A Field Study on the Spatio-temporal Distribution of PM2.5 in Shanghai's Urban Street Canyons: An Analysis of Geometrical and Meteorological Influences

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Abstract. This study reveals that the daily mass concentration of PM2.5 in the street canyons of Shanghai's Yuanshen Road exhibits a characteristic "V"-shaped pattern. Field measurements from August 22nd to 24th, 2025, also identified a clear spatial hierarchy, with pollution levels descending from road intersections to roadsides, community parks, and finally to general street canyons. Several factors were found to mitigate PM2.5 concentrations, including increased wind velocity, greater distance from emission sources, and the presence of green plants. A regression model further highlighted humidity as a more significant determinant than temperature for PM2.5 levels during the summer measurement campaign. These findings are critical for understanding and improving air quality in urban street canyons, which constitute the primary habitats for city residents and are heavily impacted by PM2.5 pollution.

Keywords: PM2.5; Urban Street Canyon; Spatial and Temporal Distribution; Air Pollution.

1. Introduction

As one of the world's most prominent cities and China's second-largest metropolis with a 2023 population of 24.87 million [1], Shanghai has grappled with a persistent air pollution issue for over a decade, stemming from its rapid development. While recent governmental and environmental initiatives have successfully reduced overall pollution, significant challenges remain. For instance, the city's average PM2.5 concentration in 2023 was 25 micrograms per cubic meter. Although this figure complies with national secondary standards, it still surpasses the WHO's recommendation, and the city continues to experience a notable number of days with mild or higher pollution levels [2].

The significant health risks posed by particulate matter, particularly PM2.5, distinguish it as a primary concern among various ambient air pollutants such as SO2, NO2, CO, and O3. The danger of PM2.5 lies in its small particle size, which facilitates its infiltration deep into the lungs, entry into the circulatory system, and even passage to the brain [3]. The resulting health impacts can be categorized as either short-term or long-term. High-level short-term exposure can trigger respiratory distress, including coughing and burning sensations in the throat, or worsen pre-existing problems. Chronic exposure, however, can lead to critical health complications, as evidenced by research linking each 10 $\mu g/m^3$ rise in PM2.5 concentration to a 15-27% increase in lung cancer mortality [4].

Urban canyons are environments formed in cities by streets surrounded by buildings. Urban canyons have been researched by Nicholson [5]. In a large city, such as Shanghai, "artificial canyons" are everywhere and make up most of the spaces in which most people will experience their daily life. Air quality in urban canyons is driven by many factors, including traffic volume, temperature, humidity, weather (i.e., wind speed), and the aspect ratio (i.e., height-to-width) of the canyon [6]. Air quality is compounded in these typically more closed off spaces. Although most of the studies and research for PM2.5 in Shanghai focused on macroscopic spaces for the city, there is limited research on the microscopic spaces of urban canyons where humans are most exposed. For this reason, the objective of this study is to research the spatial distribution of PM2.5 in urban canyons, so healthier urban planning and people's travel decisions can be made.

2. Methodology

2.1. Research Methodology

This investigation chose representative points that exhibited typical characteristics like the height-to-width ratio of buildings, the street's geometry, vegetation, and wind. Field observations were conducted at seven different points on Yuanshen Road in order to investigate the temporal and spatial distribution of PM2.5 mass concentrations.

Street canyons typically can be classified using many classifications [7]: (1) aspect ratio (H/W); (2) symmetry (e.g., symmetric, asymmetric step-up, asymmetric step-down); and (3) complex geometry (e.g., general street canyons, intersection, park, etc.). Real world street canyons fit multiple different classifications so simply using classifications will not fully capture the spatial distribution of pollutants. As a result, this research utilized the Street Canyon Enclosure Ratio (SCER) [8] which is defined as the ratio of the leeward building's height (LB) to the road's width (W) to the windward building's height (WB). The values for the SCER were derived from measurements taken during observations as well as during wind directions that were labeled leeward and windward based on the primary wind direction during the study period as illustrated in Figure 1.

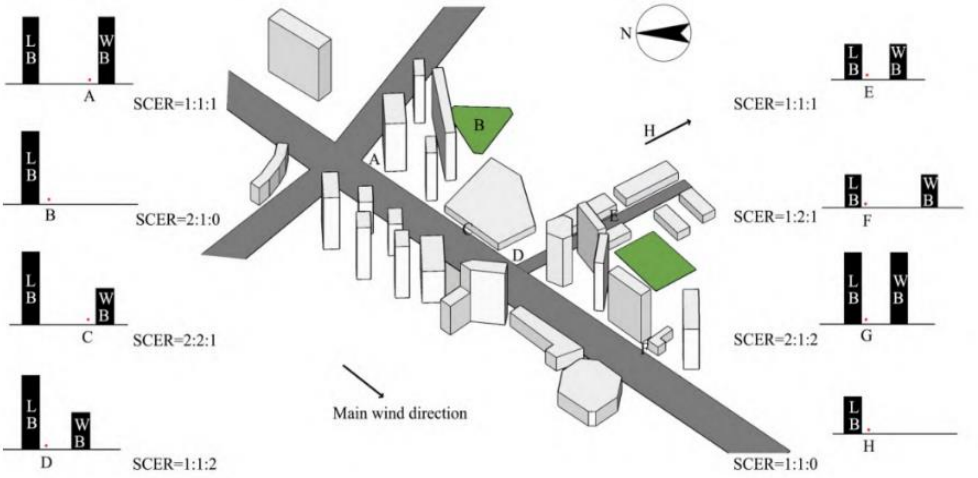


Figure 1. On-site Measurements for SCER.

2.2. Research Instruments

The devices used were hand-held PM2.5 detectors and anemometers. The PM2.5 monitor monitored three parameters (PM2.5 mass concentration, temperature, and humidity) to track what concentration of dust was present. The handheld monitor specifications are listed below:

PM2.5 range (0-100 $\mu g \cdot m^{-3}$; accuracy: ±5% FS; resolution: 0.1 $\mu g \cdot m^{-3}$)

Temperature range (-20-60 ℃; accuracy: ±0.7%; resolution: 0.1 ℃)

Relative humidity range (0-100%; accuracy: ±5%; resolution: 0.2%).

The data was recorded at a basis of every 2 hours for the duration of the monitoring period, and the monitoring height was also positioned at 1.7 m from the ground to reflected the average position of the human breathing average.

2.3. Research Period

The field campaign was carried out between August 22nd and 24th, 2025, under persistently clear meteorological conditions. During this period, all measurements were taken daily between the hours of 08:00 and 18:00.

3. Results

The assessment of temporal and spatial trends is based on the daily averages of 126 accurate data points, which were collected from seven locations throughout the three-day field campaign.

3.1. Temporal and Spatial Characteristics of PM2.5

As depicted in Figure 2, the average daily PM2.5 concentration exhibited a clear "V" shape, with an overall mean concentration of 28.54 μg·m⁻³ across all monitored street canyons. The greatest concentration of this period occurred between 08:00 and 10:00 (the average for this period was 34.96 μg·m⁻³); this coincides with the busy morning commute. The lowest mass concentration amount was during the time period of 12:00-14:00 (the average was 14.15 μg·m⁻³). A second peak is observed during the busy evening commute from 16:00 to 18:00. Keeping this in mind suggests that residents should plan to leave during early afternoon times (i.e., 12:00-14:00) and not to leave during peak morning and evening times in general.

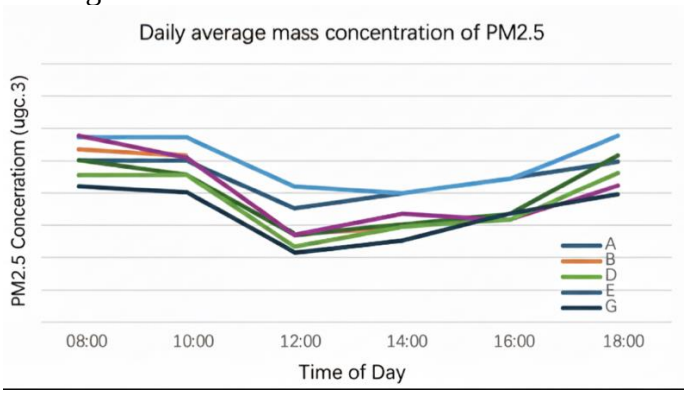


Figure 2. Daily Average Mass Concentration of PM2.5 at Measurement Sites.

The spatial analysis revealed a distinct hierarchy of PM2.5 pollution based on the functional type of the street canyon. The highest concentrations were consistently found at road junctions, followed in descending order by roadsides, community parks with green spaces, and general street canyons. This conclusion is substantiated by the specific average mass concentrations recorded at each measurement point, which are detailed in Figure 3. The ranking from highest to lowest was: Point D (35.90 μg·m⁻³), A (31.26 μg·m⁻³), C (30 μg·m⁻³), E (29.62 μg·m⁻³), B (28.90 μg·m⁻³), G (26.42 μg·m⁻³), and F (24.36 μg·m⁻³).

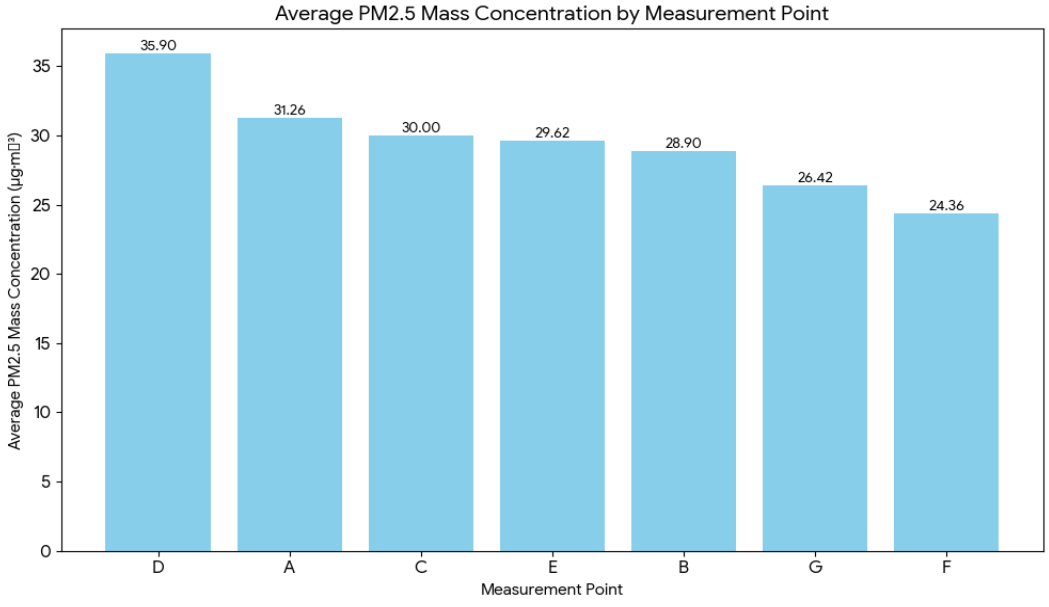


Figure 3. Average PM2.5 Mass Concentration by Measurement Point (concentration from high to low).

An analysis of each site's unique combination of morphology, traffic, and environmental features explains the observed PM2.5 variations. The highest concentrations, for instance, were found at un-vegetated intersections. Point D, an asymmetrical step-up canyon (SCER=1:1:2), recorded the peak average concentration (35.90 $\mu g \cdot m^{-3}$), which was a product of both heavy traffic and a morphology known to trap pollutants on its leeward side. Similarly, high levels at Point A, a symmetrical canyon (SCER=1:1:1) between high-rises, were attributed to prolonged vehicle idling. In contrast, the presence of vegetation and specific building layouts proved effective at mitigating pollution. Point B (asymmetrical step-down, SCER=2:1:0) benefited from the dual advantages of PM2.5-degrading flora within its park setting and a wind-blocking effect from its position on the leeward side of a tall building. Although Point C (asymmetrical step-down, SCER=2:2:1) was on a high-traffic road, it was buffered by a green belt, and its data, when compared to Point A, demonstrates that lower windward buildings reduce PM2.5. Furthermore, street geometry and ventilation were critical factors. While Point E (symmetrical, SCER=1:1:1) showed moderate pollution corresponding to its moderate traffic and green belt, Point F (wide symmetrical, SCER=1:2:1) highlighted how a wider street enhances ventilation and lowers concentrations. Finally, Point G (narrow symmetrical, SCER=2:1:2) exemplified the powerful influence of wind; here, high wind speeds combined with low traffic volumes overcame the narrow geometry to produce a very low PM2.5 concentration through enhanced diffusion.

3.2. Environmental Factors

The significant role that factors such as wind, traffic, and vegetation play in determining PM2.5 distribution in street canyons is well-documented in the scientific literature [8, 9].

3.2.1 Temperature and Humidity

A multiple linear regression model was developed to express the combined influence of temperature (t) and relative humidity (H) on the average hourly PM2.5 concentration, resulting in the final equation below:

$$\rho(PM2.5) = -587.92 + 23.35 \times t + 6.64 \times H \quad (1)$$

where t=temperature, H=humidity.

The multiple linear regression model, represented by Equation (1), possesses an R^2 value of 0.53, indicating that 53% of the variance in PM2.5 concentration can be attributed to the combined effects of temperature and humidity. Among these two factors, the analysis revealed a significant association between humidity and the mass concentration of PM2.5 during the study period. The model also yielded a weak positive association between PM2.5 and temperature. This is noteworthy, as an increase in temperature is typically expected to lower PM2.5 concentrations by expanding the atmospheric boundary layer and thereby enhancing pollutant dispersion [10]. This counterintuitive finding will be explored in greater detail in the Discussion section.

3.2.2 Wind Speed

The fate of PM2.5 within street canyons—specifically its transport, dilution, and diffusion—is heavily dependent on wind conditions [11]. A strong inverse relationship between local wind speed and PM2.5 levels was observed, underscoring the critical role of urban ventilation. This is evidenced by the spatial distribution of wind velocity, which ranged from a high of 2.43 $m \cdot s^{-1}$ at Point G to a low of 0.46 $m \cdot s^{-1}$ at Points B and E. The complete ranking was G > F (1.16 $m \cdot s^{-1}$) > A (1.01 $m \cdot s^{-1}$) > C (0.66 $m \cdot s^{-1}$) > D (0.59 $m \cdot s^{-1}$) > B = E. This spatial variance was complemented by a distinct temporal pattern shown in Figure 4, where wind speeds were consistently lower in the mornings than in the afternoons. This daily phenomenon, combined with rush hour emissions, contributes to PM2.5 retention and the high pollution levels typically seen in the morning.

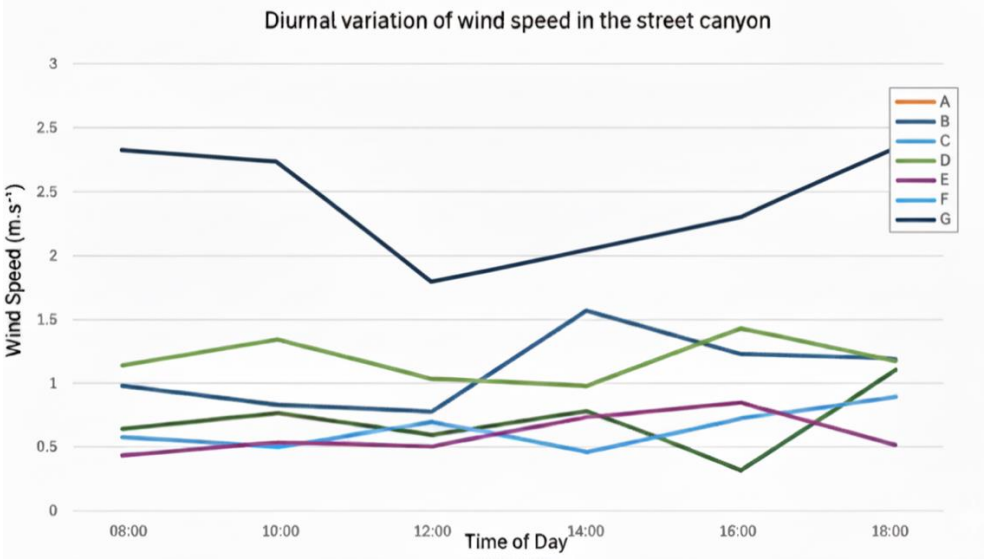


Figure 4. Diurnal Variation of Wind Speed in the Street Canyon.

4. Discussion

As with any research, the limitations of this study need to be considered. The findings of this study are based on a short-term monitoring period of only three days and conducted in the summer. For a more thorough validation of these initial conclusions and a better understanding of PM2.5 dynamics, long-term monitoring would need to be conducted throughout different seasons.

The existing body of literature generally posits a negative correlation between temperature and PM2.5, which is explained by the thermal expansion of the atmospheric boundary layer that promotes pollutant dispersal [12]. In contrast to this established principle, a notable finding from the present study was the observation of a small but positive correlation between these two variables. This suggests that the interactions which occur in street canyons are highly complex. This effect could possibly be due to local factors during the measurements, such as the dominating effects of the high background concentrations or specific photochemical reactions present in a high-temperature summer regime. This anomaly should be subject to continued investigations.

In this study, the SCER concept was applied to categorize canyon types, which was useful for spatial analysis. Nevertheless, a more precise quantitative analysis could further develop this study by modeling the relationship between SCER values and measured PM2.5 concentrations. Modeling this relationship would provide more rigorous, evidence-based justification for urban planning guidelines. Furthermore, assessing the synergistic effect of different species of plants with different canyon morphologies, as well as varying meteorological conditions, could form a fruitful approach to future research into PM2.5 degradation.

5. Conclusion

This investigation into the spatio-temporal distribution of PM2.5 within the street canyons of Shanghai's Yuanshen Road revealed a highly consistent diurnal pattern. The average daily concentration was found to follow a distinct "V" shape, characterized by peaks that coincided with the morning and evening traffic rush hours and a trough during the midday period. Spatially, PM2.5 concentrations significantly vary depending on the form and function of a street canyon, with the peak concentrations being detected at busy intersections and the lowest concentrations in areas with significant green space or better ventilation. It was also confirmed that wind speed, distance from traffic, and vegetation were important influencing factors.

The findings have real-world applications for urban planning and public health. There are numerous methods and urban design solutions such as wider street canyons, park green spaces, and

urban ventilation corridors that can reduce PM2.5 pollution at the local level. In addition, for residents exposed to PM2.5 pollution, avoiding outdoor activities during the busiest traffic hours is advisable. Lastly, this study highlighted the complicated relationship between meteorological factors and PM2.5 in micro-environments and flagged the potential for further studies on this subject matter.

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