THE INFLUENCE OF METEOROLOGICAL PARAMETERS ON PM10 CONCENTRATION IN ORADEA – A CASE STUDY FOR 2023

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RESEARCH ARTICLE

Abstract
This study investigates air quality in Oradea, Romania, during 2023, focusing on PM10 (particulate matter with an aerodynamic diameter <10 μm) and the influence of meteorological factors. Data were collected from three representative automatic monitoring stations operated by the Bihor Environmental Protection Agency and complemented with meteorological data from the Oradea Weather Station. Monthly average concentrations of PM10 were analyzed using descriptive statistics, Pearson correlation, and multiple linear regression to evaluate the relationship between PM10 and temperature, precipitation, relative humidity, and wind speed.
Results indicate a seasonal variation, with higher PM10 concentrations in winter months due to residential heating and meteorological conditions limiting dispersion, and lower levels in summer. The Pearson correlation revealed a strong negative relationship between PM10 and precipitation (r = −0.70), while correlations with other meteorological parameters were weak. The multiple linear regression model explained approximately 69% of the monthly variation in PM10, highlighting the dominant effect of wind and precipitation on pollutant dispersion. Only precipitation was statistically significant (p < 0.05).
The findings emphasize the importance of continuous air quality monitoring and suggest that meteorological conditions, particularly precipitation and wind, play a key role in controlling PM10 levels. These results can inform local strategies to mitigate air pollution, improve urban air quality, and protect public health.

Keywords: Oradea, air quality, PM10, meteorological factors, seasonal variation, multiple linear regression
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INTRODUCTION

The municipality of Oradea, the capital of Bihor County, is part of the North-West development region of Romania. The city is located in the western part of the country, near the border with Hungary, at the geographic coordinates 46°46′N and 21°55′E, and is crossed by the Crişul Repede River, which influences local atmospheric circulation and, consequently, pollutant dispersion.

The territory of the municipality covers approximately 115 km² and has a population of over 190,000 inhabitants, making it an important economic, educational, and administrative center. Urban activities, road traffic, and industrial sources can contribute to increased concentrations of atmospheric pollutants, among which PM10 particles represent a significant indicator of urban air quality.

Air quality monitoring in Oradea is particularly relevant, as PM10 measurements allow the assessment of population exposure and the identification of meteorological factors influencing the dispersion and accumulation of pollutants. In this context, the present study focuses on the analysis of PM10 concentrations in 2023 and their relationship with local meteorological conditions, providing a quantitative perspective on urban air quality.

MATERIAL AND METHOD

The study on air quality in the municipality of Oradea was based on data provided by the Bihor Environmental Protection Agency (APM Bihor), collected

through automatic stations from the National Air Quality Monitoring Network (RNMCA).

Three representative stations were operational in the municipality, covering different types of urban areas:

- BH1 – urban background station, located on Bulevardul Dacia;
- BH2 – industrial station, located in the Episcopia Bihor area;
- BH3 – traffic station, located in the Nufărul district, an area with heavy traffic.

The analyzed pollutant was PM10 (particulate matter with an aerodynamic diameter <10 μm), a relevant indicator of urban air quality. Monthly average PM10 concentrations were calculated as the arithmetic mean of daily values recorded by the monitoring stations, in order to highlight seasonal variations. The placement of the stations complies with European legislation on air quality assessment, ensuring the characterization of urban background levels, traffic influence, and industrial activity.

Meteorological data were provided by the Oradea Weather Station (National Meteorological Administration, ANM) and included:

- monthly mean temperature,
- total monthly precipitation,
- mean relative humidity,
- mean wind speed.

The correlation between these meteorological parameters and PM10 concentrations was evaluated for the year 2023 to determine the role of atmospheric conditions in pollutant dispersion and accumulation.

RESULTS AND DISCUSSIONS

Air pollution in the municipality of Oradea is caused by multiple local sources, among which road traffic is the most significant, especially in high-traffic areas (Bd. Decebal, Republicii, Magheru, Dacia, Calea Clujului, Calea Aradului, DN1 – Borş, and the Nufărul district), where PM10 concentration peaks are frequently recorded during rush hours. Residential heating, through the combustion of solid fuels (wood, coal, and plant residues), also contributes significantly, affecting particularly the Ioşia Veche, Episcopia, and Oncea areas.

Construction activities and urban works further promote dust resuspension, especially during dry periods, in the absence of effective control measures. Industrial and logistics zones in the western and northern parts of the city (Calea Borşului, Ioşia Nord) are additional important sources of suspended particles, mainly due to production activities, material handling, and freight transport. During the cold season, the effects of these sources are amplified by thermal inversions, which favor the accumulation of pollutants in the lower atmosphere.

Quantitative analysis of data for 2023 highlights the relationship between PM10 concentrations and meteorological factors, using statistical methods such as descriptive analysis, Pearson correlation, and multiple linear regression.

Monthly evolution of PM10 concentrations

The monthly evolution of PM10 concentrations in 2023 indicates a pronounced seasonal variability. Monthly average values were higher during the cold season and early spring, with peaks recorded in February (25.52 μg/m^3), December (23.63 μg/m^3), and January (21.14 μg/m^3). These levels are associated with low temperatures, the frequency of thermal inversions, and increased residential heating activities.

During the summer, PM10 concentrations reached their lowest values, particularly in June and July (16.39 μg/m^3 and 15.49 μg/m^3, respectively), due to more efficient atmospheric dispersion caused by higher temperatures, active air circulation, and a higher mixing layer.

The annual average PM10 concentration in Oradea in 2023 was 19.97 μg/m^3, below the annual limit of 40 μg/m^3 established by Law no. 104/2011. Furthermore, no exceedances of daily limit values were recorded throughout the year. These results indicate an overall acceptable air quality level, although higher values during the cold season underscore the necessity of continuous monitoring and the implementation of emission reduction measures, particularly under meteorological conditions that hinder pollutant dispersion.
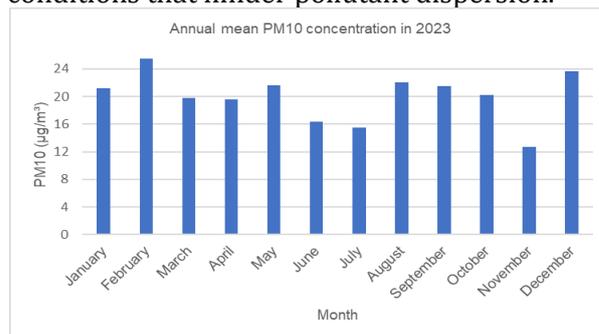

Figure 1. **Evolution of the monthly average PM10 concentration in the municipality of Oradea in 2023**

Influence of Precipitation on PM10 Concentrations

To evaluate the influence of meteorological factors on PM10 concentrations, the relationship between monthly precipitation and the monthly mean PM10 concentration in Oradea during 2023 was analyzed using the Pearson correlation coefficient.

The results indicate a strong negative correlation between the two variables (r ≈ −0.70), highlighting a decrease in PM10 concentrations with increasing precipitation. Graphical analysis and the regression line confirm this downward trend, suggesting a significant role of precipitation in the variation of suspended particle levels.

This relationship can be explained by the wet deposition process, in which particles are captured by raindrops and removed from the atmosphere. During periods of abundant precipitation, urban air is cleaned more efficiently, leading to a noticeable improvement in air quality.

These findings are consistent with the scientific literature and confirm that precipitation is an important natural factor in reducing PM10 pollution. Thus, the analysis for Oradea in 2023 demonstrates the significant impact of precipitation on urban air quality.
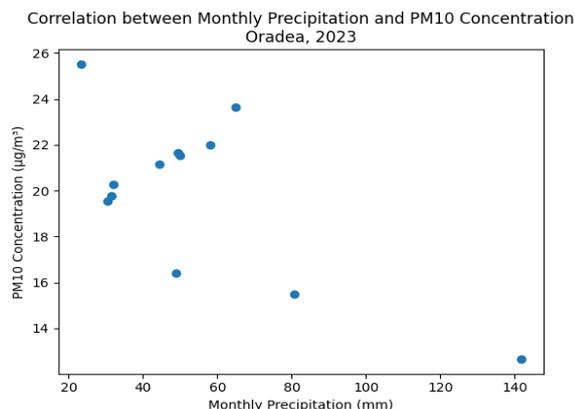

Figure 2. **Correlation between monthly precipitation and PM10 concentration in Oradea, 2023**

Correlation between PM10 and Monthly Mean Temperature

To evaluate the relationship between monthly mean temperature and PM10 concentrations in Oradea during 2023, the Pearson correlation coefficient was used. The analysis was based on the monthly average values of temperature and PM10 concentrations.

The results indicate a weak negative correlation between the two variables, with a Pearson coefficient of r ≈ −0.27. This relationship suggests a tendency for PM10 concentrations to decrease in months with higher temperatures; however, the influence of temperature on suspended particle levels is relatively limited.

Graphical representation of the data shows a slight downward trend in PM10 concentrations with increasing temperature, supported by the regression line. This behavior can be explained by enhanced convective air movements during the warm season, which favor pollutant dispersion, as well as by the reduced contribution of emissions from residential heating.

Nevertheless, the weak correlation obtained indicates that temperature is not a sole determining factor in the variation of PM10 concentrations, and other meteorological and anthropogenic factors must also be considered. These results are consistent with trends observed in the scientific literature regarding the influence of temperature on urban air pollution.
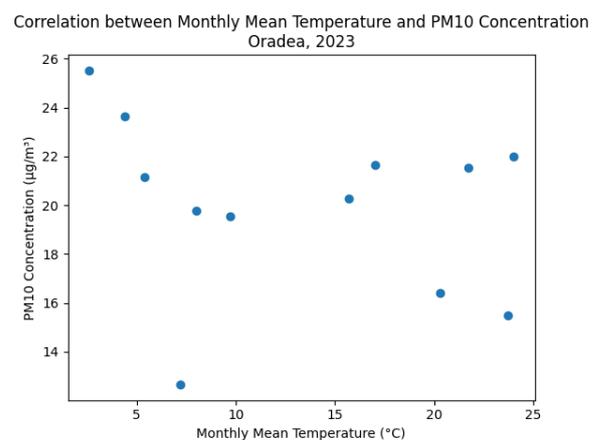

Figure 3. **Correlation between monthly mean temperature and PM10 concentration in Oradea, 2023**

Correlation between PM10 and Relative Humidity

The relationship between monthly mean relative humidity and PM10 concentrations in Oradea during 2023 was analyzed using the Pearson correlation coefficient, based on monthly average values.

The results indicate a weak positive correlation between the two variables, with a Pearson coefficient of r ≈ 0.24. This relationship suggests that during months with higher humidity, PM10 concentrations may show a

slight increasing trend; however, the influence of this meteorological parameter is limited.

Graphical representation of the data shows a subtle upward trend in PM10 concentrations with increasing relative humidity, supported by the regression line. This behavior can be explained by the atmospheric stability associated with high-humidity conditions, which may reduce pollutant dispersion and favor the accumulation of particles in the lower atmospheric layer.

Nevertheless, the low correlation value indicates that relative humidity plays a secondary role in the variation of PM10 concentrations, compared to other meteorological factors such as precipitation or air circulation. Therefore, relative humidity should be considered a factor with limited impact on suspended particle pollution levels in the studied urban environment.
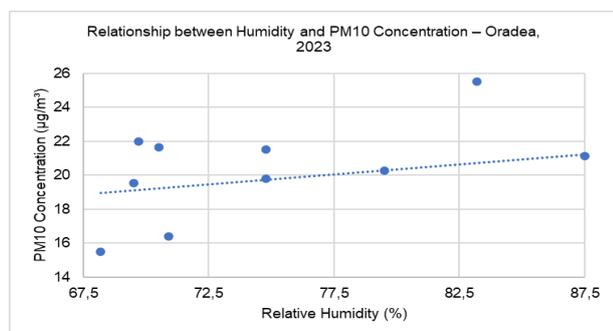

Figure 4. **Correlation between monthly mean relative humidity and PM10 concentration in Oradea, 2023**

Correlation between PM10 and Wind Speed

The influence of monthly mean wind speed on PM10 concentrations in Oradea during 2023 was analyzed using the Pearson correlation coefficient, based on monthly average values.

The results indicate a very weak positive correlation between the two variables, with a Pearson coefficient of $r \approx 0.15$. This relationship suggests that variations in wind speed had a limited influence on PM10 levels during the analyzed period.

Graphical representation of the data shows a very slight upward trend, confirmed by the regression line. Although wind is recognized as an important factor in atmospheric pollutant dispersion, its effect in Oradea was limited, most likely due to relatively low wind speeds, which remained below 4 m/s throughout the year.

The weak correlation indicates that wind speed was not a determining factor in the variation of PM10 concentrations in 2023, and a cumulative analysis of multiple meteorological parameters and anthropogenic sources is necessary for a complete interpretation of the phenomenon.
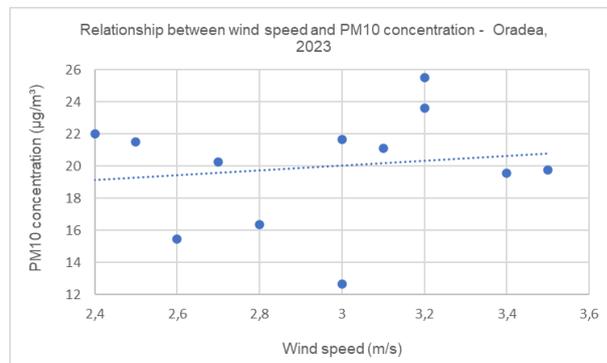

Figure 5. **Correlation between the monthly average wind speed and PM10 concentration in Oradea, 2023**

Multiple Linear Regression Model Applied to PM10

To evaluate the simultaneous influence of meteorological factors on the monthly PM10 concentrations in Oradea, a multiple linear regression model was applied. The dependent variable was PM10 concentration, while the independent variables were monthly mean temperature (T), monthly precipitation (P), mean relative humidity (U), and mean wind speed (V). The mathematical model used is:

The model coefficients were calculated automatically in Microsoft Excel (Analysis ToolPak) using the least squares method, based on the monthly average values recorded in 2023. The final equation obtained is:

Interpretation of the coefficients:

- Intercept (a = 62.10): The theoretical PM10 value in the absence of meteorological variations.
- Temperature (b_1 = −0.47): An increase of 1°C reduces PM10 by 0.47 μg/m^3, due to more efficient pollutant dispersion through convective air movements.
- Precipitation (b_2 = −0.09): Each millimeter of rainfall reduces PM10 by 0.09 μg/m^3, reflecting the wet deposition process.
- Humidity (b_3 = −0.07): A 1% increase in relative humidity leads to a modest decrease in PM10 by 0.07 μg/m^3.
- Wind speed (b_4 = −8.72): The strongest effect; a 1 m/s increase reduces PM10 by 8.72 μg/m^3, due to pollutant dispersion over large distances.

All coefficients are negative, indicating an inverse relationship: an increase in meteorological factors leads to a reduction in PM10 concentrations, with wind having the most significant effect, followed by temperature, precipitation, and humidity.

Model performance evaluation:

The coefficient of determination shows that approximately 69% of the monthly variation in PM10 concentrations is explained by the included meteorological variables. The remaining 31% may be attributed to other factors, such as local pollution sources, traffic, and topography. Among the variables, only precipitation was statistically significant ($p < 0.05$), highlighting its clear impact on reducing PM10 levels.

The multiple linear regression model provides a quantitative perspective on how meteorological conditions influence PM10 concentrations in Oradea. Wind and temperature have the most significant dispersive effects, while precipitation and humidity contribute moderately but consistently. The model can be used for air quality monitoring and for planning measures to reduce atmospheric pollution, especially in the context of urbanization and climate change.

CONCLUSIONS

This study analyzed air quality in the municipality of Oradea in 2023, focusing on PM10 (particulate matter with an aerodynamic diameter <10 μm) concentrations and the influence of meteorological factors. Based on monthly data provided by the air quality monitoring network, statistical methods such as descriptive analysis, Pearson correlation, and multiple linear regression were applied.

The annual average PM10 level in Oradea did not exceed the limits established by national and European legislation, indicating a generally good air quality situation. However, higher values during the winter months confirm the seasonal influence, determined by meteorological conditions and heating activities. Pearson correlation analysis showed a negative relationship between PM10 and precipitation ($r = -0.70$), confirming their role in reducing suspended particle concentrations. Relationships with other meteorological factors were weak or moderate.

The multiple linear regression model indicated that approximately 68.9% of the monthly variation in PM10 was explained by the four meteorological factors included in the analysis ($R^2 = 0.689$). Among these, wind speed and precipitation had the most significant negative impact on PM10 concentrations, acting as natural mechanisms for pollutant dispersion and air cleaning. Only precipitation was statistically significant ($p < 0.05$), indicating a clear relationship between rainfall amount and PM10 reduction, while the other factors contributed complementarily but with lower significance.

Continuous air quality monitoring is important, especially during the cold months, when the risk of exceeding limit values is higher. The obtained results can serve as a scientific basis for developing local strategies to reduce pollution, such as limiting heavy traffic during critical periods or promoting alternative heating sources. Extending the study to include additional atmospheric pollutants or multiple years of analysis could provide a broader perspective on urban pollution trends.

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