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ORIGINAL PAPER

AN ASSESSMENT OF PM_1 LEVELS BASED ON INDICATIVE PM_1 MEASUREMENTS AND RELATIONSHIPS WITH PM_{10} AND $PM_{2.5}$ CONCENTRATIONS, FOR THE ANALYSIS OF HOSPITAL ADMISSIONS AND MORTALITY IN THE MORAVIAN REGION

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Abstract

Background: Particulate matter (PM) air pollution is a serious concern in the city of Ostrava. Thus, in 2018, a project entitled "Validation of the relationships between PM_{10}, $PM_{2.5}$ and PM_1 concentrations, and morbidity and mortality, in the heavily polluted region in the Czech Republic," was launched. The relationship between hospital admissions and mortality in the said region is based primarily on short-term PM_{10} and $PM_{2.5}$ concentrations and indicative PM_1 measurement. The analysis of spatiotemporal variations and the relationship between PM_{10}, $PM_{2.5}$ and PM_1 data from 3 measurement sites within the city of Ostrava is presented. **Material and Methods:** The analysis was based on the daily average PM concentrations for 5 and 6 months at 2 sites, and on the annual average values (2018–2019) at the baseline station. The correlations of and variability between PM fractions, seasonal differences and explanation of the differences found were the objectives of a detailed analysis. Especially, the potential PM_1 variability and its causes were analyzed with respect to the location of the site. **Results:** The study findings confirmed good correlations between the PM fractions. Compared to PM_{10}, $PM_{2.5}$ concentrations were more predictive for PM_1 concentrations. The annual means of PM_{10}, $PM_{2.5}$ and PM_1 reached 37.5, 29.9 and 27.1 μg/m^3 in 2018, respectively, and 25.8, 19.9 and 17.9 μg/m^3 in 2019, respectively. The concentration levels in the non-heating season were significantly lower than in the heating season in the 2 years under consideration. The levels of PM_{10}, $PM_{2.5}$ and PM_1 were significantly correlated (the correlation coefficient, $r > 0.96$). The levels of $PM_{2.5}$ represented about 0.82–0.86 of PM_{10}, and the levels of PM_1 about 0.92–0.93 of $PM_{2.5}$. These ratios were found to differ in the heating and non-heating seasons, with the $PM_{2.5}$–PM_{10} ratio ranging 0.61–0.63 in the non-heating seasons. **Conclusions:** The correlations found will be used for indicative PM_1 measurements in other areas of the region. Seasonal variability should be taken into account as well. Med Pr. 2021;72(3):249–58

Key words: PM_1 concentrations, spatiotemporal PM variations, heating season differences, air pollution, $PM_{2.5}$ concentrations, PM_{10} concentrations

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INTRODUCTION

Particulate matter (PM) air pollution is a serious concern in the city of Ostrava that belongs among the most polluted areas in the Czech Republic and Europe [1]. In spite of the decrease in solid pollutant emissions from industrial sources, these sources still predominate, including mainly metallurgical plants, coke ovens and energy producers. The proportion of pollutant sources is completed by local heating and cross-border transmission of pollution from Poland.

Epidemiological studies from around the world have demonstrated the adverse effect of PM_{10} on human health. Air pollution is the second main cause of death from non-communicable diseases [2]. The European Environment Agency (EEA) estimated that 74–81% of the European urban population was exposed to long-term $PM_{2.5}$ concentrations, and 42–52%

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to long-term PM_{10} concentrations, exceeding the recommended WHO values in the period of 2015–2017. In addition, about 44% of the urban population was exposed to short-term PM_{10} concentrations exceeding the recommended WHO value [1].

Many studies and meta-analyses have confirmed that an increase in short-term PM exposures contributes to increased mortality (total, cardiovascular, cardiac and respiratory). In the European region, PM pollution can represent about 1 year of life lost for each European [3], and can cause 556 000 premature deaths [4]. The costs of medical services and the loss of productivity caused by air pollution were estimated at USD 1.6 trillion in the European region in 2010 [5].

The time-series of the relationships between the average daily PM concentrations are mostly focused on emergency treatment, hospital admissions and mortality from cardiovascular and respiratory causes [6], in the individual consecutive days or in the groups of days (0–1 – immediate effect, 2–5 – delayed effect or 0–5 – prolonged effect) [7].

The time-series results contribute to the specification of the health risk caused by immission load in a certain geographical area and show the differences between cities and regions [8]. The probable cause can be the heterogeneity of particle composition [8], and possibly exposure factor differences [9].

According to recent findings, short-term exposure to PM_{10} is related to increased morbidity from respiratory causes, and short-term exposure to $PM_{2.5}$ to increased cardiovascular mortality and morbidity, respectively [10]. According to the WHO methodology [11], the theoretical estimates of a 0.9% increase in cardiovascular mortality, and a 1.3% increase in respiratory mortality, are related to the increase in short-term PM_{10} concentrations per 10 μg/m^3.

The relationship between mortality and morbidity can be influenced by a certain specific feature of pollution – the so called immission profile, which is typical for a given place and time [12]. The knowledge of these factors has been gradually clarified with the increasing body of relevant studies that are, nonetheless, still rare. The latest studies of respiratory hospital admissions and short-term $PM_{2.5}$ exposure declare a 0.25–6.4% increase [13], but a 10 μg/m^3 increase in $PM_{2,5–10}$ was not associated with any significant increase in respiratory-related hospitalizations [14]. Older studies confirmed a 0.6–2.07% increase in hospital admissions for respiratory diseases in relation to PM_{10} exposure [15].

In terms of health risks, PM_1 particles are more dangerous compared with larger particles due to their ability to potentially spread to body organs when inhaled. Small particles diffuse deeply into the lung tissue, depositing in the alveoli through a number of mechanisms including diffusion, sedimentation, and electrostatic effects [16].

Thus, a project entitled "Validation of the relationships between PM_{10}, $PM_{2.5}$ a PM_1 concentrations, and morbidity and mortality, in the heavily polluted region in the Czech Republic" (TH03030195) was launched in 2018, with the financial support of the Technology Agency of the Czech Republic (TACR). In addition to the primary goal of the project, i.e., exploration of the short-term PM_{10} and $PM_{2.5}$ effects on mortality and morbidity, attempts were also made to identify sites for PM_1 measurements, and their selection was based on the relationship with existing PM_{10} and $PM_{2.5}$ data. The correlations and variability between the 3 measurement sites within the city of Ostrava, PM fractions, seasonal differences and explanation of the differences found were the objectives of a detailed analysis. Especially, the potential PM_1 variability and its causes were analyzed with respect to the location of the measurement site.

MATERIAL AND METHODS

Measurement sites

The measurement sites for this part of the TACR-funded project (Figure 1) were selected based on the expert knowledge of the historical data from the past 30 years of monitoring within the area of the city, the availability of measured $PM_{2.5}$ concentrations data, the proximity of pollution sources and their type differences, and the population density in the area in question. Industrial plants are located in the eastern part of the city, which is visible in Figure 1, based on the inverse dispersion model of $PM_{2.5}$ [17], whereas inhabited and densely populated areas are located in the central and western parts of the city.

Measurement data and statistical analysis

Daily average PM_{10}, $PM_{2.5}$ and PM_1 data (measurements performed by the Czech Hydro-Meteorological Institute and the Institute of Public Health in Ostrava) from 3 measurement sites in the city of Ostrava, collected in the period of January 2018–December 2019, were included in the study. Three locations of the measurement sites were used in the analysis, i.e., Ostrava-Fifejdy (hereafter: Fifejdy), where the measurement of all pollutants of interest was provided for the entire period

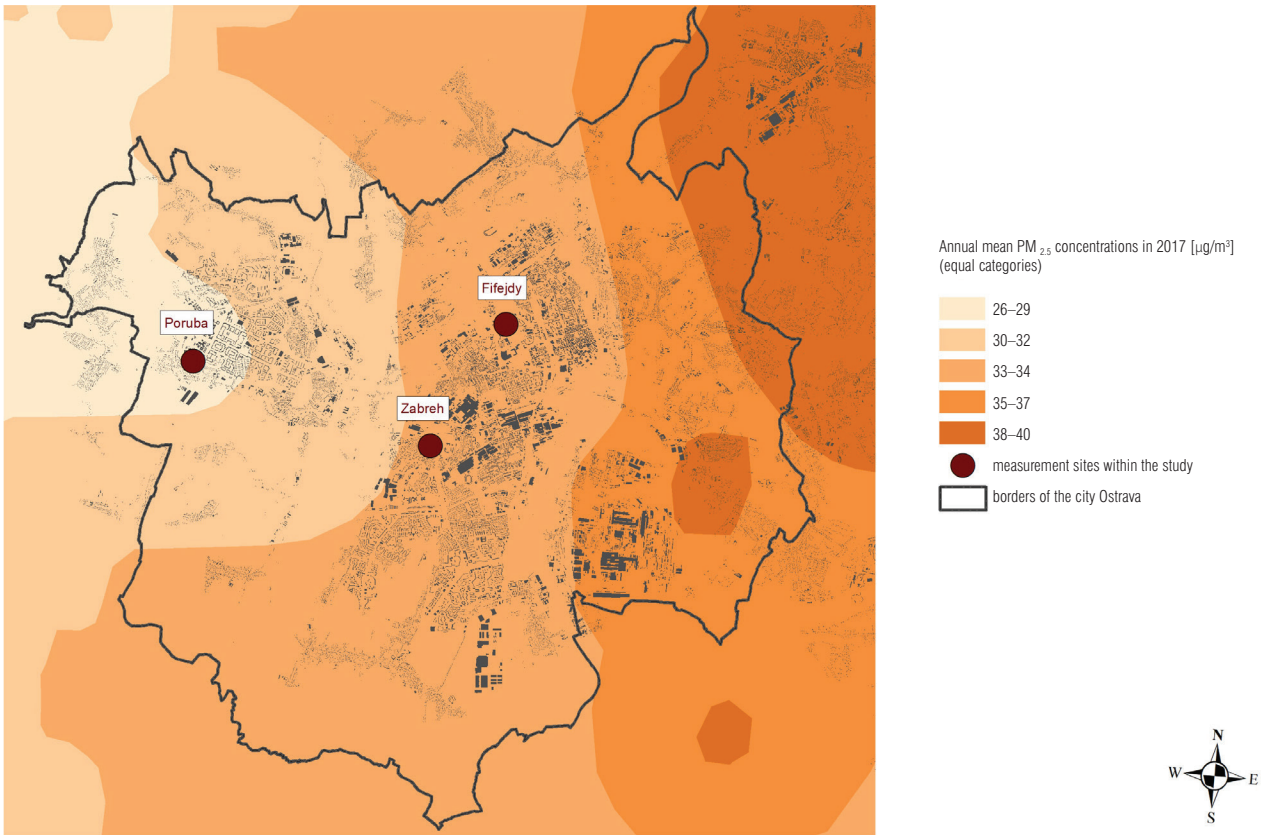

Figure 1. Concentrations of $PM_{2.5}$ in the city Ostrava in 2017 and the location of the measurement sites

(January 2018–December 2019); Ostrava-Zabreh (hereafter: Zabreh), where also PM_1 was measured in addition to the routinely collected PM_{10} and $PM_{2.5}$, in the period of February–July 2019; and Ostrava-Poruba (hereafter: Poruba), where measurements of $PM_{2.5}$ and PM_1 were added to the routinely collected PM_{10} data. The PM concentrations were measured by mobile measurement cars (MV4 6AU 5898) using PALAS FIDAS 200 dust meters.

The measurements were carried out by an authorized and accredited laboratory in accordance with the CSN EN ISO/IEC 17025:2018 standard. A fine dust measurement device, Fidas® 200, was used for the measurements, which is the EN 16450 approved fine dust aerosol spectrometer for simultaneous measurements of $PM_{2.5}$ and PM_{10}, in a weatherproof cabinet for outdoor installation. More specifically, Fidas® 200 is an optical single particle measuring device of the type approved for the simultaneous monitoring of PM_{10} and $PM_{2.5}$ in accordance with the VDI 4202-1, VDI 4203-3, EN 12341, EN 14907 and EN 16450 standards, and the EU Guide to Demonstration of Equivalence, and certified in compliance with the EN 15267-1 and EN 15267-2 standards. It is used for continuously analyzing the fine dust particles present in the ambient air in the size range of 180 nm–18 µm, and for simultaneously calculating the immission values of $PM_{2.5}$ and PM_{10}.

The device is controlled, repaired, calibrated and prophylactically examined on a yearly basis by a company holding the manufacturer's certificate. The calibration of the instrument can be verified and, if necessary, adjusted easily and quickly, at any time, even when installed on site, using a monodisperse test aerosol. In addition, Fidas® 200 offers numerous communications options, and allows full remote control and maintenance of the system, as well as online data access via an IP address. The software provided along with the system offers versatile options for evaluation (e.g., comprehensive statistics and averaging) and export of measurement data. After putting the device into operation, validation was carried out with the gravimetric methods with calculation of uncertainty. The data is daily remotely controlled including error messages.

The descriptive analysis was used for a basic description of the PM data. The Wilcoxon test and the Kruskal-Wallis test were used for the comparison of concentrations between the periods on the significance level of

5%, and the correlation was estimated using the correlation and linear regression analysis. The PM_1–$PM_{2.5}$ and $PM_{2.5}$–PM_{10} ratios were expressed as regression coefficients and 95% confidence intervals (CI). Data was analyzed using the SW STATA v. 15.

RESULTS

Analysis of all measured PM fractions between 2018 and 2019 in Fifejdy as the baseline site

The complete PM_{10}, $PM_{2.5}$ and PM_1 measurements were available from the measurement site in Fifejdy for the entire period. The annual average values of all PM fractions were by about 10 μg/m³ lower in 2019 compared with the year before. The annual means of PM_{10}, $PM_{2.5}$ and PM_1 reached 37.5, 29.9 and 27.1 μg/m³ in 2018, respectively, and 25.8, 19.9 and 17.9 μg/m³ in 2019, respectively (Table 1). The concentration levels in the second and third quarters of the year (the non-heating season) were significantly lower than in the first and fourth quarters (the heating season) in these 2 years. The levels of PM_{10}, $PM_{2.5}$ and PM_1 were significantly correlated ($R > 0.96$). The levels of $PM_{2.5}$ represented about 0.82–0.86 of PM_{10}, and PM_1 about 0.92–0.93 of $PM_{2.5}$. These ratios differed in the heating and non-heating

Table 1. The PM concentrations, ratios and correlations between the PM_{10}, $PM_{2.5}$ and PM_1 values in the study areas by period and heating vs. non-heating season

Variable	PM concentration [μg/m³] (M±SD)			Ratio (95% CI)		R^2	
	PM_{10}	$PM_{2.5}$	PM_1	$PM_{2.5}/PM_{10}$	$PM_1/PM_{2.5}$	$PM_{2.5}$–PM_{10}	PM_1–$PM_{2.5}$
Fifejdy							
year (Jan–Dec)							
2018 (N = 365)	37.5±30.5	29.9±29.6	27.13±28.0	0.86 (0.85–0.87)	0.93 (0.92–0.93)	0.971	0.999
2019 (N = 365)	25.8±19.8	19.9±18.4	17.93±17.5	0.82 (0.80–0.83)	0.92 (0.92–0.93)	0.955	0.997
heating*							
2018 (N = 182)	49.4±38.7	43.7±36.4	40.6±34.3	0.91 (0.89–0.92)	0.93 (0.93–0.94)	0.993	0.999
2019 (N = 182)	29.9±24.4	26.0±23.2	24.1±21.9	0.90 (0.89–0.91)	0.93 (0.93–0.94)	0.994	0.999
non-heating*							
2018 (N = 183)	25.7±9.3	16.1±6.8	13.8±6.2	0.63 (0.61–0.64)	0.86 (0.86–0.87)	0.970	0.995
2019 (N = 183)	21.7±12.3	13.79±8.1	11.8±7.6	0.61 (0.58–0.64)	0.88 (0.86–0.89)	0.911	0.989
Zabreh							
5 months (Feb–Jul)							
2019 (N = 157)	24.5±14.0	19.1±13.0	17.4±12.5	0.81 (0.79–0.83)	0.93 (0.92–0.94)	0.975	0.997
heating*							
2019 (N = 59)	28.2±17.4	24.9±16.0	23.3±15.4	0.89 (0.88–0.90)	0.94 (0.94–0.95)	0.997	0.999
non-heating*							
2019 (N = 98)	22.2±11.0	15.6±9.2	13.9±8.9	0.72 (0.69–0.74)	0.91 (0.89–0.92)	0.967	0.994
Poruba							
6 months (Jul–Dec)							
2019 (N = 172)	22.5±13.2	17.4±12.6	15.70±11.9	0.81 (0.80–0.83)	0.92 (0.91–0.92)	0.980	0.998
heating*							
2019 (N = 92)	27.3±15.1	23.0±13.9	21.1±13.0	0.86 (0.84–0.87)	0.92 (0.92–0.93)	0.992	0.999
non-heating*							
2019 (N = 80)	17.1±7.8	11.0±6.8	9.46±6.3	0.68 (0.65–0.71)	0.88 (0.87–0.89)	0.970	0.997

* Heating: January–March and October–December, non-heating: April–September.
R^2 – coefficient of determination.

seasons. In the heating season, the $PM_{2.5}$–PM_{10} ratio equaled 0.90–0.91 and the PM_1–$PM_{2.5}$ ratio 0.93, while in the non-heating season, the $PM_{2.5}$–PM_{10} ratio reached 0.61–0.63 and the PM_1–$PM_{2.5}$ ratio 0.86–0.88.

The higher levels of PM_{10} in 2018 were affected by a higher proportion of the $PM_{2.5}$ fraction, as can be seen in Table 1 regarding the comparison of 2018 and 2019 (86% to 82%). In 2018 the higher annual values were reached due to higher levels in the heating season.

The indicative measurement of temperatures was completed for the heating and non-heating seasons. The average temperature in the heating season was 4.2°C in 2018 and 6.0°C in 2019. In contrary, higher average temperatures were found in the non-heating season in 2018, i.e., 19.5°C, than in 2019 when the average temperature reached 18.2°C.

As the measurement of all PM fractions was available for the entire research period at the measurement site in Fifejdy, this data was used as the baseline for the subsequent comparisons of other location data.

Correlations of PM_{10}, $PM_{2.5}$ and PM_1 concentrations between the measurement sites

Significantly high correlations were found between the all PM fraction values measured in Fifejdy and Zabreh (R > 0.912) (Table 2), but the values in Zabreh were slightly lower for all measured fractions (Table 1).

The correlations between the average concentrations in Fifejdy and Poruba were weaker than in the previous comparisons. They varied from 0.48 for PM_{10}, through 0.57 for $PM_{2.5}$, to 0.59 for PM_1 (Table 2). The course of the concentrations of all PM fractions is documented in Figures 2 a, b, c.

Table 2. Correlations (R) of the PM fraction measurements between the measurement sites

PM fraction	R (Fifejdy)		
	PM_{10}	$PM_{2.5}$	PM_1
Zabreh (N = 157)*			
PM_{10}	0.989	0.970	0.949
$PM_{2.5}$	0.936	0.993	0.992
PM_1	0.912	0.987	0.993
Poruba (N = 172)*			
PM_{10}	0.479	0.562	0.568
$PM_{2.5}$	0.451	0.569	0.583
PM_1	0.445	0.571	0.586

* Number of observations.

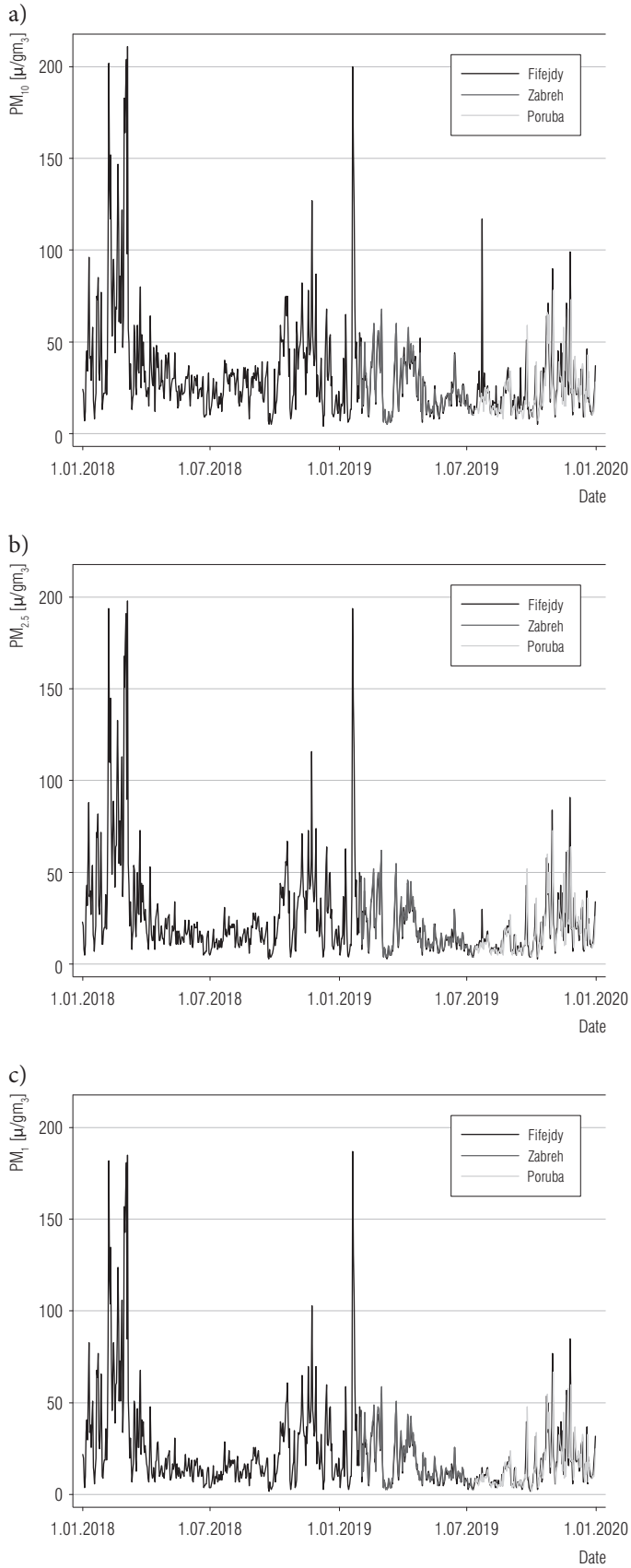

Figure 2. Distribution of: a) PM_{10}, b) $PM_{2.5}$, and c) PM_1 concentrations across the study sites – Fifejdy, Zabreh and Poruba

The meteorological conditions slightly differed between the measurement sites – average temperatures in Zabreh and Poruba were by about 1°C lower than in Fifejdy, and relative humidity was by 7–11% higher in Zabreh and Poruba.

Differences in PM fractions between the heating and non-heating seasons

As expected, the average concentrations were higher in the heating seasons. The absolutely highest concentrations of PM_{10}, $PM_{2.5}$ and PM_1 of all the study periods were found at the measurement site in Fifejdy in 2018 (Table 1). At this station, also the highest difference in all fraction means was indicated between the heating and non-heating seasons. The differences between the average concentrations in the heating and non-heating seasons varied from 6.0 μg/m³ (PM_{10} in Zabreh) to 27.6 μg/m³ ($PM_{2.5}$ in Fifejdy in 2018) (Table 1).

In spite of the differences in the measured average levels of PM concentrations in the 3 measurement sites, the overall $PM_{2.5}$–PM_{10} ratio did not vary significantly between the heating and non-heating seasons. In the heating seasons, this ratio ranged 0.86–0.91 and in the non-heating seasons 0.61–0.72 (the values and 95% CI are shown in Table 1). Similar results were found for the PM_1–$PM_{2.5}$ ratio, i.e., 0.92–0.94 in the heating seasons and 0.86–0.91 in the non-heating seasons.

DISCUSSION

The overall results of the described assessment study indicate the way how to assign values of the fine and ultra-fine PM particles for the analysis of the relationships between air pollution, on the one hand, and mortality and hospital admissions, on the other, in a wider area of the industrial Moravian-Silesian Region in the TACR-funded project. The Ostrava agglomeration accounts for 80% of the total population in the region. There are no systematic measurements of $PM_{2.5}$ concentrations in the region, and PM_1 concentrations are measured rarely. Therefore, the inter-relationships between the different PM fraction measurements originating in this region, where the sources of air pollution are similar, can help in assessing the spatial pollution load of this population. The correlations are relatively stable, and the main differences can be seen between the heating and non-heating seasons.

The actual health risk can differ between cities and regions, and the difference can be caused by the heterogeneity of particle composition [8]. Short-term aerosol concentrations pose a hazard to human health. Individual fractions of aerosol act through different mechanisms and manifest themselves as different effects on health. Recent findings have also broadened the spectrum of aerosol effects and further confirmed the complexity of PM effects in relation to human health.

The size of atmospheric PM is important as a factor determining how long the particle stays in the atmosphere, and where it deposits in the human respiratory tract. Therefore, it is important to analyze the $PM_{2.5}$–PM_{10} ratios as an indicator of fine particles, and to determine how these ratios vary both in space and time [18].

In the city of Ostrava, PM_{10} and $PM_{2.5}$ concentrations were measured in 4 areas in 1995 and 1996 as a part of the CESAR project carried out in Central and Eastern European countries (covering 6 countries). The concentration of the coarse fraction of PM_{10} was calculated as the difference between the PM_{10} and $PM_{2.5}$ concentrations. Spatial variation within the study areas was assessed by additional sampling in 1 or 2 urban background sites within each study area for 2 periods of 1 month. The variation in the PM_{10} and $PM_{2.5}$ concentrations between the study areas was about 4 times greater than the spatial variation within the study areas, suggesting that measurements at a single sampling site sufficiently characterize the exposure of the population in the study areas. It was found that PM_{10} concentrations increased considerably during the heating season, which was likely caused by local heating, and the increase in PM_{10} was mainly driven by increasing $PM_{2.5}$ [19]. These conclusions support the study results regarding the relative homogeneity between the PM fraction ratios, seasonal differences and the identification of population exposure.

The measurement of exposure using the PM_{10}–$PM_{2.5}$ difference is an older method that provides a higher variability of concentrations usually based on a limited number of monitoring stations, and it often leads to the underestimating of health effects. Studies based on $PM_{2.5}$ measurements report, in general, lower uncertainty due to lower variability of concentrations within the cities [8]. The variability increases if rural regions are included [20].

In the Czech Republic, the national system of monitoring reports high levels of PM air pollution. The borderline average annual value of PM_{10} (20 μg/m³), as recommended by WHO, was exceeded in 90% of the 104 measuring stations evaluated. The PM_{10} levels in these settings have fluctuated in the past 10 years without a noticeable trend [21]. The assessment of exposure to $PM_{2.5}$ included

68 stations. The annual limit value (25 μg/m³) was exceeded at 9 urban stations, all located in the Moravian-Silesian Region. The recommended WHO borderline annual value (10 μg/m³) was exceeded at all measuring stations, including the national background station in Kosetice (14.5 μg/m³) [21]. In the presented TACR study results, the annual concentrations of PM_{10} and $PM_{2.5}$ in Fifejdy, collected in 2018 and 2019, also exceeded the recommended WHO borderline values, but did not exceed the annual limit value of $PM_{2.5}$ in Fifejdy in 2019.

The national system of monitoring revealed that the fraction proportion in PM_{10} ranged 57%–86%, with the average proportion value reaching 76%. This ratio is primarily determined by the composition of concurrent sources. It shows a significant seasonal dependence, with higher $PM_{2.5}$ values being observed in the heating season or during atmospheric inversion ($PM_{2.5}$ of ≤90%). In the period of 2007–2015, the average $PM_{2.5}$–PM_{10} ratio ranged 72%–76% [21]. The TACR study in Ostrava provided results of the $PM_{2.5}$–PM_{10} ratio corresponding to the upper limit of the Czech values, i.e., 81–86% in the longer periods (2018 and 2019, and 5–6 months in the 2 study areas) and exceeded the average Czech value. Higher values of the ratio in the heating seasons were also confirmed in this study.

Seasonal differences were found in an Austrian study of PM_1, $PM_{2.5}$, PM_{10} and total suspended particles (TSPs) in 3 urban and 1 rural sites over a year-long period [22]. The authors stated that the database of worldwide information for PM_1 is still very poor for comparison. Generally, the data of the Austrian study fit into the Central European context as far as the long-term averages, the daily and seasonal pattern, and the ratios between various fractions are concerned. In average terms, PM_1 accounted for about 50–60%, and $PM_{2.5}$ for about 70%, of PM_{10}. The number concentrations in urban sites were in the upper European level and showed a distinct seasonal cycle [22].

The study of aerosol mass at a coastal station in Southern Europe in the period of 2004–2006 [23] found, on average, that $PM_{2.5}$ and PM_1 accounted for 60% and 40% of the PM_{10} mass, respectively. Seasonal patterns were revealed and AERONET was found adequate for the estimation of the background levels of both fine and coarse particles near the surface, with certain limitations in the case of pollution or dust abrupt episodes due to its low temporal coverage [23].

A relatively new field of the nanoparticle parameters discussed by toxicologists concerns their surface area concentration as a relevant property for causing inflammation [24]. The size distribution of fine and ultra-fine aerosol is a significant pointer for assessing the current situation in the air at sampling sites and their proximity. From a qualitative point of view, fine aerosol in the city of Ostrava is primarily represented by spherical particles and their agglomerates sized <500 nm with their composition corresponding to magnetite, as well as particles of different shapes, including clusters composed of many thousands of primary nanoparticles and fine foils containing carbon as a majority element, probably soot [25]. Air during smog situations may be compared to a working environment with a huge occurrence of nanoparticles [25].

The composition of PM particles is an important issue also in the Mediterranean basin. For instance, the $PM_{2.5}$ and PM_1 pollution study by Peteraki et al. [26] focused on the PM components with numerous anthropogenic sources and an increased potential health risk. To uncover the spatiotemporal variation of the PM profile, the key sources were identified, along with seasonal effects, and the role of the prevailing mesoscale atmospheric circulation was evaluated. In general, the pollution status was the result of a complex interaction between the local and external input with particulate organic matter and secondary inorganic aerosols being the main aerosol components. It turned out that PM_1 was a better indicator of the anthropogenic emissions while, according to the results of the factor analysis, the co-existence of various combustion sources was a determinant. The estimated carcinogenicity/mutagenicity was emission-dependent, with the maximum contribution coming from B[a]P, IndP, B[ghi]Per, B[e]P and B[b]F. Seasonally, the highest potential health risk of the polynuclear aromatic hydrocarbons mixture was recorded during the cold season [26]. The carcinogenicity/mutagenicity of PM_1 compounds should be taken into account when analyzing the health risks in Ostrava, respectively in the Moravian-Silesian Region, where the limit value of 1 ng/m³ for B[a]P was exceeded by more than twice in 2018, along with an almost 8-fold exceedance in the industrial station in Ostrava-Radvanice [21].

A study from Barcelona [27] confirmed that PM composition was highly influenced by road traffic emissions, with exhaust emissions being an important source of PM_1 and dust resuspension processes of $PM_{2.5–10}$, respectively. In fact, PM_1 is mainly composed of carbonaceous compounds (organic matter + elemental carbon) and secondary inorganic aerosols, probably reflecting soot emissions and the condensation of exhaust gaseous precursors on particle surfaces [27].

The influence of road traffic emissions on the levels of fine particles is reflected in the average annual levels of PM_1, which show a significant increasing trend, and a good correlation with the progressive rise in road traffic flow. The results also show that the monitoring of PM_1 and PM_{10} in an urban setting may be a better strategy than the combination of $PM_{2.5}$ and PM_{10} measurements [27]. The increasing traffic flow in Ostrava is a good argument for focusing the future measurement strategy on PM_1 concentrations and the analysis of the relationships between ultra-fine particles and health indicators.

Another argument for paying more attention to fine and ultra-fine particles is the study by Onat et al. [28] that confirmed a high proportion of metal in $PM_{2.5}$ particles. The ratio of fine particles ($PM_{2.5}$) to TSPs was 0.6. The authors observed that 50% of TSPs were composed of $PM_{1.0}$ and that 68–88% of the metals were found in the fine particle fractions [28].

The PM levels of various size fractions (PM_{10}, $PM_{2.5}$, and PM_1) and their controlling factors in various locations across Greece were identified in the study by Koulouri et al. [29]. Measurements were carried out in various sites in urban, suburban and natural background locations in the period of 2004–2006. At all sites, coarse particles were found to comprise a noteworthy portion of total PM_{10} particles (with the $PM_{2.5}$–PM_{10} ratios ranging 45–60%), while the fine particle mass concentrations heavily relied on those of particles in the submicron range (the PM_1–$PM_{2.5}$ ratios spanning 55–75%) [29]. Similar $PM_{2.5}/PM_{10}$ ratios demonstrated considerable temporal and spatial variability from 46 monitoring stations in the United Kingdom, and the 5-year median ranged 0.4–0.8, resulting in the overall median of 0.65 [18]. Trends in the $PM_{2.5}$–PM_{10} ratios varied during different seasons: spring showed a positive significant trend and winter showed a negative significant trend, whereas trends in autumn and summer were insignificant [18]. In contrary, this study found much higher values of both the $PM_{2.5}$–PM_{10} ratios (ranging 0.81–0.86) and the PM_1–$PM_{2.5}$ ratios (0.92–0.93).

The study results in Ostrava are better supported by the Chinese study based on 24 measurement stations across China [30], in which the PM_1–$PM_{2.5}$ ratios were >80% at most stations. Similar results, but even higher, were confirmed in Ostrava. The PM concentrations in China tended to be the highest in winter and the lowest in summer at most stations, and a similar trend was observed in Ostrava. The squared correlation coefficient (R^2) values of the linear fit between $PM_{2.5}$ and PM_{10} were higher than between PM_1 and $PM_{2.5}$ in China. Also, the $PM_{2.5}$–PM_{10} ratios in China, ranging 0.40–0.90, and the PM_1–$PM_{2.5}$ ratios of 0.66–0.91 showed higher variability than in this study. In Ostrava, the ratio between these fractions was closer to the highest values in the Chinese study and the correlation coefficient ranged 0.911–0.999. According to the Chinese study, higher values indicate that the 2 PM sizes were closer matched around their sources [30].

CONCLUSIONS

Based on the knowledge of the local pollution sources, including mainly 3 sources – industrial, local heating and traffic emissions – that are relatively equally distributed across the Ostrava-Karvina basin, and information from the presented study assessment and results, a good background was established for the analysis of the relationship between small particles and health outcomes. The study findings confirmed good correlations between the PM fractions under analysis. Compared to PM_{10}, $PM_{2.5}$ were more predictive for PM_1concentrations. The correlations found will be used for indicative PM_1 measurements in other areas of the region. Seasonal variability should be taken into account as well.

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