VARIATION OF PM₁₀ CONCENTRATION DEPENDING ON THE METEOROLOGICAL PARAMETERS IN TWO BUCHAREST MONITORING STATIONS (IN GREEN AREAS)

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Abstract. This study presents the assessment of the PM₁₀ emissions in areas from the south of Bucharest and Ilfov county, for a period of 11 years, during 2008-2018, taking into consideration the most important meteorological parameters with influence to air pollution, such as relative humidity, temperature, wind direction, and wind speed. During the study period, the mean annual concentrations of PM₁₀ decreased from 43.92 µg/m³ to 29.67 µg/m³, expressed as a percentage change the decrease was 35.45% and 29.03% at the B-4 and B-7 stations, respectively. The Pearson correlation coefficient was significantly higher in the cold season (November-April). In order to further investigate the relations of air quality and wind direction pollution roses were calculated and the results indicate that the highest concentrations of PM₁₀ occur in B-4 and B-7 at the southwestern and west direction of wind.

1. Introduction

The air pollution has multiple observable effects on the environment, the PM₁₀ (particulate matter with a diameter less than 10µm) accumulation in the atmosphere was caused mainly by fast-growing economic development, industrialization, and other anthropogenic activities (Keresztesi et al., 2019a; Rápó et al., 2018; Szép et al., 2019, 2018; Zhang et al., 2007). PM₁₀ directly

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affects the health and quality of life of the population by inducing continuous chemical stress on the body. PM₁₀ produces a large number of premature deaths around the world and an increase in the number of heart and respiratory diseases (Feng et al., 2019; Ilie et al., 2017; Korodi et al., 2017; Nhung et al., 2018).

In Eastern Europe, PM₁₀ concentrations and their effects on health are not analyzed as much as in Western Europe, which can be measured in a number of published articles (Iorga et al., 2015). However, it is obvious that most densely populated cities and industrial hotspots face many challenges regarding the environment and air quality as well due to the emissions of harmful substances by different activities existing at urban level e.g., intensive industrial operations and transportation activities or even long-range transport of air pollutants. One of the most significant sources of primary PM₁₀ emissions were domestic heating systems and combustion, road traffic, and industrial combustion (Boga et al., 2019; Keresztesi et al., 2019b; Kieseewetter et al., 2015; Petres et al., 2018; Sfiică et al., 2018). The annual mean concentration of particulate matter defined by WHO air quality guidelines is 20 µg/m³ and 50 µg/m³ for the 24-hour mean (Colvez et al., 2003). In Romania, the maximum allowed concentrations, as a lower threshold, are 20 µg/m³ for annual mean and maximum 35 days per year with average daily concentrations higher than 50 µg/m³ (104/2011, 2011). As stated out earlier, the PM₁₀ regional background can show significant variability and may have an important influence on rainwater chemistry (Keresztesi et al., 2018, 2017).

In Bucharest was measured one of the highest particulate matter concentrations according to the WHO Aphekom project, with the main objective to assess the impact of air pollution on health in 25 European cities (Petre et al., 2016). In addition to the high populated cities, high concentrations of PM₁₀ often occur in smaller settlements due to climatological characteristics like thermal inversion, atmospheric stability (Szép et al., 2018; Szép and Mátyás, 2014). Moreover, during the heating period, coal and biomass burning also has a relevant contribution to the PM₁₀ increment (Szép et al., 2016).

2. Material and methods

The study was carried out in Bucharest- the capital of Romania, with about 2.1 million inhabitants, according to the National Institute of Statistics (2019); it is the largest agglomeration in the country. The studied period covered eleven years, beginning from 1 February 2008 to 31 December 2018. The main PM₁₀ pollution in Bucharest comes from

intense traffic and industrial activities (CETs) emissions (Raicu and Iorga, 2009).

The PM_{10} concentration data were available from the National Air Quality Monitoring Network and further analyzed by IBM SPSS software version 6.0. From the 8 monitoring stations located in Bucharest for this period, only two stations fulfilled the condition when less than 25% of the data were missing, in case of station B-4- the available data represent 82.31% and from B-7-80.96%, respectively.

2.1. Sampling

Bucharest, capital of the Romania is located in the southeast of the country and is the largest and the most crowded city in Romania.

Fig. 1. Sampling sites, B-4, B-7 ("https://www.google.com/maps," n.d.)

The B-4 R0 0068A monitoring station named as Berceni, industrial-urban area type, located in Berceni street, no 10-12 having 100 m to 1 km radius area with moderate traffic of 2000-100000 vehicle/day with coordinate: latitude 44°38' N and longitude, 26°13' E, and on the 80 m altitude ("calitateaer.ro,"). The station is situated in a green area, park of the Bagdasar-Arseni Hospital, in south-eastern part of the town, at 2,5 km by its limit (Fig.1).

The B-7 RO0071A monitoring station, named as Măgurele suburban area type, located in Atomiștilor street, Nr. 407, Măgurele town, latitude, 44°35' and longitude, 26°03', elevation 80 m, in a relatively green area, at about 1,2 km south from the ring road and 7 km of the southern limit of the Bucharest (Fig.1).

2.2. Statistical analysis

The temporal and spatial variation at Urban (B-4) and Peri-urban (B-7) monitoring stations of PM₁₀ daily concentrations were statistically analyzed. During the studied period, from February 2008 to December 2018, in total, 3987 days were analyzed, and the daily PM₁₀, LCL, air temperature, relative humidity, wind speed, and wind direction was followed at both the urban and Peri-urban monitoring stations. Using the descriptive statistics, the mean, standard deviation, coefficient of variation, minimum, median, maximum, 25th- and 75th percentile values, and confidence interval was detected (Table 1). Pearson's correlation coefficient was used to determine the correlation between PM₁₀ and meteorological parameters: temperature, relative humidity, and lifting condensation level in the cold (November to April) and warm period (May-October) as well. In order to detect the PM₁₀ concentration dynamics, the pollution rose was used, taking into account the hourly PM₁₀ concentration, wind direction, and wind speed. The Lifting condensation level (LCL - the height at which the relative humidity (RH) of an air parcel will reach 100% with respect to liquid water when it is cooled by dry adiabatic lifting) was calculated (Equation 1), which are strongly related to the particulate matter concentration. Similar to the atmospheric stability and thermal inversion, the low lifting condensation favorite the PM₁₀ accumulation in the troposphere.

$$LCL = 20 + \left(\frac{T}{5}\right) * (100 - RH) \quad (1)(\text{Romps, 2017})$$

The daily PM₁₀ concentration was also used to calculate the weekly, monthly, annual trends and categories during the study period. Using the PM₁₀

concentrations four classes were defined: low $<25\mu\text{g}/\text{m}^3$, moderate 25- $37.5\mu\text{g}/\text{m}^3$, high $37.5\text{--}50\mu\text{g}/\text{m}^3$ and very high $>50\mu\text{g}/\text{m}^3$.

In order to investigate the frequency distribution of wind direction correlated with a chosen pollutant, the well-known 'openair' R package was used and the results obtained are presented as pollution roses. Hence, the main directions of pollutants were estimated and further analyzed.

3. Results and discussion

In Bucharest, the average PM_{10} concentration during the last 11 years, was $31.53 \pm 2.18 \mu\text{g}/\text{m}^3$ in B-7 monitoring station and $31.96 \pm 2.63 \mu\text{g}/\text{m}^3$ in B-4, which are significantly higher than the WHO Air Quality admissible level $20 \mu\text{g}/\text{m}^3$. The coefficient of variation (CV) in the case of PM_{10} concentration varied between 0.3-0.36, and these values were higher for the lifting condensation levels, the CV values obtained were between 0.38-0.42 (Tab. 1).

Significant differences were found between the industrial and suburban area regarding the LCL and relative humidity. This variation can be explained in light of the temperature effect of the concrete block and the lack of green spaces (Cheval and Dumitrescu, 2009).

Table 1. Results of descriptive statistics for urban and peri-urban monitoring stations

	PM ₁₀ -B4	PM ₁₀ -B7	LCL-B-4	LCL-B-7	T-B4	T-B7
Mean	31.96	31.53	1368.45	608.04	12	12
SD	9.65	11.42	581.8	231.6	9.9	10
CV	0.3	0.36	0.42	0.38	0.79	0.81
Min	16.4	7.4	543.3	220.4	-14	-16
P25	24.5	24.5	801.8	511.3	4.22	4.17
Med	29.5	31.1	1609.4	606.7	13	13
P75	37.2	37.1	1801.5	696.0	21.13	21.17
Max	68.3	75.6	2038.5	975.8	32	32
CI95%⁻	29.8	28.9	1235.8	555.2	12	11.79
CI95%⁺	34.17	34.17	1501.14	661	12.91	12.74

Abbreviations: mean - average, SD - standard deviation, CV - coefficient of variation, Min - minimum; P25 - 25th percentile; Med. - median; P75-75th percentile; Max - maximum, CI95% - Confidence interval.

3.1. PM₁₀ concentration classification

To compare the PM₁₀ concentration, the R ratio was used, which means the ratio of the high and very high categories from the list of all categories.

$$R = \frac{\Sigma \%_{\text{High}} + \Sigma \%_{\text{Veryhigh}}}{\Sigma \%_{\text{total}}} \quad (2)$$

During the study period, the above-mentioned ratio was 0.22, however significant seasonal variations were observed. For example, higher values were calculated in winter (0.31) and in autumn (0.27) while in summer (0.14) and in spring (0.19) the ratio was lower than the annual average (Fig.2). The high pollution concentration during the winter is related to increased emission from the heating and unfavorable meteorological conditions. Regarding the average number of exceedance days of PM₁₀ (>50 µg/m³) during the entire period, it represents 4.98%.

If we analyze on the seasonal basis, we can observe that the exceedance days were the highest in winter and represent 17.7% from the total winter days, followed by the autumn where the days of PM₁₀ concentrations exceeding the daily limit value of 50 µg/m³ was 13.25%.

On the other hand, the lowest percentages were recorded in spring and in summer with 6.33% and 4.0% respectively thanks to the more favorable climatological conditions.

Fig. 2. Annual and seasonal PM₁₀ categories

3.2. Variations of PM₁₀ according to meteorological data

Regarding the relationship between LCL and PM₁₀ dispersion, it is clear that during summer due to the higher LCL, the atmospheric dispersion of pollutants is stronger; the opposite phenomena are valid in winter when PM₁₀ can accumulate in the lower layer of the atmosphere. The correlations between PM₁₀ and LCL during the study period are presented in Fig. 3.

Fig. 3. Relationship between PM_{10} and meteorological parameters, left B-4 and right B-7 monitoring station

As can be seen from Fig. 3 in both cases, there is a negative correlation between PM_{10} and LCL, due to the fact the PM_{10} accumulation in the lower LCL level. The relative humidity (RH) followed strongly the PM_{10} evolution trend, low concentration in warm period, and high concentration in winter.

3.3. Weekly and annual PM_{10} evolution

Temporal trends in daily evolution of PM_{10} concentrations show a maximum peak in the middle of the week mean while the minimum values were recorded during the weekend (Fig. 4). The minimum and the maximum trend

evaluation are found to tend to correlate with the traffic intensity strongly.

Fig. 4. Weekly variation of PM₁₀ concentration

By the beginning of the week, the daily PM₁₀ concentrations start to increase, hence begin to accumulate on the atmosphere and reached the maximum concentration on Tuesday at monitoring station B-7 (32.82 µg/m³) and on Wednesday at monitoring station B-4 (33.81 µg/m³), respectively. In general, the lowest concentrations were measured on weekends, Sunday 29.73 µg/m³ (B-4) and 28.4 µg/m³ (B-7), due to reduced traffic and lower emissions on weekends.

The multiannual monthly average PM₁₀ concentrations at the two monitoring stations (Fig. 5) are presented and compared in the form of box-plots. Regarding the PM₁₀ concentrations (mean, median, and 95% percentile) between the two monitoring stations indicate that the pollution level is very similar B-4: 31.53 µg/m³ and B-7: 31.96 µg/m³, respectively.

Fig. 5. Multiannual monthly PM₁₀ concentration evaluation: left- B-4, right B-7

The green and blue boxes represent the 25 and 75 percentiles, respectively. Climatological parameters have a demonstrable effect on seasonal variation of

PM₁₀ concentrations. The lowest PM₁₀ value was measured in June. The lowest PM₁₀ value was measured in June: 24.86 µg/m³ at B-4 and 24.02 µg/m³ at B-7, when the lifting condensation level is four-time higher than in winter.

Annual evolution shows that in the first three years of the entire studied period, there is a constant decreasing tendency with an average annual decrement of 4-5%. This decreasing trend can be explained by the introduction of stricter EU environmental regulations and standards, on the other hand, by the implementation of the new Environment Protection Policy and due at B-4 station by a drastic reduction of production of the Bucharest South Power station.

Fig. 6. Annual and seasonal variation of mean PM₁₀ concentrations

The minimum values in the studied period were registered in 2014, however beginning from 2015, a modest increasing tendency was observed, except 2017, in the case of B-7 monitoring station still exceeding the maximum permissible limit. In winter, the PM₁₀ concentration was higher by almost 38% compared to the summer period. Autumn and spring the averages were analyzed as well, and a similar tendency was obtained, namely higher by 17.43% and 7.43%, respectively (Fig.6).

3.4 Pollution rose

The pollution model is based on the principle that concentration measurements at a given location for a given period should be classified as wind blowing at the moment of action. Pollution roses were generated by R package open-source software, using the available data, the PM₁₀ concentrations as well as the meteorological parameters such as wind speed and wind direction (Fig.7).

Based on the pollution rose for B-4, the main directions of pollution are from the southwest but based on the annual mean wind frequency, the dominant direction is from the northeast, and the second frequency is from the southwest.

According to the pollution rose in the suburban region (B-7), the main directions of pollution are from the west, but the main direction of wind is coming from Bucharest, from the northeast. These differences could be explained by the low frequency of the wind from this direction in both the studied monitoring station.

Fig. 7. Pollution roses, left B-4, right B-7

3.5. Pearson correlation

The Pearson correlation tables between daily means of PM₁₀ and meteorological parameters over the entire period 2008-2018 have been studied separately for the cold-(November–April) and warm (May–October) seasons (Fig. 8-9), respectively. The correlation coefficient was considered significant negative or positive if the r value was higher than 0.203 or less than -0.203.

In the cold period, PM₁₀ concentration shows a weak negative correlation with the Lifting condensation level and also a negative correlation with the temperature -0.3 and -0.28, in the B-4 and B-7 monitoring stations, respectively. The meteorological parameters correlate each other strong positive correlation was found between the LCL and temperature with B-7 ($r=0.66$) and also, a moderate positive correlation in B-4 ($r=0.38$). A negative correlation was detected between the relative humidity and temperature $r=-0.27$ and -0.63, respectively. The lowest correlation in the case of B-4 could be explained by the higher build-in area.

Fig. 8. Pearson correlations between daily PM₁₀ and LCL during the cold season (November–April), (left B-4, right B-7).

Fig. 9. Pearson correlations between daily PM₁₀ and LCL during the warm season (May–October), (left B-4, right B-7)

In warm period was not detected a significant correlation between the meteorological parameters and the PM₁₀ but was also detect significant correlations between the meteorological parameters. A moderate negative correlation was found between relative humidity and temperature ($r = -0.24$, -0.51). The differences between the monitoring station are in concordance with

the green zone area distribution. The correlation between LCL and temperature was calculated, and a moderate positive correlation ($r = 0.33$, $r = 0.56$) was obtained.

Overall can conclude that in the cold period, the correlation between PM_{10} and climatological variants was more significant compared to the warm period.

Conclusions

Taken into account the time series analyses during the studied period, the calculated annual mean PM_{10} levels in the studied areas decreased. The lowest annual concentration was measured in 2014; however, a small increase was detected in PM_{10} levels since 2015.

In winter, the concentration of PM_{10} is higher by one third than the summer value, which can be explained by the unfavorable meteorological conditions (lower lifting condensation level). On the other hand, the increased emission in the heating period. The daily variation analysis clearly shows that the maximum PM_{10} concentrations are on Wednesdays at (B-4) and on Tuesdays in case of (B-7) monitoring station. During the study winter period, the PM_{10} daily concentrations exceed the acceptable limit by 17.7%, followed by the autumn days with 13.25%. In the cold period, a significantly higher negative correlation was observed, compared to the warm period, between the lifting condensation level and relative humidity, and positive correlation with temperature, respectively.

Although the PM_{10} concentration at the studied two points has decreased until 2014, after which they started to increase slightly, the annual maximum admissible concentration is still above the allowable limit. Also, the daily limit values exceeded the maximum permissible levels almost continuously in the two studied monitoring station. At other monitoring stations placed in Bucharest, the data coverage was not sufficiently available for a representative statistical evaluation, so the data from the two measuring stations located in the green zones were used.

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