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Case Study

Examining air pollution dynamics in Ploiesti: a focus on vehicular emissions

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Abstract

This paper presented the topic of urban air pollution in Ploiesti Municipality, located 60 km north of Bucharest. The study analyzes the seasonal variations in 2023 of air pollutants such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter (PM_{10}), the impact of road traffic on air quality, as well as the monitoring measures according to the in force environmental legislation. For the air quality assessment two types of data were collected: data from the National Air Quality Monitoring Station (AQMS) of Ploiesti for the winter ÷ summer period and data obtained from field measurements carried out in November. The location of the sampling points took into account several factors such as: pollution source (road traffic, industry), measured meteorological parameters (temperature, humidity, atmospheric pressure, wind speed and direction). The experimental data were analyzed using Principal Component Analysis (PCA), and were also compared with AQMS values. The comparisons between measured and AQMS data showed significantly higher concentrations for the samples (P1, P2, P3), which could indicate the presence of local sources of SO_2 emissions or conditions favoring the accumulation of this pollutant. The PCA indicate that the higher concentrations of pollutants seemed to be associated with cooler temperatures and reduced solar radiation, suggesting a significant impact of meteorological conditions on the distribution of pollutants.

Keywords: *air pollution, air quality monitoring station, meteorology*

INTRODUCTION

In the last decades, air pollution increased at an accelerated rate. For this reason, researchers must focus on the actions required to sustain air quality.

The European Union has identified seven main air pollutants: ammonia (NH_3), nitrogen oxides (NO_x), carbon monoxide (CO), and, suspended particles with an aerodynamic diameter of less than 2.5 µm and 10 µm ($PM_{2.5}$ and PM_{10}), sulphur oxides (SO_x), etc., tropospheric ozone (O_3) and non-methane volatile organic compounds (NMVOCs) [1].

Rapid urbanization has exacerbated this issue by increasing air pollution and indicating clear signs of climate change. This worrying trend is the result of increasing economic activity, which has been driven by the need for urbanization and the desire to improve living conditions [2]. Urban air pollution became more severe due to city expansion, the advancement of industrial technologies, and the expansion of the transportation sector [3, 4]. Depending on the chemical compound emitted into the atmosphere and various sectors, there are several sources of pollution such as: industrial processes (NH_3, CO, CH_4, VOC, NO), stationary sources (CO_2, PM, NO_2) including heating, cooking, and, personal care, cleaning products; and mobile sources (CO, N_2O, SO_2, PM) such as cars, trucks, buses, road sea and air transport; natural sources such as forest fires, volcanic activity, agricultural activities.

All of these lead to human health problems and climatic change. Literature studies demonstrated a link between air pollution and human health problems such as risk of respiratory infections respiratory and cardiovascular disease [5÷8].

Based on contributions from primary sources (generated by road traffic, industry, construction) and secondary sources (refers to particulate matter formed in the atmosphere by photochemical reactions), the emission profile and chemical composition of $PM_{2.5}$ and PM_{10} can differ from city to city around the world [9]. Meteorological conditions, chemical changes that occur when air pollutants are released into the atmosphere, interaction with solar radiation, and atmospheric dispersion (including wind direction, speed, speed, and, and direction) all have an impact on air pollutant emissions [10].

Urban emissions can be influenced by a variety of factors, including fuel type, vehicle type, road traffic and pollution control methods. It is important to remember that a variety of traffic circumstances, including average speed, traffic jams, weather and more, can affect emissions [11].

Europe's air pollution control strategies have improved during the past three decades. Emission control of the automotive, industrial and residential sectors have led to a sustained decrease in emissions of air pollutants, including CO and NO_x, in several regional locations

The WHO global air quality guidelines and European norms are the two primary reference points. The EU Ambient Air Quality Directive establishes health-related air quality standards. A number of air pollutants, including particulate matter, PM_{10}, $PM_{2,5}$, NO_2, O_3, and benzo(a)pyrene, are regulated under the EU Directive and are used by the EEA to compile national air quality reports for each nation [12]. On October 26, 2022, the Ambient Air Quality Directive was revised as a section of the Green Deal for Europe [5].

The World Health Organization's suggestion was more closely matched with the European Commission's air quality criteria. The most recent WHO Air Quality Guidelines, which were revised on September 22, 2021, suggest a greater than half reduction in particle matter ($PM_{2,5}$). Since many of the chemicals that cause air pollution also contribute significantly to greenhouse gas emissions (GHG) [13], there is a strong link between air pollution and climate change. Because they promote higher rates of photochemical synthesis, warmer and drier weather can contribute to elevated air pollution levels. Future heat waves might cause wildfires to occur more frequently and with greater intensity, which would increase the amount of particulate matter (PM) and dangerous greenhouse gas emissions [14].

GHG emissions are crucial for researching ways to mitigate climate change, given our significant dependence on fossil fuels, they are also difficult to quantify [15]. GHGs include carbon dioxide (CO_2), nitrogen oxide (N_2O) and methane (CH_4). These GHGs are frequently released along with other gases such as CO, SO_2, and NO_x. Fuel combustion in industry, transport and households are important sources of air pollutant emissions, which also have an impact on health.

In Romania, the law regulating ambient air quality is Law 104/2011 and transposes the European Parliament and Council Directive 2008/50/EC [16, 17]. Legislation aimed to protect both environment and human health by assessing concentrations of pollutants such as SO_2, NO_2, and PM_{10}, $PM_{2,5}$, CO, tropospheric ozone and metals (Pb, Cd, Ni).

The aim of the study was to investigate the concentrations of air pollutants in relation to emissions from Ploiesti Municipality. The data for the study were collected from AQMS (January ÷ August). These data were examined and compare with data from samplings carried out in November in different regions of the city.

EXPERIMENTAL PART

Methodology applied

Ploiesti Municipality (North latitude: 44°56'24", East longitude: 26°1'48") is located about 60 km north of Bucharest, with a population of about 180,540 inhabitants. In the city was found several categories of industry such as: mineral oil and gas refining, waste treatment, beverage, and ferrous metals processing industry.

In this study, air pollution was analyzed in terms of NO_2, SO_2 and PM_{10} as well environmental factors, such as temperature (t), relative humidity (RH) and solar radiation flux (q). The data were

processed using PCA (Principal Component Analysis), a dimensionality reduction technique used to simplify large data sets by transforming the original variables into a smaller set of variables called principal components (PCs). These components capture the maximum amount of variation in the data, allowing for easier analysis while retaining most of the information. In this case, two factors (PC1 and PC2), for which the eigenvectors were greater than 1, were selected in the multivariate analysis.
The data under analysis were collected from the Romanian National Air Quality Monitoring Station for 2023 in winter (January, February), spring (March ÷ May) and summer (June ÷ August). For the autumn season (November), measurements were carried out in three distinct parts of the city.
The locations of the 4 AQMS (blue pin) and the three sampling points (green pin) are shown in fig. 1A. The map with the location of the points was made with the Google Earth Pro mapping program, at a scale of 20 km (fig. 1A), respectively a scale of 10 km for fig. 1B. The point 7 was located North-East of Ploiesti at a distance of approximately 26 km, the point 4 was located near the city at a distance of approximately 4 km South of the city ring road, whereas the points 2 and 6 were located in the city centre.
The sampling points were located at representative intersections of the city (Mihai Bravu Street, Republicii Boulevard, Gageni Street). The location of the measuring points took into account several factors such as the source of pollution (road traffic, industry), the measured meteorological parameters (temperature, humidity, atmospheric pressure, wind speed and direction). The measurement period of meteorological for Ploiesti from month November was: temperature of 12^{o} C, wind with a speed between 1.5÷1.7 m/s, N-NV direction, relative humidity 64÷68%, atmospheric pressure of 966÷970 mbar.

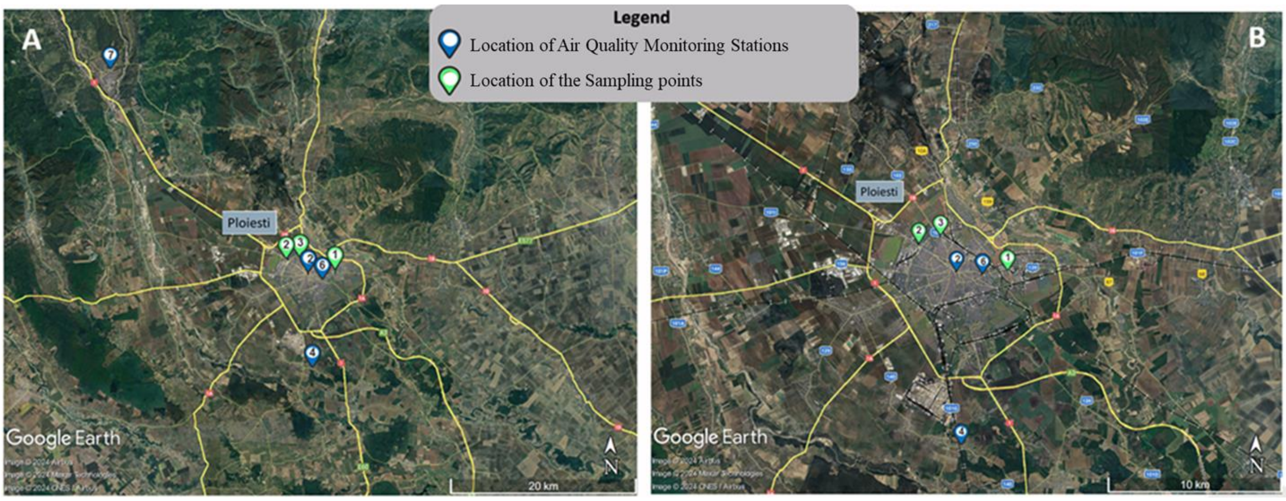

Fig. 1. Locations of the Air Quality Monitoring Stations (AQMS) in Ploiesti; monitoring stations (2, 4, 6, 7) are indicated with blue colour, and the sampling points (1÷3) are indicated in green colour.

Monitored parameters and equipment used for the sampling points
For PM_{10} sampling was used a Sven Leckel pump for particle matter collection. This device is a specialized dust collection system to extract a measurable amount of dust from a filter, including fraction separation, such as: PM10, PM2,5, total suspended particles (TSP). EN 12341:2013 [18, 19] was the standard procedure for gravimetric measurement.
The determination SO_2 in the surrounding air was carried out with HORIBA APSA-370 automatic analyzer, according to standards EN 14212:2012 and EN 14212:2012/AC:2014 [20].
For NO_2 concentration, a HORIBA APNA-370 equipment was used, in accordance with the standard method EN 14211:2012 [21].

RESULTS AND DISCUSSION

Data recorded from AQMS in 2023 winter season
Mean values of NO_2, SO_2, PM_{10}, temperature (t), humidity (RH) and solar radiation flux (q), which were recorded at the stations 2, 4, 6 and 7 (table 1 and table 2) were processed using PCA. The results

of the multivariate analysis are presented in fig. 2, table 3 and table 4. Data presented in table 1 highlight higher mean values of NO_2 (23.97 μg/m^3) and SO_2 (8.65 μg/m^3) at station 2 compared to those recorded at stations 4 and 6 as well as a higher mean value of PM_{10} (26.91 μg/m^3) at station 2 compared to that found at station 7 (22.95 μg/m^3). For the meteorological parameters, data presented in table 2 highlight a higher mean value of t (4.54°C) and lower mean values of RH (71.11%) and q (53.98 W/m^2) at station 2 compared to those recorded at the other stations. The factors loadings and scores are presented in fig. 2. The loadings represent the contributions of each initial variable to the principal components (PCs). Data presented in fig. 2 (PCA bi-plot), table 3 (factor loading matrix) and table 4 (correlation matrix) reveal the following relevant aspects: (i) a discrimination on the PC1 axis (highlighted with blue ellipses in fig. 2) between station 2 and stations 4 and 7, characterized by higher mean values of NO_2, PM_{10} and t as well as lower mean values of RH and q; (ii) a discrimination on the PC2 axis between station 2 and station 6, characterized by a higher mean value of SO_2; (iii) a very strong direct correlation between PM_{10} and t ($r = 0.962$).

Table 1. Mean values of air pollutant concentrations recorded at AQMS in winter season (μg/m^3)

AQMS	NO_2	SO_2	PM_{10}
2	23.97	8.65	26.91
4	22.41	5.74	-
6	23.08	3.61	27.10
7	-	-	22.95

Table 2. Mean values of meteorological parameters recorded at AQMS in winter season

AQMS	t, °C	RH,%	q, W/m^2
2	4.54	71.11	53.98
4	3.57	86.21	59.31
6	4.47	85.84	57.00
7	2.92	84.02	62.38

Table 3. Factor loading matrix for winter season

Variable	NO_2	SO_2	PM_{10}	t	RH	q
PC1	**-0.80**	-0.59	**-0.74**	**-0.85**	**0.88**	**0.96**
PC2	0.42	**0.74**	-0.66	-0.52	-0.48	0.27

Note: Significant values are highlighted in bold

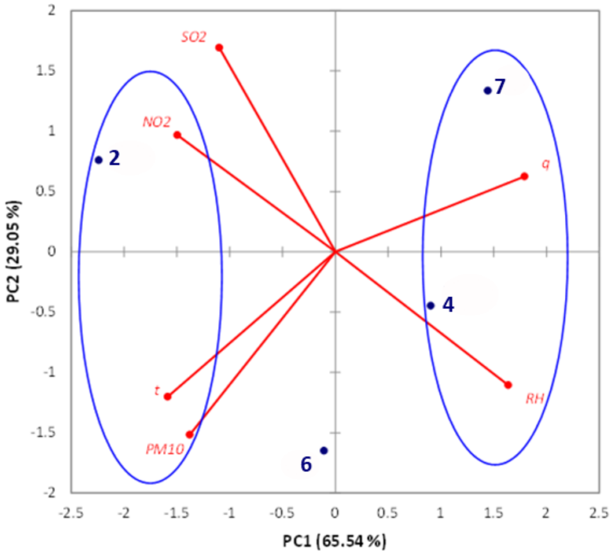

Fig. 2. Factor loadings and scores for winter season

Table 4. Values of Pearson correlation coefficient (r) for winter season

Variable	NO_2	SO_2	PM_{10}	t	RH	q
NO_2	**1**	0.6396	0.2509	0.4889	-0.8931	-0.6136
SO_2	0.6396	**1**	-0.0107	0.0874	-0.8785	-0.3903
PM_{10}	0.2509	-0.0107	**1**	**0.9620**	-0.3295	-0.8984
t	0.4889	0.0874	**0.9620**	**1**	-0.4890	-0.9496
RH	-0.8931	-0.8785	-0.3295	-0.4890	**1**	0.7099
q	-0.6136	-0.3903	-0.8984	-0.9496	0.7099	**1**

Note: Values highlighted in bold are different from 0 at a significance level 0.05 ($\alpha > 0.05$)

Data recorded from AQMS in 2023 spring season

Mean values of NO_2, SO_2, PM_{10}, temperature (t), humidity (RH) and solar radiation flux (q), which were recorded at the stations 2, 4, 6 and 7 (table 5 and table 6) were processed using PCA.

The results of the multivariate analysis, which are presented in fig. 3, table 7 and table 8, indicate the following relevant aspects: (i) a discrimination on the PC1 axis (highlighted with blue ellipses in fig. 3) between station 2 and station 6, characterized by a higher mean value of NO_2 (29.05 μg/m^3), respectively lower mean values of t (9.1°C), RH (59.89%) and q (117.1 W/m^2); (ii) a discrimination on the PC2 axis between station 6 and stations 4 and 7, characterized by higher mean values of SO_2 (7.38 μg/m^3) and PM_{10} (22.17 μg/m^3); (iii) a very strong indirect correlation between NO_2 and q (r = -0.968).

Table 5. Mean values of air pollutant concentrations recorded at AQMS in spring season (μg/m^3)

AQMS	NO_2	SO_2	PM_{10}
2	29.05	6.08	23.68
4	24.62	5.72	-
6	21.94	7.38	22.17
7	-	-	18.48

Table 6. Mean values of meteorological parameters recorded at AQMS in spring season

AQMS	t, °C	RH,%	q, W/m^2
2	9.09	59.89	117.1
4	11.94	72.87	133.2
6	12.47	70.44	144.2
7	10.16	73.46	137.2

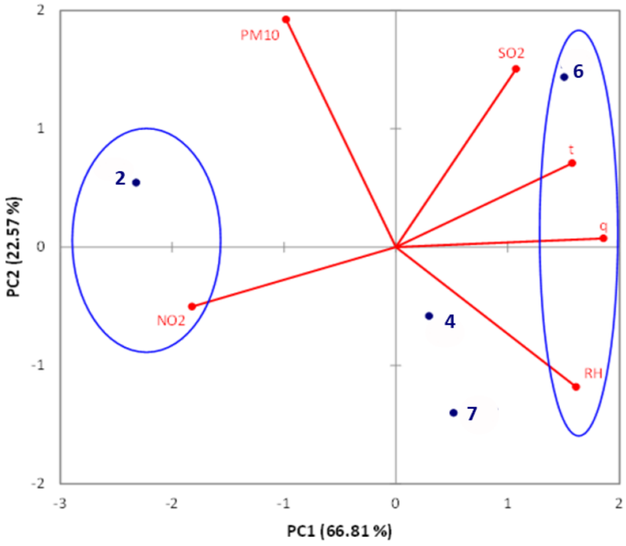

Fig. 3. Factor loadings and scores for spring season

Table 7. Factor loading matrix for spring season

Variable	NO_2	SO_2	PM_{10}	t	RH	q
PC1	**-0.98**	0.58	-0.53	**0.85**	**0.86**	**0.99**
PC2	-0.21	**0.61**	**0.79**	0.29	-0.48	0.03

Note: Significant values are highlighted in bold

Table 8. Values of Pearson correlation coefficient (r) for spring season

Variable	NO_2	SO_2	PM_{10}	t	RH	q
NO_2	**1**	-0.6430	0.3244	-0.9207	-0.7556	**-0.9675**
SO_2	-0.6430	**1**	0.0035	0.4224	0.1235	0.6461
PM_{10}	0.3244	0.0035	**1**	-0.0696	-0.7859	-0.5321
t	-0.9207	0.4224	-0.0696	**1**	0.6550	0.8034
RH	-0.7556	0.1235	-0.7859	0.6550	**1**	0.8299
q	**-0.9675**	0.6461	-0.5321	0.8034	0.8299	**1**

Note: Values highlighted in bold are different from 0 at a significance level 0.05 ($\alpha > 0.05$)

Data recorded from AQMS in 2023 summer season

Mean values of pollutant concentrations (NO_2, SO_2 and PM_{10}) and meteorological parameters (t, RH and q) are summarized in table 9 and table 10. The results of PCA, which are presented in fig. 4 (PCA bi-plot), table 11 (factor loading matrix) and table 12 (correlation matrix), indicate the following relevant aspects: (i) a discrimination on the PC1 axis (highlighted with blue ellipses in fig. 4) between station 6 and stations 4 and 7, characterized by higher mean values of SO_2 (0.08 μg/m^3), PM_{10} (21.08 μg/m^3) and t (24.39°C), respectively lower mean values of NO_2 (18.79 μg/m^3) and RH (66.91%); (ii) a discrimination on the PC2 axis between station 7, characterized by a higher mean value of q (215.5 W/m^2), and station 4, characterized by a lower mean value of q (158.5 W/m^2); (iii) very strong indirect correlations between NO_2 and SO_2 (r = -1.000), respectively between t and RH (r = -0.999).

Table 9. Mean values of air pollutant concentrations recorded at AQMS in summer season (μg/m^3)

AQMS	NO_2	SO_2	PM_{10}
4	34.45	0.04	-
6	18.79	0.08	21.08
7	-	-	15.76

Table 10. Mean values of meteorological parameters recorded at AQMS in summer season

AQMS	t, °C	RH,%	q, W/m^2
4	23.50	69.75	158.5
6	24.39	66.91	211.1
7	21.63	74.64	215.5

Table 11. Factor loading matrix for summer season

Variable	NO_2	SO_2	PM_{10}	t	RH	q
PC1	**-0.80**	**0.80**	**0.92**	**0.83**	**-0.85**	0.32
PC2	-0.60	0.60	-0.39	-0.56	0.52	**0.95**

Note: Significant values are highlighted in bold

Table 12. Values of Pearson correlation coefficient (r) for summer period

Variable	NO_2	SO_2	PM_{10}	t	RH	q
NO_2	**1**	**-1.0000**	-0.5000	-0.3159	0.3632	-0.8296
SO_2	**-1.0000**	**1**	0.5000	0.3159	-0.3632	0.8296
PM_{10}	-0.5000	0.5000	**1**	0.9796	-0.9885	-0.0688
t	-0.3159	0.3159	0.9796	**1**	**-0.9987**	-0.2678
RH	0.3632	-0.3632	-0.9885	**-0.9987**	**1**	0.2190
q	-0.8296	0.8296	-0.0688	-0.2678	0.2190	**1**

Note: Values highlighted in bold are different from 0 at a significance level 0.05 ($\alpha > 0.05$)

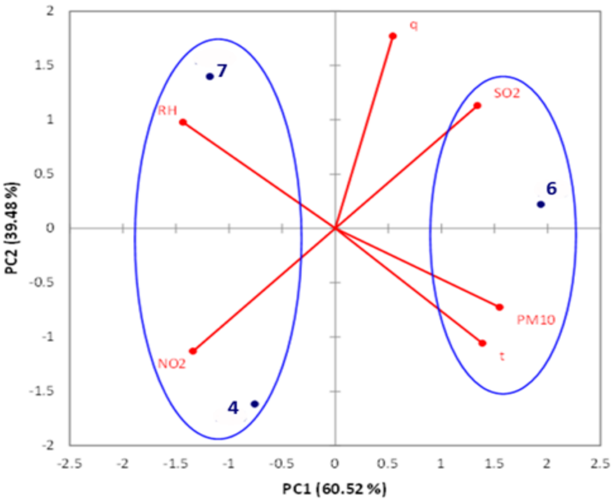

Fig. 4. Factor loadings and scores for summer season

Quantitative data evolution of pollutants AQMS and measured concentrations in November

The results obtained from collected and analyzed samples (represented with x in figures 5÷7) for PM_{10}, SO_2, NO_2 were compared with data from AQMS 6 (station 6), the only one station were was recorded values in autumn season.

Black points represent minimum and maximum values recorded by AQMS in the investigated period. Bars represent the lower quartile (delimit by the lowest 25% of the observed values), the average value, delimiting 50% between the values, the upper quartile delimits by the highest percentage of 25% of the observed values, and the squares represent the average interval of the values.

PM_{10} exhibited high variability in September with values ranging from 5.27 to 79.77 µg/m^3. PM_{10} concentration values measured in November (P1: 30 µg/m^3, P2: 44 µg/m^3, P3: 35 µg/m^3) did not exceed the allowed limit values imposed by the Romanian legislation, which is 50 µg/m^3 per 24 hours (fig. 5) [15].

Regarding SO_2 concentration, the values reported (P1: 81.10 µg/m^3, P2: 81.90 µg/m^3, P3: 173.50 µg/m^3) were situated outside of the interquartile range, but the data were situated below the maximum admissible value (350 µg/m^3 per hour), which may suggest the presence of local sources of SO_2 emissions or conditions that promote the accumulation of this pollutant (fig. 6).

Mean values of NO_2 increased progressively, in November was registered highest peak (73.57 µg/m^3), probably as a consequence of the industry and auto traffic. The sampling points were situated in the interquartile range (P1: 28.20 µg/m^3, P2: 48.80 µg/m^3, P3: 39.60 µg/m^3), without exceeding allowed limit values according to Law no.104/2011 [15], which is 200 µg/m^3 per hour (fig. 7).

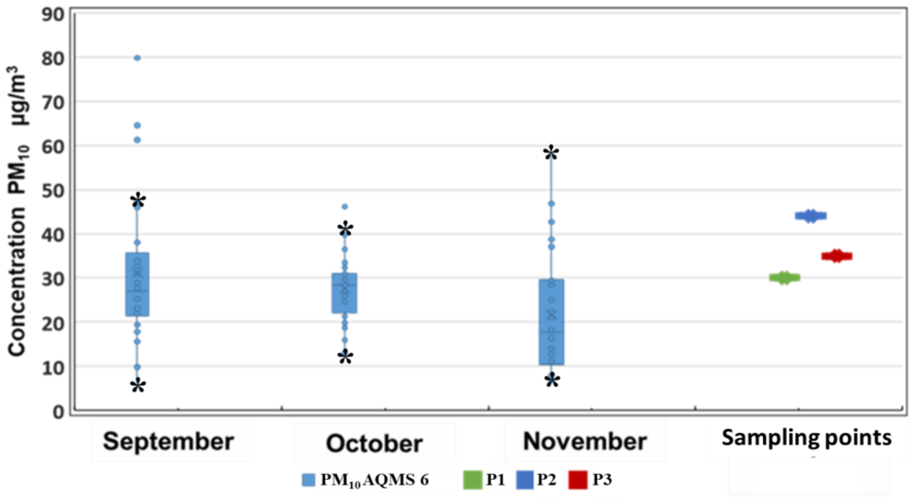

Fig. 5. Quantitative data evolution of PM_{10} concentration from AQMS compare with measured concentrations in November: green (P1), blue (P2), red (P3)

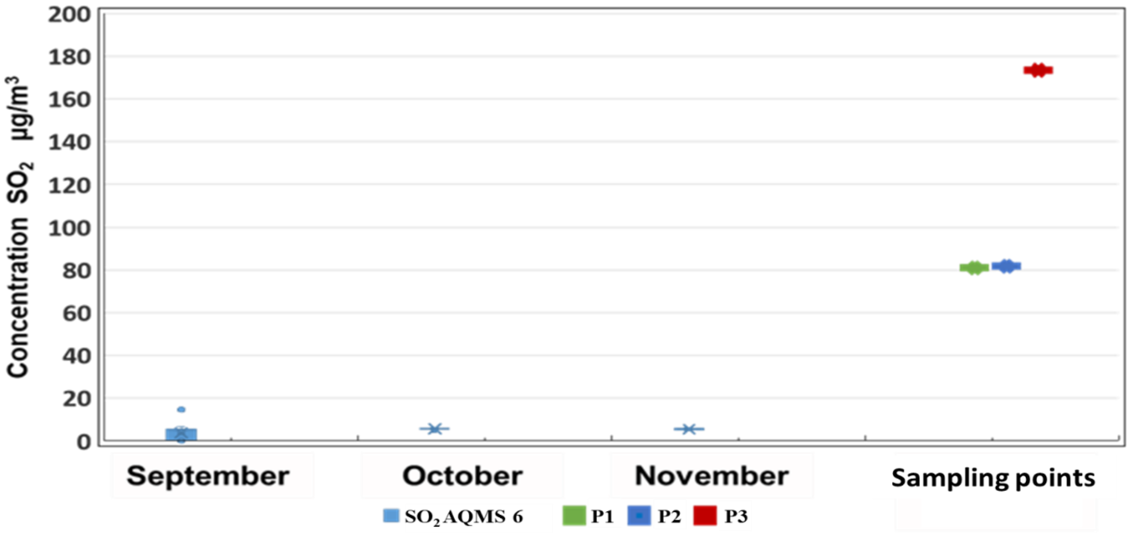

Fig. 6. Quantitative data evolution of SO_2 concentration from AQMS compare measured concentrations in November: green (P1), blue (P2), red (P3)

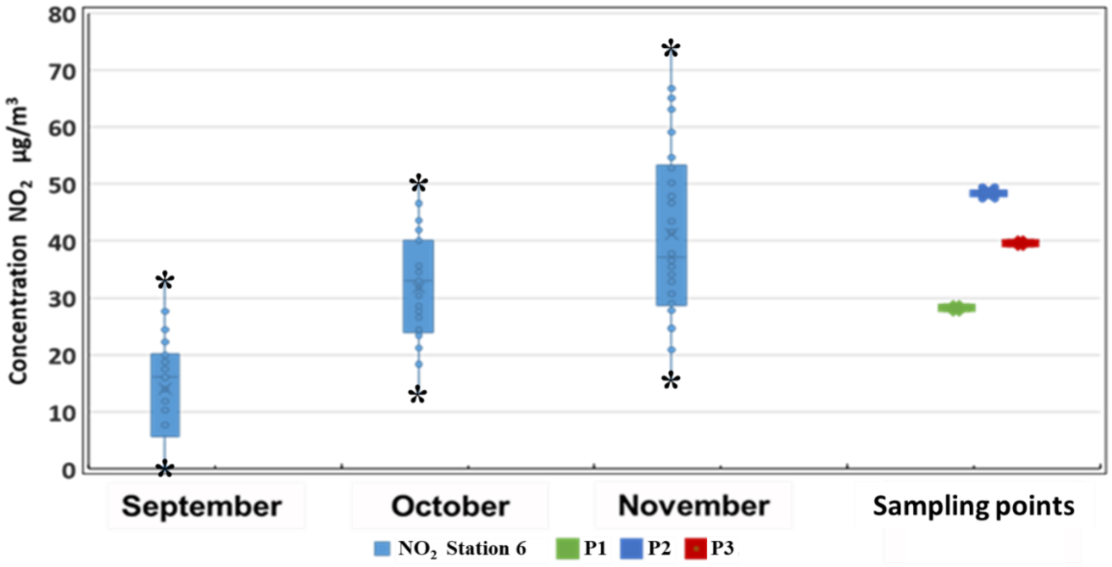

Fig. 7. Quantitative data evolution of NO_2 concentration from AQMS compare measured concentrations in November: green (P1), blue (P2), red (P3)

CONCLUSIONS

In the study were compared the concentrations of PM_{10}, SO_2, NO_2 from Ploiesti emissions, using data provided by the national air quality monitoring station for the period January to August and November, with data obtained after monitoring in November three distinct points situated in the Municipality.

Multivariate PCA analysis revealed a proportional relationship between PM_{10} and temperature. In addition, inverse proportionality relationships between q and NO_2; NO_2 and SO_2; t and RH was observed.

The values obtained for PM_{10}, SO_2, NO_2 in P1, P2, P3 showed no exceedance of the limit values. P2 sample had higher values compared to P1, P3 and may be possible causes of fossil fuel use. P3 showed a significant increase in SO_2 concentration compared to the other monitoring points, which could be the cause of gaseous accumulations due to diesel vehicles that are not operating under optimal conditions.

Sources of pollution are diverse, ranging from industrial processes, road traffic and natural sources. Europe has made progress in controlling air pollution through guidelines and directives, but continued efforts are needed to align with the latest WHO recommendations and to address the interlinked challenges of air pollution and climate change. Romania's accession to EU directives underlines the importance of legislative measures in protecting both the environment and public health. It is essential to reduce emissions and improve air quality to protect human health and the planet.

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