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RELATIONSHIP BETWEEN AIRBORNE PARTICULATE MATTER AND WEATHER CONDITIONS IN TÂRGOVIȘTE URBAN AREA DURING COLD MONTHS

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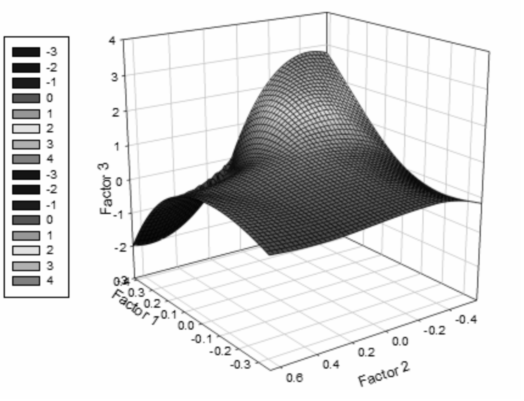
The study envisaged the assessing of potential relationships between PM10 concentrations and several meteorological parameters recorded at DB-1 (RO030401) industrial automated monitoring station located in Târgovişte urban area. The analyzed data set comprised PM10 concentrations, solar radiation (Rg), relative humidity (RH), air temperature (T), atmospheric pressure (P), wind speed (WS) and wind direction (WD) recorded hourly during January and March 2012, when residential heating had a major contribution to the overall emissions. The strongest inverse correlations ($p < 0.01$) were found between PM10 concentrations and T, as well as between PM10 concentrations and Rg. A moderate inverse correlation was observed between WD and PM10 ($p < 0.05$). RH was positively correlated with PM10, as well as P and PM10 ($p < 0.01$). The meteorological parameter that did not correlate with PM10 was WS. Factorial analysis was applied to determine the relationship of interdependence between tested variables based on the minimum set that explained the influence of weather conditions on PM10 during cold months. The latent factors explained the data variability as follows: Factor 1 (RH, T, and Rg) – 26.58%; Factor 2 (WS and WD) – 15.95%; and Factor 3 (P) – 14.53%.



INTRODUCTION

Air pollution modifies the equilibrium of an ecosystem through a variety of harmful substances. The adverse effect of air pollutants on population occurs mainly in urban and suburban areas where pollution is correlated with specific emission sources, with the socio-economic complex of the urban agglomeration, as well as with the local meteorological and topographical conditions.[1-2]

Children and elders are the most affected categories of population when exposed to air pollution. Exposure to particulate matter (PM) affects lung development in children, including reversible deficits in lung function as well as chronically reduced lung growth rate and a deficit in long-term lung function.[3] Safe levels of exposure or a threshold below which no adverse health effects occur, are difficult to establish.[4]

The PM concentrations are not only influenced by emissions of pollutants from anthropogenic and biogenic sources, but also by season and meteorology.[5] Different studies have shown strong correlations between PM concentrations and meteorological parameters.[6-8]

The rationale of the study was to analyze the multiannual pattern of PM10 concentrations in Târgoviște urban area (73,964 permanent residents –

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2011 census), which is a town in the Southeastern part of Romania under the impact of metallurgical industry, heavy traffic and other contributing sources. The continuous monitoring instrumentation of air pollution including PM10 concentrations was the DB-1 automatic air quality monitoring station. The study was required to analyze and correlate existent information regarding PM10 levels and *in-situ* weather parameters recorded at this station. This information will be useful in developing data processing algorithms within *ROKIDAIR* research project (www.rokidair.ro) funded by European Economic Area Grants that started in July 2014, which has as an overall objective to support the developing of cost effective and efficient particulate matter monitoring systems together with early warnings and expert messages capabilities. Târgoviște, together with Ploiești, have been considered as pilot towns for this project because their residential areas are under the emissions' impact of industrial sources and heavy traffic. Consequently, the PM mixtures might have different physical and chemical characteristics depending on emission sources particularities, which might determine contrasting effects on children's health.

EXPERIMENTAL

The study envisaged the assessing of potential relationships between PM10 concentrations and several meteorological parameters recorded at DB-1 (RO030401) industrial automated monitoring station located in Târgoviște urban area (stereographic 1970 coordinates: X = 379712.25 and Y = 537861.38 m; altitude of 271 m; position in 2009-2013). DB-1 had an area of representativity between 100 m and 1 km (Fig. 1), but was surrounded closely by new constructions, which have diminished the monitoring performances for a larger area.

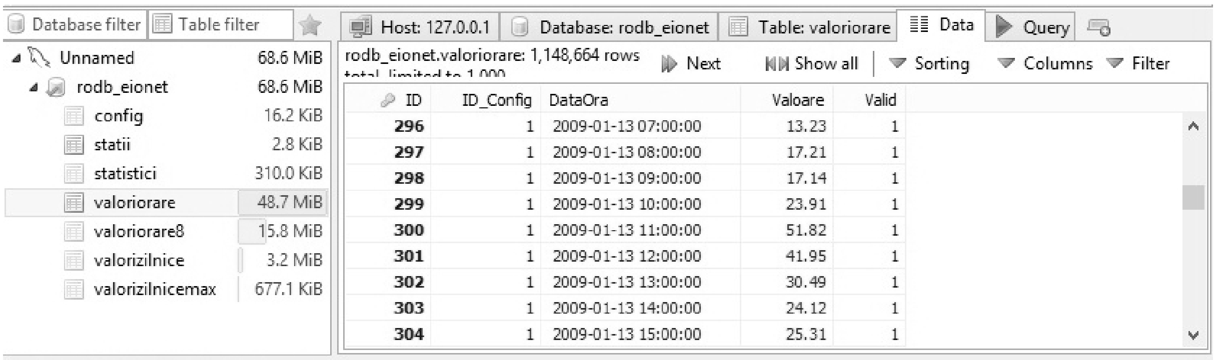
The analyzed data set for correlations comprised PM10 concentrations, solar radiation (Rg), relative humidity (RH), air temperature (T), atmospheric pressure (P), wind speed (WS), and wind direction (WD). Data were recorded hourly between January and March 2012 (n = 2184 × 7 variables), when decentralized residential heating had an increased contribution to the overall emissions in the area.

DB-1 station has monitored PM10 levels using a Unitec LSPM10 analyzer, which complies with the EU Directive EN 12341, reference method: PM10 sampling standards (2.3 m^3/h) and gravimetric determination of the PM10 (16 membrane filters). The instrument measured the average of instantaneous values for each 6 minutes, the hourly averages and the 24 hours averages, using the principle of orthogonal nephelometry. A controlled pump with constant flow collected ambient air through the selective sampling head (PM10 or PM2.5) into the instrument. At this level, particle concentration was estimated by measuring the light scattered from an excitation beam. The light beam was focused in a spectral narrow band into the detector using a special collimator device. Then, the signal was output continuously to the microprocessor for data elaboration. The analyzer performed an automatic calibration every 6 minutes. Potential drift was compensated, ensuring high analysis stability.[9] The recorded hourly averages (micrograms/nm^3) and station alarms were transmitted at 18 minutes of each hour via GSM/GPRS to the local server of the RNMCA system (EDA → EDAC → OEsys).[10] After the manual validation, data were transmitted by the national authorities to the AirBASE network.[11]

The DB-1 files extracted from AirBASE were imported in *ROKIDAIR* MySQL database (Fig. 2) to perform data processing and to extract information concerning PM10 trends in correlation with the weather parameters. Pearson's correlation was applied between each pair of variables to find significant bivariate associations. The resulted correlation coefficients evaluated the strength of the linear relationship between PM10 and the meteorological variables recorded on-site.

SPSS (SPSS Inc., Chicago, IL, 2011) was used to perform factor analysis using the recorded time series. Factor analysis (FA) was performed using the principal components (PCA) method based on Varimax with Kaiser Normalization (6 iterations).[12] The classification structures of meteorological variables and the latent factors controlling PM10 concentrations were retrieved for the January-March 2012 interval.

Fig. 1 – Location of the DB-1 automatic station of air quality monitoring in Târgoviște city (orthophoto from 2010).



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297	1	2009-01-13 08:00:00	17.21	1
298	1	2009-01-13 09:00:00	17.14	1
299	1	2009-01-13 10:00:00	23.91	1
300	1	2009-01-13 11:00:00	51.82	1
301	1	2009-01-13 12:00:00	41.95	1
302	1	2009-01-13 13:00:00	30.49	1
303	1	2009-01-13 14:00:00	24.12	1
304	1	2009-01-13 15:00:00	25.31	1

Fig. 2 – Visualization of the PM10 dataset recorded at DB-1 automated station (Târgovişte urban area) in *ROKIDAIR* MySQL database populated by importing AirBASE EIONET records.

RESULTS AND DISCUSSION

1. Annual trends of PM10 concentrations in Târgovişte

Firstly, the validated daily time series from AirBASE were used to analyze the annual PM10 evolution in Târgovişte. The DB-1 station started to operate in the summer of 2008. Because the first complete annual time series was 2009, there were three annual available time series for analysis of the DB-1 station data *i.e.*, 2009, 2010 and 2012. Because 2012 was a leap year with 366 days, the value corresponding to the day of February 29 (-999 – invalidated) was omitted to ensure data consistency. Fig. 3 presents the PM10 daily concentrations recorded during each year.

The most elevated peaks were observed in 2010 and 2012 mainly between the end of January and end of March, and in December.

There were several days with invalidated data (value = -999) in each year. Table 1 shows that 2012 was the year with most of the validated data, followed by 2010 and 2009. The same ranking was applicable for the daily mean and maximum values. In 2012, the annual daily mean was 28.77 µg m^{-3}, while the maximum value was 98.32 µg m^{-3}. Table 1 presents the comparison of the daily time series recorded at DB-1 station in Târgovişte for various years and for the period between January and March when residential heating contributed to the total emissions. Multiple range tests were performed using LSD (Least Significant Differences) test. There were significant differences between the means of the pairs: 2009-2010 ($p < 0.01$), 2010-2012 and 2009-2012 ($p < 0.001$). Significant differences were observed also for the PM10 daily means of the January-March intervals. The maximum daily values of the year were reached during these cold months in 2010 and 2012. The maximum of the cold months recorded in 2009 was close to the annual maximum of the year.

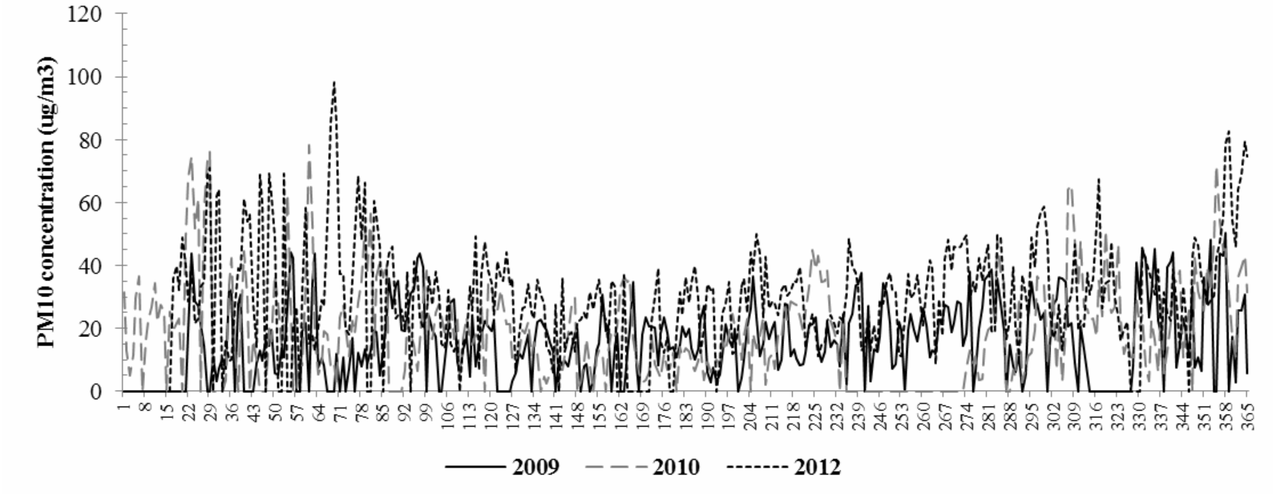

Fig. 3 – Time series of PM10 daily concentrations recorded at DB-1 automatic station of air quality monitoring in Târgovişte city.

Table 1

Comparison of the daily time series recorded at DB-1 station in Târgovişte for various years and for the period between January and March when residential heating contributed to the total emissions; multiple range tests were performed using LSD test: difference is significant as follows: * $p < 0.05$ level, ** $p < 0.01$ level, *** $p < 0.001$ level

Year	Count	Missing data (days)	Mean	Maximum	Pair	Difference	Difference Limit
2009	365	79	15.46	50.15	2009-2010	-3.08**	±3.02
2010	365	70	18.55	78.41	2010-2012	-10.21***	±3.86
2012	366	49	28.77	98.32	2009-2012	-13.31***	±3.86
2009 (January-March)	90	37	11.15	43.98	2009-2010	-12.32***	±10.22
2010 (January-March)	90	19	23.47	78.41	2010-2012	-6.24*	±6.05
2012 (January-March)	91	27	29.72	98.32	2009-2012	-18.57***	±10.22

Table 2

Descriptive statistics of the hourly PM10 and weather data recorded between January 2012 and March 2012

Indicator	PM10 particles	Pressure	Solar Radiation	Temperature	Relative humidity	Wind speed	Wind direction
Unit	$\mu g\cdot m^{-3}\cdot h^{-1}$	*mbar*	$W\cdot m^{-2}\cdot h^{-1}$	*°C*	*%*	$m\cdot s^{-1}$	*°*
Hourly Mean	84.27	980.77	70.83	1.90	77.98	0.34	128.06
Median	92.51	981.56	6.49	0.00	86.92	0.27	45.09
Std. Deviation	18.56	26.79	132.18	3.84	19.40	0.26	112.38
Variance	344.46	717.62	17471.06	14.77	376.27	0.07	12628.31
Skewness	-1.79	-34.13	2.76	2.18	-1.65	4.86	0.59
Kurtosis	3.07	1247.78	7.88	4.27	2.86	26.68	-1.18
Maximum	98.32	998.44	788.75	19.35	99.55	2.54	359.78
Coeff. of variation (%)	22.02	2.73	186.62	202.29	24.87	75.69	87.75

Secondly, the hourly time series recorded between January and March 2012 were used to find the relationships between PM10 particles and meteorological parameters. Mean, median, standard deviation, maximum, skewness, kurtosis, and the coefficient of variation (C.V.%) were used as numerical descriptors of time series dispersion and distribution (Table 2).

The statistical indicators described the local conditions of the residential area where the DB-1 station was located. The PM10 concentrations were high (CV = 22.02%), the values being concentrated around the mean with a right-skewed mesokurtic distribution. The mean of atmospheric pressure was situated in the lowest part of the normal range (between 980 and 1050 millibars).

Solar radiation and temperature values ranged within the normal interval of the months for Târgovişte location. The relative humidity had a mean of 78% and a median of 87% and was dependent on the temperature and pressure. Wind speed measurements showed low values typical to calm winds. This was because the station was surrounded by constructions that attenuated the surface air currents. In the station location, these air currents had the main direction towards Northeast considering the median value of 45°, while the main multiannual (45 years average) direction of wind in Târgovişte was Northwest.

2. Correlation of PM10 levels with weather parameters

Table 3 presents the degree of association between parameters during cold months using a correlation matrix. The strongest inverse correlations ($p < 0.01$) occurred between PM10 concentrations and temperature, as well as between PM10 concentrations and solar radiation. A moderate inverse correlation was observed between wind direction and PM10 ($p < 0.05$). Relative humidity was positively correlated with PM10, as well as atmospheric pressure and PM10 ($p < 0.01$). The only meteorological parameter that did not correlate with PM10 was the wind speed, but this was due the positioning of DB-1 station between the buildings, which lowered significantly the wind speed.

Table 3

Correlation matrix of PM10 particulate matter and meteorological parameters (hourly averages) at DB-1 automatic station using the Pearson's correlation coefficient:* Correlation is significant at $p < 0.05$ level (two-tailed);** Correlation is significant at $p < 0.01$ level (two-tailed)

N=2184

Variables	PM10 particles	Pressure	Solar Radiation	Temperature	Relative humidity	Wind speed	Wind direction
PM10 particles	1	**0.069****	**-0.129****	**-0.257****	**0.153****	0.002	**-0.040***
Pressure		1	-0.003	-0.091	0.113	0.055	-0.002
Solar Radiation			1	0.266	-0.325	-0.009	0.079
Temperature				1	-0.358	-0.030	0.106
Relative humidity					1	0.113	-0.186
Wind speed						1	-0.144
Wind direction							1

Previous studies performed in this location using Spearman rank correlations have pointed out that PM10 correlated with NO_x, SO_2 and CO concentrations ($p < 0.05$).[13] The results pointed out the major influence of the industrial emissions on the concentrations recorded at that time in the residential areas of Târgovişte found in the range of DB-1 station.

Other studies have shown that the PM concentrations of fine particles decreased at higher wind velocities because of a dilution effect.[14] The particles concentration can also be influenced by the wind direction.[15,16] Not only the wind, but also the air temperature plays a role in the variation of PM concentrations. Several studies pointed out that increasing air temperature can determine higher values of PM concentrations.[6-8,17] Correlations were found with other meteorological parameters such as humidity and precipitation.[7-9,18,19] These studies have shown that meteorology at the local-scale is an important influencing factor of air quality in urban areas. In Belgium, an increase in wind speed, precipitation, and/or RH decreased the PM2.5 and PM10. An increase in the air temperature would support the particles accumulation. However, this trend was experienced only for a couple of sites, while air temperature was rather anti-correlated with both PM2.5 and PM10 aerosols.[20] In this regard, the results concerning the influence of temperature on PM10 values in Târgovişte during cold months of 2012 were in agreement with these reports.

3. Factor analysis of PM10 and weather data

The exploratory factor analysis was applied to reduce the number of factors that explain the variability within the PM10 and meteorological data set. The input matrix started with 2184 objects (number of measurements) by 7 variables (PM10 and 6 meteorological parameters). There were three eigenvalues meeting the Kaiser criterion (>1), which pointed out three factors for selection.

They accounted a cumulative variance of 57% from the total variability in the data (Table 4). Rotation was performed using the Varimax with Kaiser Normalization method using 6 iterations. The rotated component matrix provided the same structure of the original latent factors (Table 5). The most significant factor loadings (> 0.5) were accounted for each factor.

Table 4

Factorial analysis applied to PM10 and meteorological data set: total variance explained; PCA extraction method based on eigenvalues (> 1); three factors extracted

Component	Initial eigenvalues		
	Total	% of Variance	Cumulative %
1	**1.861**	26.585	26.585
2	**1.117**	15.955	42.540
3	**1.017**	14.532	57.072
4	0.885	12.643	69.715
5	0.833	11.895	81.610
6	0.689	9.849	91.460
7	0.598	8.540	100.000

Table 5

Factorial analysis of PM10 and meteorological data set: component extraction

Component	Component Matrix Extraction Method: PCA (3 components extracted)			Rotated Component Matrix Extraction Method: PCA Varimax with Kaiser Normalization (Rotation converged in 6 iterations)		
	1	2	3	1	2	3
PM10	-0.469	-0.339	0.204	-0.525	-0.186	0.259
Pressure	-0.225	0.060	**0.881**	-0.075	0.048	**0.907**
Solar radiation	**0.605**	0.202	0.328	**0.675**	-0.037	0.240
Temperature	**0.711**	0.210	-0.016	**0.731**	-0.032	-0.116
Relative humidity	**-0.741**	0.071	-0.061	**-0.676**	0.313	0.057
Wind speed	-0.204	**0.747**	0.146	0.080	**0.756**	0.209
Wind direction	0.359	**-0.591**	0.256	0.171	**-0.697**	0.171

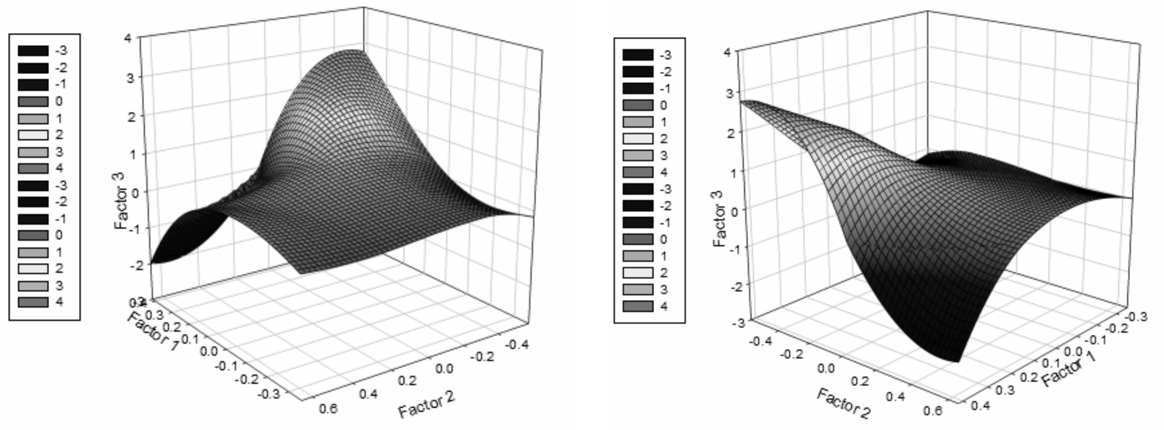

Fig. 4 – Component plot in rotated space based on component score coefficient matrix of the meteorological parameters in relationship with PM10 concentrations at DB-1 industrial station (Târgovişte city) – front and lateral views.

The relationship between the component scores coefficients was plotted based on the component score coefficient matrix of meteorological parameters in relationship with PM10 concentrations at DB-1 industrial station (Fig. 4). The structure of the first factor was formed by three variables *i.e.*, temperature, solar radiation, and relative humidity.

The second factor comprised the wind speed and the wind direction, while the third factor had one variable *i.e.*, the atmospheric pressure. It was found that the correlated factor loadings were relative humidity and wind direction, while the other four factors were anti-correlated.

CONCLUSIONS

The frequencies of significant PM10 pollution episodes were quite large during wintertime, particularly in January and February, in correlation with the specific meteorological conditions that occurred in the atmosphere of Târgovişte city in the cold season. The concentrations of PM10 have increased significantly from 2009 to 2012. In 2012, the annual daily mean was 28.77 µg m^{-3}, while the maximum value was 98.32 µg m^{-3}, as compared to the mean of 15.46 and maximum of 50.15 µg m^{-3} in 2009. Unfortunately, in the last two years there were no data available for continuing the comparison.

PM10 concentrations and temperature were negatively correlated during cold months of 2012, as well as PM10 concentrations and solar radiation. A moderate inverse correlation was also observed between wind direction and PM10. Relative humidity was positively correlated with PM10, as well as atmospheric pressure and PM10. The only meteorological parameter that did not correlate with PM10 was the wind speed. The PCA results explained more than half of the data variance with three factors. The latent factors were as follows: Factor 1 (relative humidity, temperature, and solar radiation) – 26.58%; Factor 2 (wind speed and wind direction) – 15.95%; and Factor 3 (atmospheric pressure) – 14.53%.

The analysis of historical time series of PM10 recorded in Târgovişte will support the development of a hybrid neural network model with a forecasting knowledge base developed by predictive data mining and other machine learning techniques in the *ROKIDAIR* project. The required inputs will be the time series with PM2.5 data, meteorological data, and the topographic characteristics of critical polluted areas along with the characterization of the neighbouring air pollution sources. The present results will also facilitate the fine-tuning of a complex monitoring plan for respirable dusts evaluation in Târgovişte, which has been started in 10 representative points using portable particulate matter analyzers and a portable automatic weather station.

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