Plant-Based Solutions to Air Pollution in Bangkok: The Role of Urban Green Spaces

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ABSTRACT

In recent years, Bangkok has emerged as one of the most affected cities globally by air pollution, with rising levels of particulate matter 2.5 ($PM_{2.5}$) posing severe threats to human health and the environment. Urban Green Spaces (UGS) have proven to be a powerful tool in mitigating air pollution and other environmental hazards. This research explores how UGS can mitigate this issue by examining the correlation between UGS and $PM_{2.5}$ levels across urban and suburban districts in Bangkok. $PM_{2.5}$ concentrations are compared in areas adjacent to roads versus city parks. The methodology includes data collection from secondary sources and analysis using one-way ANOVA, independent-sample T-tests, and the Mann–Kendall test with Sen's slope. The findings reveal a steady increase in UGS across the most studied districts in Bangkok between 2008 and 2022, with notable expansions in the Ratchathewi, Pathumwan, Nong Chok, and Lat Krabang Districts. Regarding $PM_{2.5}$ concentrations, seasonal variations were observed, with higher $PM_{2.5}$ levels during the beginning and end of the year. Monitoring stations near roads consistently recorded higher levels, often exceeding the 24-hour standard, while park stations generally maintained lower $PM_{2.5}$ levels. However, some park stations occasionally exceeded acceptable levels. Comparative analysis showed that $PM_{2.5}$ concentrations were significantly lower in parks than nearby roads, with reductions ranging from 26% to 43%. This indicates that UGS effectively reduces $PM_{2.5}$ pollution, emphasizing the importance of incorporating green infrastructure in urban planning. These findings highlight the necessity for sustainable measures and ongoing efforts to manage air pollution, particularly during high-risk periods, to maintain improved air quality in Bangkok.

Keywords: Urban green space (UGS)/ Air pollution/ $PM_{2.5}$/ Bangkok/ Air quality mitigation

1. INTRODUCTION

Bangkok, the bustling capital of Thailand, has experienced rapid urban development, bringing significant environmental challenges. Air pollution has emerged as a critical issue, driven by a dense population exceeding 10 million, extensive traffic congestion, industrial activities, and biomass burning. Of particular concern is the rise of $PM_{2.5}$, fine particulate matter with diameters of less than 2.5 micrometers, which poses serious health risks to the city's inhabitants. These particles can penetrate the respiratory system, leading to various health problems, including respiratory and cardiovascular diseases.

Air pollution, defined as unwanted chemicals or substances that degrade air quality [1], is a growing threat in Bangkok. The World Health Organization [2] estimates that approximately 4.2 million people globally suffer from air pollution-related health issues yearly. The situation is particularly alarming in Bangkok, with annual $PM_{2.5}$ concentrations exceeding the WHO's recommended 10 µg/m³ limit. The city's air quality index (AQI) often reaches unhealthy levels, especially during the dry season from January to March, when $PM_{2.5}$ concentrations peak, reducing visibility and public health concerns [3].

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Urban green spaces (UGS) have been identified as a potential mitigating factor for air pollution in cities. Previous studies have shown that green spaces like parks, gardens, and tree-lined streets can reduce air pollution by capturing and filtering air-borne particles, including $PM_{2.5}$ [4]. Numerous studies worldwide have explored the relationship between urban green spaces and air quality, mainly focusing on $PM_{2.5}$ concentrations. Research consistently suggests that areas with more green cover tend to have lower levels of $PM_{2.5}$ compared to non-green or densely built-up areas. In London, a study by Nowak et al. [5] found that urban trees and green spaces contributed to reducing $PM_{2.5}$ concentrations by filtering air-borne particulate matter. The trees were estimated to remove 7-9 tonnes of $PM_{2.5}$ annually, improving air quality, particularly in neighborhoods with extensive tree cover. A study conducted in Beijing, China, where $PM_{2.5}$ levels are among the highest globally, revealed that parks and green belts played a crucial role in mitigating air pollution. Research by Chen et al. [6] showed that $PM_{2.5}$ levels were significantly lower in green areas compared to non-green urban areas, with reductions of up to 20-30% near large parks and forested zones. In Strasbourg, France, research by Wissal et al. [7] highlighted that green spaces, particularly large parks and tree-lined streets, contributed to lower $PM_{2.5}$ concentrations. The study found that areas with greater green cover reduced particulate matter by approximately 15%, indicating that even smaller urban green spaces can substantially impact local air quality. Similarly, a study in Mexico City by Baumgardner et al. [8] showed that urban forests and green spaces could remove around 8.8 tonnes of $PM_{2.5}$ annually. The study concluded that urban greening efforts could be a practical solution for improving air quality in megacities suffering from high levels of air pollution. Despite these benefits, Bangkok lacks sufficient green space, with only 7.59 m² per person based on the registered population, and even less when considering the total population [9]. This is significantly below the WHO's recommendation of at least 9 m² of green space per person [10].

Given the pressing nature of air pollution in Bangkok and the potential of UGS to alleviate it, this study aims to explore the relationship between the availability of UGS and $PM_{2.5}$ levels in urban and suburban districts of Bangkok. The research focuses on two key objectives: (i) identifying trends in UGS and $PM_{2.5}$ levels across the city; (ii) assessing differences in $PM_{2.5}$ concentrations between non-green areas (e.g., along roads) and green areas (e.g., city parks). By examining these factors, the study provides valuable insights for policymakers and urban planners, highlighting the importance of expanding and maintaining urban green spaces as a natural solution to Bangkok's air pollution crisis.

2. METHODOLOGY

2.1 Study area

Bangkok, Thailand's capital, is located at approximately 13.736717° N latitude and 100.523186° E longitude, with an elevation of 2.3 meters above sea level. As a central hub for transportation, finance, and commerce, the city faces significant air pollution challenges due to its dense population (10.72 million as of 2021), extensive traffic, and industrial activities. The city's climate is influenced by monsoonal winds, which impact the dispersion of pollutants. Bangkok's air quality is significantly impacted by $PM_{2.5}$, primarily from vehicular emissions, industrial activities, and biomass burning [11]. To monitor air quality, the Pollution Control Department (PCD) and Bangkok Metropolitan Administration (BMA) operate a network of monitoring stations. As of 2022, 23 PCD stations and 70 BMA stations measure pollutants like $PM_{2.5}$ and other key air quality parameters [12].

This study selected monitoring stations based on three criteria: location (urban vs. suburban), surrounding environment, and proximity (within 1 km between paired stations). This approach aimed to capture the variability in air pollution across different urban contexts in Bangkok. In the urban area, two pairs of monitoring stations were selected. The first pair includes Santiphap Park and Din Daeng Road, 953 meters apart. Santiphap Park is characterized by vegetation that may help reduce pollution levels, whereas Din Daeng Road experiences higher pollution levels due to heavy traffic and nearby tollways. The second pair comprises Lumpini Park and Rama IV Road, with a separation of 929 meters. Lumpini Park's greenery is expected to mitigate pollution levels in contrast to the high-traffic environment of Rama IV Road. In the suburban areas, two additional pairs of monitoring stations were

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chosen. The third pair includes Lat Krabang Park and Lat Krabang Road, which are 354 meters apart. Air pollution from airport activities, commuter traffic, and industrial operations impacts this area. The fourth pair consists of Nong Chok Public Park and Liap Wari Road, separated by 397 meters. Pollution sources in this area include vehicle emissions, nearby industrial sites, and transboundary smoke. This selection strategy ensured that paired stations in green and non-green areas were close enough to be subject to similar local meteorological and traffic conditions, allowing for a more accurate comparison of $PM_{2.5}$ concentrations between urban and suburban settings.

In non-green areas, traffic emissions are a predominant source of $PM_{2.5}$. Vehicular emissions can contribute significantly to particulate matter concentrations, often accounting for a substantial portion of overall $PM_{2.5}$ levels. Other anthropogenic sources, including industrial emissions and construction activities, can exacerbate $PM_{2.5}$ concentrations, especially during peak traffic times. Green areas, while typically benefiting from the natural filtration provided by vegetation, are not entirely free from $PM_{2.5}$ contamination. Resuspension of soil particles and organic matter can contribute to $PM_{2.5}$ concentrations, particularly during dry weather or through human activities such as park maintenance. Additionally, green areas near busy roads may experience infiltration of traffic-related pollutants, which can diminish the air quality benefits usually associated with vegetation. Advanced source apportionment techniques can be applied in future studies to accurately quantify the contributions of various PM2.5 sources in both green and non-green areas. These approaches help identify specific sources contributing to $PM_{2.5}$ levels, providing valuable insights for developing targeted interventions to improve air quality.

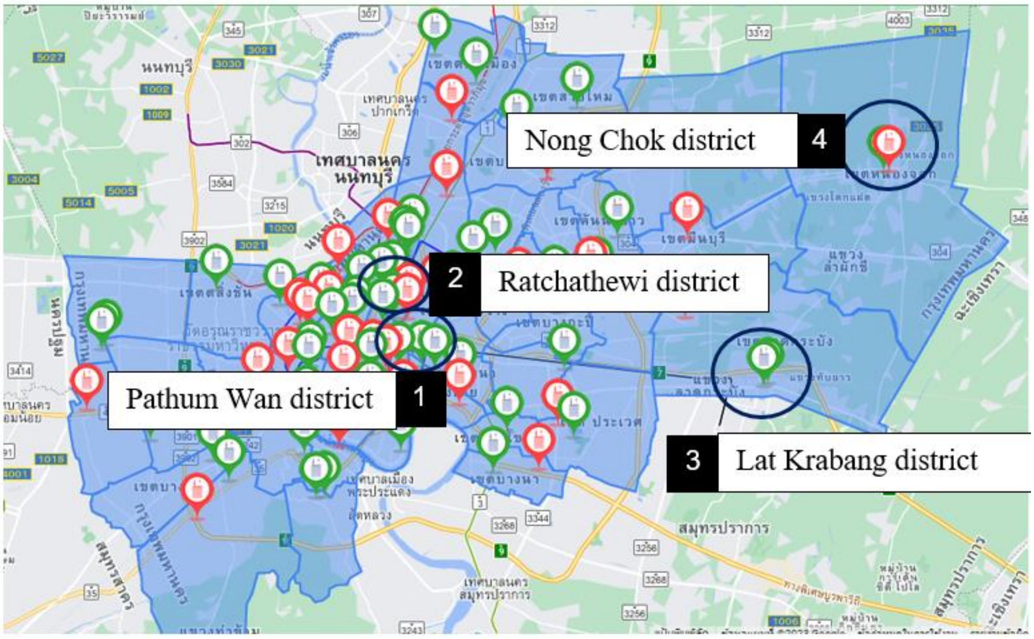

Figure 1. Selected air pollution monitoring stations in this study: Pair (1) and (2): stations located in the urban area; Pair (3) and (4) stations located in the sub-urban of Bangkok.

2.2 Data collection

2.2.1 Air pollution levels

Data on $PM_{2.5}$ concentrations are being collected from monitoring stations within the study area. This data, provided by the PCD and the Environment Department of the BMA, covers 2021 to 2022. The air pollution levels are recorded as average concentrations per 24 hours, allowing for a detailed analysis of particulate matter in Bangkok's urban and suburban areas. This study focuses on $PM_{2.5}$ concentrations based on data provided by government authorities. However, the dataset did not include environmental factors such as temperature, relative humidity, precipitation, and wind, which may also influence air pollution levels. Future research could benefit from integrating these variables better to understand the dynamics of $PM_{2.5}$ in different urban contexts.

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2.2.2 Urban green spaces

Information on UGS is obtained from the Bangkok Green Office and categorized by the Public Park Office and the Environment Department of BMA. The data includes all types of UGS, measured in square meters, and spans 2008 to 2022. This comprehensive dataset enables the study to evaluate the distribution and impact of green spaces on air quality across Bangkok.

2.3 Data analysis

This research employed quantitative methods to analyze and interpret the collected data, utilizing descriptive and inferential statistical techniques to examine the characteristics of UGS and $PM_{2.5}$ levels and their relationships.

The PCD and BMA data were represented graphically to assess trends in UGS and $PM_{2.5}$ levels from 2008 to 2022. One-way ANOVA was applied to evaluate variations in $PM_{2.5}$ concentrations over the years, determining whether there were significant changes in pollution levels over time. The Mann-Kendall test and Sen's slope estimator were employed to analyze UGS trends. These analyses were conducted using Microsoft Excel with the XLSTAT add-in.

An independent-sample t-test was used to compare $PM_{2.5}$ levels between monitoring stations near main roads and those within UGS in Bangkok's urban and suburban areas. The significance level (alpha) was set at 0.05, with the analysis performed using Minitab software.

3. RESULTS AND DISCUSSION

3.1 Trend of urban green spaces in Bangkok

3.1.1 Urban districts

Using the Mann-Kendall trend test, figure 2 illustrates the temporal trends in UGS within the Ratchathewi and Pathumwan Districts from 2008 to 2022. In the Ratchathewi District, significant upward trends were observed in neighborhood and pocket parks, with pocket parks expanding by 45% and neighborhood parks by 16% over the study period. The Sen's slope values indicate that neighborhood parks in Ratchathewi are increasing at an average rate of 3,946 square meters per year, while pocket parks are expanding at 2,560 square meters yearly. However, no significant growth was detected in community and street parks within this district.

Similarly, the Pathumwan District showed significant positive neighborhood, street, and pocket park trends. Pocket parks experienced an 83% increase, neighborhood parks grew by 76%, and street parks expanded by 30% between 2008 and 2022. The Sen's slope analysis reveals that neighborhood parks in Pathumwan are expanding at a rate of 5,302 square meters per year, pocket parks at 3,456 square meters per year, and street parks at 704 square meters per year. As with Ratchathewi, community and district parks in Pathumwan did not exhibit a significant trend in growth over the study period.

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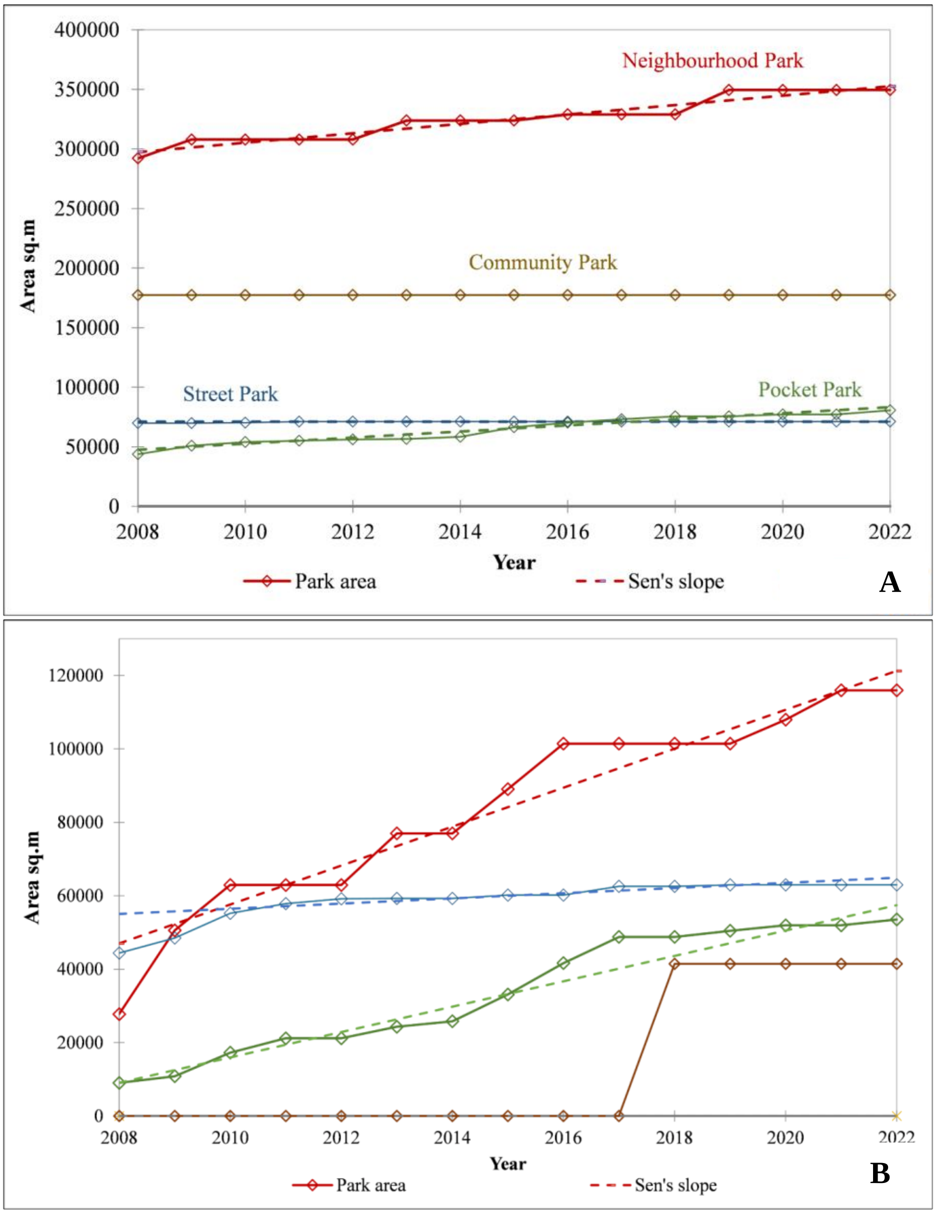

Figure 2. Mann-Kendall trend and Send's slope of UGS in the Ratchathewi (A) and Pathumwan (B) Districts from 2008 to 2022

3.1.2 Sub-urban districts

Figure 3 depicts the trends in UGS within the Nong Chok and Lat Krabang Districts from 2008 to 2022, utilizing the Mann-Kendall trend test. Significant upward trends were observed in Nong Chok District for neighborhood, street, and pocket parks. Street parks experienced a 38% increase from 2008 to 2022, pocket parks saw a 93% growth from 2014 to 2022, and neighborhood parks increased by 69% between 2013 and 2022. The Sen's slope analysis suggests that neighborhood parks in Nong Chok are expanding at 14,277 square meters per year, street parks at 9,520 square meters per year, and pocket parks at 4,224 square meters per year. Conversely, community parks did not exhibit a significant trend in growth during this period.

Similarly, the Lat Krabang District significantly grew in neighborhood, street, and pocket parks. Between 2008 and 2022, street parks increased by 91%, neighborhood parks by 88%, and pocket parks by 86%. According to Sen's slope estimates, neighborhood parks in Lat Krabang are growing at a rate of 10,516 square meters per year, street parks at 9,239 square meters per year, and pocket parks at 3,451 square meters per year. As in Nong Chok, community parks in Lat Krabang did not show a significant growth trend over the study period.

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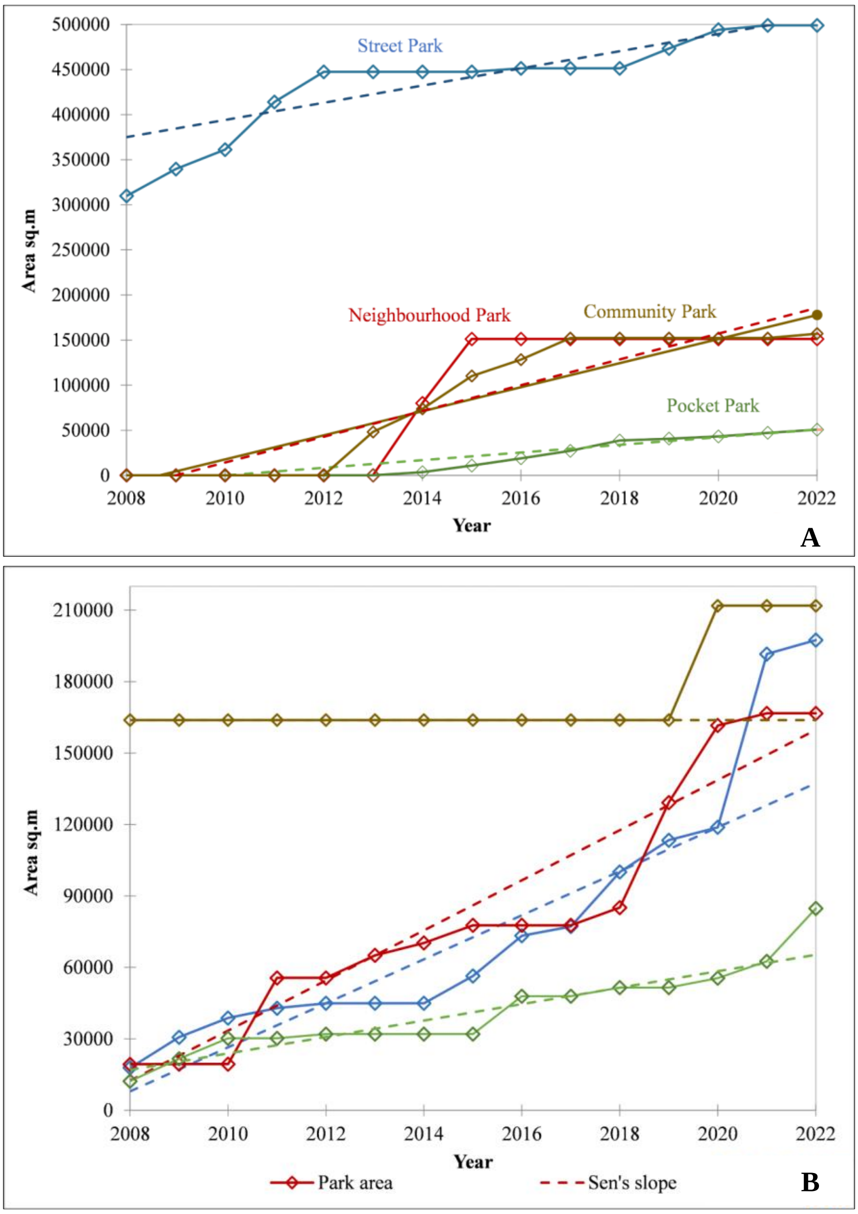

Figure 3. Mann-Kendall trend and Send's slope of UGS in the Nong Chok (A) and Lat Krabang (B) Districts from 2008 to 2022

In comparison between urban and suburban zones, the suburban districts of Nong Chok and Lat Krabang experienced a more robust and rapid expansion of UGS, particularly in neighborhood, street, and pocket parks, both in percentage growth and annual area increases. In contrast, the urban districts of Ratchathewi and Pathumwan saw slower growth, with only select park types expanding significantly, while community and district parks showed no notable growth across urban and suburban areas. This suggests that suburban districts are experiencing a more aggressive development of UGS, potentially due to larger available spaces, recent developments in residential zones compared to previous years, and different urban planning policies. These newer residential developments likely incorporate UGS as part of efforts to create more livable environments, contributing to the observed increase in green spaces. In comparison, urban districts face challenges due to denser populations and limited available land, slowing the pace of UGS expansion.

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3.2 Trends of $PM_{2.5}$ levels in monitoring stations near roads and parks

$PM_{2.5}$ concentrations in urban and suburban districts exhibited clear seasonal patterns across 2021 and 2022, with significantly higher levels observed between January to April and October to December. These periods often exceeded Thailand's 24-hour $PM_{2.5}$ standard of 37.5 µg/m³, particularly during colder months.

3.2.1 Urban districts

In the Ratchathewi District, the Din Daeng Road monitoring station consistently recorded high $PM_{2.5}$ levels, especially during the early and late parts of the year (Figure 4 A- red line). In 2021, several exceedances were observed, peaking at 106 µg/m³, while in 2022, the maximum concentration was slightly lower at 79 µg/m³. Despite a decrease in exceedance days, statistical one-way ANOVA analysis found no significant differences in the overall $PM_{2.5}$ concentrations between 2021 and 2022 ($p > 0.05$). At Santhiphrap Park, a similar seasonal trend was observed, with the highest levels in January, February, and December (Figure 4 A- green line). In 2021, there were 12 exceedance days (maximum 73 µg/m³), while 2022 saw only 3 exceedance days (maximum 69 µg/m³). Like Din Daeng Road, no significant difference was found between the two years (one-way ANOVA, $p > 0.05$).

In Pathumwan District, the Ratchadamri Road station showed elevated $PM_{2.5}$ levels from January to March and October to December (Figure 4 B- red line). The highest concentration in 2021 reached 89 µg/m³, with 20 exceedance days, compared to 73 µg/m³ and 10 exceedance days in 2022. The monitoring station at Lumpini Park, established in late 2020, followed a similar pattern, with significantly higher $PM_{2.5}$ concentrations in the early and late parts of both years (Figure 4 B- green line). The park saw 7 exceedance days in 2021 (maximum 71 µg/m³) and only 1 in 2022 (maximum 57 µg/m³), though the one-way ANOVA analysis again showed no significant difference between the years ($p > 0.05$).

3.2.2 Suburban districts

In Lat Krabang District, $PM_{2.5}$ levels near the road were highest from January to February and October to December, with 32 exceedance days in 2021 (peak 104 µg/m³) and 21 in 2022 (peak 84 µg/m³) (Figure 5 A- red line). Phanakhron Park followed a similar seasonal trend but had fewer exceedance days: 11 in 2021 (maximum 94 µg/m³) and only 2 in 2022 (maximum 60 µg/m³) (Figure 5 A- green line). Statistical analysis indicated no significant differences between the two years (one-way ANOVA, $p > 0.05$).

In Nong Chok District, the district administration and park stations showed seasonal peaks in $PM_{2.5}$ concentrations. The district administration station recorded 36 exceedance days in 2021 (maximum 97 µg/m³) and 17 in 2022 (maximum 78 µg/m³), while the park station had 16 exceedance days in 2021 (peak 85 µg/m³) and 8 in 2022 (peak 71 µg/m³) (Figure 5 B). Despite a reduction in exceedance days, the overall seasonal trends persisted, with no significant year-to-year differences (one-way ANOVA, $p > 0.05$).

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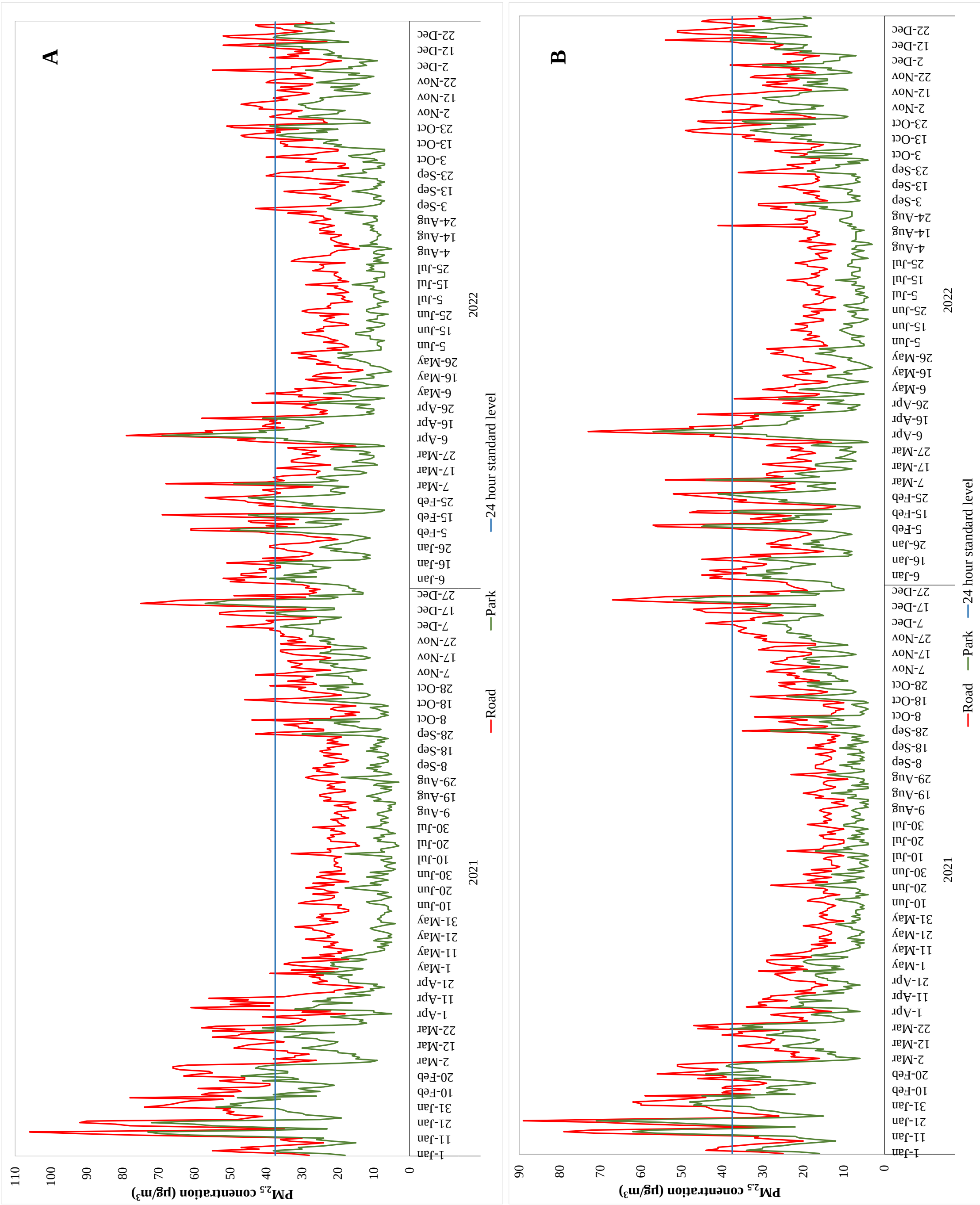

Figure 4. Daily $PM_{2.5}$ concentration of studied monitoring stations in the Ratchathewi (A) and Pathumwan Districts (B) in 2021 and 2022

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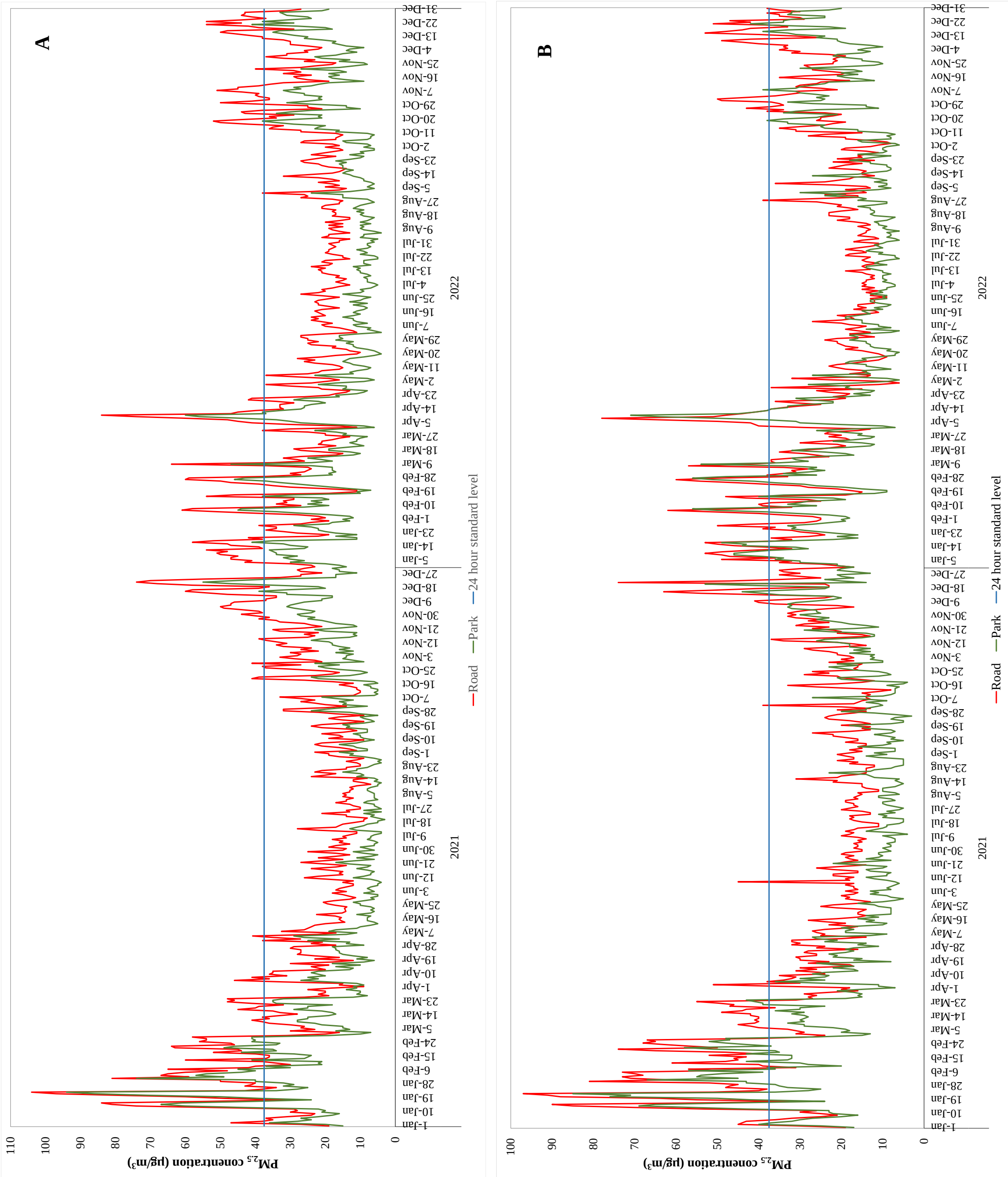

Figure 5. Daily $PM_{2.5}$ concentration of studied monitoring stations in the Nong Chok (A) and Lat Krabang (B) Districts in 2021 and 2022

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3.3 Comparative of $PM_{2.5}$ levels in monitoring stations near roads and parks

3.3.1 Urban districts

- *Ratchathewi District*

The mean daily $PM_{2.5}$ concentration at the monitoring station near Din Daeng Road was 32.5 µg/m³ in 2021 and 30.9 µg/m³ in 2022. In contrast, the monitoring station located within Santiphap Park recorded significantly lower mean concentrations of 18.1 µg/m³ in 2021 and 17.7 µg/m³ in 2022. The difference in $PM_{2.5}$ levels between the two stations was statistically significant (T-test, $p < 0.05$), with higher levels consistently observed near Din Daeng Road. These findings suggest that the monitoring station near Din Daeng Road, which is located closer to traffic and urban activities, experiences higher $PM_{2.5}$ concentrations compared to the station in Santiphap Park, a more green and sheltered area. The consistent disparity in $PM_{2.5}$ levels between the two stations highlights the impact of urban infrastructure and traffic emissions on air quality within a relatively small geographical area.

- *Pathumwan District*

The mean daily $PM_{2.5}$ concentration at the monitoring station near Rama IV Road was recorded at 24.7 µg/m³ in 2021 and slightly increased to 25.7 µg/m³ in 2022. In contrast, the monitoring station situated in Lumpini Park consistently measured lower $PM_{2.5}$ levels, with mean daily concentrations of 15.6 µg/m³ in 2021 and 14.97 µg/m³ in 2022. Statistical analysis using a T-test indicated a significant difference in $PM_{2.5}$ concentrations between the two stations ($p < 0.05$), with the station near Rama IV Road consistently exhibiting higher concentrations. These findings suggest that the proximity to Rama IV Road, a major urban traffic artery, contributes to the elevated $PM_{2.5}$ levels at that monitoring station compared to Lumpini Park, which benefits from its green space and distance from heavy traffic. This comparison emphasizes the critical role of traffic emissions in urban air pollution and highlights the importance of urban green spaces in mitigating air pollution levels.

3.3.2 Suburban districts

- *Lat Krabang District*

The mean daily $PM_{2.5}$ concentrations at the monitoring station near Lat Krabang Road were 27.8 µg/m³ in 2021 and 27.6 µg/m³ in 2022. In contrast, the monitoring station located in Lat Krabang Park recorded significantly lower mean daily concentrations, measuring 17.5 µg/m³ in 2021 and 16.91 µg/m³ in 2022. Statistical analysis using a T-test confirmed a significant difference in $PM_{2.5}$ levels between the two stations ($p < 0.05$), with consistently higher concentrations observed at the station near Lat Krabang Road. These findings suggest that the proximity of the monitoring station to Lat Krabang Road, a busy traffic route, is a major contributor to the elevated $PM_{2.5}$ levels observed there. In comparison, the station in Lat Krabang Park, which benefits from green space and distance from heavy traffic, consistently recorded lower $PM_{2.5}$ concentrations.

- *Nong Chok District*

The mean daily $PM_{2.5}$ concentrations at the monitoring station near Liap Wari Road were 27.7 µg/m³ in 2021 and 25.5 µg/m³ in 2022. In contrast, the monitoring station in Nong Chok Park recorded lower mean daily concentrations of 19.8 µg/m³ in 2021 and 2022. Statistical analysis using a T-test confirmed a significant difference in $PM_{2.5}$ levels between the two stations ($p < 0.05$), with higher concentrations observed near Liap Wari Road. These results suggest that the proximity of the monitoring station to Liap Wari Road, a major traffic route, contributed to the elevated $PM_{2.5}$ concentrations observed at that station. On the other hand, the station in Nong Chok Park, benefiting from its location within a green space and further from road traffic, consistently recorded lower $PM_{2.5}$ levels. This underscores the impact of traffic emissions on air quality in urban areas and highlights the mitigating role of green spaces like Nong Chok Park in reducing $PM_{2.5}$ pollution.

The lower $PM_{2.5}$ concentrations observed in parks compared to areas near roads can be attributed to several factors, with one primary mechanism being the presence of vegetation and green spaces. According to Qu et al. [13], parks generally have a higher density of trees and plants than urban

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areas near roads. Vegetation is a natural filter for particulate matter through dry deposition, where particles settle on surfaces like leaves and absorption via stomata and wax-covered surfaces. This natural filtering effect effectively reduces $PM_{2.5}$ concentrations in the air surrounding parks. Additionally, parks are often designed with physical barriers such as trees, buildings, or other structures that help shield them from direct exposure to road emissions. These barriers provide some level of protection against the transport of pollutants into park areas [14].

Another important factor is the dispersion and dilution of particulate matter. As $PM_{2.5}$ particles are emitted from vehicles and other sources near roads, they disperse and dilute as they move away from the source. This process allows particulate matter to become more diffuse, resulting in lower concentrations in areas further away, such as parks [13]. The distance of monitoring stations in parks from major roadways also plays a role. Since parks are often located further from busy roads, they experience less direct impact from traffic emissions, contributing to lower $PM_{2.5}$ levels [15].

3.4 Solutions for reducing air pollution

This research highlights the need to integrate green spaces into urban planning to mitigate air pollution. Variations in pollution levels across monitoring sites demonstrate the potential of green areas to act as natural filters, creating healthier environments for Bangkok's citizens. A key solution is implementing urban greening initiatives, including expanding parks, planting roadside trees, and creating green roofs, vertical gardens, and buffers near industrial zones. These efforts will increase vegetation and reduce air pollution in high-emission areas [16].

Collaboration with governmental, academic, non-governmental, and community organizations is essential. Government entities can create supportive policies and allocate resources, while NGOs and academic institutions can contribute research, advocate for sustainable practices, and implement educational campaigns. Community involvement ensures that green spaces meet local needs, promoting social cohesion and ownership of these projects [17]. Effective monitoring and evaluation will ensure these initiatives' long-term success and impact on air quality.

In addition to greening, air pollution control measures must be prioritized. Promoting sustainable transportation, such as public transit, electric vehicles, and bike-sharing, will help reduce vehicle emissions. Collaborating with industries to adopt cleaner technologies and enforce stricter environmental standards is crucial to reducing industrial pollution. Integrating green infrastructure into urban development plans is vital. City planners, architects, and environmental agencies should consider green spaces in transportation and building projects, contributing to a more sustainable and livable city.

4. CONCLUSIONS

This study investigated the relationship between UGS and air pollution across urban and suburban Bangkok districts. The analysis of UGS trends from 2008 to 2022 in urban and suburban districts reveals that suburban districts such as Lat Krabang and Nong Chok have experienced significant growth in neighborhood, street, and pocket parks, contributing to better air quality. Conversely, Ratchathewi and Pathumwan's more densely populated urban districts saw slower expansion in UGS, constrained by limited space and competing urban development pressures. The comparative analysis of $PM_{2.5}$ levels between monitoring stations near roads and parks shows that areas closer to major traffic routes, such as Din Daeng Road and Lat Krabang Road, consistently recorded higher $PM_{2.5}$ concentrations compared to stations located within parks, such as Santiphap Park and Lumpini Park. The significant differences in $PM_{2.5}$ levels between road and park sites emphasize the impact of vehicular emissions and the potential of green spaces to mitigate air pollution. These findings prove that integrating green spaces into Bangkok's urban landscape effectively reduces air pollution. Expanding UGS enhances the city's aesthetic and ecological value and creates healthier, more livable environments for its residents.

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