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SEASONAL AND DIURNAL DYNAMICS OF SIZE-RESOLVED PARTICULATE MATTER IN AN URBAN AREA OF GALAȚI, ROMANIA, BASED ON CONTINUOUS RAPID-E MONITORING

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Abstract

Fine and ultrafine particulate matter (PM) is a major environmental and public health issue, particularly in densely populated urban areas exposed to significant anthropogenic emissions. This study presents an analysis of PM concentrations based on size in a high-traffic area of Galați, Romania, using the REXDAN Research Center monitoring system and the RAPID-E real-time analyzer. The continuous measurements were carried out between December 31, 2023 (10:00 p.m.) and December 31, 2025 (10:00 p.m.), covering the particle size fractions of 0.3, 0.5, 1 and 5 µm. In addition to an earlier study of daily and weekly variations, this work examines seasonal variability as well as diurnal (day/night) contrasts. Statistical and temporal analyses were used to characterize fluctuations in PM concentrations and to identify trends related to weather conditions and anthropogenic activities. The results improve the understanding of particulate dynamics in urban settings and support the development of effective air quality management strategies.

Key words: *diurnal variation, particulate matter (PM), RAPID-E monitoring system, seasonal variability, urban air quality.*

INTRODUCTION

Atmospheric pollutants, such as particulate matter (PM), NO_2, SO_2, CO_2, CO and O_3, have a significant influence on air quality and originate from a wide range of sources and processes, including atmospheric and chemical reactions, mechanical resuspension, biological activity, industrial emissions, agricultural activities and other pollution-generating processes (Manisalidis et al., 2020; World Health Organization, 2021; European Environment Agency, 2024).

These pollutants require continuous monitoring and control due to their effects on the environment, ecosystems and, most importantly, public health. Among them, particulate matter is considered one of the most harmful air pollutants, as it can directly or indirectly affect multiple internal organs. Fine and ultrafine particles, particularly those with diameters below 1 µm, may penetrate deep into the respiratory system, enter the bloodstream and reach sensitive organs such as the heart and brain, potentially causing severe and long-term health effects (Ngoc et al., 2017; Yang et al., 2021; Garcia et al., 2023). The most vulnerable population groups include elderly people, children and individuals with pre-existing health conditions, for whom exposure to particulate matter may act as an aggravating factor (Kirešová et al., 2023; Hamanaka & Mutlu, 2025).

In urban areas, the main sources of pollutants such as NO_2, SO_2 and particulate matter are fossil fuel combustion, road traffic and industrial activities (Karagulian et al., 2015; Roșu et al., 2020; World Health Organization, 2021). However, atmospheric particles may also originate from natural sources, including desert dust, volcanic eruptions and sea salt aerosols, which are difficult or impossible to control directly (Lonati & Giugliano, 2006; Ramgolam et al., 2008; Baldacchini et al., 2019). Atmospheric particles can occur in different physical states: some are entirely liquid, others are solid, while certain particles consist of a solid core surrounded by a liquid layer. Their

chemical composition is complex and may include inorganic ions, metallic compounds, elemental carbon, organic substances and crustal materials (Wilson et al., 2002; Mugica et al., 2009; Tao et al., 2017). In addition, many atmospheric particles are hygroscopic, meaning that they can absorb atmospheric moisture and retain water within their structure.

At the European level, air quality limit values are already established for PM_{10} and $PM_{2.5}$, requiring continuous monitoring and data collection. However, as previously mentioned, particles with diameters below 1 μm may have particularly important health implications. To address the need for high-resolution monitoring of fine and ultrafine airborne particles, the Rapid-E+ device, developed as an advanced version of the Rapid-E system, has become a valuable tool for monitoring airborne particles such as pollen, fungal spores and bacteria (Sikoparija et al., 2024; Bruffaerts et al., 2025). This device employs optical detection technology combined with laser illumination to measure particles within the 0.3-100 μm size range with high accuracy. Therefore, Rapid-E+ provides a rapid and reliable method for the continuous monitoring of airborne particles (Šauliene et al., 2019).

The present article represents a continuation of a previous study that investigated the variation of particulate matter during weekdays and weekends (Cristea et al., 2025). In addition to the earlier analysis of daily and weekly variability, the present work investigates seasonal variability and differences between diurnal and nocturnal intervals. Statistical and temporal analyses were applied to characterize fluctuations in suspended particle concentrations and to identify trends associated with meteorological conditions and anthropogenic activities. The results contribute to a better understanding of atmospheric particle dynamics in urban environments and provide support for the development of effective air quality monitoring and management strategies.

MATERIALS AND METHODS

Study area and localization

For this study, continuous measurements of suspended particle concentrations were carried out in the municipality of Galați, one of the most important urban centers in north-eastern Romania. The monitoring campaign was conducted over a two-year period, from December 31, 2023, to December 31, 2025. The measurements were performed at the REXDAN Research Infrastructure (REXDAN RI), located on George Coșbuc Boulevard no. 98, Galați, Romania (45°26'6.66"N, 28°2'14.02"E).

The monitoring site was selected because it is in an urban area characterized by intense road traffic and active urban dynamics, both of which may influence local particulate matter concentrations. In addition, the location provided suitable conditions for the simultaneous operation of the aerosol monitoring system and the meteorological station within the same research infrastructure.

To obtain relevant data on atmospheric particle concentrations and local meteorological conditions, two complementary monitoring systems were used: the Rapid-E+ aerosol monitoring device and the ACTRIS RADO Galați meteorological station. The Rapid-E+ device was installed in the courtyard of the REXDAN RI, while the meteorological station was located on the rooftop of the same facility. This configuration allowed the continuous acquisition of particle concentration data together with meteorological parameters representative of the local urban environment from Galati city. The location of the Rapid-E+ device was previously presented in Cristea et al. (2025).

The main objective of this study was to assess the temporal variability of suspended particles in an urban environment and to investigate their relationship with local atmospheric parameters.

Equipment and data used

The particulate matter measurements were performed using the Rapid-E+ system, an advanced real-time bioaerosol sensor developed for the detection, characterization and classification of individual airborne particles. During the two-year monitoring period, the Rapid-E+ system and the ACTRIS RADO Galați meteorological station operated simultaneously, enabling the direct comparison and correlation of particle concentration data with local meteorological parameters.

The instrument uses proprietary laser-based optical technology, combining scattered light pattern analysis with fluorescence spectroscopy,

which allows the characterization of aerosols in complex atmospheric environments (Plair SA, 2025a; 2025b). The integration of GPU-based processing improves the speed of data acquisition and processing, enabling efficient real-time monitoring of ambient air (Plair SA, 2025b).

The Rapid-E+ sensor continuously detects and characterizes airborne particles with diameters ranging from 0.3 to 100 µm (Plair SA, 2025a). The raw particle counts provided by the instrument are cumulative and correspond to particles above specific size thresholds. Thus, the 0.3 µm channel represents particles between 0.3 and 100 µm, the 0.5 µm channel corresponds to particles between 0.5 and 100 µm, the 1 µm channel includes particles between 1 and 100 µm, and the 5 µm channel represents particles between 5 and 100 µm (Plair SA, 2025b). These cumulative data were subsequently used to derive size-resolved particle fractions for further analysis.

The device can operate autonomously and remotely, allowing continuous data acquisition and access to measurements from any location. Rapid-E+ is designed for the real-time monitoring of airborne biological and non-biological particles, including pollen, fungal spores and bacteria, and is therefore suitable for applications in air quality assessment, biological risk monitoring, public health studies and environmental research (Plair SA, 2025b). The main technical specifications and operational features of the instrument are described in the previous study by Cristea et al. (2025) and on the official Rapid-E+ webpage (Plair SA, 2025a).

Figure 1 shows the Rapid-E+ system installed at the REXDAN RI. The instrument is placed inside a climate-controlled protective enclosure, which reduces direct exposure to external environmental factors, while the air intake tube is positioned externally to ensure continuous sampling of ambient air.

The ACTRIS RADO Galati meteorological station was used to continuously monitor local atmospheric conditions during the study period. The station recorded meteorological data at a temporal resolution of 5 minutes, providing detailed information on short-term atmospheric variability. The monitored parameters included air temperature, relative humidity, atmospheric pressure, visibility, wind speed and wind direction.

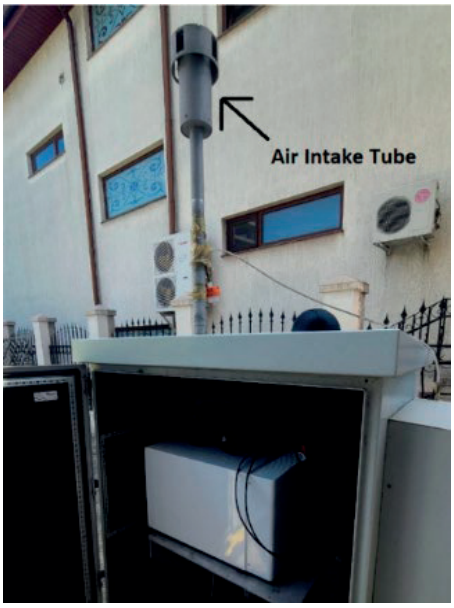


Figure 1. Rapid-E+ equipment installed at the REXDAN RI, showing the protective enclosure and the external air intake tube used for ambient air sampling of PM during 2024-2025 measurements

The meteorological data were used to evaluate the influence of local atmospheric conditions on airborne particle concentrations and size distribution. Continuous monitoring allowed the identification of temporal variations and supported the analysis of possible relationships between meteorological parameters and aerosol concentrations. The collected meteorological datasets were further used for comparison and correlation analyses with the Rapid-E+ measurements in order to assess the influence of atmospheric conditions on urban particle dynamics.

Figure 2 presents the ACTRIS RADO Galați meteorological station installed on the rooftop of the REXDAN RI. More technical specifications of the meteorological sensors can be found in the corresponding ACTRIS and Cloudnet instrument database entries (DJUG CS106, 2026; DJUG Ultrasonic Anemometer 2D, 2026; DJUG Weather Station, 2026).



Figure 2. ACTRIS RADO Galați meteorological station installed on the rooftop of the REXDAN RI used for continuous records of local atmospheric parameters for the 2024-2025 measurements

The Rapid-E+ system and the ACTRIS RADO Galați meteorological station operated simultaneously, enabling the direct comparison and correlation of particle concentration data with local meteorological parameters.

Data processing and statistical analysis

The analysis was based on particle number concentrations measured by the Rapid-E+ system within the 0.3-100 µm size range and on meteorological data recorded by the ACTRIS RADO Galați meteorological station. Since the Rapid-E+ instrument provides cumulative particle counts above specific diameter thresholds, a subtraction method was applied between consecutive cumulative channels to obtain size-resolved particle fractions.

Therefore, the broad measurement range was divided into four distinct size intervals: 0.3-0.5 µm, 0.5-1 µm, 1-5 µm and 5-100 µm. Each interval represents the isolated contribution of particles within the corresponding diameter range. If the instrument provides cumulative counts above each size threshold, namely $N_{\geq 0.3}$, $N_{\geq 0.5}$, $N_{\geq 1}$and $N_{\geq 5}$, the size-resolved fractions were calculated as follows:

$$N_{0.3-0.5} = N_{\geq 0.3} - N_{\geq 0.5} \quad (1)$$

$$N_{0.5-1} = N_{\geq 0.5} - N_{\geq 1} \quad (2)$$

$$N_{1-5} = N_{\geq 1} - N_{\geq 5} \quad (3)$$

$$N_{5-100} = N_{\geq 5} \quad (4)$$

where $N_{(\geq x)}$ represents the cumulative particle number concentration measured for particles with diameters greater than or equal to x µm, while N_{a-b} represents the particle number concentration calculated for the size interval between a and b µm.

All meteorological datasets were filtered and averaged to hourly values to ensure temporal compatibility with the particulate matter dataset. Pearson correlation analysis was then applied to evaluate the relationships between meteorological parameters and particle concentrations for each size fraction. The resulting correlation coefficients were represented as heatmaps to visualize the strength and direction of the relationships. The strength of the Pearson correlations was interpreted based on the absolute value of the correlation coefficient: weak correlations were considered for $|r| < 0.30$, moderate correlations for $0.30 \leq |r| < 0.50$, and strong correlations for $|r| \geq 0.50$. Positive values indicate that particle concentrations increase with the corresponding meteorological parameter, whereas negative values indicate an inverse relationship. Although statistical significance was assessed using p-values, only moderate and strong correlations were considered relevant for physical interpretation. Very weak correlations, even when statistically significant, were not interpreted as physically meaningful.

To assess the statistical significance of the observed correlations, a p-value analysis was performed for the Pearson correlation coefficients. This allowed the identification of statistically significant relationships and helped determine whether the observed correlations were unlikely to have occurred due to random variation in the dataset. Statistical significance was indicated directly on the Pearson correlation heatmaps using asterisks: $p < 0.05$, $p < 0.01$, and $p < 0.005$. Only moderate and strong correlations were considered relevant for physical interpretation.

RESULTS AND DISCUSSIONS

The results are presented in three complementary stages to evaluate the relationships between meteorological parameters and size-resolved particulate matter fractions. First, the overall Pearson correlation

patterns were analyzed for the entire 2024-2025 monitoring period, as shown in Figure 3. Second, the dataset was divided by season to identify seasonal differences in the strength and direction of the correlations. Finally, daytime and nighttime conditions were analyzed separately to assess whether diurnal atmospheric variability influenced the relationships between meteorological parameters and particle concentrations. For each condition an explanation attempt is done based on the recorded data for weather (meteorological parameters) corellated with the PM classes. Figure 3 summarizes the overall correlations between local meteorological parameters and the size-resolved particulate matter fractions derived from the Rapid-E+ measurements. Positive correlation coefficients indicate that particle concentrations tend to increase with increasing values of the corresponding meteorological parameter, whereas negative coefficients indicate an inverse relationship.

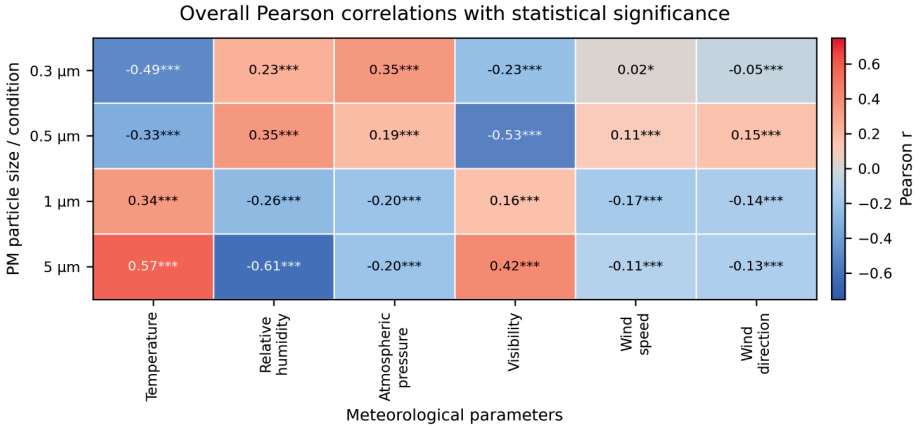


Figure 3. Overall Pearson correlation heatmap between meteorological parameters and size-resolved particulate matter fractions during the 2024-2025 monitoring period in Galați, Romania. Asterisks indicate statistical significance: ***$p < 0.005$, *$p < 0.01$, $p < 0.05$

Figure 3 shows the overall Pearson correlations between meteorological parameters and particle size fractions for the entire 2024-2025 monitoring period. The strongest negative correlation was observed between relative humidity and the 5 µm fraction (r = −0.61), suggesting that higher humidity was generally associated with lower concentrations of coarse particles, possibly due to particle removal, deposition or hygroscopic growth effects. A strong positive correlation was observed between temperature and the 5 µm fraction (r = 0.57), while visibility was negatively correlated with the 0.5 µm fraction (r = −0.53), indicating that fine particles may contribute to reduced atmospheric visibility. The 0.3 µm and 0.5 µm fractions generally showed correlation patterns opposite to those of the 1 µm and 5 µm fractions, especially for temperature, relative humidity, pressure and visibility. In contrast, wind speed and wind direction showed weak correlations with all particle fractions, suggesting a limited influence on the overall dataset. Most correlations were statistically significant, with *p*-values generally below 0.005 as presented in Figure 3 with asterisks that indicate the statistical significance: ***$p < 0.005$, *$p < 0.01$, $p < 0.05$. Similar approach was conducted for the other correlation heat maps presented in below figures.

Figure 4 highlights the seasonal variability of the relationships between meteorological parameters and particle size fractions. Stronger correlations were generally observed during winter, spring and autumn, while summer showed weaker and more variable associations, indicating that the influence of meteorological conditions on particulate matter is season dependent.

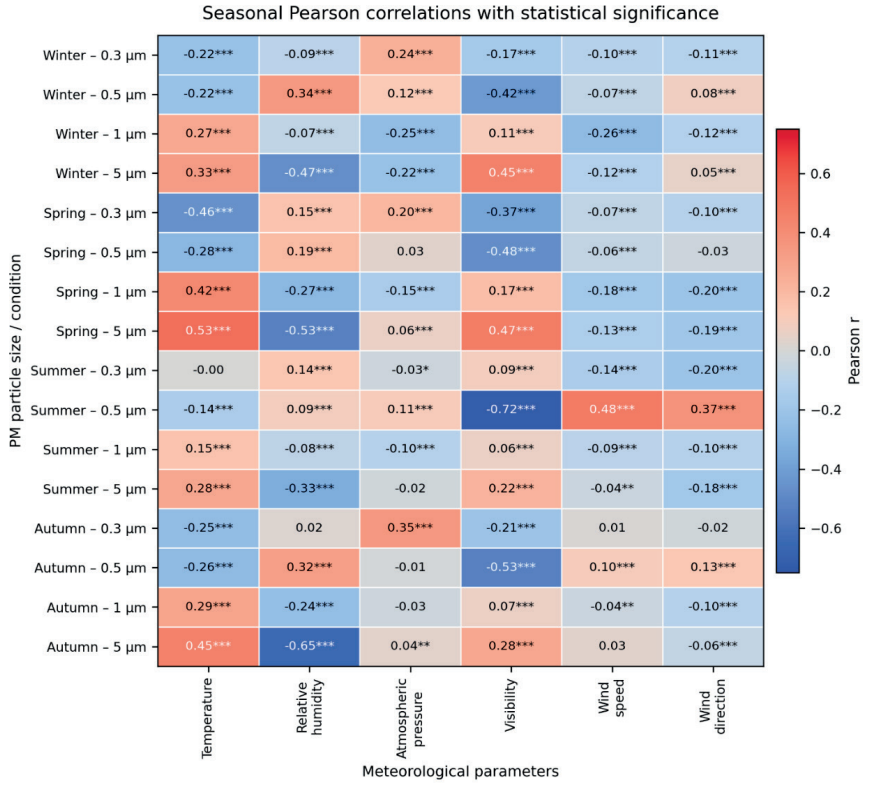


Figure 4. Seasonal variability of Pearson correlations between meteorological parameters and size-resolved particulate matter fractions during the 2024-2025 monitoring period in Galați, Romania. Asterisks indicate statistical significance: ***$p < 0.005$, *$p < 0.01$, $p < 0.05$

In winter, the 5 µm fraction showed a moderate positive correlation with visibility (r = 0.45) and a moderate negative correlation with relative humidity (r = −0.47). In spring, the strongest positive correlation was observed between temperature and the 5 µm fraction (r = 0.53), suggesting that warmer and drier conditions may favor coarse particle resuspension. During summer, most correlations were weak, except for the strong negative relationship between visibility and the 0.5 µm fraction (r = −0.72), indicating a strong optical effect of fine particles. In autumn, the 5 µm fraction was positively correlated with temperature (r = 0.45) and strongly negatively correlated with relative humidity (r = −0.65), again suggesting the sensitivity of coarse particles to humidity-related processes. The *p*-value analysis presented in Figure 4 (asterisks) indicated that most seasonal correlations were statistically significant, although weaker relationships involving pressure, wind speed and wind direction should be interpreted with caution.

Figure 5 presents the seasonal Pearson correlations calculated for daytime conditions. In winter, the 5 µm fraction showed a strong positive relationship with visibility (r = 0.52) and a moderate negative relationship with relative humidity (r = −0.43). This pattern suggests that coarse particles were less abundant under more humid daytime conditions, possibly due to humidity-related removal processes, while clearer atmospheric conditions were associated with higher coarse particle concentrations. In spring, the 5 µm fraction was moderately correlated with temperature (r = 0.48) and visibility (r = 0.45), indicating that warmer and clearer conditions may favor the presence or resuspension of coarse particles.

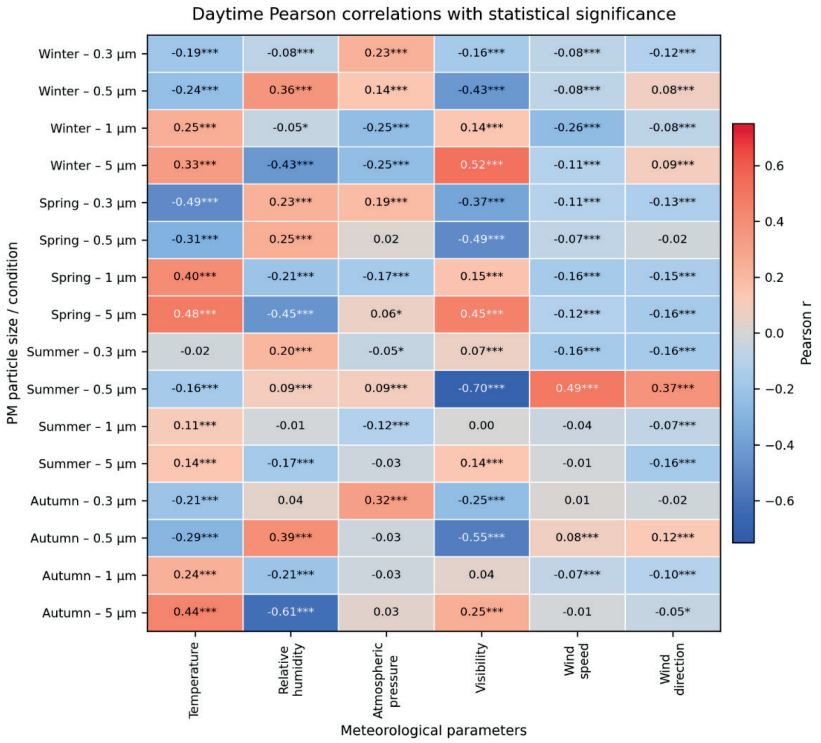


Figure 5. Daytime seasonal variability of Pearson correlations between meteorological parameters and size-resolved particulate matter fractions during the 2024–2025 monitoring period in Galați, Romania. Asterisks indicate statistical significance: ***$p < 0.005$, *$p < 0.01$, $p < 0.05$

During summer, most correlations were weak, except for the strong negative relationship between visibility and the 0.5 µm fraction (r = −0.70), suggesting that fine particles had an important role in reducing atmospheric visibility through light scattering. Moderate positive correlations were also observed between the 0.5 µm fraction and wind speed (r = 0.49), as well as wind direction (r = 0.37), which may indicate the influence of local transport processes. In autumn, the 5 µm fractions showed a moderate positive correlation with temperature (r = 0.44) and a strong negative correlation with relative humidity (r = −0.61), again indicating the sensitivity of coarse particles to humidity-related atmospheric processes.

Figure 6 shows the seasonal Pearson correlations calculated for nighttime conditions. In winter, the 5 µm fraction was moderately positively correlated with visibility (r = 0.41) and moderately negatively correlated with relative humidity (r = −0.48), showing a pattern like that observed during daytime. In spring, the 5 µm fractions showed a strong positive correlation with temperature (r = 0.53) and a strong negative correlation with relative humidity (r = −0.56), suggesting that warmer and drier nighttime conditions may favor the persistence of coarse particles.

During summer, the strongest nighttime relationship was observed between visibility and the 0.5 µm fraction (r = −0.74), indicating a strong influence of fine particles on visibility reduction. In autumn, the 5 µm fraction was strongly negatively correlated with relative humidity (r = −0.65), while temperature remained moderately positively correlated with the same fraction (r = 0.36). These results suggest that nighttime particle dynamics are strongly influenced by humidity and atmospheric stability, which may reduce vertical mixing and favor particle accumulation near the surface.

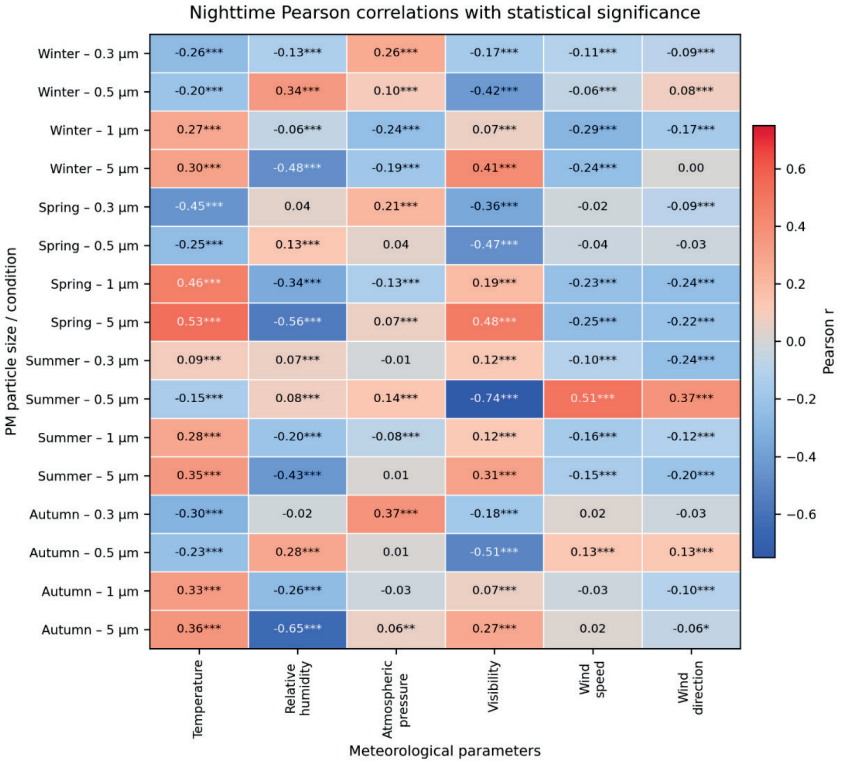


Figure 6. Nighttime seasonal variability of Pearson correlations between meteorological parameters and size-resolved particulate matter fractions during the 2024-2025 monitoring period in Galați, Romania. Asterisks indicate statistical significance: ***$p < 0.005$, *$p < 0.01$, $p < 0.05$

Overall, the daytime and nighttime patterns were broadly similar, but several correlations were slightly stronger during nighttime, particularly those involving relative humidity, visibility and the 5 µm fractions.

This may reflect more stable nocturnal atmospheric conditions, reduced dispersion and enhanced particle accumulation.

The *p*-value analysis presented in Figure 6 (asterisks) indicated that several correlations were statistically significant, especially those involving temperature, relative humidity and visibility, whereas weaker correlations involving atmospheric pressure, wind speed and wind direction should be interpreted with caution.

As shown in Table 1, most moderate and strong correlations were statistically significant, with *p*-values below 0.005.

Table 1. Main statistically significant moderate and strong correlations identified during the 2024-2025 monitoring period

An.	Cond.	PM	Par.	r	*p*-value
Ov.	Full	5 µm	RH	−0.61	<0.005
Ov.	Full	5 µm	T	0.57	<0.005
Ov.	Full	0.5 µm	Vis.	−0.53	<0.005
Seas.	Sum.	0.5 µm	Vis.	−0.72	<0.005
Seas.	Aut.	5 µm	RH	−0.65	<0.005
Day	Sum.	0.5 µm	Vis.	−0.70	<0.005
Night	Sum.	0.5 µm	Vis.	−0.74	<0.005
Night	Spr.	5 µm	T	0.53	<0.005
Night	Spr.	5 µm	RH	−0.56	<0.005
Night	Aut.	5 µm	RH	−0.65	<0.005

Note. An. = analysis; Cond. = condition; Ov. = overall analysis; Seas. = seasonal analysis; Day = daytime; Night = nighttime; Full = full monitoring period; Spr. = spring; Sum. = summer; Aut. = autumn; PM = particulate matter fraction; Par. = meteorological parameter; T = temperature; RH = relative humidity; Vis. = visibility. The table includes only strong correlations, defined as $|r| \geq 0.50$. The sign of r indicates the direction of the relationship.

The strongest and most consistent relationships were observed for relative humidity, temperature and visibility, especially in relation to the 0.5 µm and 5 µm particle fractions.

CONCLUSIONS

The results of this study highlight the influence of local meteorological conditions on size-resolved particulate matter dynamics in the urban area of Galați during the 2024-2025 monitoring period. The strongest relationships were observed for temperature, relative humidity and visibility, particularly in relation to the 0.5 µm and 5 µm particle fractions. The 5 µm fraction showed strong sensitivity to humidity-related processes, with negative correlations with relative humidity, while its positive correlations with temperature suggest that warmer and drier conditions may favor the persistence or resuspension of coarse particles.

The negative correlations between visibility and the 0.5 µm fraction, especially during summer and nighttime conditions, indicate that fine particles may play an important role in reducing atmospheric visibility through light scattering. Seasonal analysis showed that the relationships between meteorological parameters and particulate matter were not constant throughout the year, with stronger correlations generally observed during winter, spring and autumn, and weaker or more variable associations during summer.

The comparison between daytime and nighttime conditions indicated broadly similar patterns, but several correlations were slightly stronger during nighttime. This suggests that more stable nocturnal atmospheric conditions, reduced vertical mixing and lower dispersion may contribute to particle accumulation near the surface. In contrast, atmospheric pressure, wind speed and wind direction showed weaker and less consistent relationships with particle concentrations and should therefore be interpreted with caution.

Overall, the combined use of the Rapid-E+ monitoring system and the ACTRIS RADO Galați meteorological station proved suitable for continuous, high-resolution investigation of urban aerosol dynamics. The results provide useful insight into the interaction between meteorological variability and particle size distribution and support the use of integrated monitoring systems for urban air quality assessment.

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