

Evaluation of atmospheric particulate matter removal and influencing factors of common urban trees in Fuzhou, China

XIAOYUN WANG

541981557@qq.com

Aimin FU

Research Article

Keywords: Fuzhou, urban trees, atmospheric particulate matter, reduction effect, carrying capacity, correlation analysis

Posted Date: October 22nd, 2025

DOI: <https://doi.org/10.21203/rs.3.rs-7629494/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Evaluation of atmospheric particulate matter removal and influencing factors of common urban trees in Fuzhou, China

WANG Xiaoyun^{1,*}, FU Aimin²

¹School of Ecological Environment and Urban Construction, Fujian University of Technology, Fuzhou 350008, China

²Fujian Ningde Nuclear Power Company Limited, Ningde 355200, China

*Email: 541981557@qq.com

Abstract

Five common urban tree species in Fuzhou, China, were selected to quantify the dry deposition of atmospheric particles and related water-soluble ions per unit leaf area using a three-layer membrane filtration method. Particulate matter (PM) measured included total suspended particles (TSP), PM₁₀ ($d_p \leq 10 \mu\text{m}$), and PM_{2.5} ($d_p \leq 2.5 \mu\text{m}$), while water-soluble ions included NO₃⁻ and SO₄²⁻. The average dry deposition fluxes on leaf surfaces were 1.09, 0.058, 0.011, 0.021, and 0.027 mg/(m²·h) for TSP, PM₁₀, PM_{2.5}, NO₃⁻, and SO₄²⁻, respectively. Corresponding average dry deposition rates were 0.61, 0.06, 0.021, 0.179, and 0.173 cm/s. Three-way analysis of variance showed that TSP flux exhibited significant interactions among time, region, and tree species. Sulfate interception trends indicated that *Bischofia javanica* captured more SO₄²⁻ than other species, suggesting potential long-range transport of SO₂ in December. Over the dry deposition periods (81–432 h), leaf surfaces did not reach saturation. Spearman correlation analysis revealed that dry deposition fluxes were positively correlated with atmospheric concentrations, with stronger correlations for larger particles. TSP deposition rates were weakly negatively correlated with temperature, relative humidity, and wind speed, with only temperature and relative humidity being significant. In contrast, PM₁₀ and PM_{2.5} deposition rates were positively correlated with relative humidity and negatively correlated with wind speed.

Keywords: Fuzhou; urban trees; atmospheric particulate matter; reduction effect; carrying capacity; correlation analysis

1. Introduction

Atmospheric particulate matter (PM) is a major component of air pollution, consisting of solid or liquid microscopic particles suspended in the atmosphere (Wang et al. 2020). Total suspended particles (TSP, $d_p \leq 100 \mu\text{m}$) are among the most common urban pollutants and often contain hazardous substances such as heavy metals, oxides, organic compounds, bacteria, and viruses. Coarse particles (PM₁₀, $d_p \leq 10 \mu\text{m}$) can contribute to chronic rhinitis and bronchitis, whereas fine particles (PM_{2.5}, $d_p \leq 2.5 \mu\text{m}$)—owing to their high specific surface area—easily adsorb toxic compounds. These fine particles can deposit in the bronchi and alveoli, penetrate the bloodstream, and contribute to respiratory and cardiovascular diseases. In 2013, the International Agency for Research on Cancer classified PM_{2.5} as a Group 1 carcinogen (Loomis et al. 2013). The deposition mechanisms of PM vary with particle size. Gravitational settling is dominant for larger particles ($d_p > 20 \mu\text{m}$), inertial impaction due to turbulence governs mid-sized particles ($d_p = 2\text{--}20 \mu\text{m}$), and Brownian diffusion primarily influences fine particles ($d_p < 2 \mu\text{m}$) (Zwerver et al. 1985). Under specific meteorological conditions, the persistence of PM in the atmosphere intensifies haze episodes and exacerbates urban heat island effects (Zhang et al. 2023). Atmospheric

deposition—comprising dry processes (e.g., gravitational settling, diffusion, turbulence) and wet processes (e.g., precipitation scavenging, vapor adsorption)—is the principal pathway for PM removal. Most studies focus on dry deposition, since wet deposition is typically more efficient and therefore less uncertain in its contribution to particulate removal (Li et al. 2023; Yan et al. 2021).

Beyond their aesthetic and ecological functions, urban forests mitigate air pollution by retaining PM on leaves, branches, stems, and roots (Fang et al. 2024; Xu et al. 2019). However, removal efficiency varies across microenvironments, methodological approaches, and spatiotemporal scales (Liu et al. 2020). Existing studies primarily quantify PM removal through foliar accumulation (Li et al. 2024; Lin et al. 2019; Kailibinuer et al. 2022), yet limited field data and methodological inconsistencies restrict the general applicability of these findings. Urban forests affect air quality through both dry deposition and dispersion processes. While foliage captures PM at the local scale, net improvements in air quality depend on interactions with atmospheric diffusion (Zhang et al. 2021; Li et al. 2021), underscoring the need for empirical validation.

The United States Department of Agriculture Forest Service's i-Tree Eco model (2006), developed under the big-leaf theory, estimates pollutant removal by urban forests using tree inventory data, empirical leaf area algorithms, dry deposition velocities, and air quality monitoring records. It has been widely applied across diverse urban contexts, including streets (Riondato et al. 2020), parks (Su 2023), campuses (Zhang 2023), urban cores (Wu et al. 2019; Selmi et al. 2016), and metropolitan regions (Nowak et al. 2013), to quantify ecological benefits through pollutant removal. Because leaf-level PM reduction becomes more pronounced at broader spatial scales, i-Tree Eco generally outperforms micro-scale models (e.g., ENVI-met) for city-wide assessments (de Jalón et al. 2019; Nowak et al. 2016; Riley et al. 2018), although its application at park- and street-tree scales is becoming increasingly common.

Located in a subtropical zone, Fuzhou supports high tree species diversity and heterogeneous leaf morphology. This contrasts sharply with the limited temperate species used to parameterize PM_{2.5} dry deposition in i-Tree Eco, which may introduce substantial model uncertainty. Additional empirical data are therefore required to validate the model's accuracy in quantifying pollutant removal by Fuzhou's urban forests. To address this gap, we selected five dominant native tree species representing two urban forest types: street trees and park plantings. Field sampling and laboratory extraction techniques were employed to quantify foliar retention capacities for TSP, PM₁₀, and PM_{2.5}. By integrating multi-source empirical field data with i-Tree Eco parameters, we analyzed PM reduction dynamics. Specifically, this research examined the following: spatiotemporal variations in atmospheric PM and associated water-soluble ion deposition on foliage; interactions between dry deposition flux/velocity and meteorological drivers; applications of retention characteristics for spatiotemporal pollution monitoring; evidence of long-range pollution transport mechanisms.

2. Study area and methods

2.1. Study area description

Fuzhou (26.08°N, 119.31°E) is located in the eastern subtropical region of Fujian Province, China, along the Taiwan Strait. Three densely populated districts—Gulou, Taijiang, and Cangshan—spanning north to south within the urban core were selected for this study (Fig. 1). Each district hosts an official air quality monitoring station providing continuous data. Five native tree species common to all sites were studied: *Chukrasia tabularis*, *Ficus microcarpa*, *Camphora officinarum*, *Bischofia javanica*, and *Mangifera indica*. Species were selected for their ecological suitability to Fuzhou's climate and the diversity of leaf traits including leaf type (compound/simple), surface morphology, and leaf area, to allow a comprehensive assessment of PM retention. Monitoring stations recorded hourly data on PM (TSP, PM₁₀, and PM_{2.5}) as well as meteorological parameters (e.g., temperature, relative humidity, and wind speed).

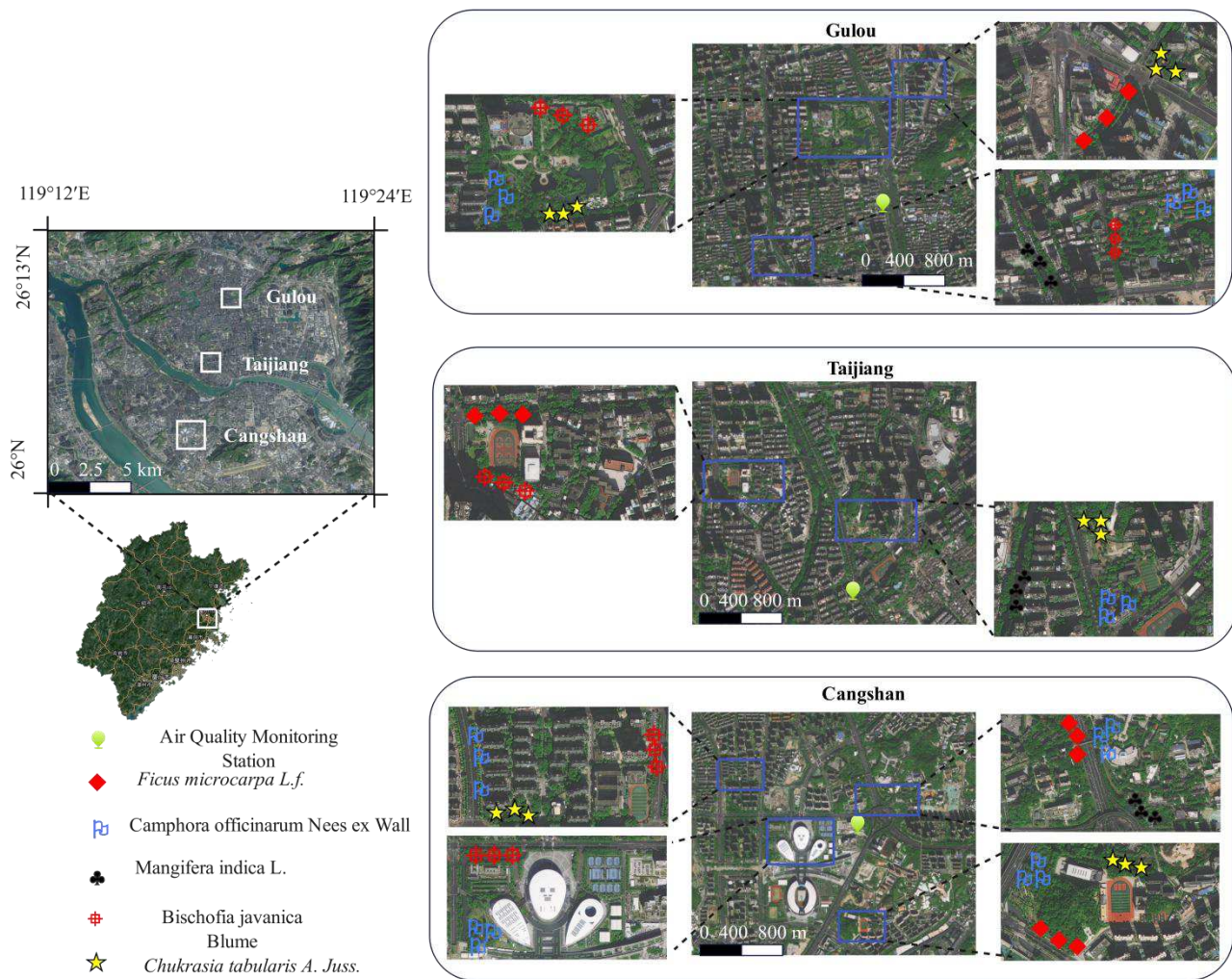


Fig. 1 Geographical location of the study area and distribution of observation sample points

2.2. Sample collection

At each sampling point, three trees of each species were selected for repeated measurements. To maintain consistent sampling conditions, collection was conducted daily from 10:00 to 12:00. Leaves were randomly sampled from different directions within the canopy at a height of 3–5 m above the ground. For larger leaves, 60–80 pieces were collected per tree, while 100–120 pieces were collected for smaller leaves, ensuring that all samples were healthy and pest-free. Collected leaves were immediately placed in sealed bags and transported to the laboratory for storage at 4°C. A total of 12 sampling sessions were conducted across 2023 (September 6, October 7, November 15, and December 20) and 2024 (January 16, February 15, March 15, April 9, May 15, June 12, July 25, and August 31) covering a range of dry deposition periods from 81 to 432 h to capture seasonal variations. The experiment primarily quantified the dry deposition of TSP and water-soluble ions, with the final two sessions also measuring PM₁₀ and PM_{2.5}.

2.3. Sample processing

Prior to washing, leaves were gently brushed on both sides using a soft-bristled brush to remove dust. The leaves were then placed in a 1.5-L wide-mouth glass bottle with 400 mL of distilled water and covered. The bottle was shaken for 5 min and then allowed to soak for 1 h. Subsequently, the bottle was placed in an ultrasonic cleaner (Fuyang F-100SD, Beijing, China) and sonicated for 5 min. After removal of the leaves, 1 mL of the cleaning solution was drawn and filtered through a 0.2-μm hydrophilic polysulfone needle filter (American Pall) into a clean sample bottle for subsequent analysis of water-soluble ions. The remaining solution was first passed

through a 100- μm stainless steel sieve to remove larger debris and then sequentially filtered through 10-, 2.5-, and 0.2- μm polycarbonate membrane filters (American Whatman). The wide-mouth bottle was rinsed twice with distilled water to recover any remaining suspended material. Before use, filter membranes were rinsed with 50 mL of distilled water and dried in a constant-temperature oven at 60°C for 1 h. Pre-weights were measured using an electronic precision balance (Shimadzu UW6200H, Japan), with each measurement repeated three times under stable relative humidity between 35% and 40%. An electrostatic eliminator (Farnell QUICK440A) was used to remove static interference and establish a stable blank value. The three filtered membranes were then re-measured using the same drying and weighing procedures. Suspended particle retention (dry deposition) on the leaf samples was calculated from the mass differences of the filter membranes according to pore size fractions: for 10-, 2.5-, and 0.2- μm pores, particle masses were defined as PM_{10-100} , $\text{PM}_{2.5-10}$, and $\text{PM}_{0.2-2.5}$, respectively. TSP mass was calculated as the sum of PM_{10-100} , $\text{PM}_{2.5-10}$, and $\text{PM}_{0.2-2.5}$; PM_{10} mass as the sum of $\text{PM}_{2.5-10}$ and $\text{PM}_{0.2-2.5}$; $\text{PM}_{2.5}$ mass as $\text{PM}_{0.2-2.5}$. After cleaning and drying, leaf samples were measured for single-sided leaf area using a leaf-area-measuring instrument (YMJ-B, 2022). The total single-sided area of all leaves from each plant sample was taken as the total leaf area for that sample (Wang et al. 2020).

2.4. Water-soluble ion analysis

A 1-mL aliquot of each water sample was analyzed for NO_3^- and SO_4^{2-} using an ion chromatography system (Dionex DX-120). The analysis employed an AS9-HC anion column with an AG-24A guard column and an ASRS-300 suppressor to minimize interference. The eluent consisted of a solution of 3-mmol/L sodium bicarbonate and 2.4-mmol/L sodium carbonate.

2.5. Calculation of dry deposition of suspended particles

The amount of suspended particles recovered by washing was taken as the dry deposition on the leaf surface. Following the i-Tree Eco model, the dry deposition flux is calculated using Eq. (1):

$$F = V_d \times C, \quad (1)$$

where F is the dry deposition flux ($\mu\text{g}/\text{m}^2 \cdot \text{s}$), V_d is the dry deposition velocity (m/s), and C is the atmospheric pollutant concentration ($\mu\text{g}/\text{m}^3$). The measured dry deposition must be normalized by the leaf surface area used in the washing process and the deposition time. The leaf surface area corresponds to the total area of sampled leaves, while the deposition time is determined from hourly rainfall data obtained from the air quality monitoring stations. The dry deposition time was defined as the interval between the last rainfall and the current sampling event. Rainfall was considered sufficient to remove retained suspended particles when it exceeded a threshold of 1 mm, consistent with previous studies (Nowak et al. 2013; Gonzalez-Sosa et al. 2017). In such cases, the end of dry deposition is marked, and the next deposition period begins. Dry deposition velocity and atmospheric pollutant concentrations were obtained from nearby air quality monitoring stations. For i-Tree Eco model parameters, the average dry deposition velocity of PM_{10} was set at 0.64 cm/s, accounting for a 50% resuspension rate, while the dry deposition velocity of $\text{PM}_{2.5}$ was calculated based on wind speed, resuspension rate, and additional factors using data from the National Center for Climate Data (Nowak et al. 2013).

To assess whether a carrying threshold exists for the dry deposition of suspended particles on leaf surfaces and to evaluate the effectiveness of rainwater in cleaning leaves, this study categorized initial rainfall amounts into four levels: 1–2 mm, 2–10 mm, 10–20 mm, and >20 mm. This classification allowed examination of how suspended particle deposition varies with the progression of dry deposition time. Because sample trees may experience different atmospheric particle concentrations during the same deposition period, resulting in variable deposition rates, the influence of concentration was removed using Eq. (2):

$$D = A/C, \quad (2)$$

where D is the dry deposition distance (m) and A is the dry deposition amount ($\mu\text{g}/\text{m}^2$). It should be noted that D does not represent the actual particle movement distance but rather the dry deposition condition corresponding to each set of dry deposition velocity data over different deposition times.

2.6. Statistical analysis

To examine differences in dry deposition flux and rates of suspended particles and associated water-soluble ions across sampling times, regions, and tree species, a three-way analysis of variance was performed. When significant differences were detected, multiple comparisons were conducted using the Holm–Sidak method ($\alpha = 0.05$). Dry deposition flux and rate data were log-transformed prior to analysis. Spearman’s correlation was then used to assess relationships between dry deposition flux and atmospheric concentrations, as well as between dry deposition rates and meteorological factors. All statistical analyses were conducted using SPSS 25.0, and results were visualized with Origin 2018.

3. Results and discussion

3.1. Dry deposition flux

Analysis of TSP revealed significant effects of all single and combined factors—time, region, and tree species—on dry deposition flux. Regionally, *Camphora officinarum* ($P < 0.001$) and *Bischofia javanica* ($P < 0.05$) in the Gulou district exhibited significantly higher fluxes than other species. In the Taijiang district, *Ficus microcarpa* had higher deposition fluxes than *Bischofia javanica*,s and *Chukrasia tabularis* ($P < 0.05$). In Cangshan, *Bischofia javanica* and *Ficus microcarpa* exhibited higher fluxes, whereas *Mangifera indica* were significantly lower than other species ($P < 0.001$) (Fig. 2a). Overall, species differences were most pronounced in Cangshan, with the highest flux disparity reaching 2.5 times, whereas in Taijiang, differences were smaller, with the maximum variation around 25%. Over most months, *Mangifera indica* exhibited lower dry deposition fluxes than other species. However, in the Cangshan district, their fluxes were generally higher than in other areas. Significant differences among tree species were observed in most months, except for June and July, when no significant differences were detected (Fig. 2b, 2c). Analysis of monthly trends across districts and species revealed a pronounced peak in dry deposition flux in February. Considering variations in time, region, and tree species, the average TSP dry deposition flux on leaf surfaces was $1.09 \text{ mg}/(\text{m}^2 \cdot \text{h})$.

3.2. Water-soluble ions

Analysis showed that the dry deposition fluxes of NO_3^- and SO_4^{2-} on leaf surfaces were significantly affected by time, region, and tree species for all single factors and interactions, except for the interaction of SO_4^{2-} , which was not significant. Regionally, the NO_3^- flux of *Ficus microcarpa* and *Mangifera indica* was consistently lower than that of other species across all three districts (Fig. 2d). In contrast, the SO_4^{2-} flux of *Camphora officinarum* and *Mangifera indica* was significantly lower than other species only in the Cangshan district (Fig. 2g), while in Taijiang, *Bischofia javanica* exhibited the highest SO_4^{2-} flux (Fig. 2g). Temporally, significant differences in NO_3^- flux among species were observed in most months, except December, February, and April. In general, *Camphora officinarum* had the highest NO_3^- flux, whereas *Ficus microcarpa* and *Mangifera indica* exhibited the lowest (Fig. 2e). For SO_4^{2-} , no significant differences among tree species were observed from December 2023 to April 2024, including March, when high variability contributed to nonsignificance. In other months, *Bischofia javanica* generally exhibited the highest SO_4^{2-} flux, while *Camphora officinarum* and *Mangifera indica* showed the lowest (Fig. 2h). Regionally, NO_3^- flux showed no significant differences across districts in any month (Fig. 2f). In contrast, SO_4^{2-} flux in the Gulou district was higher than in the other two districts for more than half of the sampling months (Fig. 2h). Monthly trends indicated that NO_3^- flux fluctuated throughout the study period, whereas SO_4^{2-} flux peaked notably in December (Fig. 2f, 2i). Integrating fluxes across time, region, and tree species, the average dry deposition fluxes on leaf surfaces were $0.021 \text{ mg}/(\text{m}^2 \cdot \text{h})$ for NO_3^- and $0.027 \text{ mg}/(\text{m}^2 \cdot \text{h})$ for SO_4^{2-} .

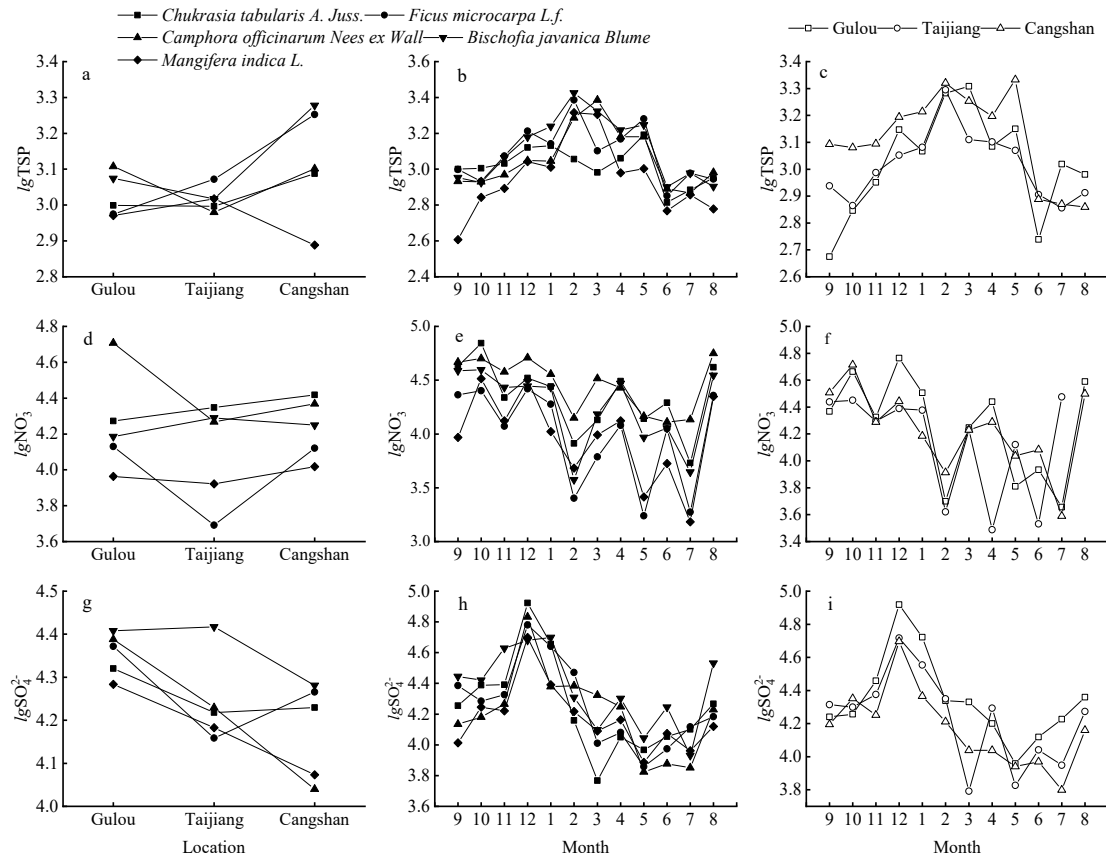


Fig. 2 Trends in leaf surface dry deposition fluxes of TSP (a–c), NO_3^- (d–f), and SO_4^{2-} (g–i) across locations, time, and tree species

3.3. PM_{10} and $\text{PM}_{2.5}$

Measurements of PM_{10} and $\text{PM}_{2.5}$ were conducted only in July and August. No significant interactions among time, region, and tree species were observed for dry deposition fluxes. Among the main effects, fluxes of both PM_{10} and $\text{PM}_{2.5}$ were significantly higher in July than in August ($P < 0.001$) (Fig. 3a, 3b). Regionally, PM_{10} flux differed significantly, with higher values in the Gulou and Taijiang districts compared to Cangshan ($P < 0.05$) (Fig. 3c). For $\text{PM}_{2.5}$, a significant species effect was observed, with *Ficus microcarpa* exhibiting higher fluxes than *Camphora officinarum* ($P < 0.01$) (Fig. 3d). Integrating fluxes across time, region, and species, the average dry deposition fluxes on leaf surfaces were $0.058 \text{ mg}/(\text{m}^2 \cdot \text{h})$ for PM_{10} and $0.011 \text{ mg}/(\text{m}^2 \cdot \text{h})$ for $\text{PM}_{2.5}$.

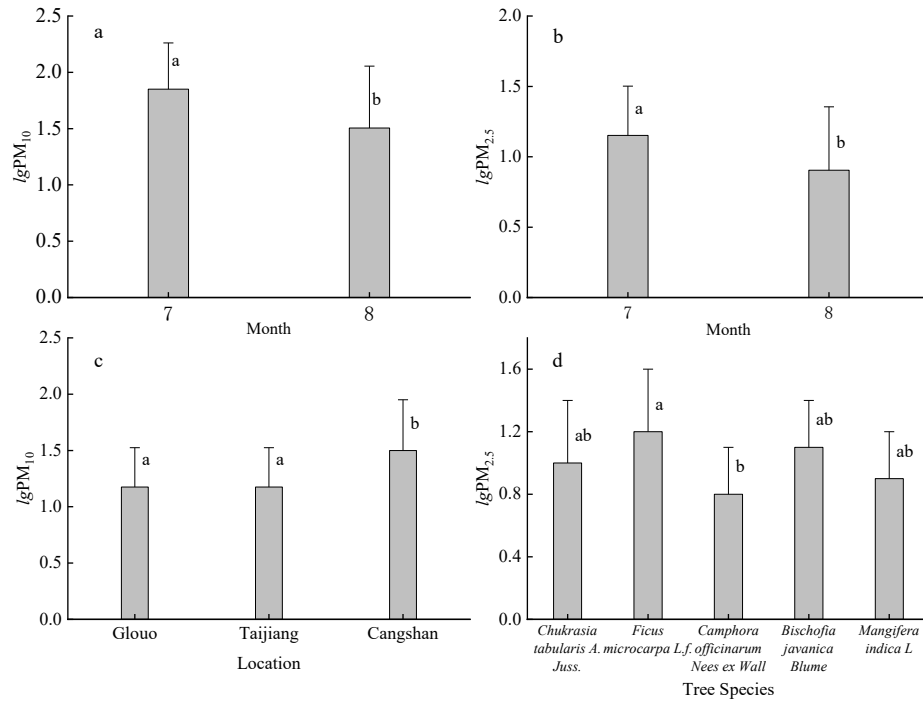


Fig. 3 Trends in leaf surface dry deposition fluxes of PM_{10} and $PM_{2.5}$ across locations, time, and tree species

3.4. Spatial and temporal distributions of the dry deposition flux of suspended particles

The significant three-way interaction observed for TSP dry deposition flux indicates that the interception capacity of tree species for suspended particles varies with both time and region. For instance, except in February and March, *Chukrasia tabularis* generally exhibited a significantly higher interception capacity for TSP compared to *Mangifera indica*. From a spatial perspective, higher dry deposition fluxes were primarily recorded in the Cangshan sample area (Fig. 2a). This pattern may be related to differences in tree growth conditions across regions and times. For example, Chinese tallow begins shedding leaves in January and does not fully regrow its canopy until April. Leaf shedding is more pronounced in the Gulou and Taijiang areas, whereas in Cangshan, partial foliage persists during January and February. Such seasonal changes in canopy structure influence the aerodynamic properties of suspended particles, as a sparse canopy facilitates particle dispersion and reduces interception efficiency. Additionally, regional differences in microclimate conditions may also contribute to the inconsistent interception performance of the same tree species. Given the numerous and complex influencing factors, localized experiments are therefore essential for accurately evaluating the interception capacity of different species on suspended particles. Monitoring across multiple regions and time periods remains necessary to capture such variability. For PM_{10} and $PM_{2.5}$, the smaller number of measurements limited the analysis, and the influencing factors were less complex than for TSP, with only single-factor main effects observed. The main effect of time indicates that PM_{10} and $PM_{2.5}$ levels were significantly higher in July than in August (Fig. 3a, 3b), a pattern consistent across tree species and regions. Air quality monitoring confirmed that suspended particle concentrations in July exceeded those in August. Similarly, the dry deposition flux of TSP was higher from winter to early spring across regions and species (Fig. 2b, 2c). This period corresponds to Fuzhou's air pollution season, characterized by weak vertical atmospheric mixing, low rainfall, and reduced wind speeds, which hinder pollutant dispersion and lead to deteriorated air quality. Overall, these findings suggest that tree leaves act as biological carriers that intercept suspended particles during periods of high pollution, thereby contributing to atmospheric pollutant removal while simultaneously serving as effective bioindicators of particle pollution.

The dry deposition of TSP on leaf surfaces appears more strongly influenced by road dust than PM_{10} and $PM_{2.5}$, particularly for street trees that are directly exposed to traffic-related emissions. Because road dust exhibits small-scale but highly variable interference, conducting multi-period and multi-regional measurements is essential

for accurately comparing the interception capacity of trees for TSP (Liu et al. 2024). The waxy cuticle of leaves can enhance the retention of fine particles within its surface layer (Weerakkody et al. 2018); however, its smooth structure is less favorable for the deposition of larger particles (Liu et al. 2012). Experimental results further confirm that the waxy cuticle on *Mangifera indica* is less effective for TSP interception, as reflected in their consistently lower dry deposition flux compared to other species in most sampling periods (Fig. 2c). By contrast, the differences among the other four tree species were relatively small, consistent with the findings of Xu et al. (2018), who reported that most broad-leaved species in Beijing exhibited comparable TSP interception capacities. For PM₁₀ and PM_{2.5}, although measurements were limited to July and August—months that fall within the non-polluted season—the canopy layer was fully developed during this period, thereby minimizing the influence of leaf fall on canopy structure. This allowed the analysis to focus more directly on differences in leaf surface characteristics among tree species, which reflect their varying interception capacities for suspended particles. The results demonstrated that the dry deposition flux of PM_{2.5} on *Ficus microcarpa* was significantly higher than that on *Camphora officinarum* (Fig. 3d). In general, the microstructural characteristics of leaf surfaces are the primary factors influencing differences in fine PM interception among tree species (Chen et al. 2017; Wang Qin et al. 2023). Numerous studies have shown that leaves with hairy or rough surfaces capture suspended particles more effectively than smoother leaves (Leonard et al. 2016). *Ficus microcarpa* are relatively rougher than *Camphora officinarum*, which enhances their ability to intercept suspended particles. In contrast, *Camphora officinarum* have a simpler arrangement, longer petioles, and lighter single leaves compared with other species, making them more susceptible to wind-induced oscillation that can promote the resuspension of deposited particles.

The average TSP dry deposition flux in this study was 1.09 mg/(m²·h), which is substantially lower than the value reported by Cai et al. (2017), approximately 7.8 times higher. This discrepancy may result from differences in washing procedures. In particular, some studies lack a clear definition of suspended particles and measure only the total material intercepted on leaf surfaces without excluding non-specific particles using a 100 µm sieve. Without distinguishing particle size ranges, measurements can be confounded by plant debris, trichomes, or coarse dust, leading to substantial overestimation of TSP deposition. By contrast, the results of this study align more closely with findings from less polluted areas or from studies that explicitly defined particle size ranges (Xu et al. 2018). Additionally, the PM₁₀ and PM_{2.5} dry deposition fluxes measured in this study were also markedly lower than those reported in previous studies. For example, Chen et al. (2016) found values that were approximately 5 and 12 times higher, respectively, while Xu et al. (2018) reported fluxes that were about 140 and 640 times higher, respectively. This discrepancy can be largely attributed to the fact that the PM₁₀ and PM_{2.5} measurements in this study were conducted during non-polluted seasons in a region with consistently good air quality. Overall, these comparisons highlight that the dry deposition flux of suspended particles on leaves is strongly influenced by temporal and spatial conditions, ambient pollution concentrations, tree species characteristics, and methodological differences, leading to pronounced regional variability.

3.5. Spatiotemporal distribution of the water-soluble ion dry deposition flux

The results of this study show that the dry deposition flux of NO₃⁻ on leaf surfaces exhibited both two- and three-factor interactions, whereas SO₄²⁻ showed only two-factor interactions. This suggests that the spatiotemporal variation of SO₄²⁻ deposition flux is more consistent than that of NO₃⁻. For example, the SO₄²⁻ flux varied over time across different regions, but it displayed similar patterns among tree species (significant interaction between time and region) (Fig. 2i). This indicates that all tree species are capable of intercepting SO₄²⁻, making them suitable candidates for biological monitoring across different regions and time periods. Notably, except for the period from December 2023 to April 2024, *Bischofia javanica* exhibited the highest SO₄²⁻ interception among tree species, and this trend was consistent across all three sampling areas (significant interaction between tree species and time; Fig. 2h). Additionally, the interception of SO₄²⁻ by *Bischofia javanica* was consistently higher than that of other tree species across all sample areas, with the most pronounced and

stable trend observed in the Taijiang sample area, where the pattern was evident month by month (significant interaction between tree species and region; Fig. 2h). Overall, *Bischofia javanica* demonstrates a clear advantage in intercepting SO_4^{2-} under varying temporal and spatial conditions. In contrast, although NO_3^- exhibited three-factor interactions, the general trend revealed broadly similar patterns among tree species and regions across the months. However, significant regional differences were observed in the interception efficiency of *Camphora officinarum* and *Ficus microcarpa* (Fig. 2d). Furthermore, the leaf-surface NO_3^- dry deposition flux of *Ficus microcarpa* and *Mangifera indica* was consistently lower than that of the other tree species across different regions and times, suggesting that these two species are relatively weak in intercepting NO_3^- .

The monthly variation in the dry deposition flux of water-soluble ions shows that SO_4^{2-} reaches its peak in December, whereas TSP peaks in February and March (Fig. 2e). This highlights significant temporal differences in the water-soluble ion composition of TSP. Both SO_4^{2-} and NO_3^- can originate from the photochemical transformation of gaseous precursors (SO_2 and NO_x), becoming major components of PM, particularly $\text{PM}_{2.5}$. However, in this study, SO_2 concentrations exhibited little variation across months and did not significantly increase during the pollution season. Consequently, the observed peak in SO_4^{2-} dry deposition may be more closely related to direct pollution emissions. In winter, the strong northeast monsoon in Fuzhou can transport substantial SO_2 emissions from northern China, southward, which may further contribute to the elevated SO_4^{2-} deposition. In contrast, the dry deposition flux of NO_3^- on leaf surfaces in this study exhibits a fluctuating, multi-peak temporal pattern across months. Atmospheric SO_4^{2-} is mainly associated with industrial flue gas emissions or long-range pollution transport, and its deposition typically occurs above the canopy. By comparison, atmospheric NO_3^- pollution is closely linked to traffic emissions, which vary depending on vehicle flow and vehicle types. As a result of its origin from near-surface emissions, NO_3^- deposition is more strongly influenced by microclimatic conditions and human activities, leading to dynamic temporal variations in its leaf surface dry deposition flux.

3.6. Dry deposition rate

The calculation of dry deposition rates across different tree species, based on measurements from the same monitoring station, shows that variations among tree species are consistent with the trends observed in dry deposition flux. With respect to regional and temporal differences, only the dry deposition rate of TSP exhibits a significant two-factor interaction. In most months, the Cangshan sample area recorded significantly higher TSP deposition rates compared to the other two areas (Fig. 4a). For the main effects of regional variables, the dry deposition rate of PM_{10} in the Gulou area is significantly higher than in the Cangshan area ($P = 0.021$; Fig. 4b). Regarding temporal variables, the dry deposition rates of PM_{10} and $\text{PM}_{2.5}$ are significantly higher in July than in August ($P = 0.011$) (Fig. 4c, 4d). Considering leaf surface dry deposition rates of TSP, PM_{10} , and $\text{PM}_{2.5}$ across different times, regions, and tree species, the mean values are 0.61, 0.06, and 0.021 cm/s, respectively. For water-soluble ions, the annual average flux was converted into deposition rates using Eq. (1). The resulting average dry deposition rates of NO_3^- and SO_4^{2-} on leaf surfaces are 0.179 and 0.173 cm/s, respectively.

The TSP dry deposition rates across different areas exhibit similar monthly trends, showing an overall bimodal pattern during the study period. This suggests that regional differences exert relatively minor effects, whereas temporal variation is the dominant factor. The similarity across areas may be attributed to the wide spatial influence of seasonal meteorological conditions, which shape comparable monthly patterns. However, the generally low correlation between TSP deposition rates and meteorological factors indicates that additional influences may be involved. In a related study conducted in Guangzhou, China, [Chen et al. \(2012\)](#) reported a TSP dry deposition rate of 1.44 cm/s in urban forest landscapes, approximately 2.3 times higher than the value observed in this study. Although the passive dry deposition method employed in earlier studies offers practical advantages, it typically uses polyvinyl chloride boards as substitutes for leaves, thereby reflecting dry deposition at the forest landscape scale rather than on actual foliage. While this surrogate surface allows for rapid and simple measurements, it does not fully capture the complexity of natural conditions, where leaf movement in the wind

may cause partial resuspension of deposited particles. By contrast, the present study involved direct sampling and measurement of leaves. Although this approach was more time-consuming and labor-intensive, it provided more accurate estimates of TSP dry deposition on leaf surfaces. Based on data integrated across regions, sampling periods, and tree species, the total average TSP dry deposition rate on leaf surfaces was approximately 0.61 cm/s. Because TSP deposition is primarily governed by gravitational settling, it is comparatively stable, whereas finer particles such as PM_{2.5} are more sensitive to wind speed and atmospheric turbulence. Accordingly, the average deposition velocity measured in this study can serve as a representative value for estimating TSP flux intercepted by urban forests in other areas of Fujian Province.

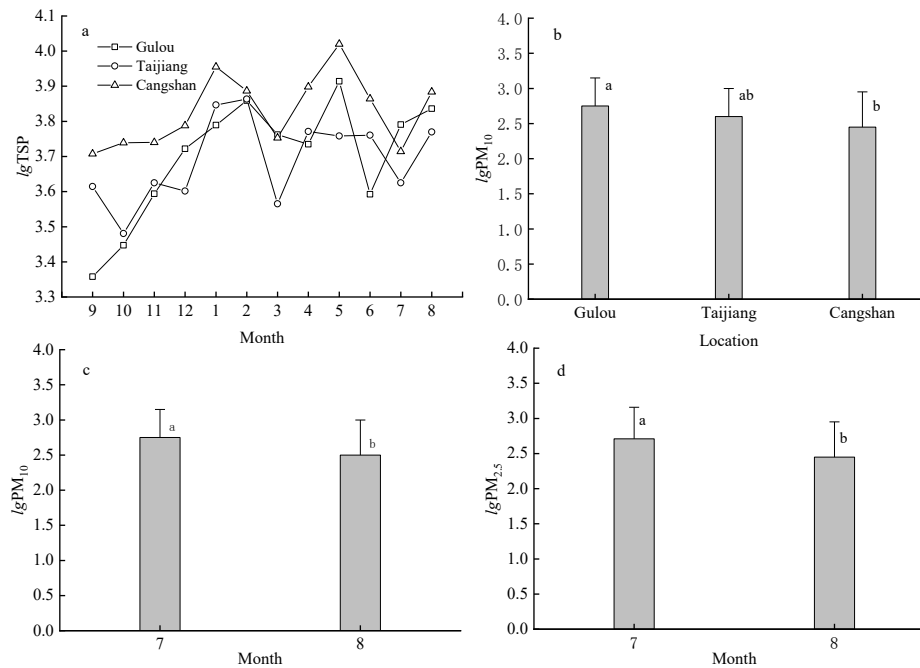


Fig. 4 Trends in leaf surface dry deposition velocities of TSP, PM₁₀, and PM_{2.5} across different locations and months

For PM₁₀ and PM_{2.5}, the dry deposition rates and fluxes on leaf surfaces exhibited similar trends (Figs. 3 and 4), suggesting that the temporal and spatial variability of environmental concentrations of these particles was relatively low compared to the variation in deposition flux. In the i-Tree Eco model, the average dry deposition rate of PM₁₀ is set to a fixed value of 0.64 cm/s, implying that changes in PM₁₀ deposition flux are primarily driven by ambient concentration levels. Notably, this fixed rate is more than ten times higher than the measured value of 0.06 cm/s in this study, although it is comparable to the measured TSP deposition rate. These findings indicate that using i-Tree Eco to simulate PM₁₀ removal by urban forests in the study area could lead to substantial overestimation. For PM_{2.5}, the average measured dry deposition rate of 0.027 cm/s in this study closely matches the i-Tree Eco parameter of 0.03 cm/s at a wind speed of 1 m/s. Notably, the wind speed data in the model are derived from air quality monitoring stations located on rooftops (approximately 15–17 m above ground), whereas wind speed at tree canopy height in urban street valleys is generally lower. Furthermore, the leaf surface particle washing method employed here primarily quantifies the insoluble fraction of PM_{2.5}, and losses of dissolved components, such as inorganic salts, during washing are difficult to account for. Taking these factors into consideration, the PM_{2.5} dry deposition rate parameter in i-Tree Eco likely reflects actual dry deposition conditions accurately, indicating that the model has strong potential for simulating PM_{2.5} removal by urban forests in Fuzhou.

The dry deposition rates of NO₃⁻ and SO₄²⁻ on leaf surfaces in this study were similar, averaging 0.179 and 0.173 cm/s, respectively. Due to limitations of the extraction method, it was not possible to distinguish the

contributions of particles of different size ranges. The measured deposition primarily reflects the total release of substances intercepted on the leaf surface, which explains why the rates for NO_3^- and SO_4^{2-} are higher than those for PM_{10} and $\text{PM}_{2.5}$. Conventional dry deposition models typically simulate NO_3^- and SO_4^{2-} deposition considering only fine particles. The rates calculated from total leaf surface interception in this experiment are broadly consistent with these models, suggesting that their application to urban forests may overestimate actual deposition. Given the limited spatial and temporal resolution of atmospheric ion concentration data in this study, additional field measurements are needed to validate these findings.

3.7. Total suspended particulate matter deposition trends on leaf surfaces

To evaluate whether a threshold exists for TSP dry deposition on leaves and to assess the leaching effect of initial rainfall on deposition removal, Eq. (2) was used to calculate dry deposition distance. Data from five tree species were integrated, and deposition distances were categorized by rainfall level to examine how they varied with deposition duration. As shown in Fig. 5, dry deposition distance increased significantly with deposition time ($y = 28.24x - 1099.89$; $R^2 = 0.667$, $P < 0.001$). At the lowest rainfall level (1–2 mm), deposition distance also increased with deposition time but remained close to the regression line, indicating no significant difference compared with higher rainfall levels. This suggests that low rainfall did not substantially influence the residual TSP on leaves.

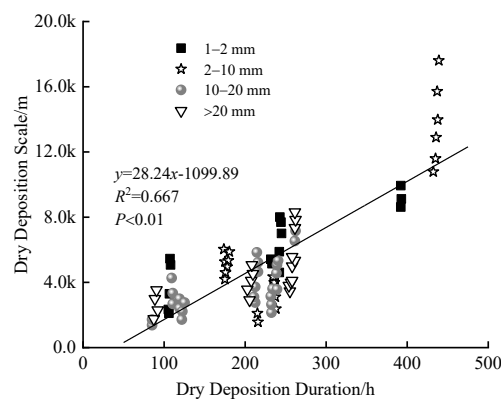


Fig. 5 Linear regression between TSP dry deposition distance and deposition time on leaf surfaces. Each value represents the mean of five tree species. Differences in initial daily rainfall during dry deposition are indicated by color gradients ($n = 108$)

The dry deposition of suspended particles on leaf surfaces may reach a saturation threshold, potentially introducing inaccuracies in flux calculations. A clearer understanding of particle retention capacity, including wash-off dynamics under different rainfall intensities and accumulation patterns across deposition durations, is essential for accurately quantifying the interception efficiency of urban trees. Deposition flux on leaf surfaces increases with particle concentration and deposition velocity but is offset by resuspension processes (Wang et al. 2015), leading to a dynamic equilibrium. Results from this study indicate that deposition periods ranged from 81 to 432 h across seasons, and within this range, the TSP dry deposition distance showed no significant reduction or plateau (Fig. 5). This phenomenon aligns with previous findings showing that canopy dust interception can persist for up to 20 days after rainfall, with saturation typically occurring at 18–21 days (Zhou et al. 2020) or 24 days (Liu et al. 2012). In this study, the maximum TSP dry deposition on leaf surfaces was observed after 432 h of deposition, averaging approximately 1.4 g/m^2 across all tree species. This value is comparable to Liu et al. (2013), who reported that dust deposition in commercial and traffic areas reached saturation at about 1.16 g/m^2 after 24 days of deposition across four tree species. However, since the maximum dry deposition duration during the

monitoring period was limited to about 18 days per month, it was not possible to determine a definitive saturation threshold for TSP accumulation on leaf surfaces.

Previous studies indicate that rainfall amount, duration, and intensity exert varying influences on the leaching of particles from leaf surfaces (Xu et al. 2017). In this study, rainfall events were categorized to examine differences in the leaching efficiency of TSP from leaves under different conditions. Results show that even with 1–2 mm of rainfall, the dry deposition distance increased linearly with time, closely matching the trend lines for all rainfall categories (Fig. 5). If residual effects were present under low rainfall, an upward deviation would be expected; however, no such deviation was observed. Instead, all rainfall categories followed a consistent growth trend, indicating that variations in rainfall leaching had only minor effects on TSP dry deposition. These results suggest that as little as 1–2 mm of rainfall is sufficient to effectively wash TSP from leaf surfaces without leaving significant residues. Establishing an accurate initial matrix for the dry deposition of suspended particles on leaf surfaces is essential for calculating deposition flux, as residual effects can lead to overestimations of the interception capacity of urban forests. Fine particles such as $PM_{2.5}$ are less easily leached by rainfall than larger particles. This may be attributed to the microstructural properties of leaf surfaces, which more effectively retain small particles and result in a higher residual fraction of $PM_{2.5}$ compared with TSP after rainfall events. Xu et al. (2020) noted that fewer than 10% of studies on leaf–particle interactions address rainfall-leaching efficiency. To more accurately quantify the role of urban forests in intercepting atmospheric suspended particles, further experimental research is needed on the retention and leaching dynamics of deposited particles, particularly fine $PM_{2.5}$.

Based on the above findings, atmospheric PM is initially retained on tree leaf surfaces through dry deposition. During rainfall events, these particles are subsequently washed from the leaf surface and deposited onto the ground as wet deposition, thereby completing their removal from the atmosphere. This continuous cycle is illustrated in Fig. 6.

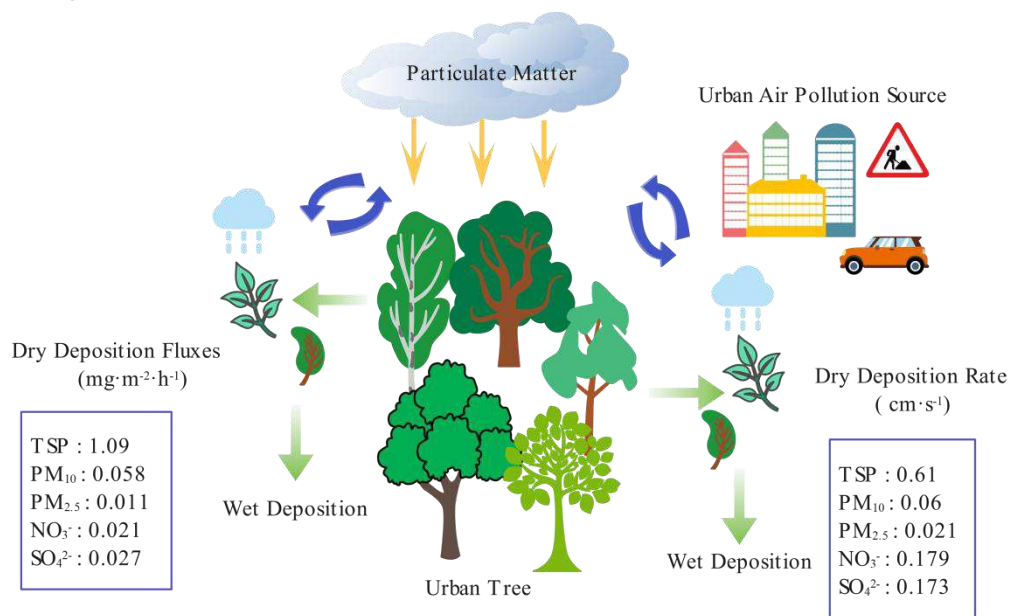


Fig. 6 Graphical abstract of atmospheric particulate matter removal by urban trees

3.8. Correlation analysis

3.8.1. Sedimentation flux and atmospheric concentration

Figure 7 shows the dry deposition flux of suspended particles of different sizes, all exhibiting significant positive correlations with their corresponding atmospheric concentrations. Among them, TSP demonstrates the strongest correlation ($\rho = 0.394$, $P < 0.001$), while PM_{10} ($\rho = 0.329$, $P = 0.005$) and $PM_{2.5}$ ($\rho = 0.209$, $P = 0.025$) show weaker associations.

In general, the dry deposition flux of suspended particles increases with higher ambient concentrations. The strength and significance of this relationship are critical for assessing whether urban trees can effectively intercept and mitigate air pollution under conditions of elevated pollutant levels (Zhang et al. 2021). However, such correlations are often less evident in field observations, potentially due to (1) limited representativeness of concentration data for the specific experimental sites; (2) resuspension of deposited particles or residual effects following rainfall; and (3) unmonitored local-scale pollution events or other environmental interferences. Additionally, large fluctuations in dry deposition rates may reduce the correlation between atmospheric concentration and flux. The results of this study show that the dry deposition flux of suspended particles of different sizes on leaf surfaces is significantly positively correlated with atmospheric concentrations (Fig. 6). This suggests that urban trees in the study area exhibit stronger interception capacity when particle pollution levels are elevated. Spearman correlation and linear regression analyses further indicate that TSP shows a stronger correlation than PM₁₀ and PM_{2.5}, likely due to the longer monitoring period and more stable deposition rates. In contrast, smaller particles are more sensitive to microclimatic variability, making the relationship between dry deposition flux and concentration less evident under field conditions.

3.8.2. Dry deposition rate and meteorological factors

Table 1 shows that the dry deposition rate of TSP is negatively correlated with meteorological variables—temperature, relative humidity, and wind speed. Among these, only temperature ($P < 0.001$) and relative humidity ($P < 0.01$) show statistically significant correlations. Spearman correlation and linear regression analyses indicate weak negative correlations with temperature ($\rho = -0.194$) and relative humidity ($\rho = -0.126$). For PM₁₀ and PM_{2.5}, the dry deposition rates are significantly positively correlated with relative humidity, with $\rho = 0.356$ ($P < 0.01$) and $\rho = 0.366$ ($P < 0.01$), respectively. In contrast, both show significant negative correlations with wind speed, with $\rho = -0.173$ ($P < 0.05$) and $\rho = -0.358$ ($P < 0.01$), respectively.

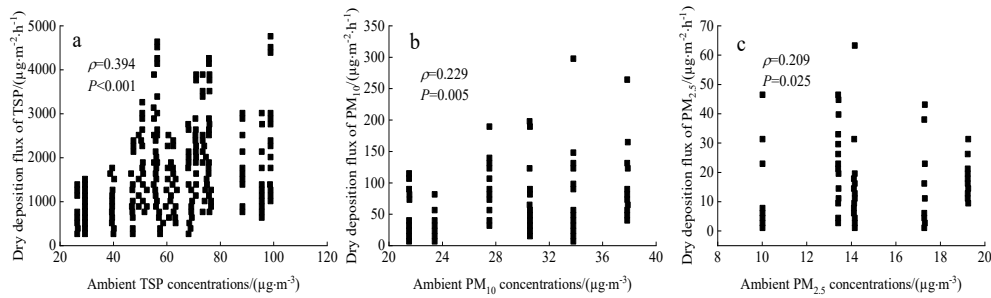


Fig. 7 Spearman correlation between the dry deposition flux of suspended particles and atmospheric concentrations (TSP: $n = 540$; PM₁₀, PM_{2.5}: $n = 90$)

Table 1 Spearman correlation and linear regression analysis of dry deposition rates of suspended particles with meteorological factors

Temperature Relative Wind V_d -TSP				Temperature Relative Wind V_d -PM ₁₀ V_d -PM _{2.5}			
	humidity	speed			humidity	speed	
Temperature	1			Temperature	1		
Relative humidity	0.121**	1		Relative Humidity	0.583***	1	
Wind speed	0.523***	-0.058	1	Wind Speed	-0.036	-0.734***	1
V_d -TSP	-0.194***	-0.126**	-0.053	V_d -PM ₁₀	0.033	0.356**	-0.173*
				V_d -PM _{2.5}	0.165	0.366**	-0.358**

Dry deposition velocity of the TSP: V_d -TSP; dry deposition velocity of PM₁₀: V_d -PM₁₀; dry deposition velocity of PM_{2.5}: V_d -PM_{2.5}; and *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$

Regarding meteorological factors, the dry deposition rate of suspended particles is generally considered to be influenced by wind speed. Smaller particles tend to remain suspended in the atmosphere, and airflow provides the kinetic energy necessary to facilitate their deposition. Wind tunnel experiments have confirmed that, to some extent, higher wind speeds can enhance the dry deposition rate of PM_{2.5} on leaf surfaces, forming the basis for parameter adjustments in dry deposition models such as i-Tree Eco (Chen et al. 2012). However, the results of this study show that the dry deposition rates of PM₁₀ and PM_{2.5} are significantly, though weakly, negatively correlated with wind speed (Table 1). This discrepancy may be explained by the relatively low wind speeds recorded during the monitoring period. In Fuzhou, wind speeds are typically stable and low throughout the year, except during typhoons. During the dry deposition periods observed in this study, the average wind speed was generally below 2 m/s, which may have weakened the positive influence of wind on deposition, or even contributed to the negative correlation observed. Additionally, wind speed data from rooftop air quality monitoring stations may be overestimated compared to conditions around tree canopies closer to the ground. While moderate increases in wind speed can enhance the transport of suspended particles from pollution sources to deposition surfaces, excessively high wind speeds can promote particle resuspension, thereby reducing the dry deposition rates recorded by passive sampling. Tree structural characteristics also play an important role. Variations in canopy morphology influence airflow and particle dispersion; for example, dense and complex canopies tend to reduce wind speed within the canopy, allowing particles to recirculate and increasing the likelihood of deposition on leaf surfaces. The interactions among wind field conditions, tree characteristics, and suspended particles are complex, resulting in variable correlations between wind speed and dry deposition rates in field experiments. Regarding temperature and relative humidity, only relative humidity shows a weak positive correlation with PM₁₀ and PM_{2.5} deposition rates (Table 1). This aligns with previous studies showing that higher relative humidity can increase particle mass through hygroscopic growth, enhancing deposition. However, during the dry deposition experiment in this study, relative humidity remained relatively stable, limiting its influence and explaining the lack of a significant correlation.

4. Conclusion

(1) This study investigated five common native urban trees in Fuzhou City to evaluate their capacity to remove atmospheric PM and the factors influencing this process. Considering temporal, spatial, and species-specific variations, the average leaf surface dry deposition fluxes of TSP, PM₁₀, PM_{2.5}, NO₃⁻, and SO₄²⁻ were 1.09, 0.058, 0.011, 0.021, and 0.027 mg/(m²·h), respectively, with corresponding average dry deposition velocities of 0.61, 0.06, 0.021, 0.179, and 0.173 cm/s.

(2) The TSP dry deposition flux showed significant three-factor interactions across time, region, and tree species. Monthly trends of sulfate interception revealed that *Bischofia javanica* was the most effective among the studied species, indicating a potential influence of long-range pollution transport in December.

(3) The dry deposition flux of atmospheric PM by urban trees is significantly positively correlated with environmental concentrations. The correlation is strongest for TSP ($\rho = 0.394$, $P < 0.001$), and weaker for PM₁₀ ($\rho = 0.329$, $P = 0.005$) and PM_{2.5} ($\rho = 0.209$, $P = 0.025$). The TSP dry deposition rate shows weak negative correlations with meteorological factors, with temperature ($P < 0.001$) and relative humidity ($P < 0.01$) being significant. In contrast, PM₁₀ and PM_{2.5} dry deposition rates are significantly positively correlated with relative humidity and negatively correlated with wind speed.

(4) Several research challenges remain in the study of atmospheric particle dry deposition on leaf surfaces, including potential dissolution losses during extraction, the leaching effect of rainfall of varying amounts and intensities, spatial heterogeneity of deposition within the canopy, and the dynamic equilibrium under prolonged dry deposition.

Statements and Declarations

Acknowledgments This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. There are no additional contributors to acknowledge.

Funding No funding was received for conducting this study.

Author Contributions Conceptualization: Wang Xiaoyun; Methodology: Wang Xiaoyun; Formal analysis and investigation: Fu Aimin; Writing – original draft: Fu Aimin; Writing – review and editing: Wang Xiaoyun; Funding acquisition: Wang Xiaoyun; Resources: Wang Xiaoyun; Supervision: Wang Xiaoyun

Data availability Data is provided within the manuscript or supplementary information files.

Competing interests The authors declare no competing interests.

5. References

- Cai MF, Xin ZB, Yu XX (2017) Spatio-temporal variations in PM leaf deposition: A meta-analysis. *Environ Pollut* 231:207-218. <https://doi.org/10.1016/j.envpol.2017.07.105>
- Chen LX, Liu CM, Zou R, Yang M, Zhang ZQ (2016) Experimental examination of effectiveness of vegetation as bio-filter of particulate matters in the urban environment. *Environ Pollut* 208:198-208. <https://doi.org/10.1016/j.envpol.2015.09.006>
- Chen L, Peng S, Liu J, Hou Q (2012) Dry deposition velocity of total suspended particles and meteorological influence in four locations in Guangzhou, China. *J Environ Sci* 24:632-639. [https://doi.org/10.1016/s1001-0742\(11\)60805-x](https://doi.org/10.1016/s1001-0742(11)60805-x)
- Chen W, Zhang FJ, Zhu YJ, Yang L, Bi PS (2022) Analysis of the impact of multiscale green landscape on urban. *Air Qual Atmos Health* 15:1319-1332. <https://doi.org/10.1007/s11869-022-01153-8>
- De Jalon SG, Burgess PJ, Yuste JC, Moreno G, Graves A, Palma JH, Crous-Duran J, Kay S, Chiabai A (2019) Dry deposition of air pollutants on trees at regional scale: A case study in the Basque Country. *Agric For Meteorol* 278:107648. <https://doi.org/10.1016/j.agrformet.2019.107648>
- Fang YH, Zhao LY, Dou BY, Wang SX, Zhou C (2024) Reduction effect of green infrastructure on PM_{2.5} in the built-up areas of urban agglomerations in the Yangtze River's middle reaches. *Acta Ecol Sin* 44:117-128. <https://doi.org/10.20103/j.stxb.202212273681>
- Gonzalez-Sosa E, Braud I, Piña RB, Loza CA, Salinas NM, Chavez CV (2017) A methodology to quantify ecohydrological services of street trees. *Ecohydrol Hydrobiol* 17:190-206. <https://doi.org/10.1016/j.ecohyd.2017.06.004>
- Kailibinuer N, Ümüt H, Nasiman N, Baidourela A, Reheman M (2022) Particulate matter retention amount by leaves of common tree species in Urumqi People's Park. *Chin J Ecol* 41:528-535. <https://doi.org/10.13292/j.1000-4890.202203.030>
- Leonard RJ, McArthur C, Hochuli DF (2016) Particulate matter deposition on roadside plants and the importance of leaf trait combinations. *Urban For Urban Green* 20:249-253. <https://doi.org/10.1016/j.ufug.2016.09.008>
- Li JX, Han LJ, Zhang ZM, Zhou WQ, Li WF, Qian YG (2023) Assessment on the reduction of atmospheric PM_{2.5} by urban forest and its ratio to the total PM_{2.5} pollutant in the Chinese major cities. *Acta Ecol Sin* 43:2640-2649. <https://doi.org/10.5846/stxb202201030008>
- Li SY, Niu YB, Fan J, Yu HL, Huang JY (2021) Analysis on dust retention capability of greening tree species surrounding coal-fired power plant based on leaf surface micro-structure. *Chin J Ecol* 40:604-614. <https://doi.org/10.13292/j.1000-4890.202102.018>
- Li XH, Mu S, Zhang X, Xi ZH, Jiang B, Wang S, Qiu L, Gao T (2024) Comparison of the reduction effects of

green space on atmospheric particulate matter concentration in northern cities. *Acta Ecol Sin* 44:4051-4063. <https://doi.org/10.20103/j.stxb.202307071464>

Li ZH, Cheng LI, Haoze TA, Jiayi WE, Jiong CH, Guixiang PE (2023) Reduction effect and influencing factors of typical urban woodlands on atmospheric particulate matter in Guangzhou. *Ecol Environ Sci* 32:341-350. <https://doi.org/10.16258/j.cnki.1674-5906.2023.02.014>

Liu L, Guan D, Peart MR (2012) The morphological structure of leaves and the dust-retaining capability of afforested plants in urban Guangzhou, South China. *Environ Sci Pollut Res* 19:3440-3449. <https://doi.org/10.1007/s11356-012-0876-2>

Liu L, Guan D, Peart MR, Wang G, Zhang H, Li Z (2013) The dust retention capacities of urban vegetation—a case study of Guangzhou, South China. *Environ Sci Pollut Res* 20:6601-6610. <https://doi.org/10.1007/s11356-013-1648-3>

Loomis D, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, Guha N, Baan R, Mattock H, Straif K, International Agency for Research on Cancer Monograph Working Group IARC (2013) The carcinogenicity of outdoor air pollution. *Lancet Oncol* 14:1262-1263. [https://doi.org/10.1016/s1470-2045\(13\)70487-x](https://doi.org/10.1016/s1470-2045(13)70487-x)

Nowak DJ, Hirabayashi S, Bodine A, Hoehn R (2013) Modeled PM_{2.5} removal by trees in ten U.S. cities and associated health effects. *Environ Pollut* 178:395-402. <https://doi.org/10.1016/j.envpol.2013.03.050>

Nowak DJ, Hirabayashi S, Bodine A, Hoehn R (2013) Modeled PM_{2.5} removal by trees in ten U.S. cities and associated health effects. *Environ Pollut* 178:395-402. <https://doi.org/10.1016/j.envpol.2013.03.050>

Nowak DJ, Hoehn RE, Bodine AR, Greenfield EJ, O'Neil-Dunne J (2016) Urban forest structure, ecosystem services and change in Syracuse, NY. *Urban Ecosyst* 19:1455-1477. <https://doi.org/10.1007/s11252-013-0326-z>

Riley CB, Herms DA, Gardiner MM (2018) Exotic trees contribute to urban forest diversity and ecosystem services in inner-city Cleveland, OH. *Urban For Urban Green* 29:367-376. <https://doi.org/10.1016/j.ufug.2017.01.004>

Riondato E, Pilla F, Sarkar Basu A, Basu B (2020) Investigating the effect of trees on urban quality in Dublin by combining air monitoring with i-Tree Eco model. *Sustain Cities Soc* 61:102356. <https://doi.org/10.1016/j.scs.2020.102356>

Selmi W, Weber C, Rivière E, Blond N, Mehdi L, Nowak D (2016) Air pollution removal by trees in public green spaces in Strasbourg city, France. *Urban For Urban Green* 17:192-201. <https://doi.org/10.1016/j.ufug.2016.04.010>

Wang Q, Feng JH, Huang Y, Wang PC, Xie MT, Wan H, Su ZL, Wang RP, Wang ZY, Yu LS (2020) Dust-retention capability and leaf surface micromorphology of 15 broad-leaved tree species in Wuhan. *Acta Ecol Sin* 40:213-222. <https://doi.org/10.5846/stxb201808241808>

Weerakkody U, Dover JW, Mitchell P, Reiling K (2018) Quantification of the traffic-generated particulate matter capture by plant species in a living wall and evaluation of the important leaf characteristics. *Sci Total Environ* 635:1012-1024. <https://doi.org/10.1016/j.scitotenv.2018.04.106>

Wu J, Wang Y, Qiu S, Peng J (2019) Using the modified i-Tree Eco model to quantify air pollution removal by urban vegetation. *Sci Total Environ* 688:673-683. <https://doi.org/10.1016/j.scitotenv.2019.05.437>

Xu X, Xia J, Gao Y, Zheng W (2020) Additional focus on particulate matter wash-off events from leaves is required: A review of studies of urban plants used to reduce airborne particulate matter pollution. *Urban For Urban Green* 48:126559. <https://doi.org/10.1016/j.ufug.2019.126559>

Xu XW, Yu XX, Mo L, Xu Y, Bao L, Lun X (2019) Atmospheric particulate matter accumulation on trees: A comparison of boles, branches and leaves. *J Clean Prod* 226:349-356. <https://doi.org/10.1016/j.jclepro.2019.04.072>

Xu X, Zhang Z, Bao L, Mo L, Yu X, Fan D, Lun X (2017) Influence of rainfall duration and intensity on particulate matter removal from plant leaves. *Sci Total Environ* 609:11-16. <https://doi.org/10.1016/j.scitotenv.2017.07.141>

- Yan Q, Xu LS, Duan YH, Pan LC, Liu LW, Yang YY (2021) Dust retention capacity and dust particle size of 20 commonly used greening tree species. *Chin J Ecol* 40:3259-3267. <https://doi.org/10.13292/j.1000-4890.202110.027>
- Zhou M, Wang X, Lin X, Yang S, Zhang J, Chen J (2020) Automobile exhaust particles retention capacity assessment of two common garden plants in different seasons in the Yangtze River Delta using open-top chambers. *Environ Pollut* 263:114560. <https://doi.org/10.1016/j.envpol.2020.114560>
- Zwerver S, Ham JV (1985) *Interregional air pollution modelling: The state of the art*. Springer Group, Boston