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THE IMPACT OF CLIMATIC FACTORS ON PM2.5 AND PM10 LEVELS IN TÂRGU MUREȘ, TRANSYLVANIA

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Abstract

This study examines the relationship between climatic factors (temperature, humidity, and atmospheric pressure) and PM2.5 and PM10 concentrations in the urban area of Târgu Mureș, using data collected between August 2021 and November 2024 (1,091 effective days). Results indicate that higher humidity and atmospheric pressure increase PM2.5 and PM10 levels, while temperature has a significant negative effect. Correlations between PM2.5 and PM10 suggest a simultaneous rise during winter periods, highlighting the influence of weather conditions on urban air quality. This research contributes to understanding the determinants of air pollution and supports the implementation of measures to improve quality of life.

Key words: Air pollution; PM2.5; PM10; Urban air quality; Climatic factors; Seasonal trends

(1). Introduction

Air pollution remains one of the most pressing environmental and public health challenges in urban areas globally [1, 2]. Among the various pollutants, particulate matter, specifically PM2.5 and PM10, has garnered significant attention due to its harmful effects on human health, ecosystems, and overall quality of life [3,4,5]. The interaction between air quality and socio-economic development has become a focal point in urban research, where human activities intersect with meteorological conditions to shape pollution dynamics [4]. This study investigates these relationships in Târgu Mureș, a mid-sized city in Romania, over a three-year observation period.

Located in the central region of Transylvania, Târgu Mureş is characterized by marked seasonal fluctuations in air quality, driven by a combination of local meteorological conditions and urban activities.

During the colder months, particulate matter concentrations tend to rise due to increased residential heating and reduced atmospheric dispersion[5,6]. The city's topography, along with its seasonal climatic patterns, exacerbates pollution levels, aligning with broader European trends where urban air quality deteriorates during winter months due to similar factors [7,8].

This study contributes to the growing discourse on urban air quality, building upon existing research that emphasizes the interconnectedness of environmental sustainability, air quality, and socio-economic factors. Previous work by Bacoș & Gabor [9] explored the dynamics of circular tourism and sustainability, highlighting how environmental factors like air quality significantly impact tourism competitiveness and regional development. These findings reinforce the need for integrated urban planning approaches that address both pollution control and economic growth. By focusing on Târgu Mureș, this research adds a localized perspective to the broader understanding of how climatic factors influence air quality and, consequently, urban livability.

Further, researchers [10] delved into the environmental and economic interplay within tourism-dependent areas, underlining the importance of sustainable practices in mitigating pollution. This study aligns with those findings by providing actionable insights into the drivers of PM2.5 and PM10 pollution in urban environments. The consistent influence of temperature and humidity on particulate matter levels observed in Târgu Mureș echoes the broader implications discussed in these works, particularly the need for adaptive measures that integrate environmental, social, and economic goals [11,12,13].

Meteorological elements such as temperature, humidity, and atmospheric pressure play a significant role in determining the levels of particulate matter [14]. Low temperatures contribute to increased emissions from heating systems and reduce atmospheric mixing, which traps pollutants close to the surface [15]. Concurrently, high humidity facilitates the aggregation and retention of particles, compounding pollution levels, particularly during damp and cold conditions. Although the influence of atmospheric pressure is less direct, stable high-pressure systems can reduce pollutant dispersion, further contributing to the accumulation of particulate matter[16].

Addressing the causes of air pollution is essential for protecting public health and enhancing urban sustainability [11]. Clean air is increasingly seen as a fundamental component of livable cities, influencing not only health outcomes but also economic activities like tourism. Numerous studies have highlighted the dual impact of air quality, where poor conditions negatively affect both residents' well-being and the economic attractiveness of urban destinations. For Târgu Mureș, integrating air quality management with urban planning and policy development is vital for balancing economic growth and environmental sustainability [10].

Air quality indices are increasingly utilized to assess the effectiveness of environmental policies and interventions. In Europe, stringent air quality standards have led cities to adopt innovative solutions to combat pollution and build resilience against environmental degradation [17]. Guidelines from organizations such as the European Environment Agency provide valuable benchmarks for improving urban air quality, offering a foundation for best practices and successful policy implementations[15].

Despite advancements in air quality monitoring and regulations, significant gaps remain in addressing localized pollution sources. In Târgu Mureș, the lack of detailed data on industrial emissions, traffic patterns, and heating practices limits the scope of effective interventions. This underscores the need for an integrated approach that combines technological advancements, community engagement, and strict enforcement of environmental policies to address air quality challenges at their roots[18].

This research contributes to the growing discourse on air quality by examining the influence of meteorological and seasonal factors on PM2.5 and PM10 concentrations in Târgu Mureș. Using data collected over 1,091 days, the study provides a comprehensive analysis of the relationships between climatic variables and air pollution. The findings highlight the dominant roles of temperature and humidity in shaping particulate matter levels, with atmospheric pressure playing a supplementary role [19].

The insights gained from this study have practical implications for policymakers, urban planners, and public health professionals. Strategies such as modernizing heating systems, promoting cleaner energy sources, and expanding green infrastructure are essential to mitigating pollution during high-risk periods. The strong correlation between PM2.5 and PM10 suggests that policies targeting one pollutant can also reduce the other, maximizing the efficiency of air quality management efforts [20, 21].

Furthermore, the study emphasizes the need for real-time meteorological monitoring to enable proactive responses to changing pollution levels. Incorporating temperature, humidity, and pressure data into urban air quality models can provide early warnings and facilitate timely interventions. For a city like Târgu Mureș, these measures are critical for balancing urban development with environmental health.

By bridging statistical analysis and practical application, this research underscores the importance of tailored air quality management strategies. The findings not only deepen the understanding of urban pollution dynamics but also offer actionable recommendations for improving public health and urban sustainability. As cities globally face the dual challenges of environmental degradation and urbanization, the insights from this study provide valuable lessons for designing more sustainable and livable urban environments [22].

(2). Materials and Methods

This research was conducted in the urban areas of Mureș County, located in the region of Transylvania, Romania. The area is characterized by a temperate-continental climate, with distinct cold winters and warm summers, which significantly influence air quality patterns. The urban zones monitored include densely populated areas with diverse anthropogenic pollution sources, making it a relevant case for assessing the relationship between particulate matter and climatic factors.

Air quality data were sourced from sensors deployed as part of the Strop de Aer network, a citizen science initiative aimed at improving public awareness and monitoring of environmental quality in Romania. The sensors utilized in this study employed the Nova Fitness SDS011 Optical Particle Counter, which measures particulate matter concentrations (PM2.5 and PM10). Additional parameters such as temperature, relative humidity, and atmospheric pressure were recorded simultaneously.

The sensors operated with a high temporal resolution, recording data every two minutes. These high-frequency measurements were aggregated into daily averages to facilitate the analysis and minimize short-term variability. The dataset covers a period from August 2021 to November 2024. Out of the total monitoring period, approximately seven percent of the days were excluded due to incomplete or missing data, leaving 1,091 days for the final analysis.

Strop de Aer sensors have been previously evaluated in comparison with Federal Equivalent Method (FEM) instruments, such as the GRIMM EDM 180 and the Teledyne API T640. These evaluations demonstrated strong correlations between Strop de Aer sensors and reference instruments for PM2.5, with coefficients of determination (R^2) ranging between 0.77 and 0.83 for hourly averages. However, correlations for PM10 were weaker, with R^2 values ranging from 0.14 to 0.30. While the sensors are known to underestimate particulate matter concentrations slightly, they accurately track temporal variations, making them suitable for studying relative changes in urban air quality.

Below are described the detailed ***technical specifications and performance characteristics*** of the sensors.

The system utilizes the SDS011 Optical Particle Counter by Nova Fitness to monitor particulate matter concentrations, specifically focusing on PM2.5 (fine particles with a diameter of ≤ 2.5 μm) and PM10 (coarse particles with a diameter of ≤ 10 μm). The sensor employs a light scattering principle to detect and count particles, providing valuable data on air quality. In addition to particulate matter, it also measures other environmental parameters such as ambient temperature, relative humidity, and atmospheric pressure, offering a more comprehensive understanding of the air quality conditions.

The sensor is designed to record data with high temporal resolution, capturing readings every two minutes. This frequent data collection enables it to detect fine temporal variations in air quality. It also features a heated inlet that activates when humidity exceeds 60-70%, mitigating the effects of moisture on particulate measurements and ensuring more accurate readings during high-humidity conditions.

In terms of performance, the SDS011 demonstrates relatively low intra-model variability, with PM2.5 exhibiting an absolute variability of about 0.44 µg/m³ (8.8% relative variability) and PM10 showing an absolute variability of around 0.93 µg/m³ (7.1% relative variability). The sensor offers consistent measurements across different units of the same model. When compared to reference-grade instruments, such as the GRIMM EDM 180 and Teledyne API T640, the sensor shows strong correlations for PM2.5, with R^2 values ranging from 0.77 to 0.83 for hourly averages. While it slightly underestimates PM2.5 concentrations, it reliably tracks temporal variations. For PM10, the correlations are weaker, with R^2 values ranging from 0.14 to 0.30 for hourly averages, indicating that the sensor is less reliable for measuring these larger particles.

The raw data underwent a rigorous quality assurance and quality control process. Invalid data points, including outliers, negative values, and incomplete records, were systematically removed. The processed data were then averaged daily to provide consistent and comparable observations across the study period. This approach ensured the integrity of the dataset while maintaining its granularity for statistical analysis.

A comprehensive statistical approach was employed to examine the interplay between particulate matter concentrations and climatic variables.

Basic *descriptive statistics* were computed for all variables, including particulate matter (PM2.5 and PM10), temperature, humidity, and atmospheric pressure. Seasonal variations were explored to understand temporal patterns and their potential impact on air quality.

Pearson correlation coefficients were calculated to quantify the relationships between particulate matter concentrations and climatic parameters. Special attention was given to the interdependence between PM2.5 and PM10 levels.

Ordinary Least *Squares regression* models were developed to assess the influence of temperature, humidity, and atmospheric pressure on particulate matter concentrations. These models provided quantitative estimates of the extent to which climatic factors contribute to variations in PM2.5 and PM10 levels.

Concentrations of particulate matter were compared across seasons, with a particular focus on winter months. This period was hypothesized to exhibit higher pollution levels due to increased humidity and lower temperatures, which may exacerbate the persistence of particulate matter in the atmosphere.

The Strop de Aer network operates as a community-driven initiative, offering accessible and cost-effective air quality monitoring solutions. Despite some limitations, such as a slight underestimation of particulate matter concentrations compared to reference-grade instruments, these sensors provide robust data for identifying trends and relative changes in urban air quality. The network's sensors also feature a proprietary heated inlet mechanism that activates under high humidity conditions, improving data reliability during periods of elevated moisture.

All data processing, statistical analysis, and visualization were performed using industry-standard tools to ensure accuracy and reproducibility. This structured methodology highlights the utility of citizen science networks in environmental research and underscores the importance of climatic factors in shaping urban air quality dynamics.

This methodological framework serves as the foundation for exploring the intricate relationships between particulate matter concentrations and climatic variables, contributing to the broader understanding of urban environmental challenges.

(3). Results

The descriptive statistics for PM2.5, PM10, temperature, humidity, and atmospheric pressure, based on daily mean values recorded over the study period, are summarized in Table 1. These statistics provide a comprehensive overview of the central tendency, variability, and distribution of the monitored variables, offering valuable insights into air quality and meteorological conditions in the study area.

Table 1: Descriptive Statistics

		PM 2.5 (daily mean)	PM 10 (daily mean)	Temperature	Humidity	Pressure
N		980	980	1048	1049	1048
Mean		9.7143	15.6215	11.9245	65.8585	975.9567
Median		7.0007	10.4965	11.4583	66.5102	975.9615
Mode		8.94	2.26[a]	-9.94[a]	100.00	952.79[a]
Std. Deviation		7.73102	12.74131	8.49532	15.32592	7.58575
Minimum		1.22	2.26	-9.94	19.20	952.79
Maximum		54.77	88.30	32.49	100.00	1002.41
Percentiles	25	4.4770	7.1059	4.9563	53.8402	971.2244
	50	7.0007	10.4965	11.4583	66.5102	975.9615
	75	12.8147	20.4208	19.2512	76.5038	980.7356

a. Multiple modes exist. The smallest value is shown

The percentile data further illustrates the distribution of the variables. For instance, the 25th percentile for PM2.5 is 4.48 µg/m³, and the 75th percentile is 12.81 µg/m³, highlighting the variability in pollutant concentrations. Similarly, the interquartile range (IQR) for PM10 suggests greater dispersion compared to PM2.5. Temperature and humidity percentiles reflect the seasonal climatic variability, while the pressure percentiles indicate a consistent atmospheric state.

The analysis of daily mean PM2.5 concentrations over the study period (August 2021 to November 2024) is presented in Figure 1. The time series highlights significant variability in PM2.5 levels, with a distinct seasonal pattern.

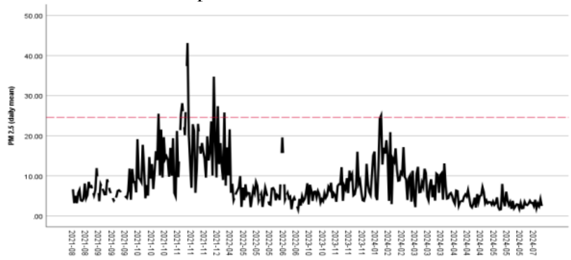

Fig. 1: Daily mean concentrations of PM 2.5

Similarly, the distribution of daily mean PM10 concentrations is depicted in Figure 2. The data reveal a consistent pattern of elevated PM10 levels during the colder months, with several sharp peaks exceeding the WHO guideline of 50 µg/m³ for daily exposure. These exceedances are attributed to similar factors affecting PM2.5, including increased emissions from heating and the accumulation of particulate matter under stable atmospheric conditions. The trend underscores the episodic nature of PM10 pollution, with occasional extreme values punctuating the overall seasonal variability. In contrast, PM10 concentrations remain relatively lower during the summer, suggesting a reduced impact of localized emission sources and enhanced dispersion mechanisms during this period.

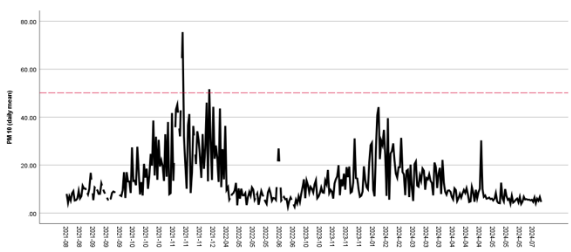

Fig. 2: Daily mean concentrations of PM 2.5

To better understand the relationships between particulate matter concentrations (PM2.5 and PM10) and key meteorological variables (temperature, humidity, and atmospheric pressure), a comprehensive correlation analysis was performed.

The correlation results (Table 2) reveal a very strong positive relationship between PM2.5 and PM10 (\(r = 0.981, p < 0.01 \)), reflecting their similar behavior and likely shared sources, such as combustion processes, traffic emissions, and industrial activities.

Table 2: Pearson Correlation

		PM 2.5 (daily mean)	PM 10 (daily mean)	Temperature	Humidity
PM 10 (daily mean)	Pearson Correlation	.981**	--		
Temperature	Pearson Correlation	-.612**	-.632**	--	
Humidity	Pearson Correlation	.426**	.402**	-.483**	--
Presure	Pearson Correlation	.194**	.233**	-.089**	-.201**

*All correlations are significant at P<0.01, except for the correlation between temperature and pressure (P=0.004 P=0.004).

The relationships between the variables are further clarified through the scatterplots presented in the analysis. For PM2.5, the visualizations (Figure 1) highlight a strong positive relationship with PM10, reflecting their shared sources and similar behaviors. Additionally, the inverse relationship between PM2.5 and temperature is clearly illustrated, emphasizing how colder conditions lead to higher pollutant concentrations. The scatterplots also reveal a positive association between PM2.5 and humidity, suggesting that higher moisture levels contribute to particulate retention, while the relationship with pressure appears less pronounced.

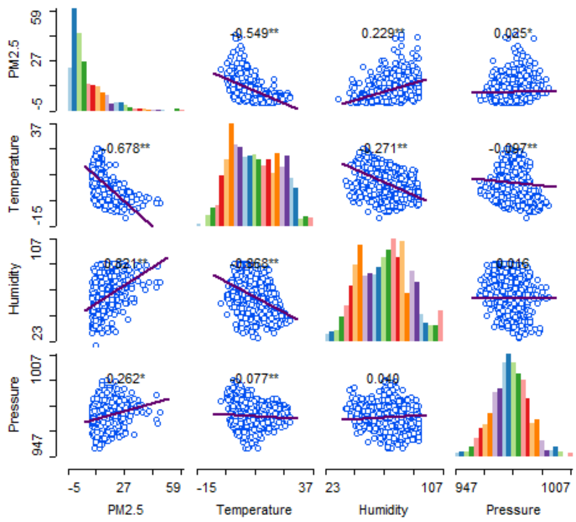

Fig. 2: Scatterplot Matrix of PM2.5 and Meteorological Variables with Correlation Coefficients

The relationship between PM2.5 concentrations and meteorological variables—temperature, humidity, and atmospheric pressure—is depicted in Figure 3 (a, b, c), which combines scatterplots and boxplots for a detailed analysis of trends and distributions.

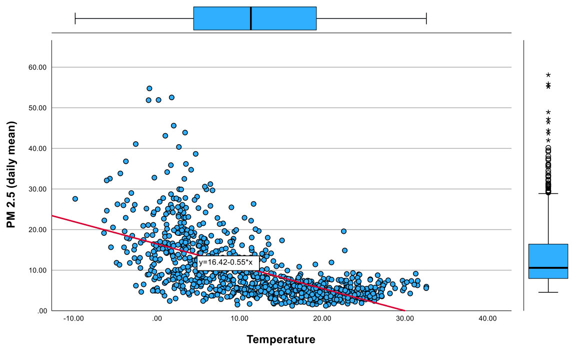

Fig.3a: Scatterplot and Boxplot of PM2.5 Daily Mean vs. Temperature

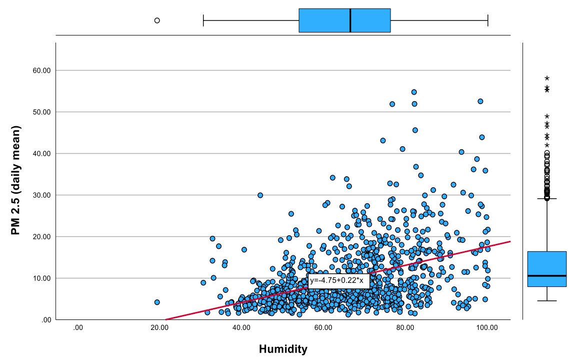

Fig.3b: Scatterplot and Boxplot of PM2.5 Daily Mean vs. Humidity

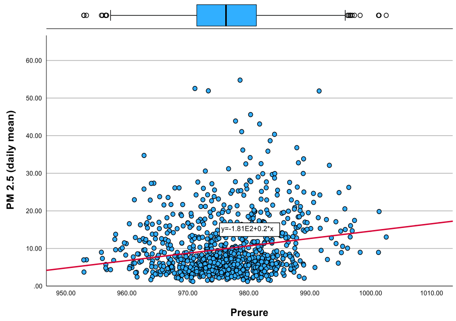

Fig.3c: Scatterplot and Boxplot of PM2.5 Daily Mean vs. Pressure

Similarly, the patterns for PM10, as shown in Figure 4, align closely with those of PM2.5. The impact of temperature and humidity on PM10 levels is evident, reinforcing their role as critical factors in air quality dynamics. The strong interdependence between PM2.5 and PM10 is also visible, confirming the close link between these two types of particulate matter. Together, these scatterplots offer a detailed and intuitive understanding of the interactions between particulate matter and meteorological variables.

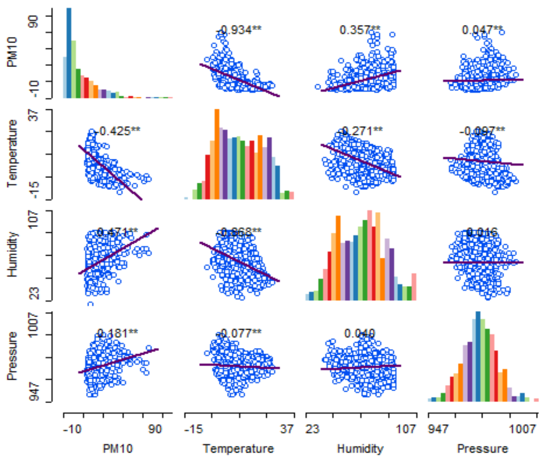

Fig.4: Scatterplot Matrix of PM10 and Meteorological Variables with Correlation Coefficients

The influence of meteorological factors, including temperature, humidity, and atmospheric pressure, on PM10 concentrations is visualized in Figure 5 (a, b, c). These scatterplots and boxplots together provide a comprehensive understanding of the trends and variability in PM10 levels.

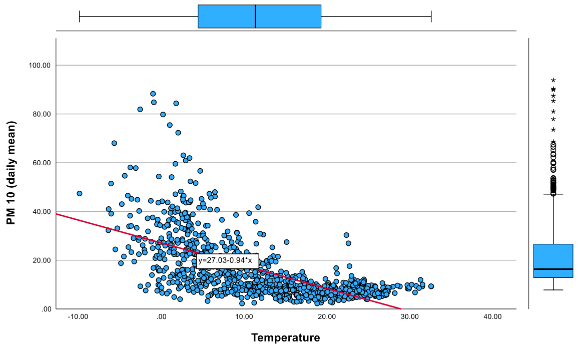

Fig.5a: Scatterplot and Boxplot of PM10 Daily Mean vs. Temperature

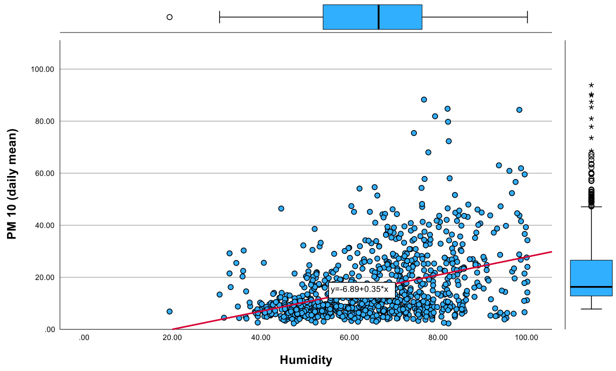

Fig.3b: Scatterplot and Boxplot of PM2.5 Daily Mean vs. Humidity

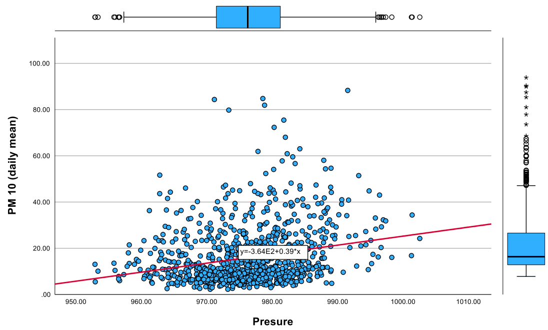

Fig.5c: Scatterplot and Boxplot of PM10 Daily Mean vs. Pressure

The regression model as showed bellow for PM2.5 with predictors temperature, humidity, and pressure demonstrates significant negative effects of temperature (\(\beta = -0.425, p < 0.001 \)) on PM2.5, suggesting that higher temperatures reduce particulate concentrations. Humidity exhibits a positive relationship (\(\beta = 0.128, p < 0.001 \)), indicating that increased moisture is associated with elevated PM2.5 levels. Atmospheric pressure also contributes positively (\(\beta = 0.206, p < 0.001 \)), though with a smaller effect size.

```
REGRESSION
----------
SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES ESTIMATION
Data set            :  medii_zilnice Pm 2,5 pm10, umiditate, temperatura
Dependent Variable  :        PM10  Number of Observations:  919
Mean dependent var  :     16.0236  Number of Variables   :    4
S.D. dependent var  :     12.9368  Degrees of Freedom    :  915

R-squared           :    0.458446  F-statistic           :     258.194
Adjusted R-squared  :    0.456671  Prob(F-statistic)     :           0
Sum squared residual:     83293.9  Log likelihood        :     -3374.9
Sigma-square        :     91.0316  Akaike info criterion :      6757.8
S.E. of regression  :     9.54105  Schwarz criterion     :     6777.09
Sigma-square ML     :     90.6354
S.E of regression ML:     9.52026

-----------------------------------------------------------------------------
       Variable      Coefficient       Std.Error     t-Statistic   Probability
-----------------------------------------------------------------------------
          CONSTANT      -365.927          42.183        -8.67475      0.00000
       Temperature     -0.754222       0.0426339        -17.6907      0.00000
          Humidity      0.180554        0.025678         7.03148      0.00000
          Pressure      0.388116       0.0425454         9.12238      0.00000
-----------------------------------------------------------------------------

REGRESSION DIAGNOSTICS
MULTICOLLINEARITY CONDITION NUMBER   359.044965
TEST ON NORMALITY OF ERRORS
TEST                  DF           VALUE            PROB
Jarque-Bera            2         2170.9306          0.00000

DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                  DF           VALUE            PROB
Breusch-Pagan test     3          268.3306          0.00000
Koenker-Bassett test   3           61.6790          0.00000
SPECIFICATION ROBUST TEST
TEST                  DF           VALUE            PROB
White                  9          119.7092          0.00000
============================== END OF REPORT ================================
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```
REGRESSION
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SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES ESTIMATION
Data set            :  medii_zilnice Pm 2,5 pm10, umiditate, temperatura
Dependent Variable  :       PM2.5  Number of Observations:  919
Mean dependent var  :     9.97534  Number of Variables   :    4
S.D. dependent var  :      7.8499  Degrees of Freedom    :  915

R-squared           :    0.432121  F-statistic           :     232.086
Adjusted R-squared  :    0.430259  Prob(F-statistic)     :           0
Sum squared residual:     32158.8  Log likelihood        :     -2937.6
Sigma-square        :     35.1463  Akaike info criterion :      5883.2
S.E. of regression  :     5.92843  Schwarz criterion     :     5902.49
Sigma-square ML     :     34.9933
S.E of regression ML:     5.91551

-----------------------------------------------------------------------------
       Variable      Coefficient       Std.Error     t-Statistic   Probability
-----------------------------------------------------------------------------
          CONSTANT      -195.053         26.2109        -7.44168      0.00000
       Temperature     -0.425994        0.026491        -16.0807      0.00000
          Humidity      0.128003       0.0159553         8.02259      0.00000
          Pressure      0.206492        0.026436         7.81101      0.00000
-----------------------------------------------------------------------------

REGRESSION DIAGNOSTICS
MULTICOLLINEARITY CONDITION NUMBER   359.044965
TEST ON NORMALITY OF ERRORS
TEST                  DF           VALUE            PROB
Jarque-Bera            2         2062.0791          0.00000

DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                  DF           VALUE            PROB
Breusch-Pagan test     3          275.8313          0.00000
Koenker-Bassett test   3           64.7344          0.00000
SPECIFICATION ROBUST TEST
TEST                  DF           VALUE            PROB
White                  9          107.1473          0.00000
============================== END OF REPORT ================================
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The plots presented in the figure 6 confirm that higher frequencies of elevated PM2.5 concentrations occur at lower temperature and higher humidity levels, aligning with the regression outcomes.

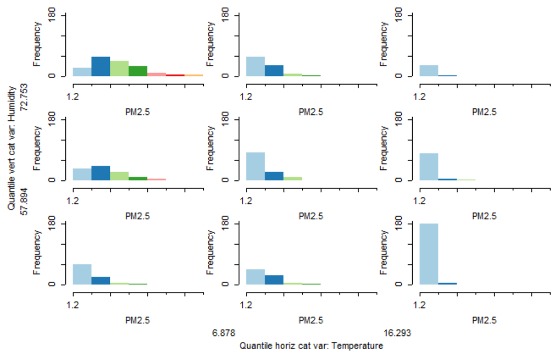

Fig.6: Frequency Distribution of PM2.5 Across Temperature and Humidity Quantiles

The regression output for PM10 demonstrates significant effects for all predictors, as shown bellow. Temperature exhibits a strong negative association ($\beta = -0.754, p < 0.001$), aligning with its influence on PM2.5, while humidity has a smaller but significant positive effect ($\beta = 0.180, p < 0.001$). Atmospheric pressure also shows a positive relationship ($\beta = 0.388, p < 0.001$). The model achieves an adjusted R^2 of 0.456, indicating its ability to explain nearly half of the variability in PM10 concentrations.

The quantile-based frequency distributions of PM10 relative to temperature and humidity, presented in Figure 7, provide additional context for these findings. Higher PM10 concentrations are more frequent at lower temperatures and higher humidity levels, reinforcing the regression results. Compared to PM2.5, PM10 exhibits a slightly broader distribution under high humidity conditions, reflecting differences in particle behavior and aggregation dynamics.

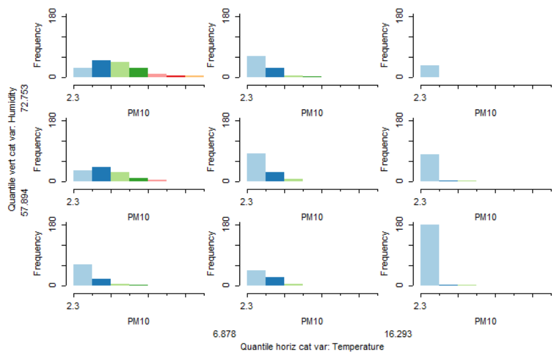

Fig.7: Frequency Distribution of PM10 Across Temperature and Humidity Quantiles

(4). Discussion

The dataset includes 980 valid observations for PM2.5 and PM10, with 111 missing values due to gaps in sensor data. For temperature, humidity, and atmospheric pressure, valid observations range from 1,048 to 1,049, with fewer missing entries. The mean PM2.5 concentration is 9.71 µg/m³, and the mean PM10 is 15.62 µg/m³, both of which remain below their respective daily World Health Organization (WHO) thresholds. However, maximum values for PM2.5 (54.77 µg/m³) and PM10 (88.30 µg/m³) exceed these limits, highlighting critical pollution episodes during the study period.

Temperature shows a mean value of 11.92°C, with a broad range from -9.94°C to 32.49°C, reflecting the seasonal variability in the region. Humidity has a mean of 65.86%, with notable fluctuations ranging from 19.20% to 100%. Atmospheric pressure remains relatively stable, with a mean of 975.96 hPa and a narrow standard deviation of 7.59 hPa, suggesting limited day-to-day variability in this parameter.

The descriptive statistics underscore the dynamic nature of air quality parameters and their dependence on meteorological conditions. The variability in particulate matter concentrations emphasizes the influence of episodic pollution events, particularly during colder months, while the stability of atmospheric pressure and broader temperature and humidity ranges reflect the region's climatic characteristics.

The results highlight a pronounced seasonal trend, with higher concentrations of PM2.5 and PM10 observed during colder months. This pattern can be attributed to the combined effects of anthropogenic activities, such as increased emissions from residential heating and transportation, and meteorological conditions that limit pollutant dispersion. The interplay of these factors underscores the need for targeted air quality management strategies that address heightened pollution risks during winter.

Peaks are most prominent during the colder months, particularly in late autumn and winter, which are likely associated with increased residential heating and atmospheric stagnation. The World Health Organization (WHO) daily exposure limit of 25 µg/m³ is exceeded on numerous occasions, indicating critical periods of poor air quality. Conversely, lower concentrations are observed during warmer months, potentially due to enhanced atmospheric dispersion and reduced combustion activities. These findings emphasize the seasonal influence on PM2.5 pollution and the need for targeted interventions during high-risk periods.

According to table 2, Both pollutants exhibit significant negative correlations with temperature ($r = -0.612$ for PM2.5 and $r = -0.632$ for PM10, $p < 0.01$). This pattern suggests that colder temperatures exacerbate particulate matter levels, possibly due to increased emissions from heating and reduced atmospheric mixing during winter.

Humidity is positively correlated with PM2.5 ($r = 0.426, p < 0.01$) and PM10 ($r = 0.402, p < 0.01$), indicating that higher humidity levels can enhance the aggregation and persistence of particles in the atmosphere. Conversely, temperature and humidity show a significant negative correlation ($r = -0.483, p < 0.01$), consistent with seasonal trends where colder weather coincides with higher relative humidity.

Atmospheric pressure has weaker but significant positive correlations with PM2.5 ($r = 0.194, p < 0.01$) and PM10 ($r = 0.233, p < 0.01$). These results suggest that stable high-pressure conditions may contribute to the accumulation of particulate matter by limiting atmospheric dispersion. However, the overall influence of pressure appears to be secondary compared to temperature and humidity.

Temperature and humidity emerge as the most significant meteorological drivers of particulate matter concentrations. The inverse relationship between temperature and PM levels reveals the role of cold weather in exacerbating air pollution. Colder temperatures increase emissions from heating and reduce atmospheric mixing, creating conditions conducive to pollutant accumulation. Simultaneously, humidity positively correlates with PM levels, indicating its role in particle aggregation and retention, especially during damp and cold periods. These findings are consistent with existing literature, which emphasizes the critical role of temperature and humidity in shaping air quality.

Building on the correlation analysis, which highlighted significant relationships between particulate matter (PM2.5 and PM10) and meteorological variables such as temperature, humidity, and atmospheric pressure, regression modeling and frequency distribution analyses were conducted to further explore these dynamics. While correlations provided insights into the strength and direction of associations, the regression models offer a more nuanced understanding of how each variable contributes to variations in particulate matter concentrations. Additionally, the quantile-based frequency distributions illustrate the behavioral patterns of PM2.5 and PM10 under different climatic conditions, complementing the statistical findings with a visual representation. This combined approach enables a comprehensive assessment of the factors driving air quality fluctuations.

Atmospheric pressure, while having a weaker influence, still provides meaningful insights. High-pressure systems are associated with stable atmospheric conditions, which can enhance pollutant retention by limiting vertical dispersion. However, the relationship with pressure is less direct compared to temperature and humidity, suggesting that its impact on air quality may vary depending on specific local conditions. Including pressure in the analysis adds depth to the understanding of meteorological influences on particulate matter pollution.

An important observation is the strong correlation between PM2.5 and PM10, reflecting their shared sources and similar behaviors under varying meteorological conditions. This interdependence suggests that mitigation strategies targeting one pollutant are likely to have dual benefits in reducing both. Such findings highlight the potential for integrated air quality management approaches that address emissions from heating, transportation, and industrial activities, particularly during high-risk periods.

The scatterplot and boxplot in Figures 3 a-reveal a clear negative relationship between PM2.5 concentrations and temperature. The trendline equation ($y = 16.42 - 0.55x$) highlights that PM2.5

levels decrease as temperatures increase. This trend suggests that colder temperatures, typically associated with winter months, contribute to higher pollution levels due to increased emissions from heating and reduced atmospheric mixing. The boxplot further illustrates this pattern, with more frequent high PM2.5 values and outliers observed at lower temperatures, underscoring the impact of cold weather on air quality.

Figure 3b shows a positive relationship between PM2.5 concentrations and humidity, as indicated by the trendline ($y = 4.75 + 0.22x$). Higher humidity levels appear to facilitate the aggregation and persistence of fine particles, leading to elevated PM2.5 concentrations. The boxplot confirms this trend, with PM2.5 levels clustering at higher humidity values and a number of outliers representing extreme pollution events. This finding highlights the role of moisture in sustaining higher pollution levels, particularly during damp or rainy periods.

The relationship between PM2.5 and atmospheric pressure, shown in Figure 3c, is less pronounced compared to temperature and humidity. The trendline ($y = 1.81 + 0.02x$) indicates a weak positive correlation, suggesting that higher atmospheric pressure may slightly contribute to PM2.5 accumulation by stabilizing atmospheric conditions. The scatterplot shows a diffuse distribution of points, while the boxplot indicates relatively stable PM2.5 levels across most pressure ranges. A few outliers at lower pressure levels suggest isolated pollution episodes under specific conditions.

The scatterplot in Figure 5a demonstrates a clear inverse relationship between PM10 concentrations and temperature. The trendline ($y = 27.03 - 0.94x$) shows that PM10 levels significantly decrease as temperatures rise. This trend is indicative of colder conditions, particularly during winter months, which are associated with increased heating emissions and limited atmospheric mixing. The boxplot highlights a concentration of high PM10 values and outliers at lower temperatures, underscoring the seasonal impact of cold weather on air quality.

As shown in Figure 5b, there is a positive correlation between PM10 concentrations and humidity levels ($y = 6.89 + 0.35x$). This indicates that higher humidity may facilitate the retention and aggregation of particles in the atmosphere, leading to elevated PM10 levels. The boxplot reveals a clustering of PM10 concentrations at higher humidity ranges, with occasional outliers representing extreme pollution events. These findings suggest that humid conditions contribute to poorer air quality, especially during periods of high moisture.

Figure 5c illustrates a weaker, yet positive, association between PM10 concentrations and atmospheric pressure. The trendline ($y = 3.64 + 0.39x$) suggests that higher pressure may slightly favor pollutant accumulation by stabilizing the atmosphere. The scatterplot shows a diffuse distribution of PM10 values, while the boxplot indicates fairly consistent concentrations across pressure ranges. However, outliers at lower pressure levels point to episodic pollution events under specific conditions.

The study also emphasizes the role of urban activities and local topography in influencing particulate matter levels. In Târgu Mureș, colder months coincide with increased heating emissions and stagnant atmospheric conditions, exacerbated by the city's topography, which can trap pollutants near the surface. These dynamics call for localized solutions, such as optimizing residential heating systems, promoting cleaner fuels, and implementing traffic management measures during peak pollution periods. Urban planning strategies that improve ventilation, such as increasing green spaces or managing building density, can also mitigate the impact of stagnant conditions.

Another notable finding is the difference in behavior between PM2.5 and PM10 under varying meteorological conditions. While both pollutants are similarly influenced by temperature and humidity, PM10 shows a broader distribution, particularly at higher humidity levels. This distinction may be attributed to PM10's larger particle size, which allows for different dispersion and aggregation dynamics compared to finer PM2.5 particles. Such insights are crucial for designing pollutant-specific mitigation strategies, especially in regions with high dust or industrial emissions.

The robustness of the statistical models used in this study further validates the findings. Significant results from diagnostic tests, such as the Breusch-Pagan and Jarque-Bera, confirm the suitability of the models for analyzing air quality dynamics. These diagnostics enhance the reliability of the conclusions, providing a solid foundation for policy recommendations. The combined use of regression analysis and frequency distribution visualizations strengthens the credibility of the results, offering both statistical precision and intuitive insights.

We can mention there is a need for comprehensive air quality management strategies that consider both seasonal patterns and meteorological influences. Localized interventions, such as improving heating efficiency, regulating traffic, and enhancing urban infrastructure, are essential for mitigating particulate matter pollution in Târgu Mureș. Moreover, the findings emphasize the importance of integrating real-time meteorological monitoring into air quality management frameworks, enabling timely and effective responses to high-risk periods. By addressing these factors, urban areas can develop more effective strategies to protect air quality and public health.

(5). Conclusions

This study investigates the relationship between meteorological factors and particulate matter pollution in Târgu Mureș, a mid-sized urban area in

Transylvania. The results highlight that temperature and humidity are the dominant drivers of seasonal variations in PM2.5 and PM10 concentrations. Higher pollutant levels were observed during colder months, driven by increased heating emissions and atmospheric conditions that reduce dispersion. Humidity further exacerbates these concentrations by enhancing particle aggregation and retention. Although the role of atmospheric pressure is weaker, it contributes to pollution dynamics by stabilizing atmospheric conditions, particularly during high-pressure episodes.

The strong correlation between PM2.5 and PM10 underscores their shared sources and behaviors, pointing to the potential effectiveness of integrated mitigation strategies. Emissions from residential heating, transportation, and industrial activities are key contributors to pollution in Târgu Mureș, particularly during winter. Interventions such as promoting energy-efficient heating systems, regulating traffic in high-emission periods, and transitioning to cleaner fuels could significantly improve air quality. Given the observed seasonal patterns, these efforts should be targeted during colder months when pollution risks are at their peak.

This study also highlights the importance of integrating meteorological data into urban air quality management strategies. Real-time monitoring of temperature, humidity, and atmospheric pressure could support dynamic predictive models, enabling timely interventions tailored to local conditions. In a city like Târgu Mureș, where seasonal variations in weather and pollution are pronounced, such data-driven approaches could help reduce the health impacts of particulate matter pollution. Urban infrastructure improvements, such as increasing green spaces or enhancing drainage systems, could also mitigate the effects of humidity on particulate matter levels.

While this research provides valuable insights, there are several limitations that should be acknowledged. First, the analysis is based on data from a single air quality sensor in Târgu Mureș, which may not fully capture the spatial variability of pollution across the city. The results are therefore more representative of the specific location of the sensor rather than the city as a whole. Second, the study focuses on the relationship between particulate matter and a limited set of meteorological variables, while other factors, such as wind speed, solar radiation, or pollutant-specific sources, were not considered. Finally, the absence of direct health impact assessments limits the ability to quantify the full implications of pollution levels on the local population.

Future research should aim to address these limitations by incorporating data from a broader network of air quality sensors across Târgu Mureș and including additional environmental and socio-economic variables. Expanding the study to other urban areas with similar climatic conditions would also help generalize the findings. Moreover, evaluating the health and economic benefits of implementing targeted air quality interventions could provide policymakers with a stronger basis for action.

In conclusion, this study offers a detailed understanding of how temperature, humidity, and atmospheric pressure influence particulate matter pollution in Târgu Mureș. The findings emphasize the importance of adopting seasonal and location-specific measures to mitigate pollution, particularly during the colder months. By addressing these challenges, urban areas like Târgu Mureș can develop more effective strategies to improve air quality and safeguard public health.

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