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Spatio-temporal Assessment of PM10 and its Correlation with Meteorological Parameters: A Case Study in Cumilla, Bangladesh

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Research Article

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Abstract

Particulate matter (PM10) is one of the major environmental and public health issues in Bangladesh. This study is focused on the spatiotemporal variations of PM10, and its relationships with the most important meteorological parameters (temperature, relative humidity, and rainfall) in the city of Cumilla, Bangladesh. The study is based on the empirical data collected from the monitoring station of the Department of Environment, Bangladesh during the month of January to April 2026, and analyzed statistically using Pearson correlation matrix and trend analysis. The values obtained show the high concentration of PM10 in the dry winter period with the highest concentration occurring in the month of February at an average of 210.7 µg/m3, which is higher than the national limits. On the other hand, April, the start of pre-monsoon season, experienced a significant decrease in PM10 concentration of 88.3 µg/m³. The correlation coefficient shows good negative correlation between PM10 and temperature (r = -0.87) and rainfall (r = -0.89). The methodology and results offer a solid basis for local environmental authorities to forecast the peaks of pollution and design mitigating policies for the seasonal sources such as biomass burning and brick kilns.

1. Introduction

Urban Agglomerations in Bangladesh experience significant air pollution and the resulting impacts on health, infrastructure resilience and sustainable development are a major concern (Pavel et al. 2021). Particulate matter with aerodynamic diameter less than 10 micrometers (PM10) is a major pollutant which is mostly generated from brick kiln operations, construction activities and vehicular emissions (Zeb et al. 2024; Salam et al. 2021). These emission sources combine with relatively stable atmospheric conditions during the dry winter season, leading to some very bad pollution episodes in the region.

The dispersion and deposition of PM10 can be influenced by meteorological conditions like relative humidity, rainfall and temperature, which can be explained as the natural process, however, the exact dispersion process in regional hubs, such as Cumilla, is inadequately documented (Islam et al. 2021). It is important to understand the meteorological interactions of PM10, so the air quality forecast and environmental engineering intervention is correct. This paper thus examines the monthly fluctuation of PM10 and its empirical correlation with the atmospheric dynamics from January to April 2026 in Cumilla.

2. Study Area and Data Acquisition

Cumilla is a significant urban and commercial hub of Bangladesh and is faced with the rapid growth of infrastructure. The data for this research is obtained strictly from the report of the Department of Environment at the Cumilla monitoring station. It comprises a set of real-time daily measurements that are collected and combined into monthly averages for January, February, March and April 2026. Target parameters were the concentration of PM10 (µg/m3), the average temperature (°C), the average relative

humidity (%) and the average rainfall (mm). The monthly average values of these parameters are summarized in Table 1.

3. Methodology

The analytical framework is based on quantitative statistical analyses to identify spatial patterns and relationships. The data was normalized before calculating the Pearson Correlation Matrix to determine the linear association between PM10 and meteorological factors. The study procedure is as shown in Fig. 1.

The strength and direction of the linear relationship between PM10 and each meteorological parameter were quantified using the Pearson correlation coefficient (r), calculated as:

$$r = \Sigma[(x_i - \bar{x})(y_i - \bar{y})] / \sqrt{\{\Sigma(x_i - \bar{x})^2 \cdot \Sigma(y_i - \bar{y})^2\}}$$

where x_i and y_i are the individual monthly average values of the two variables being compared (for example, PM10 and temperature), and $\bar{x}$ and $\bar{y}$ are the mean values of each variable over the study period (January–April 2026). The numerator represents the covariance between the two variables, while the denominator normalizes this by the product of their individual standard deviations, constraining r to a range of − 1 to + 1. A value close to − 1 indicates a strong negative (inverse) linear relationship, a value close to + 1 indicates a strong positive relationship, and a value near 0 indicates little to no linear association. In this study, r was computed pairwise between PM10, temperature, humidity, and rainfall using the four monthly averages in Table 1, producing the correlation matrix shown in Fig. 3.

Table 1
Monthly averages of PM10 and meteorological matrix variables.

Month (2026)	Avg PM10 (µg/m³)	Avg Temp (°C)	Avg Humidity (%)	Avg Rainfall (mm)
Jan	186.5	19.2	77.3	0.0
Feb	210.7	22.0	66.6	0.0
Mar	112.3	25.2	76.3	0.01
Apr	88.3	26.9	80.6	0.03

4. Results and Discussion

4.1 Temporal Variations in PM10

Based on results of analytical profiling, the highest PM10 load is observed in mid winter in Cumilla, as shown in Fig. 2. The highest average peak reading was achieved in February at 210.7 µg/m³ and the highest daily peak reading was 335.8 µg/m³. These observations are in line with the previous research (Gulshan et al. 2021) that shows that wintertime atmospheric inversions can lead to the accumulation of

pollutants released from the regional brick kilns. During the transition period towards the pre-monsoon season, in April, the concentration of PM10 dropped significantly by about 58% to 88.3 μg/m³.

4.2 Meteorological Influence and Correlation

Meteorological conditions act as dominant catalysts in the distribution of particulate matter. The Pearson Correlation matrix (Fig. 3) provides quantitative insights into these relationships.

There is a strong negative relationship between PM10 and Temperature (r = -0.87). The atmospheric convection/dispersion of pollutants was aided by the increase in the boundary layer heights as the temperatures gradually increased from 19.2°C in January up to 26.9°C in April (Zeb et al. 2024). The first two months of the year received very small amount of rainfall, followed by the months of March and April (maximum events of 10.60 mm). As is shown in the correlation matrix, rainfall is negatively correlated with PM10, r = -0.89, which is due to the physical scrubbing of the lower atmosphere by wet scavenging and washout of rain droplets. The correlation between relative humidity was relatively low (r = -0.78) and was not linear, and was largely independent of direct particulate loading.

4.3 Scatter Plot Analysis of PM10 and Meteorological Parameters

Scatter plots for the four highest pairwise linear correlations that were identified from the Pearson Correlation Matrix were created: PM10 vs. temperature, PM10 vs. rainfall, PM10 vs. relative humidity, and temperature vs. rainfall. The four monthly average values of each plot shown in Table 1 are used on each plot, and a linear trend line is added to show the direction of association.

Figure 4 indicates a definite decrease in the average concentration of PM10 with an increase in the average temperature of the month, from 186.5 μg/m³ in January to 88.3 μg/m³ in April. The negative slope of the curve (r = -0.87) supports this explanation: as the temperature rises, there is increased mixing of the air within the atmosphere, and expansion of the boundary layer, which causes particulate matter to disperse more readily and not become concentrated closer to the ground.

The best correlation in this study is shown in Fig. 5. The two months with the highest PM10 loading, January and February, experienced rainfall of almost zero (0.0 mm) with a slight increase of rainfall in March and April (0.01 and 0.03 mm), respectively, and corresponding to the most significant decrease in PM10 loading. This is almost an inverse relationship (r = -0.89), consistent with the wet scavenging mechanism, that is, even small increases in rainfall wash suspended particles out of the air.

The association between relative humidity and PM10 is weaker but still relatively strong as seen in Fig. 6. The highest PM10 concentrations were observed in February with the lowest humidity (66.6%) and the lowest PM10 concentrations were observed in April with the highest humidity (80.6%). The correlation between humidity and PM10 exposure is not as direct as with temperature and precipitation, however, as January has high humidity (77.3%) and high PM10 (186.5 μg/m³), it implies that the PM10 exposure

associated with high humidity is rather complex and would need to be related to other factors such as temperature and seasonal emissions.

Another secondary relationship within the dataset, illustrated in Fig. 7, was found between temperature and rainfall, as they both rose over the study period (r = 0.87), which is related to the seasonal shift in the region from the dry and cool winter to the warmer and wetter pre-monsoon. This positive correlation is important because it helps to explain the decrease in PM10 seen from January to April, which is compounded by both temperature and rainfall.

5. Conclusion

This study establishes the relationship between PM10 pollution and meteorological dynamics in a systematic way in the context of empirical data from January to April 2026 in Cumilla. Results indicate that the particulate matter concentration was alarmingly high during February, this was largely due to decrease in temperature and precipitation, meaning that the winter is the critical vulnerability time duration. The significant negative relationship between PM10 and temperature, and PM10 and precipitation indicate that the most important natural methods of abatement are dispersion and wet deposition. These empirical understandings are important for civil and environmental engineers to shape time bound infrastructural and industrial regulations to reduce peak pollution levels in the fast-growing areas of Bangladesh during the season.

Declarations

Ethical Approval

This is not applicable. This study did not involve human participants, human data, or animals; it is based solely on secondary, publicly reported environmental monitoring data.

Consent to Participate

This is not applicable.

Consent to Publish

This is not applicable.

Competing Interests

The author declares no competing interests.

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Authors' Contributions

Abu Bakor Siddique Patwary is the sole author of this manuscript and was responsible for the conceptualization, data collection, formal analysis, and writing of the manuscript.

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Data Availability Statement

The data used in this study were obtained from the Department of Environment, Bangladesh, and are available from the corresponding author upon reasonable request.

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Figures

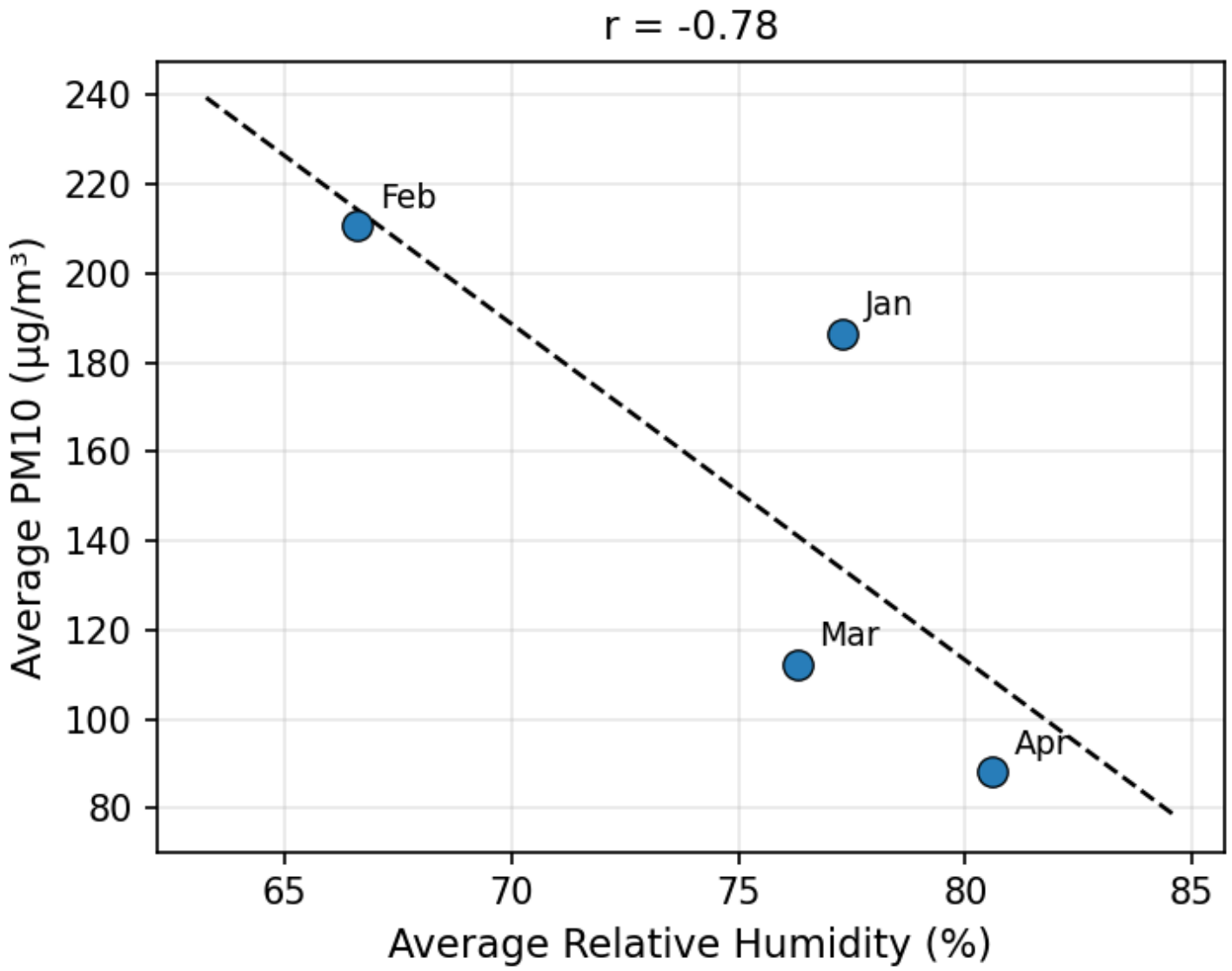


Figure 1

Methodological framework representing the step-by-step processes of the environmental research.

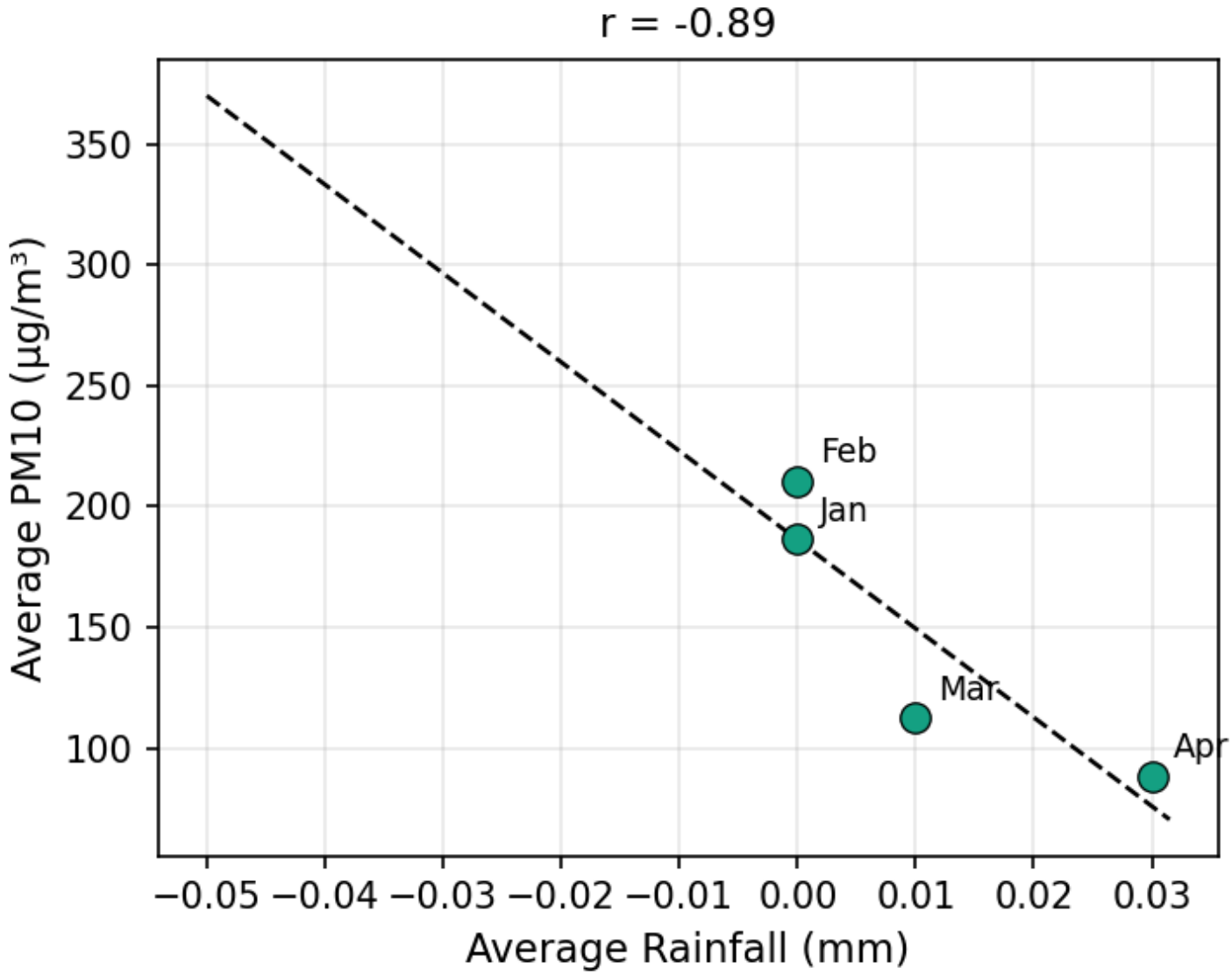


Figure 2

Comparative monthly temporal variations of average PM10 against Temperature and Humidity.

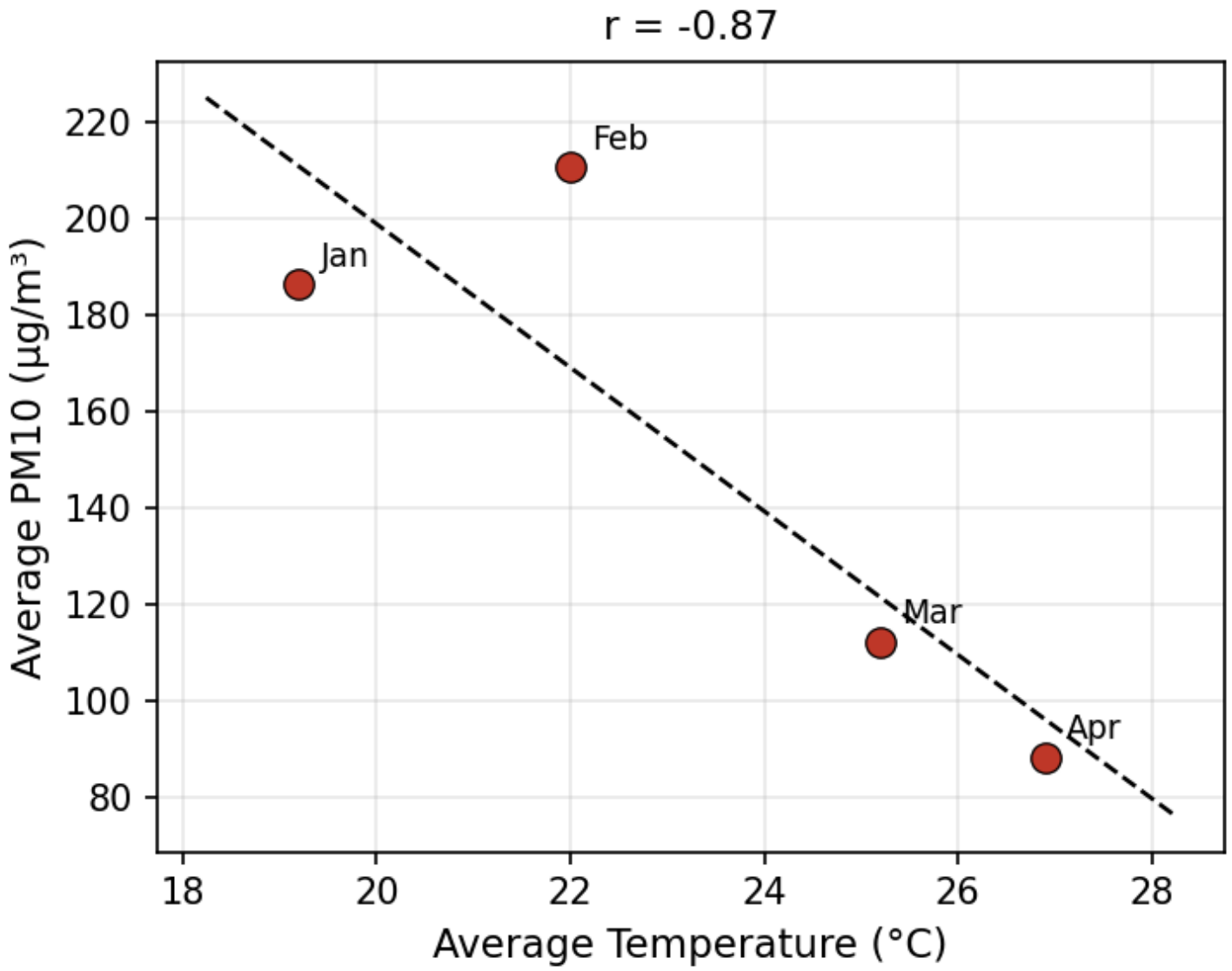


Figure 3

Pearson Correlation Heatmap detailing the interaction between PM10 and atmospheric variables.

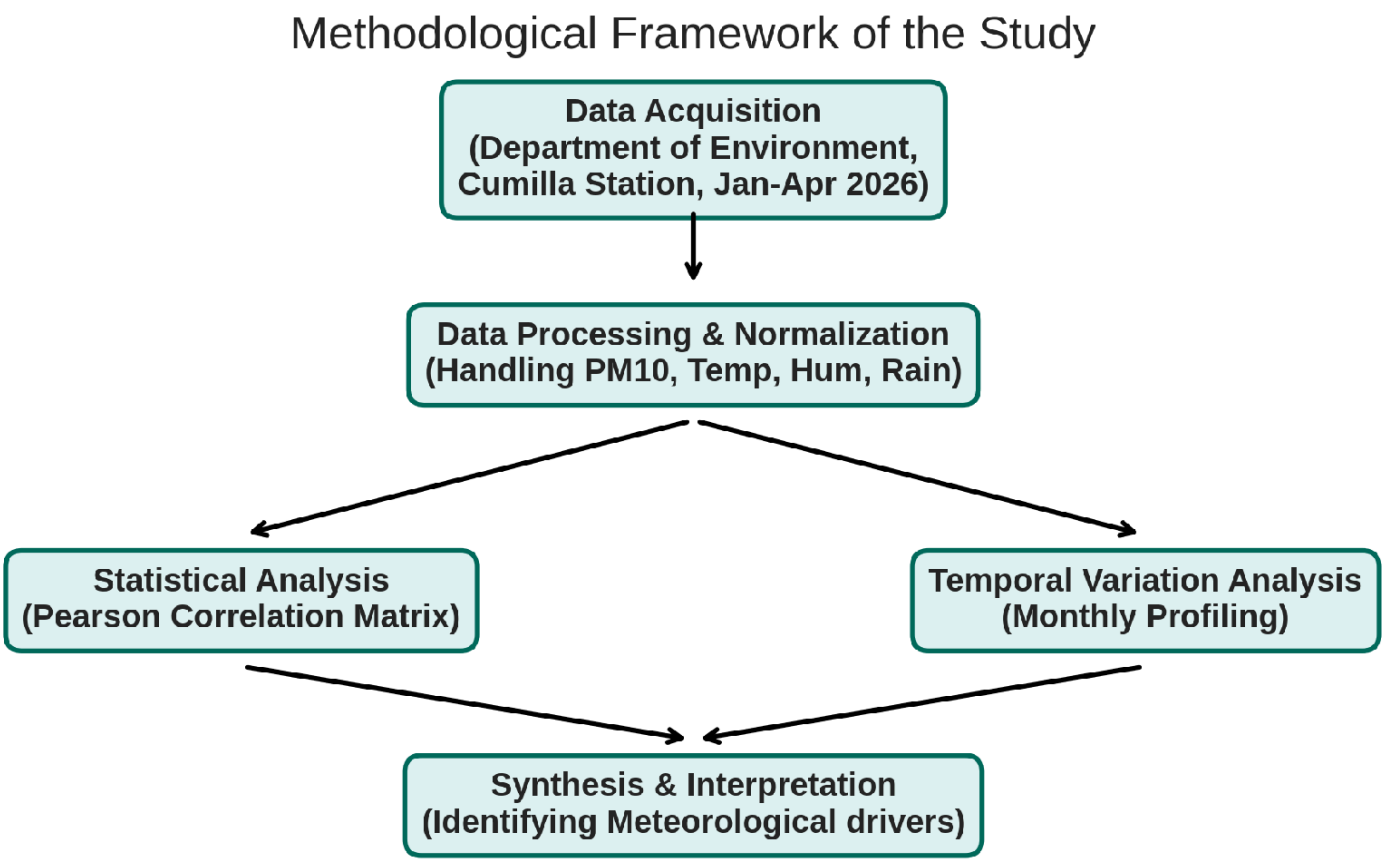


Figure 4

Scatter plot of average PM10 against average temperature (r = -0.87).

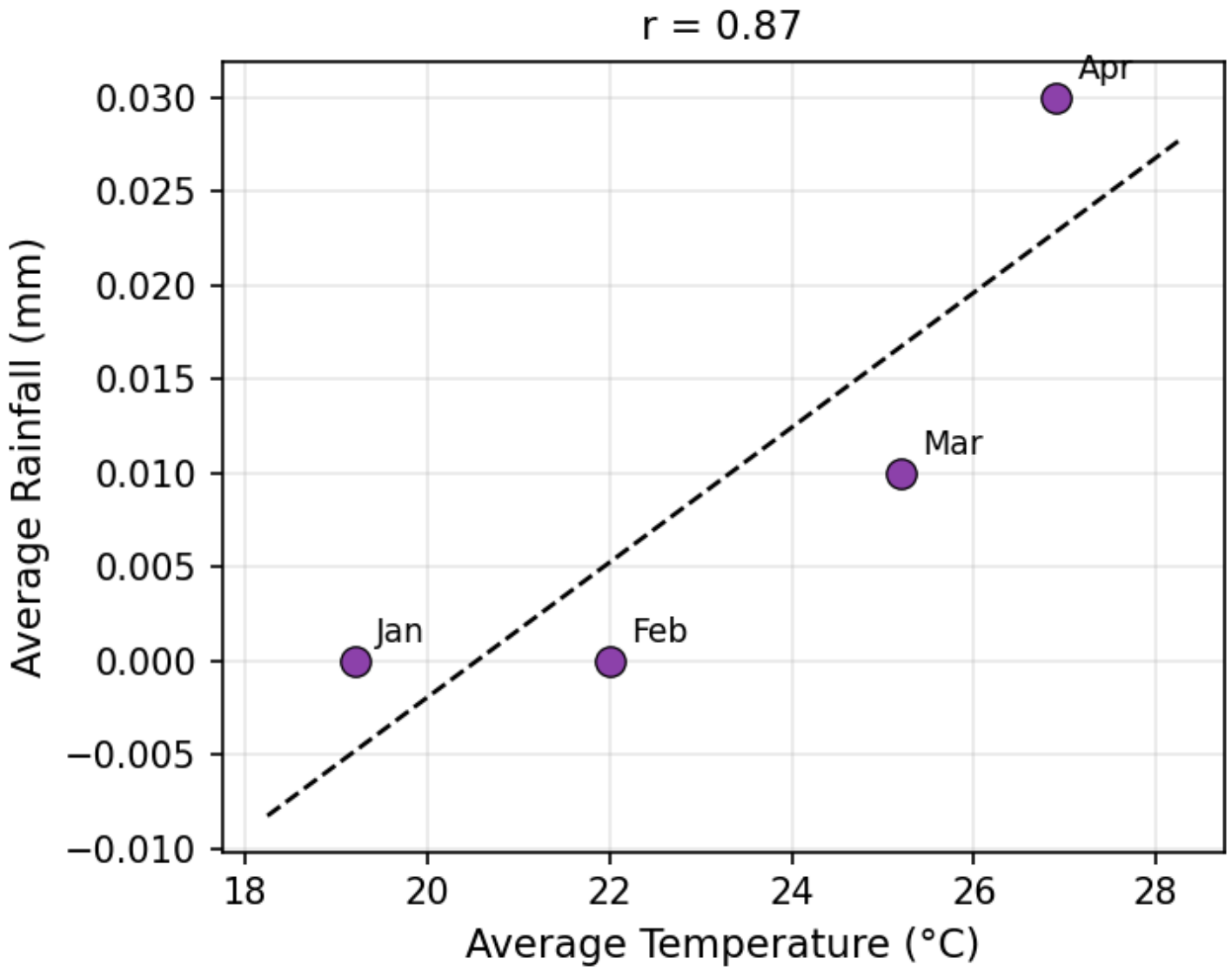


Figure 5

Scatter plot of average PM10 against average rainfall (r = -0.89).

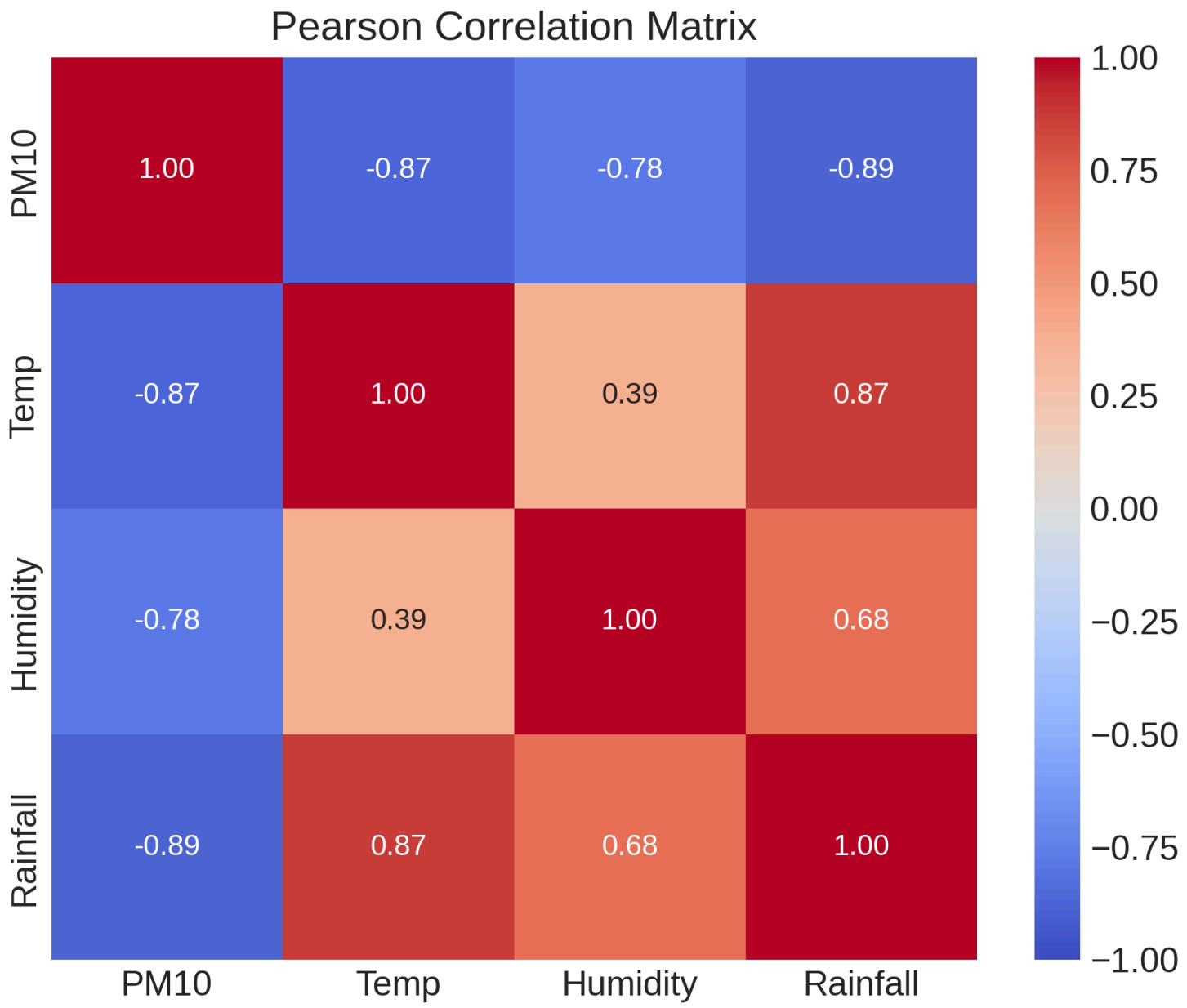


Figure 6

Scatter plot of average PM10 against average relative humidity (r = -0.78).

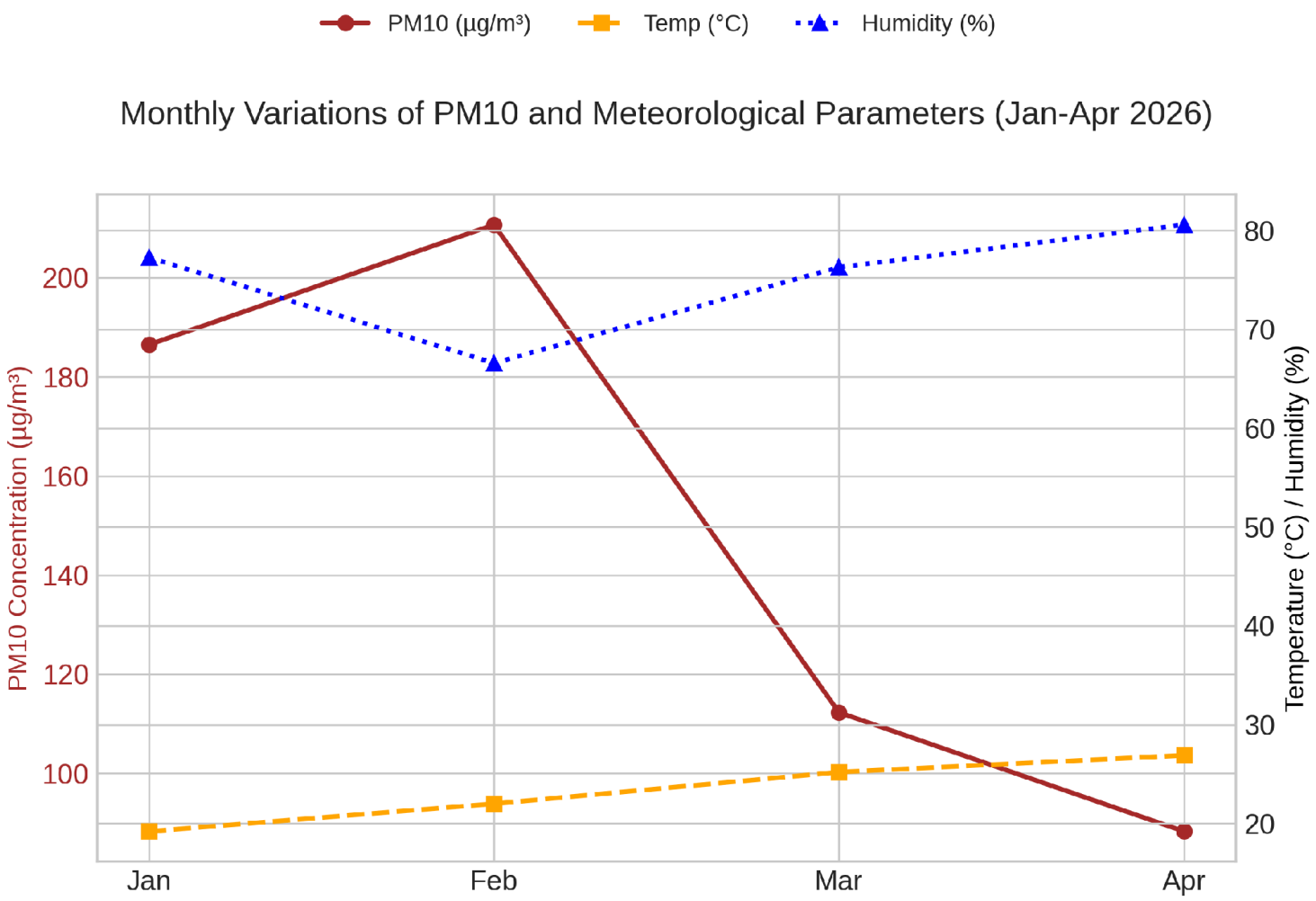


Figure 7

Scatter plot of average temperature against average rainfall (r = 0.87).