Assessment of Outdoor Pollution with Submicrometric and Fine Particulate Matter in Ploiesti City, Romania

STEFANIA IORDACHE[1]*, DANIEL DUNEA[1]*, CORNEL IANACHE[2], LAURENTIU PREDESCU[1], DUMITRU DUMITRU[1]

[1]Valahia University of Targoviste, Faculty of Environmental Engineering and Food Science, 13 Sinaia Alley., 130004 Targoviste, Romania

[2] Petroleum Gas University of Ploiesti, Faculty of Mechanical and Electrical Engineering, 39 Bucuresti Blvd., 100680, Ploiesti, Romania

Airborne particulate matter (PM) is a major environmental problem in urban areas mainly because of its demonstrated impact on human health. The present work aimed to assess the outdoor pollution to fine ($PM_{2.5}$), and submicrometric (PM_1) particulate matter that includes the ultrafine fraction - UFP), in Ploiesti city, which is a major urban-industrial area in the Southeast of Romania. This is the first study in an urban area of Romania that analyzes the spatiotemporal variation of $PM_{2.5}$ and PM_1. Particulate matter samples collected in sequential monitoring campaigns performed in 2015 were investigated using 12 relevant sampling points. A precision optical portable monitoring system with a laser beam (Dusttrak™ DRX 8533EP) was used for PM assessments.. It was observed that Ploiesti inner city presented "moderate" and "unhealthy for sensitive groups" conditions for particulate pollution with $PM_{2.5}$ depending on the area of the city. The difference between the PM_{10} and PM_1 medians of all sampling points was only 2.2 $\mu g \times m^{-3}$, PM_4 and PM_1 of 1.5 $\mu g \times m^{-3}$, and $PM_{2.5}$ and PM_1 of 0.8 $\mu g \times m^{-3}$ respectively ($p > 0.05$ – DL5% = ±5.8 $\mu g\ m^{-3}$). The correlation between the PM fractions was very significant ($p < 0.01$; $r = 0.996$). The results pointed out that PM_1, which has an increased impact on human health, because it includes the UFP, was the most frequent fraction in Ploiesti inner city.

Keywords: $PM_{2.5}$, PM_1, size-segregated mass fractions, air pollution mapping, meteorological time series

Many recent epidemiological studies highlighted that airborne particulate matter (PM) became a major environmental problem in urban areas mainly because of its impact on human health. The International Agency for Research on Cancer (IARC) has classified the outdoor air pollution as carcinogenic to humans (Group 1) noticing an increasing risk of lung cancer with increasing levels of exposure to PM and air pollution independently of the region of the world. In the last decade, various studies provided evidence of the adverse effects of fine and ultrafine particulates on human health [1-5]. These studies have pointed out that particulate air pollution is associated with exacerbations of respiratory symptoms, increasing of hospital admissions and mortality from both respiratory and cardiovascular diseases.

PM represents a complex mixture of organic and inorganic pollutant species varying significantly between locations and originating from natural and anthropogenic sources. These particles are classified into several categories depending on their aerodynamic diameter e.g., PM_{10} are particles with diameter less than 10µm, $PM_{2.5}$ represents particles having less than 2.5 µm in diameter; this fraction include also the submicrometric particles (PM_1) with particle sizes less than 1.0 ìm in diameter; *the ultrafine particles* are particles having less than 0.1 µm in diameter ($PM_{0.1}$).

High levels of $PM_{2.5}$ in urban areas are mainly associated with traffic-related emissions, particularly from vehicles with diesel engines. A significant part of $PM_{2.5}$ levels in urban areas derives also from industrial combustion plants and residential heating. Natural sources contribute with a small percentage to fine particulate concentrations level in urban areas.

Numerous studies regarding PM air pollution in Europe were reported from Western, Central or Northern Europe (e.g., [6-11]). In comparison, the available information concerning the urban air pollution in Eastern Europe is still very scarce. The characteristics of PM can vary from a region to another due to the spatial and temporal dependence of the pollutant, so they cannot be fully replicated to other geographical space [12]. Accordingly, a suitable approach for each zone of interest is necessary. Some PM studies were conducted in Romania for several urban areas [13-15], including Ploiesti city [16,17]. These are mainly focused on the characterization of spatial and temporal variation of PM_{10} or $PM_{2.5}$. Relatively few studies reported human health effects from either submicrometric particles or ultrafine particles (UFP). To our knowledge, one of the first studies that evaluated the effect of $PM_{2.5}$ air pollution on the exacerbation of respiratory illness in sensitive children that lives in urban areas of Romania was recently published [18].

The present work aimed to assess the outdoor pollution with fine and submicrometric particulate matter, fraction that includes the ultrafine fraction, in Ploiesti city (197,542 permanent residents), which is an urban-industrial area from Southeast of Romania. Having in view the recent demonstrated adverse health effects of submicrometric and ultrafine particles (UFP) especially on vulnerable people (e.g., sensitive children, elder persons, persons with respiratory sensibilities), the assessment of their concentrations level became a priority for developing reliable systems of air quality management. The present study analyzes the spatiotemporal variation of fine and submicrometric particles in a major urban area of Romania based on PM samples collected in sequential monitoring campaigns performed in 2015 in Ploiesti urban area using 12 relevant sampling points.

* email: stefania.iordache@yahoo.com; dan.dunea@valahia.ro

Experimental part

Study area and data collection

Ploiesti is one of the largest urban agglomerations in Romania, which is located in the south-east of Romania (44°562 243 N Lat.; 26°012 003 E Long.; 150 m a.s.l.). Ploiesti city is an important industrial center, which experienced a rapid economic growth in the last decade. Its industrial activity is concentrated especially on the oil processing industry. Most important, Ploiesti is the only city in Europe surrounded by four oil refineries. Even if the oil production in the region is declining steadily, a significant processing industry still operates. Unfortunately, the urban residential areas are located close to the industrial facilities, which are the main stationary emission sources. Due to the large population, Ploiesti city has also a heavy traffic density. Mobile emission sources have an important contribution to the local emissions of air pollutants. Industrial activity and heavy traffic were identified as the main PM pollution sources in Ploiesti city. Long-term exposure to PM and heavy metals contained in the urban aerosols of Ploiesti, can lead to potential adverse effects in population, especially for residents located in the most impacted areas.

The data for the present study was collected in monitoring campaigns that were performed twice a month, between January and October 2015, using 12 sampling points in Ploiesti. The criteria for establishing the monitoring points have considered various aspects (i.e., previous measurements, data analysis, and receptor modeling based on emission source profiles) and also their proximity to schools, kindergartens, and the pediatric hospital. A quasi-radial positioning of the 12 monitoring points was established to insure an optimal characterization of PM levels in Ploiesti residential area (fig. 1). Each measurement campaign was performed during the *rush* hours (7.00-9.00 a.m.; 12.00-2.00 p.m. or 3.00-7.00 p.m.) to assess the potential exposure of population to high PM concentrations. To avoid the influence of increased relative humidity (RH) on PM measurements, they were performed following a minimum period (2 or 3 days) after a rainy day. Consequently, 20 PM time series were obtained for each sampling point and used in the current study.

A precision optical portable monitoring system, which is able to measure fine and submicrometric fractions with a laser beam i.e, Dusttrak™ DRX 8533EP with environmental enclosure) was used in the monitoring campaigns. The system can simultaneously measure both size fractions and mass. Size-segregated mass fractions corresponding to PM_1, $PM_{2.5}$, PM_4 (Respirable), PM_{10} and Total PM fractions are determined. The flow rate of the external pump was 3 $l \times min^{-1}$, a flow that is commonly inhaled by adult persons [19]. Particles were collected on 37 mm quartz fiberglass filters (QM-A Whatman, Maidstone, Kent, UK) that were placed in suitable cassettes of the Dusttrak equipment. The samples were stored at -20 °C before analysis. Filters used for $PM_{2.5}$ monitoring were weighed before and after sampling using a thermo-analytical electronic balance with a precision of ± 1μg, after 48 h storage in desiccators in a room with controlled relative humidity (45 ± 5%) and temperature (20 ± 2 °C). Filters were used in sampling after triplicate consecutive weighing within ± 2 μg. PM concentrations of each stage with different particle size ranges were estimated gravimetrically three times by measuring consecutive within 2 μg threshold.

In order to minimize the effect of relative humidity on PM measurements, the monitoring campaigns were conducted using a controlled heated inlet with an auto zero module mounted on Dusttrak™ instrument. A Greisinger multiparameter device was used to measure on-site weather parameters (temperature, relative humidity, wind speed, and air pressure) during PM samplings. Available data from the official monitoring network including 6 automated stations were recorded and analyzed using the geospatial analysis capabilities of ROkidAIR *e*-platform [20].

Data processing

The accurate locations of each sampling point were established using the GPS measurements (WGS-84 reference system), which facilitated the development of the thematic maps in QGIS software (www.qgis.org). Geospatial analysis techniques were used to establish the overlapping results between the distributions of particulate matter fractions. In situ data were used to obtain $PM_{2.5}$ isolines of concentrations, which were overlapped on the specific layers of Ploiesti, using GIS capabilities. Inverse distance weighting algorithm (IDW) was used for interpolation to obtain the specific isolines of $PM_{2.5}$ concentration. Descriptive and associative statistics of the recorded time-series were obtained using SPSS software (SPSS Inc., Chicago, IL, 2011). Pearson correlation was applied to identify the strength of the linear relationship between the PM fractions.

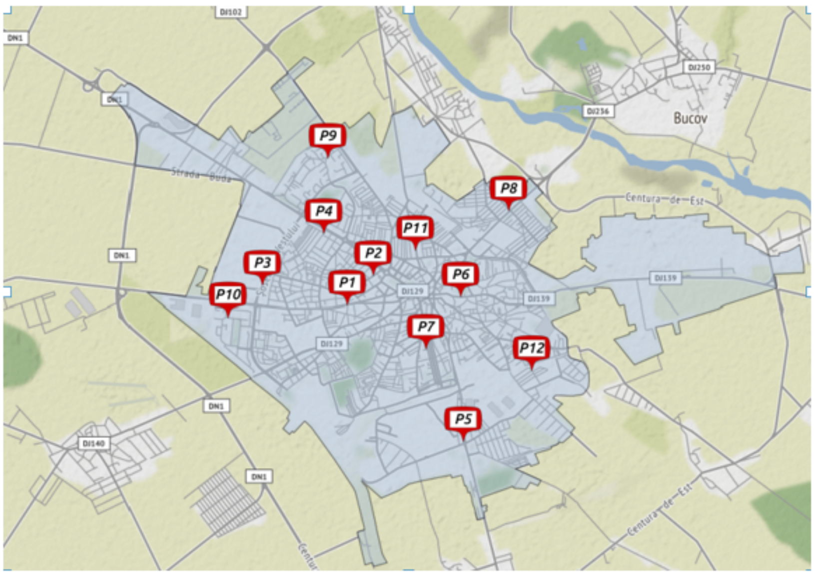

Fig. 1. Map of Ploiesti urban agglomeration showing the 12 PM sampling points used in the monitoring plan.

Results and discussions

Particulate matter in Ploiesti urban agglomeration measured by the RNMCA official network

A network of six automated stations routinely monitors air pollution in Ploiesti urban agglomeration, from which 4 of them are located in the inner city and two in suburban areas (fig.1). Only one $PM_{2.5}$ gravimetric analyzer exists in this official infrastructure i.e., PH-2 station. This is one of the reasons for which we have developed an adequate spatiotemporal approach to assess in a more elaborate way the impact of particulate matter in the inner city, focusing especially on the submicrometric fraction (PM_1), which is not measured by authorities.

Table 1 presents the main statistical indicators that characterize the evolution of PM in the area of Ploiesti urban agglomeration using the data recorded by the six automated stations of the National Air Quality Monitoring Network (www.calitateaer.ro) between January and October 2015. Unfortunately, a multi-site comparison could not be performed because some analyzers were not operational and the captured data had few values for several parameters, below acceptance limit for data aggregation (~90%), due to technical issues.

Despite this information hiatus, the available data related to air pollution shows that the averages of concentrations were below the limit values provided by the Romanian environmental regulations. However, the maximum values of PM concentrations suggest that critical pollution episodes occurred in Ploiesti during the monitored period. Positive skewness values for all analyzed time series explain a predominant frequency of the concentrations in the interval located below the limit value. Long *tails* were associated with peak values with extreme concentrations that are very contrasting compared to the general trend. Kurtosis showed that all pollutants presented leptokurtic distributions (thin tails). Consequently, the distribution indicators denote that long term exposure of residents was not a high risk factor in Ploiesti in 2015, but extreme pollution episodes might have a clear health impact, if they are occurring during the outdoor program of the residents. Vulnerable persons (e.g., children, elders, asthmatics, adults with lung diseases) are exposed of higher risks in

Table 1

DESCRIPTIVE STATISTICS OF PM CONCENTRATIONS RECORDED IN PLOIESTI URBAN AGGLOMERATION BETWEEN JANUARY AND OCTOBER 2015 (CONCENTRATIONS IN µg m^{-3}) BY THE RNMCA STATIONS

	Automated Monitoring Station	PH-1	PH-2	PH-5	PH-6	PH-3	PH-4
	Location	Inner city				Suburbs	
	Type	Urban traffic	Background urban	Urban traffic	Industrial	Background suburban	Background suburban
	Airbase ID code	RO0175	RO0176	RO0179	RO0180	RO0177	RO0178
$PM_{2.5}$	N (hourly values)	-	4264	-	-	-	-
LV=25 µg m^{-3} y^{-1}	Average	-	14.34	-	-	-	-
	Median	-	13.32	-	-	-	-
	Maximum	-	69.28	-	-	-	-
	Skewness	-	0.55	-	-	-	-
	Kurtosis	-	4.65	-	-	-	-
PM_{10}	N (hourly values)	3580	-	6917	-	7242	-
LV=40 µg m^{-3} y^{-1}	Average	24.61	-	28.26	-	27.26	-
	Median	21.73	-	26.3	-	25.01	-
	Maximum	147.04	-	131.01	-	126.29	-
	Skewness	1.01	-	1.05	-	1.38	-
	Kurtosis	5.22	-	5.24	-	6.21	-

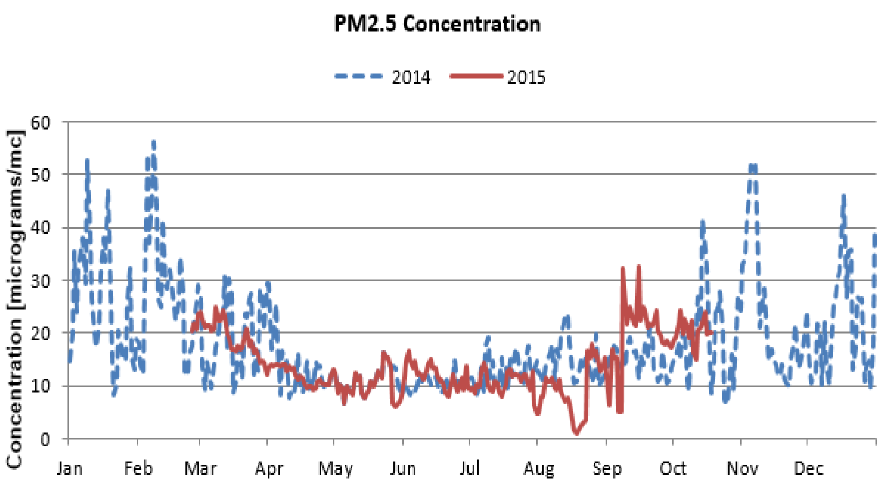

Fig. 2. Time series of $PM_{2.5}$ fraction recorded at PH-2 urban station (Ploiesti city center) in 2014 and 2015 (daily average values)

those situations, requiring the support of a reliable and accessible early warning system [20].

The average concentration of $PM_{2.5}$ in Ploiesti (measured by the PH-2 automatic station) was 18.6 mg m^{-3}, based on the average concentrations of the 2009-2012 interval, which ranged from 16.9 to 20.7 $\mu g\ m^{-3}$. The trend of $PM_{2.5}$ concentration (14.3 $\mu g\ m^{-3}$) in 2015 measured at PH-2 station showed a decreasing as compared to the historical time series (fig. 2). Many of the $PM_{2.5}$ values (i.e., 73.9%) were recorded into the 5.2-17.8 $\mu g\ m^{-3}$ interval.

The PH-2 station is located in a residential - commercial area with a distance from the nearest building of 10 m, and the height of nearest obstacles of 20 m. The station is 30 m away from a major road and is surrounded on four sides by small streets at distances between 50 and 300 m. The main wind direction is from north-east. Traffic intensity is moderate with a volume of traffic between 2,000 and 10,000 vehicles/day. The main emission sources near the station are non-industrial combustion plants, combustion in manufacturing, production processes, the use of solvents, road traffic and other mobile sources. These topographical and emission conditions are influencing the local concentrations, which are lower than the ones commonly occurring near industrial areas of Ploiesti in residential zones. Furthermore, the classical *monitoring for conformity* performed by the environmental authorities to comply with air quality regulations (i.e. limit values) assumes that, if the concentrations of monitored air pollutants are within acceptable limits, then the effects will be also within acceptable limits. Monitoring for regulations compliance is not concerned with establishing the actual effects resulted from the level of pollutants emissions, even if it is below the limit values set by legislation. Every individual has unique activity patterns that will result in a different exposure to air pollution. Outdoor exposure to air pollutants might be easier characterized having approaches of cause-effect or status-trend types based on the pollutants concentration, inhalation rate, and time of outdoor exposure [21].

Consequently, we designed a multisite experimental plan to assess in detail the spatiotemporal variations of fine and submicrometric fractions of particulate matter at city level (fig.1).

Fine and submicrometric fractions of particulate matter in Ploiesti city

Data collected during the monitoring campaigns have been analyzed statistically for each PM fraction in order to establish the status and variability of airborne particulate matter's levels in Ploiesti city. The aggregated results of data collected in 12 sampling points in 2015 during the *rush* hours are presented in table 2 using median, minimum, maximum and coefficient of variations for size-segregated mass fraction concentrations corresponding to PM_1,

Table 2

MEDIANS OF PM CONCENTRATIONS IN PLOIESTI CITY ($\mu g\ m^{-3}$) – MEDIAN OF ALL MEASUREMENTS PERFORMED IN 12 SAMPLING POINTS USING DUSTTRAK™ DRX 8533EP OPTICAL PRECISION INSTRUMENT WITH ENVIRONMENTAL ENCLOSURE BETWEEN JANUARY-OCTOBER 2015 (HOURLY SAMPLING RATE); P1-P12 SAMPLING POINTS SHOWED IN FIGURE 1

Monitoring Points												
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
PM1												
Median	30	26	38	26	48.5	35	27.5	38	26	27	34.5	30.5
Minimum	23.5	21.5	25	19	33.5	24	23.5	22	19.5	18.5	24.5	25
Maximum	57	37.5	106	115	186.5	117	46.5	351	57	60	57	42
Coefficient of variation (%)	34.8	27.3	32.8	47.4	45.4	38.8	35.2	38.5	31.3	39.4	38.7	15.8
PM2.5												
Median	30.5	26.5	40	27	49.5	35	28	39	26.5	28	35.5	31.5
Minimum	24.5	22	26	20	34	25	24	22	20.5	19	25	26
Maximum	58.5	39.5	125	116	188	117	48.5	354	59.5	61.5	58.5	43.5
Coefficient of variation (%)	33.5	26.3	34.3	45.3	45.7	38.3	33.7	38.2	30.1	38.1	38.2	16.5
PM4												
Median	30.5	27	40	27	50.5	36	28.5	41	27.5	29	36.5	32
Minimum	24.5	22	27	21	35	25	24	23	20.5	19.5	26	26.5
Maximum	58.5	42	143	117	189	117	50.5	360	61.5	62	60	43.5
Coefficient of variation (%)	38.1	32.9	36.5	50.3	54.9	43.2	38.8	44.6	38.8	45.3	48.8	20
PM10												
Median	31.5	27	41.0	28	51	37	29	42	28	29.5	37.5	32.5
Minimum	25	22	27	22	35	25	25	23	20.5	19.5	26	27.5
Maximum	60.5	44	150	117	190.5	117	57.5	373	63.5	63.5	63.5	50
Coefficient of variation (%)	37	32.9	37.1	47.5	55.3	42.4	37.9	44.8	39	43.5	46.1	20.8

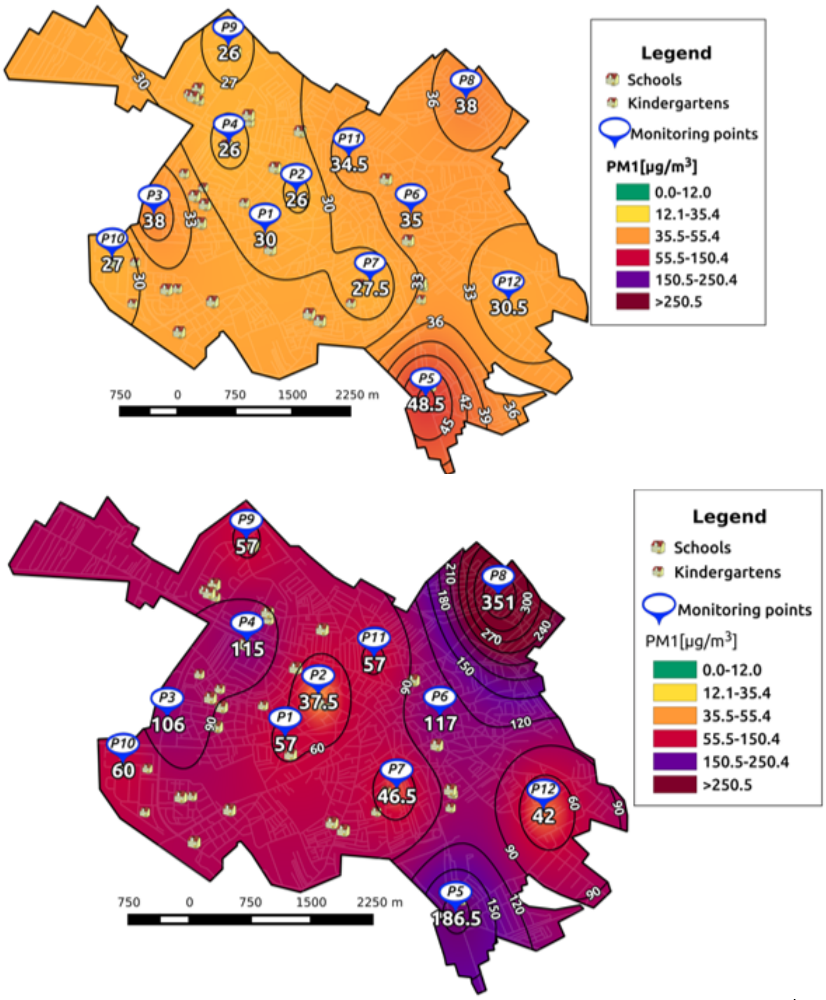

Fig. 3. PM_1 concentrations in Ploiesti city based on median values (a) and maximum values (b)

$PM_{2.5}$, PM_4 (Respirable), and PM_{10}. Compared to the PH-2 station data, the $PM_{2.5}$ concentrations were consistently higher due to the sampling interval, location conditions and to the fact that optical analyzers might provide higher values than gravimetric ones.

The difference between the PM_{10} and PM_1 medians of all sampling points was only 2.2 $\mu g \times m^{-3}$, PM_4 and PM_1 of 1.5 $\mu g \times m^{-3}$, and $PM_{2.5}$ and PM_1 of 0.8 $\mu g \times m^{-3}$ respectively ($p > 0.05$ – DL5% = ±5.8 $\mu g\ m^{-3}$). The correlation between the PM fractions was very significant ($p < 0.01$; $r = 0.996$). These results suggest that the most frequent fraction in Ploiesti inner city was PM_1, which is the most dangerous to human health because it includes the UFP fraction (less than 100 nanometers in diameter). These UFPs can be deposited deeply into the lung where the residence time can be up to several months and might be assimilated in the circulatory system following the gas exchange [22]. Diseases related to UFPs exposure are primarily related to lung cancer and heart diseases. Other type of pathology that may be the result of exposure to UFPs is Crohn's disease and the epithelium of the gut [23].

Since the outdoor measurement of UFP is a difficult task requiring sophisticated equipment, we monitored the submicrometric fraction using a reliable optical system with a sensor-controlled heated inlet. There were many very significant statistical differences ($p < 0.001$) between locations (DL0.1% = ±2.65 $\mu g\ m^{-3}$). Consequently, a comprehensive presentation of the spatial variability resulted from drawing thematic maps of PM_1 using the revised breakpoints and corresponding index bands recommended by [24] for $PM_{2.5}$.

The resulted maps show the concentrations of PM_1 in Ploiesti city, based on median values and maximum values (figs.3a and 3b) following the aggregation of concentrations obtained through measurements performed between January and October 2015. The IDW algorithm estimated the potential isolines of PM_1 concentrations. Figure 3a displays the most impacted areas i.e., P5 (under heavy traffic impact), P3 (under industrial and heavy traffic impact) and P8 (under the north-east oil refinery impact).

Therefore, in 2015, most of Ploiesti inner city had *moderate* and *unhealthy for sensitive groups* conditions according to US EPA revised breakpoints. Since there is no standard available for PM_1 yet, and PM_1 fraction usually records lower values compared to $PM_{2.5}$ the air quality conditions are even worst. The maximum values presented in figure 3b confirm the elevated outdoor exposure to submicrometric PM concentrations.

Submicrometric PM fraction and weather parameters in Ploiesti city

Local weather parameters are important influencing factors of air quality in urban areas [25-27]. An increase in wind speed, precipitations, and/or RH decreases the $PM_{2.5}$ and PM_{10} levels. Depending on local topographic and wind conditions, an increase of the air temperature supports the accumulation of particles. We selected for this work 4 points, 2 in west and 2 in east of the city. The data recorded between June and October was presented because the outdoor program of residents is longer, which increases the potential exposure to PM high concentrations . Table 3 presents the aggregated data of the monitored database. It was observed that temperature was higher in the eastern sampling points (P3 and P4) compared to western ones, while RH was higher in western points (P6 and P8). Temperature was positively correlated with PM_1 favoring the particle accumulation ($p < 0.03$). RH had a higher

Table 3
RELATIONSHIP BETWEEN THE MONTHLY AVERAGES OF PM_1 FRACTION AND WEATHER PARAMETERS IN PLOIESTI IN 4 SAMPLING POINTS THAT SHOWED HIGH CONCENTRATIONS

Month	Sampling point	Temperature	Relative Humidity	Pressure	Wind speed	PM_1 average	PM_1 Peak value
-	-	(°C)	(%)	(hPa)	(m/s)	(μg m^{-3})	(μg m^{-3})
June	P3	26.8	32.8	993.5	0.7	36.5	264.0
	P4	27.8	33.2	993.3	0.6	10.0	183.5
	P6	26.0	39.8	995.4	0.8	13.0	129.0
	P8	25.7	37.6	994.3	0.8	19.0	458.5
July	P3	33.7	37.4	993.5	0.4	43.5	130.0
	P4	35.5	34.5	993.5	0.6	33.5	54.5
	P6	28.5	54.8	996.1	0.2	45.5	87.0
	P8	29.3	51.3	995.2	0.4	45.5	157.5
August	P3	34.2	29.6	1000.1	0.8	39.0	140.5
	P4	35.3	29.8	1000.8	0.2	36.5	72.5
	P6	29.8	41.9	1003.1	0.7	45.5	163.0
	P8	30.9	40.2	1002.2	0.6	66.0	534.5
September	P3	28.0	38.8	991.5	0.2	37.5	223.5
	P4	27.3	38.6	992.0	0.1	33.5	116.5
	P6	26.2	41.8	994.2	0.2	44.5	391.5
	P8	24.8	43.2	993.3	0.6	60.5	1466.5
October	P3	13.7	62.3	1001.1	0.0	60.0	194.0
	P4	12.6	63.9	1003.5	0.1	25.5	38.0
	P6	9.8	69.6	1005.6	0.1	63.5	898.5
	P8	10.1	75.6	1004.6	0.1	142.5	526.0
Average		25.5	43.8	972.3	0.4	45.1	311.5

influence on PM_1 fraction ($p < 0.002$) showing an inverse correlation. Atmospheric pressure ranged within the normal interval (980-1050 hPa), while wind speed had very low values showing stable atmospheric conditions during samplings. The results suggest that it is important to monitor weather parameters during PM sampling since specific site conditions are difficult to be assessed only using data from a distant meteorological station or modeling algorithms. Weather parameters are useful for describing the conditions of occurring pollution episodes. We presented the instantaneous peak values to underline that PM_1 concentrations can reach very high values (up to 1466 μg m^{-3}) for short periods of time. This peak values can have harmful effects, if their occurrence coincides with respiratory inhalation.

Conclusions

Fine and ultrafine particles have a high potential impact on human health. Spatiotemporal and qualitative PM data are essential for epidemiological studies to consolidate the knowledge on influences that particle size and composition may have on human health.

The current study investigated the spatiotemporal variability of fine and submicrometric fractions of PM in an important urban agglomeration from Romania i.e., Ploiesti city. Concentrations of fine PM around schools and kindergartens were determined using a radial network of mobile monitoring points during the relevant hourly intervals for exposure assessments. Our observation revealed that contribution of $PM_{2.5}$ in total PM was more than 96%, while PM_1 fraction was 94%. Collected data were used to create air pollution health risk maps that can ensure a comprehensive presentation of the spatial variability of PM_1. According to these results, it was observed that Ploiesti inner city presented *moderate* and *unhealthy for sensitive groups* conditions for particulate pollution with $PM_{2.5}$ depending on the area of the city. The monitoring of weather parameters during the PM sampling campaings is required to assess adequately the specific site conditions that are influencing the microclimate and pollutants dispersion, and consequently the exposure characteristics during pollution episodes.

The study pointed out that the current minimum number of sampling points for fixed measurements of $PM_{2.5}$ concentrations (1 point for 0-249,000 residents) is not sufficient because the $PM_{2.5}$ levels showed an increased spatiotemporal variability at town's scale. Consequently, the number of fixed sampling points in Ploiesti should be increased and the continuous monitoring should be performed using Beta attenuation analyzers in high-populated areas with critical PM levels (e.g., P8, P3 and P5).

The obtained results underlined the importance of developing reliable monitoring plans of fine and ultrafine particulate matter to ensure a better protection of inner city residents against air pollution threats. To cope with this demand, the monitoring programs must provide results that can be used to detect temporal trends and spatial variability of air pollutants and should establish more or less empirical links between human activities and the associated environmental effects.

Acknowledgments: This study received funding from the European Economic Area Financial Mechanism 2009 - 2014 under the project ROKIDAIR "Towards a better protection of children against air pollution threats in the urban areas of Romania" contract no. 20SEE/30.06.2014

References

1. DUNEA, D., IORDACHE, ST., LIU, H-Y., BØHLER, T., POHOATA, A., RADULESCU, C., (**2016),** Quantifying the impact of PM2.5 and associated heavy metals on respiratory health of children near metallurgical facilities**,** *Environmental Science and Pollution Research,* 23(15), p. 15395–15406.

2. BEELEN, R., RAASCHOU-NIELSEN, O., STAFOGGIA, M., ANDERSEN, Z.J., WEINMAYR, G., HOFFMANN, B., et al., 2014. Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. Lancet 383 (9919), 785–795. http://dx.doi.org/10.1016/S0140-6736(13)62158-3.

3. BROOK, R.D., RAJAGOPALAN, S., POPE, C.A. 3RD, BROOK, J.R., BHATNAGAR, A., DIEZ-ROUX, A.V., HOLGUIN, F., HONG, Y., LUEPKER, R.V., MITTLEMAN, M.A., PETERS, A., SISCOVICK, D., SMITH, S.C. JR, WHITSEL, L., KAUFMAN, J.D., 2010. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation 121:2331–78.

4. HOEK, G., KRISHNAN, R.M., BEELEN, R., PETERS, A., OSTRO, B., BRUNEKREEF, B., KAUFMAN, J.D., 2013. Long-term air pollution exposure and cardio-respiratory mortality: a review. Environ. Health 12 (1), 43.

5. KREWSKI, D., JERRETT, M., BURNETT, R.T., MA, R., HUGHES, E., SHI, Y., TURNER, M.C., POPE, C.A. 3RD, THURSTON, G., CALLE, E.E., THUN, M.J., BECKERMAN, B., DELUCA, P., FINKELSTEIN, N., ITO, K., MOORE, D.K., NEWBOLD, K.B., RAMSAY, T., ROSS, Z., SHIN, H., TEMPALSKI, B., 2009. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. Res. Rep. Health Eff. Inst. 140, 5–114.

6. ALLAN, J. D., WILLIAMS, P. I., MORGAN, W. T., MARTIN, C. L., FLYNN, M. J., LEE, J., NEMITZ, E., PHILLIPS, G. J., GALLAGHER, M. W., COE, H., 2010. Contributions from transport, solid fuel burning and cooking to primary organic aerosols in two UK cities. Atmos. Chem. Phys., 10, 647-668, doi:10.5194/acp-10-647-2010.

7. BASAGAÑA, X., JACQUEMIN, B., KARANASIOU, A., OSTRO, B., QUEROL, X., AGIS, D., ALESSANDRINI, E., ALGUACIL, J., ARTIÑANO, B., CATRAMBONE, M., DE LA ROSA, J.D., DÍAZ, J., FAUSTINI, A., FERRARI, S., FORASTIERE, F., KATSOUYANNI, K., LINARES, C., PERRINO, C., RANZI, A., RICCIARDELLI, I., SAMOLI, E., ZAULI-SAJANI, S., SUNYER, J., STAFOGGIA, M., 2015. Short-term effects of particulate matter constituents on daily hospitalizations and mortality in five South-European cities: Results from the MED-PARTICLES project. Environ. Int. 75:151–158.

8. BILENKO, N., BRUNEKREEF, B., BEELEN, R., EEFTENS, M., DE HOOGH, K., HOEK, G., KOPPELMAN, G.H., WANG, M., VAN ROSSEM, L., GEHRING, U., 2015. Associations between particulate matter composition and childhood blood pressure—The PIAMA study. Environ Int.;84:1-6. doi: 10.1016/j.envint.2015.07.010.

9.CESARONI, G., FORASTIERE, F., STAFOGGIA, M., ANDERSEN, Z.J., BADALONI, C., BEELEN, R., CARACCIOLO, B., DE FAIRE, U., ERBEL, R., ERIKSEN, K.T., FRATIGLIONI, L., GALASSI, C.,et al., 2014. Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE Project. BMJ 348 f7412; doi: http://dx.doi.org/10.1136/bmj.f7412

10.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, Part 4, 621-629.

11. TAINIO, M., TUOMISTO, J.T., PEKKANEN, J., KARVOSENOJA, N., KUPIAINEN, K., PORVARI, P., SOFIEV, M., KARPPINEN, A., KANGAS, L., KUKKONEN, J., 2010. Uncertainty in health risks due to anthropogenic primary fine particulate matter from different source types in Finland. Atmos. Environ., 44(17), 2125-2132.

12.SHI, W., WONG, M.S., WANG, J., ZHAO, Y., 2012. Analysis of airborne particulate matter ($PM_{2.5}$) over Hong Kong using remote sensing and GIS. Sensors, 12, 6825-6836; doi:10.3390/s120606825.

13.VASILESCU, J., NEMUC,A., MARMUREANU,L., NICOLAE, D. (2011), Aerosol size distribution and composition near Bucharest during May 2010, Environ Eng Manag J, 10 (1), 121-126, 2011

14.MARMUREANU, L., DEACONU, L., VASILESCU, J., AJTAI, N., TALIANU, C., (2013), Combined optoelectronic methods used in the monitoring of SO_2 emissions and imissions, Environ Eng Manag J, 12(2), p 277-282;

15.RADULESCU, C., IORDACHE, ST., DUNEA, D., STIHI, C., DULAMA, I., (2015), Risks assessment of heavy metals on public health associated with atmospheric exposure to PM2.5 in urban area, Romanian Journal of Physics, 60(7-8) p. 1171-1182

16. DUNEA, D., IORDACHE, ST., RADULESCU, C., POHOATA, A., DULAMA, I., (2016) A multidimensional approach to the influence of wind on the variations of particulate matter and associated heavy metals in Ploiesti city**,** Romanian Journal of Physics , 61 (7-8) pp 1354-1368

17. DUNEA, D., IORDACHE, ST., ALEXANDRESCU, D.C., DINCÃ, N., 2014. Screening the Weekdays/Weekend patterns of air pollutant concentrations recorded in southeastern Romania, Environ. Eng. Manag. J., 13(12), 3105-3114.

18.DUNEA, D., IORDACHE, ST., POHOATA, A. (2016) Fine Particulate Matter in Urban Environments: A Trigger of Respiratory Symptoms in Sensitive Children, Int J Environ Res Public Health., 13(12): 1246. doi: 10.3390/ijerph13121246

19. ZUURBIER, M., HOEK, G., VAN DEN HAZEL, P., BRUNEKREEF, B., 2009. Minute ventilation of cyclists, car and bus passengers: an experimental study. Environ Health, 8, 48. doi: 10.1186/1476-069X-8-48.

20. IORDACHE, ST., DUNEA, D., LUNGU, E., PREDESCU, L., DUMITRU, D., IANACHE, C., IANACHE, R., 2015. A cyberinfrastructure for air quality monitoring and early warnings to protect children with respiratory disorders – Proceedings of Control Systems and Computer Science (CSCS), 20th International Conference on Control Systems and Computer Science, pp.789 - 796, doi: 10.1109/CSCS.2015.39

21.ZUURBIER, M., HOEK, G., VAN DEN HAZEL, P., BRUNEKREEF, B., 2009. Minute ventilation of cyclists, car and bus passengers: an experimental study. Environ Health, 8, 48. doi: 10.1186/1476-069X-8-48.

22.*** World Health Organization, 2011. Exposure to air pollution (particulate matter) in outdoor air. Copenhagen, WHO Regional Office for Europe, (ENHIS Factsheet 3.3), http://www.euro.who.int/data/assets/pdf_file/ 0018/97002/ENHIS_ Factsheet_3.3_July_2011.pdf

23.LOMER, M.C., THOMPSON, R.P., POWELL, J.J., 2002. Fine and ultrafine particles of the diet: influence on the mucosal immune response and association with Crohn's disease. Proceedings of the Nutrition Society 2002, 61(1), 123-130.

24. *** US EPA, 2012. The National Ambient Air Quality Standards for Particle Pollution: Revised air quality standards for particle pollution and updates to the Air Quality Index (AQI). US EPA Technical bulletin.

25. DUNEA, D., IORDACHE, ST., IANACHE, C., 2015. Relationship between airborne particulate matters and weather conditions in Targoviste urban area during cold months. Rev. Roum. Chim. 60(5-6), 595-601.

26. PANDOLFI, M., QUEROL, X., ALASTUEY, A., JIMENEZ, J. L., JORBA, O., DAY, D., ORTEGA, A., CUBISON, M. J., COMERÓN, A., SICARD, M., et al., 2014. Effects of sources and meteorology on particulate matter in the Western Mediterranean Basin: An overview of the DAURE campaign, J. Geophys. Res. Atmos., 119, 4978–5010, doi:10.1002/2013JD021079.

27.TAI, A., MICKLEY, L., JACOB, D.J., 2010. Correlations between fine particulate matter (PM2.5) and meteorological variables in the United States: Implications for the sensitivity of PM2.5 to climate change, Atmos. Environ. 44, 3976-3984

Manuscript received: 10.01.2017