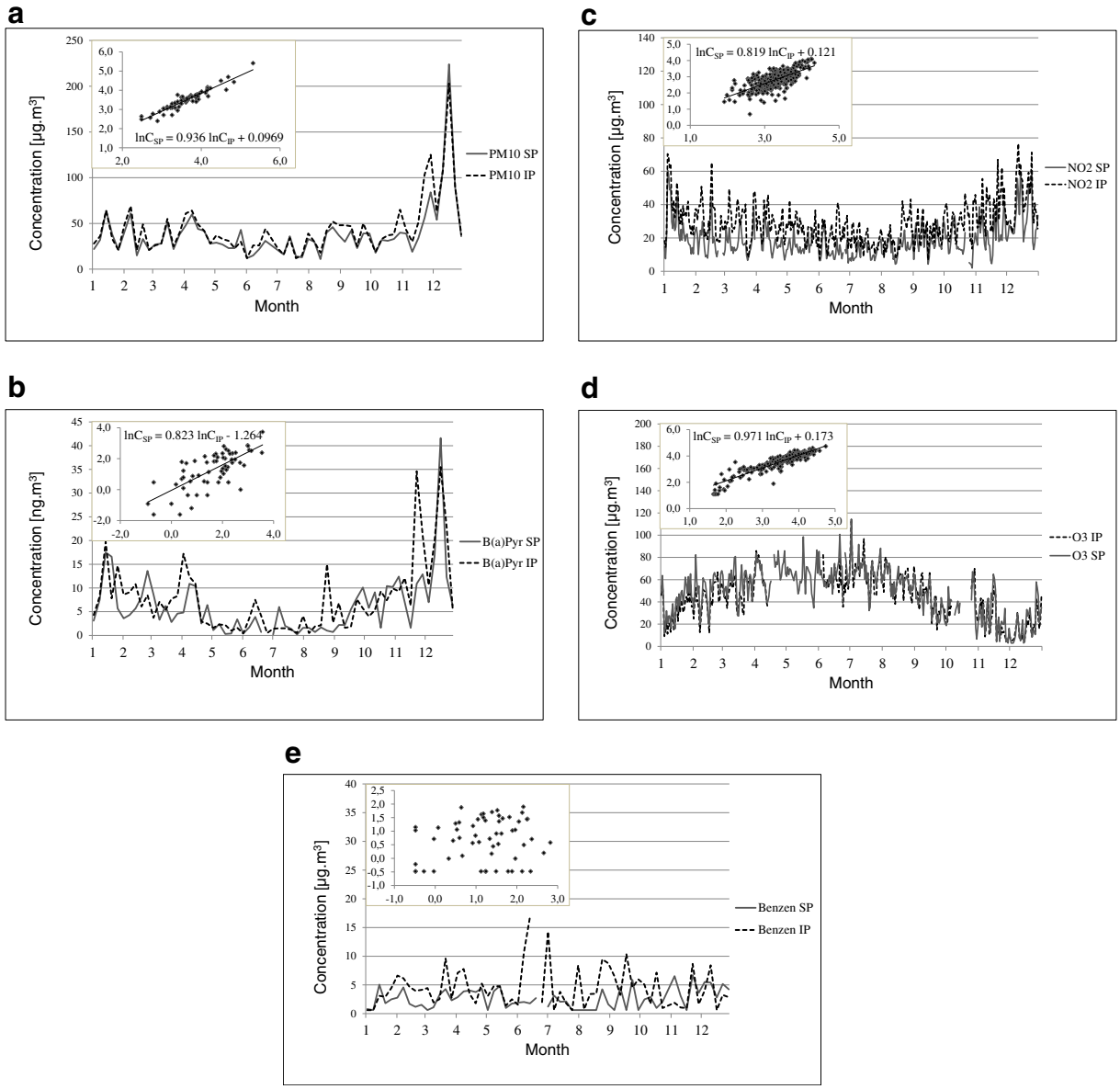

Fig. 2 Correlation of concentrations of particulate matter PM_{10} (**a**), benzo(a)pyrene (**b**), nitrogen dioxide (**c**), ozone (**d**), and benzene (**e**)

axis, there is SP and along the horizontal axis, there is the IP area. Outer graphs in Fig. 2a–e presents pollutant concentrations versus time during the year. Except for ozone, all pollutant concentrations were higher in the IP than in the SP. Correlations between concentrations of a certain pollutant at the IP site and the same pollutant at the SP site were statistically significant for all substances with the exception of benzene. The most significant correlations between the SP and IP sites were found for PM_{10} ($r = 0.940$) and ozone ($r = 0.923$). The Table 3 shows relative frequencies of wind directions and related concentrations of PM_{10}. It demonstrates the relationship of wind direction and pollutant concentration. For a preview of the wind direction distribution see the Fig. 1.

Relationships between concentrations of different pollutants at the same site

Many statistically significant correlations between different pollutants at the same industrial or suburban site of the city were identified. Comparisons of pollutant

Table 3 Relative frequencies and related concentrations of PM_{10} according to wind direction

Sector k		R_k		C_k (μg.m^3)		C_k ratio
		IP (%)	SP (%)	IP	SP	SP/IP
1	N	1.57	4.18	37.283	43.875	1.177
2	NNE	4.61	23.26	47.516	47.864	1.007
3	NE	9.37	4.70	65.002	63.021	0.970
4	ENE	7.33	1.77	58.259	45.471	0.780
5	E	0.96	0.19	55.501	44.673	0.805
6	ESE	1.10	0.17	50.334	41.482	0.824
7	SE	1.39	0.17	49.009	38.291	0.781
8	SSE	0.17	0.32	51.766	37.493	0.724
9	S	0.38	1.92	44.822	35.100	0.783
10	SSW	1.33	16.15	36.373	28.718	0.790
11	SW	24.07	24.69	35.193	26.878	0.764
12	WSW	10.19	1.84	35.819	23.134	0.646
13	W	1.40	0.39	31.523	19.145	0.607
14	WNW	3.77	0.92	25.616	19.943	0.779
15	NW	7.82	0.75	23.869	20.741	0.869
16	NNW	0.15	0.25	30.759	27.921	0.908
windless	(<0.5 m/s)	24.37	18.33	55.225	49.459	0.896

R_k relative frequency of wind direction from sector k over 1 year period, C_k average concentrations of the PM10 in the air over 1 year period from sector k

concentration measurements for pollutants in the IP and SP are shown in Tables 4 and 5, respectively. The highest correlations were found between PM_{10} and NO_2 (r_{IP} = 0.728; r_{SP} = 0.734), NO_2 and B(a)P (r_{IP} = 0.787; r_{SP} = 0.697), and between NO_2 and ozone (r_{IP} = −0.706; r_{SP} = −0.686). The least significant correlations were observed between benzene and the other pollutants (r = 0.022 to 0.470).

Surprisingly, a close relationship was found between PM_{10} concentrations in the IP and SP (r = 0.940; Table 2). Relatively high PM_{10} concentrations were found in the studied locations, with respect to the permitted limits. In the SP, they reached 90% of the IP values (Fig. 2a, Tables 1 and 2). Similar results were found in an Italian study on correlations between pollutant levels in various parts of the city of Taranto. After statistical evaluation of measurement data, the authors came to the conclusion that PM_{10} concentrations in different locations were much more correlated than other pollutants, with correlation coefficients ranging from 0.8 to 0.9 (Mangia et al. 2012). Also, a study from Berlin, Germany showed correlation coefficients for PM_{10} in a range between 0.77 and 0.87 (Mücke et al. 2014). The existence of correlations between industrial and suburban sites for PM_{10} was investigated using a computational model in Romania. The correlation was r = 0.626 (Barbulescu and Barbes 2014), that is, slightly lower than in the present study but also significant. Consistent with our results are those found in a study from Birmingham, AL, USA showing a PM_{10} correlation coefficient of r = 0.899 between various sites of the city, with the correlation being dependent on the distance from pollutant sources (Blanchard et al. 2014). This fact also corresponds to our conclusion. The present study recorded the highest PM_{10} values in December, as did other authors (Aher et al. 2014; Aalto et al. 2005). Similar concentrations were also measured in the suburban part of the city of Caserta, Italy, with wind intensity and direction being the most important factors, suggesting that industrial plants situated on the windward side were the main local pollution sources, as for particulate matter (Iovino et al. 2014). Although the monitored suburban part of the city is located on the windward side and should not be affected by the

Table 4 Comparison of pollutant concentration measurements in the IP

Statistics	C_n-C_m	C_n-C_m	C_n-C_m	C_n-C_m	C_n-C_m
Pollutants	PM_{10}-B(a)P	PM_{10}-O_3	PM_{10}-NO_2	PM_{10}-Benz	B(a)P-O_3
N′	61	47	61	59	47
r	0.6998	−0.621	0.728	0.102	−0.568
a	−10.229	6.404	1.139	0.740	1.423
p (a)	<0.001	<0.001	<0.001	0.315	0.00358
a_{min} (95% CI)	−11.546	5.302	0.603	−0.723	0.491
a_{max} (95% CI)	−8.911	7.506	1.675	2.202	2.355
b	1.354	−0.782	0.598	0.133	−0.676
p (b)	<0.001	<0.001	<0.001	0.509	<0.001
b_{min} (95% CI)	0.994	−1.078	0.451	−0.268	−0.714
b_{max} (95% CI)	1.715	−0.486	0.745	0.534	−0.639
Pollutants	B(a)P-NO_2	B(a)P-Benz	O_3-NO_2	O_3-Benz	NO_2-Benz
N′	61	59	47	46	59
r	0.787	0.225	−0.706	0.022	0.326
a	5.082	2.147	4.827	1.184	−0.848
p (a)	<0.001	<0.001	<0.001	0.0759	0.287
a_{min} (95% CI)	4.711	1.025	4.372	−0.129	−2.429
a_{max} (95% CI)	5.452	3.269	5.282	2.497	0.733
b	0.334	−0.213	−0.420	0.027	0.620
p (b)	<0.001	<0.001	<0.001	0.882	0.012
b_{min} (95% CI)	0.266	−0.257	−0.546	−0.337	0.144
b_{max} (95% CI)	0.402	−0.168	−0.293	0.391	1.097

N′ number of paired data, *Cm* concentration of m pollutant, *Cn* concentration of n pollutant, *r* correlation coefficient, *a* regression coefficient (y-intercept), *b* regression coefficient (slope), *p (a)* statistical significance of the regression coefficient a, *p (b)* statistical significance of the regression coefficient b

industrial site, strong correlations were found between concentrations of the PM_{10} in the IP and SP (Fig. 1 and Table 3).

A high correlation of $r = 0.923$ was also found for O_3 concentrations. The ozone concentration in the SP was equal to 107% of the IP value (Fig. 2d, Tables 1 and 2). This phenomenon has been confirmed by some other studies, such as those performed in Spain and Turkey, with higher O_3 concentrations being reported in rural measuring stations in the southwest of the Iberian Peninsula. As in our study, the highest O_3 concentrations were observed during the summer months (Domínguez-López et al. 2014; Tecer and Tagil 2014; Gómez-Carracedo et al. 2015). Another study examining the variety of O_3 concentrations in industrial and suburban sites of Southern Italy concluded that O_3 concentrations at suburban sites are higher in comparison with those in urban areas and, once again, the pollutant concentrations were higher in the summer months (Schipa et al. 2009). Our results can also be compared with those from Delhi-NCR, India showing that mean O_3 concentrations in rural areas were equal to approximately 130% of the levels in areas burdened with traffic (Kumar et al. 2014). The authors calculated the means for only the summer, autumn, and winter time of 1 year (Kumar et al. 2014) while our results covered all seasons of the year. Thus, our results may be considered more accurate.

The permitted limit for B(a)P concentration was exceeded in both Přívoz and Polanka nad Odrou. High B(a)P values, particularly in Central and Eastern Europe, have been a well-known problem (Guerreiro et al. 2016). The B(a)P concentration in the SP was equal to 80% of the IP level, a statistically significant correlation ($r = 0.717$; Fig. 2b, Tables 1 and 2). A similar study focused on these areas and based on computational models found a slightly lower correlation range of $r = 0.55$ to 0.58 (Zalel et al. 2014).

Table 5 Comparison of pollutant concentration measurements in the SP

Statistics	C_n-C_m	C_n-C_m	C_n-C_m	C_n-C_m	C_n-C_m
Pollutants	PM_{10}-B(a)P	PM_{10}-O_3	PM_{10}-NO_2	PM_{10}-Benz	B(a)P-O_3
N′	60	57	57	59	57
r	0.561	−0.580	0.734	0.409	−0.509
a	−9.865	6.150	0.457	−1.308	1.889
p (a)	<0.001	<0.001	0.138	0.0343	<0.001
a_{min} (95% CI)	−11.528	5.199	−0.151	−2.515	1.141
a_{max} (95% CI)	−8.202	7.100	1.066	−0.100	2.637
b	1.216	−0.708	0.689	0.579	−0.319
p (b)	<0.001	<0.001	<0.001	0.00129	<0.001
b_{min} (95% CI)	0.745	−0.977	0.517	0.236	−0.450
b_{max} (95% CI)	1.687	−0.440	0.861	0.921	−0.188
Pollutants	B(a)P-NO_2	B(a)P-Benz	O_3-NO_2	O_3-Benz	NO_2-Benz
N′	57	59	55	56	56
r	0.697	0.372	−0.686	−0.399	0.470
a	4.588	2.086	4.792	2.434	−1.331
p (a)	<0.001	<0.001	<0.001	<0.001	0.0151
a_{min} (95% CI)	4.097	1.155	4.222	1.342	−2.394
a_{max} (95% CI)	5.079	3.018	5.362	3.526	−0.268
b	0.305	0.244	−0.524	−0.465	0.713
p (b)	<0.001	0.00376	<0.001	0.00229	<0.001
b_{min} (95% CI)	0.220	0.082	−0.678	−0.756	0.347
b_{max} (95% CI)	0.389	0.406	−0.371	−0.174	1.078

N′ number of paired data, *Cm* concentration of m pollutant, *Cn* concentration of n pollutant, *r* correlation coefficient, *a* regression coefficient, *b* regression coefficient (slope), *p (a)* statistical significance of the regression coefficient a, *p (b)* statistical significance of the regression coefficient b

Nitrogen dioxide concentrations in the SP were equal to 65% of the IP values, with a correlation of $r = 0.679$ (Fig. 2c, Tables 1 and 2). Nearly the same correlation was found in the aforementioned Delhi-NCR study showing the highest concentration in the winter but covering only three seasons (Kumar et al. 2014). Once again, our data are more representative. The significant relationship was confirmed in a study on concentration of nitrogen oxides at urban and industrial sites on the Romanian coast that used a computational model (Barbulescu and Barbes 2014). Our observations are in line with these conclusions, although very low spatial NO_2 correlations were reported in other studies, such as that from the city of Taranto, Italy (Mangia et al. 2012).

In the present study, benzene was rather exceptional as its concentrations in the SP and IP showed no correlation (Fig. 2, Tables 1 and 2). This was a surprising finding, suggesting the presence of completely different major sources of benzene than those of the other pollutants. Moreover, differences between concentrations in the SP and IP were highest for benzene, in comparison with all the other pollutants. This fact points to the clear dominance of burning of organic substances in cities, which is generally known (Zhang et al. 2013).

Our results, mostly consistent with those in similar studies, suggest that the long-term mean concentrations of air pollutants in suburban city areas are significantly influenced not only by sources located along the prevailing wind direction (i.e., along the southwest direction in this case) but also by sources from other directions and by atmospheric diffusion events. According to Directive 2008/50/EC, results obtained by measurement are still considered more credible, as opposed to mathematical modeling. Thus, based on both the present study and other studies cited above, it may be concluded that suburban areas are usually more strongly influenced by pollutants from the industrial part of the town than expected. The close association may be used to optimize the

monitoring network using concentrations estimated by calculations and to verify the current model calculations.

Moreover, significant correlations were revealed between various pollutants measured at the same site (Tables 4 and 5). The most statistically significant correlations were found between PM_{10} and NO_2 ($r_{IP} = 0.728$; $r_{SP} = 0.734$). Similar correlations between $PM_{2.5}$ and NO_2 were found in some other studies (Eeftens et al. 2012, Beckerman 2008). Particulate matter concentrations are generally considered a good indicator for estimating concentrations of other air pollutants (Martuzzi et al. 2006). A significant correlation was also demonstrated between NO_2 and B(a)P ($r_{IP} = 0.787$; $r_{SP} = 0.697$). This is consistent with a Korean study showing a correlation between aromatic hydrocarbons and NO_2 of $r = 0.668$ (Moon et al. 2006). An equally significant correlation was found between NO_2 and O_3 ($r_{IP} = -0.706$, $r_{SP} = -0.686$). The inverse relationship between concentrations of O_3 and other pollutants is a commonly known fact that has been detected in other studies (Gómez-Carracedo et al. 2015). These results show that significantly close relationships between different pollutants measured at the same site can also be used to optimize the monitoring network.

Conclusions

Many studies have investigated the relationship between different pollutants and the time of day or season of the year, or between health problems of people and the amount of pollutants in the air. This article should provide an incentive to monitor air pollutants in a more economical way. Despite the fact that the monitored suburban part of the city is located on the windward side and, therefore, should not be affected by the industrial site, strong correlations were found between concentrations of the same pollutant in the IP and SP.

Moreover, strong correlations were also found between different pollutants monitored at the same site. This finding could be used to reduce the number of sampling points which are expensive to operate, partly replacing them with computational models. In each site, however, specific effects may have an impact on the amount of air pollutants. This may be solved by representative measurements to verify the degree of correlation of air pollutants in a particular site and creating a computational model. There are many types of models that are able to predict the concentrations of pollutants, depending on certain environmental parameters (e.g., the area of land or impact of the transportation sector), but only a few models directly applying the correlations between pollutants.

In our case, the computations to estimate the concentration of PM_{10}, B(a)P, and O_3 in the SP could be applied with certainty with respect to the concentrations obtained by measurements in the IP of the city. Furthermore, local concentrations of PM_{10}, B(a)P, and O_3 could be estimated based on NO_2 concentrations in the SP and IP. A similar approach could considerably simplify the network for monitoring air pollutants wherever needed.

References

Aalto, P., Hämeri, K., Paatero, P., Kulmala, M., Bellander, T., Berglind, N., et al. (2005). Aerosol particle number concentration measurements in five European cities using TSI-3022 condensation particle counter over a three-year period during health effects of air pollution on susceptible subpopulations. *Journal of the Air and Waste Management Association, 55*(8), 1064–1076. doi:10.1080/10473289.2005.10464702 ISSN 1096-2247.

Aher, S. B., Dobhal, B. S., & Awasthi, R. S. (2014). Spatial and temporal variations of SO_2, NO_x, PM_{10} and TSPM concentration in ambient air of Jalna City, India. *International Journal of Agriculture, Environment and Biotechnology, 7*(3), 571–579. doi:10.5958/2230-732X.2014.01362.X ISSN 0974-1712.

Barbulescu, A., & Barbes, L. (2014). Models for pollutants' correlation in the Romanian littoral. *Romanian Reports in Physics, 66*(4), 1189–1199 http://www.rrp.infim.ro/2014_66_4/A26.pdf.

Beckerman, B., Jerrett, M., Brook, J. R., Verma, D. K., Arain, M. A., & Finkelstein, M. M. (2008). Correlation of nitrogen dioxide with other traffic pollutants near a major expressway. *Atmospheric Environment, 42*(2), 275–290. doi:10.1016/j.atmosenv.2007.09.042 ISSN 13522310.

Blanchard, C. L., Tanenbaum, S., & Hidy, G. M. (2014). Spatial and temporal variability of air pollution in Birmingham, Alabama. *Atmospheric Environment, 89*, 382–391.

Dėdelė, A., & Miškinytė, A. (2015). Estimation of inter-seasonal differences in NO_2 concentrations using a dispersion ADMS-Urban model and measurements. *Air Quality, Atmosphere and Health, 8*(1), 123–133. doi:10.1007/s11869-014-0272-9 ISSN 1873-9318.

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.

Domínguez-López, D., Adame, J. A., Hernández-Ceballos, M. A., Vaca, F., De la Morena, B. A., & Bolívar, J. P. (2014). Spatial and temporal variation of surface ozone, NO and NO_2 at urban, suburban, rural and industrial sites in the southwest

of the Iberian Peninsula. *Environmental Monitoring and Assessment, 186*(9), 5337–5351.

Duyzer, J., van den Hout, D., Zandveld, P., & van Ratingen, S. (2015). Representativeness of air quality monitoring networks. *Atmospheric Environment, 104*, 88–101. doi:10.1016/j.atmosenv.2014.12.067 ISSN 13522310.

Eeftens, M., Tsai, M., Ampe, C., Anwander, B., Beelen, R., Bellander, T., et al. (2012). Spatial variation of $PM_{2.5}$, PM_{10}, $PM_{2.5}$ absorbance and PM_{coarse} concentrations between and within 20 European study areas and the relationship with NO_2—Results of the ESCAPE project. *Atmospheric Environment, 62*, 303–317. doi:10.1016/j.atmosenv.2012.08.038 ISSN 13522310.

Gómez-Carracedo, M. P., Andrade, J. M., Ballabio, D., Prada-Rodríguez, D., Muniategui-Lorenzo, S., Consonni, V., et al. (2015). Impact of medium-distance pollution sources in a Galician suburban site (NW Iberian peninsula). *Science of the Total Environment, 512-513*, 114–124. doi:10.1016/j.scitotenv.2015.01.029 ISSN 00489697.

Guerreiro, C. B. B., Horálek, J., De Leeuw, F., & Couvidat, F. (2016). Benzo(a)pyrene in Europe: Ambient air concentrations, population exposure and health effects. *Environmental Pollution, 214*, 657–667. doi:10.1016/j.envpol.2016.04.081 ISSN 02697491.

Iovino, P., Canzano, S., Leone, V., Berto, C., Salvestrini, S., & Capasso, S. (2014). Contribution of vehicular traffic and industrial facilities to PM_{10} concentrations in a suburban area of Caserta (Italy). *Environmental Science and Pollution Research, 21*(23), 13169–13174. doi:10.1007/s11356-013-2209-5 ISSN 0944-1344.

Jirik, V., Machaczka, O., Miturova, H., Tomasek, I., Slachtova, H., Janoutova, J., Velicka, H., & Janout, V. (2016). Air pollution and potential health risk in Ostrava region—A review. *Central European Journal of Public Health, 24*(Supplement), S4–S17. doi:10.21101/cejph.a4533 ISSN 12107778.

Kumar, A., Singh, D., Singh, B. P., Singh, M., Anandam, K., Kumar, K., et al. (2014). Spatial and temporal variability of surface ozone and nitrogen oxides in urban and rural ambient air of Delhi-NCR, India. *Air Quality, Atmosphere and Health, 8*(4), 391–399.

Mangia, C., Gianicolo, E. A., Bruni, A., Vigotti, M. A., & Cervino, M. (2012). Spatial variability of air pollutants in city of Taranto, Italy and its potential impact on exposure assessment. *Environmental Monitoring and Assessment, 185*(2), 1719–1735.

Martuzzi, M., Mitis, F., & Iavarone, I. (2006). *Health impact of PM_{10} and ozone in 13 Italian cities*. Copenhagen: World Health Organization Europe ISBN 9289022930.

Moon, H.-B., Kannan, K., Lee, S.-J., & Ok, G. (2006). Atmospheric deposition of polycyclic aromatic hydrocarbons in an urban and a suburban area of Korea from 2002 to 2004. *Archives of Environmental Contamination and Toxicology, 51*(4), 494–502. doi:10.1007/s00244-006-0002-x ISSN 0090-4341.

Mücke, H.-G., Wagener, S., Werchan, M., & Bergmann, K.-C. (2014). Measurements of particulate matter and pollen in the city of Berlin. *Urban Climate, 10*, 621–629.

Rossner, P., Svecova, V., Schmuczerova, J., Milcova, A., Tabashidze, N., Topinka, J., et al. (2012). Analysis of biomarkers in a Czech population exposed to heavy air pollution. Part I: Bulky DNA adducts. *Mutagenesis, 28*(1), 89–95. doi:10.1093/mutage/ges057 ISSN 0267-8357.

Schipa, I., Tanzarella, A., & Mangia, C. (2009). Differences between weekend and weekday ozone levels over rural and urban sites in Southern Italy. *Environmental Monitoring and Assessment, 156*, 509–523.

Spangl, W, Schneider, J., Moosmann, L., Nagl, C. (2007). USEPA. Draft final report: Representativeness and classification of air quality monitoring stations [online]. Vienna, [cit. 2015-10-15].

Tecer, L. H., & Tagil, S. (2014). Impact of urbanization on local air quality: Differences in urban and rural areas of Balikesir, Turkey. *Clean Soil Air Water, 42*(11), 1489–1499. doi:10.1002/clen.201200640 ISSN 18630650.

Wu, J., Liao, X., Peng, J., Huang, X. L. (2015). Simulation and influencing factors of spatial distribution of $PM_{2.5}$ concentrations in Chongqing. Huan Jing Ke Xue= Huanjing Kexue / Bian Ji, Zhongguo Ke Xue Yuan Huan Jing Ke Xue Wei Yuan Hui 'Huan Jing Ke Xue' Bian Ji Wei Yuan Hui. [online], 36(3), 759-67 [cit. 2016-05-23]. ISSN 02503301.

Zalel, A., Yuval, Svecova, V., Sram, R. J., Bartonova, A., & Broday, D. M. (2014). Modeling airborne benzo(a)pyrene concentrations in the Czech Republic. *Atmospheric Environment, 101*, 166–176. doi:10.1016/j.atmosenv.2014.11.031 ISSN 13522310.

Zhang, Y., Wang, X., Barletta, B., Simpson, I. J., Blake, D. R., Fu, X., et al. (2013). Source attributions of hazardous aromatic hydrocarbons in urban, suburban and rural areas in the Pearl River Delta (PRD) region. *Journal of Hazardous Materials, 250-251*, 403–411. doi:10.1016/j.jhazmat.2013.02.023 ISSN 03043894.