Investigation of the Spatiotemporal Distribution of PM_{10}, $PM_{2.5}$, and PM_1 from Motor Vehicles in Roadside Environments

The Case Study of Padang City, Indonesia

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ABSTRACT

This study examines the spatial and temporal distribution of PM_{10}, $PM_{2.5}$, and PM_1 concentrations in Padang City, Indonesia, focusing on the impact of motor vehicle emissions. Measurements were conducted at distances ranging from 5 m to 100 m from major roadways and at different times of the day to evaluate the effects of traffic patterns and meteorological conditions on air quality. The findings revealed that Particulate Matter (PM) concentrations are significantly higher near roads, with PM_{10} peaking at over 55 µg/m³ in the afternoon at 5 m from the roadway. Similarly, $PM_{2.5}$ and PM_1 also reach the maximum levels of 45 µg/m³ and 35 µg/m³, respectively, during peak traffic hours. While meteorological factors, such as temperature, wind speed, relative humidity, and pressure, exhibit weak correlations with the PM levels, traffic volume emerges as the primary contributor to air pollution. These results underscore the need for effective traffic management and emission reduction strategies to mitigate pollution and protect public health. The current study's recommendations include enhancing roadside air quality monitoring, and conducting further research on seasonal variations and the specific contributions of different vehicle types to PM pollution dynamics.

Keywords-spatiotemporal distribution; particulate matter; motor vehicle emissions; meteorological factors

I. INTRODUCTION

Urban air pollution is a global issue that significantly affects public health. Among various pollutants, PM poses one of the most challenging problems in environmental studies. PM refers to a complex mixture of solid and liquid particles suspended in the air, with their behavior being influenced by their size and chemical composition. The aerodynamic diameter, a measure of how particles move through the air, is commonly used to classify PM into different size groups. These size fractions include PM_1, $PM_{2.5}$, PM_4, PM_7, and PM_{10}, where the number indicates the particle's diameter in micrometers [1]. For instance, PM_{10} includes particles less than 10 µm in diameter and $PM_{2.5}$ less than 2.5 µm.

The health risks associated with PM exposure are well-documented. Long-term exposure to $PM_{2.5}$, PM_{10}, and PM_1 increases the risk of cardiovascular and respiratory diseases. Due to their small size, they can infiltrate the respiratory system and, in some cases, enter the bloodstream, with $PM_{2.5}$ having a more significant effect on respiratory diseases [2]. Specifically, $PM_{2.5}$ and PM_{10} exposure are positively associated with cardiovascular and respiratory diseases at increased levels, with higher exposure levels leading to increased mortality and morbidity [3], while PM_1 exposure is associated with acute respiratory responses, particularly in the elderly with chronic respiratory diseases, leading to increased airway inflammation and decreased pulmonary function [4]. A study conducted in Zhejiang province, China, demonstrated that PM_1, $PM_{2.5}$, and PM_{10} are significant risk factors for mortality due to cardiovascular and respiratory diseases, as well as all-cause mortality. Notably, PM_1 accounted for most of the short-term mortality effects attributed to $PM_{2.5}$ and PM_{10} exposure [5].

PM pollution originates from both primary and secondary sources. Primary PM is directly emitted from activities, such as construction sites, wildfires, wood burning, gravel pits, agricultural activities, and dusty roads. In contrast, secondary PM forms in the atmosphere through complex chemical reactions. $PM_{2.5}$ precursors, such as nitrogen oxides (NO_x), Volatile Organic Compounds (VOCs), sulfur dioxides (SO_2), and ammonia, contribute to the formation of secondary fine particulates. Precursors that lead to the formation of $PM_{2.5}$ are emitted by a variety of sources, including power plants, industry, vehicles, small businesses, buildings, and homes [6]. Traffic emissions are a significant source of PM_{10}, $PM_{2.5}$, and PM_1 in the urban areas of developing countries, with higher concentrations being observed in high-traffic regions [7]. Morning and evening rush hours typically have higher pollutant levels due to increased vehicle emissions. According to research in the metropolitan area of Barcelona [8], traffic and combustion sources are particularly significant for $PM_{2.5}$ and PM_1, while crustal and natural sources contribute more to PM_{10}. Additionally, authors in [9] concluded that traffic is the primary source of PM emissions in Chennai, India, with high PM ratios being observed during peak hours, as well as violations of the national and WHO air quality standards. In Kolkata megacity, vehicular emissions contribute significantly to $PM_{2.5}$ concentrations, which exceed the national air quality standards [10].

Traffic emissions and meteorological conditions significantly influence the spatial and temporal patterns of PM_1, $PM_{2.5}$, and PM_{10} concentrations. A study conducted in Wuhan, China [11], revealed that the $PM_{2.5}/PM_{10}$ ratio has seasonal, monthly, and daily variations, with spatial gradients increasing from the urban core to the urban fringe and suburban areas. Authors in [12], indicated that $PM_{2.5}$ and PM_{10} concentrations in Delhi are higher at night, with $PM_{2.5}$ concentrations being higher during the week, and PM_{10} concentrations on Weekends (WE). Additionally, in [13], the meteorological conditions varied throughout the day and in different seasons affecting PM concentrations and distribution. At the same time, weather phenomena, such as temperature inversions can trap pollutants near the ground surface, leading to increased PM levels [14].

In Indonesia, studies on the spatial and temporal patterns of air pollution remain limited, particularly in Padang City, the capital of West Sumatra, which is located within the Equatorial climate zone. The region's tropical climate, characterized by high humidity and temperatures, interacts with pollutants to create complex atmospheric conditions that affect the behavior and impact of the PM [15]. Moreover, traffic congestion in Indonesia's major cities significantly contributes to elevated PM concentrations in roadside ambient air, posing a serious public health concern. [16]. To address these challenges, comprehensive studies are required that combine detailed data collection, pollution mapping, and real-world monitoring. Analyzing factors like meteorology, traffic flow, and the city's layout is crucial for creating effective solutions to mitigate pollution and protect the public health.

II. METHODOLOGY

A. Study Area and Measurement Locations

A detailed analysis of PM_1, $PM_{2.5}$, and PM_{10} concentrations was conducted in Padang City, Indonesia, with a primary focus on the emissions from motorized vehicles. The field measurements were carried out along Bypass Road II, a major urban thoroughfare characterized by high traffic volume. To capture the spatial distribution of PM concentrations, sampling was performed at multiple distances from the road: 5 m, 10 m, 15 m, 20 m, 50 m, and 100 m. These distances were selected to evaluate the gradient of pollutant dispersion from the roadway and assess how PM concentrations decrease with an increasing distance. A map of the measurement locations is provided in Figure 1.

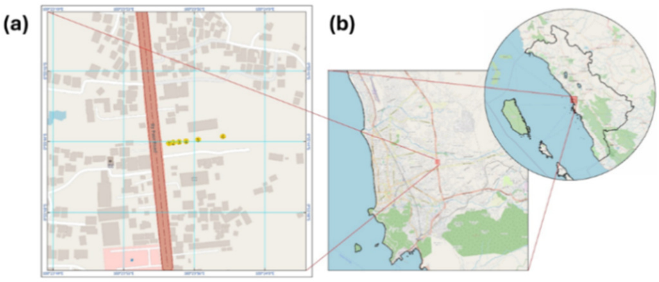

Fig. 1. Description of the field campaign: (a) the sampling location: Bypass Road II Padang City, (b) the experimental site.

B. Instrumentation and Measurement Setup

Pollutant concentrations were measured using the "Haz-Dust EPAM-5000", a portable device known for accurately capturing real-time data on PM. This unit integrates traditional filter-based techniques with advanced real-time monitoring methods. The EPAM 500 operates on the near-forward light scattering principle using infrared radiation. Airborne particles passing through the device's infrared beam scatter light, which is detected by a photodetector placed at a 90-degree angle to the light source. The intensity of scattered light is proportional to the particle concentration, enabling a precise measurement of the PM levels in mg/m³. To ensure reliability, the device features an internal signal processing system that minimizes noise and drift corrections, delivering high resolution, low detection limits, and stable baselines.

The air monitor was positioned at a height of 1.5 m, corresponding to the average human breathing zone, to ensure that the collected data reflect the human exposure levels. During the experiment, the equipment was sequentially moved from one point to another to observe the pollutant concentration. The observation time at each measurement point was controlled at 5 minutes for each PM parameter and it took around 20 minutes to complete one observation at each measurement point [17]. During each interval, concentrations were recorded every 10 seconds resulting in 30 data points per parameter per location.

C. Temporal Data Collection

The measurements were conducted over a 7-day period, consisting of 5 weekdays (WD) and one WE, capturing data at different times of the day to account for variations in traffic patterns. This included peak traffic hours in the morning and afternoon and off-peak hours, providing a comprehensive temporal analysis of the PM concentrations. Measurements of PM_{10}, $PM_{2.5}$, and PM_1 concentrations, using the EPAM 5000, were carried out for two hours during the morning rush hour (06.30-08.30 WIB), afternoon off-peak hours (11.00-13.00 WIB), and afternoon rush hour (16.00-18.00 WIB). The placement of sampling points was based on the dominant wind direction and speed during sampling, as shown in Figure 2.

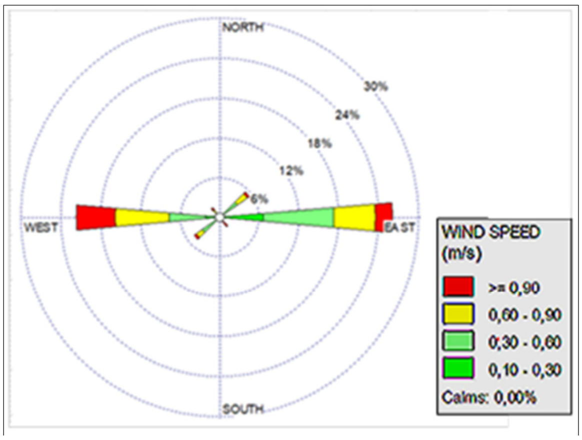

Fig. 2. Wind rose plot for Bypass Road II, Padang City.

D. Meteorological Data

The meteorological conditions, including temperature, humidity, air pressure, wind direction, and wind speed, were recorded using an environment meter. These parameters were measured every 10 minutes to assess their potential influence on PM dispersion.

E. Traffic Data Collection

To analyze the relationship between the traffic volume and PM concentrations, vehicles were categorized into three distinct groups based on their characteristics:

- Heavy Vehicles (HV): Motor vehicles with more than four wheels, including buses and trucks.
- Light Vehicles (LV): Two-axle motor vehicles with four wheels and an axle distance of 2.0-3.0 m, such as passenger cars, microbuses, pick-ups, and small trucks.
- Motorcycles (MC): Vehicles with two or three wheels, including motorcycles and three-wheeled motorized vehicles.

The vehicle speeds were monitored using a speed gun, providing essential data to correlate the traffic patterns, vehicle types, and PM levels. The traffic volume was calculated by converting the number of vehicles into a passenger-car-unit (pcu) using a standard conversion equation based on [18]:

$$q = (N_{LV} \cdot F_{LV}) + (N_{HV} \cdot F_{HV}) + (N_{MC} \cdot F_{MC}) \quad (1)$$

where q is the traffic volume (pcu/h), N_{LV} is the number of vehicles per hour (veh/h) for light vehicles, N_{HV} is the number of veh/h for heavy vehicles, N_{MC} is the number of veh/h for each type of motorcycle, F_{LV} is the passenger car equivalent value (emp = 1) for light vehicles, F_{HV} is the passenger car equivalent value (emp = 1.2) for heavy vehicles, and $F_{MC}$is the passenger car equivalent value (emp = 0.25) for motorcycles.

F. Data Analysis

The collected data were analyzed to identify patterns in PM distribution related to motor vehicle activities. Statistical analysis was employed to determine the relationship between the traffic variables and PM concentrations, providing insights into the study area's primary contributors to air pollution.

III. RESULTS AND DISCUSSION

A. Characteristics of Traffic Flow and Relationship with PM_{10}, $PM_{2.5}$, and PM_1 Concentrations

Figure 3 illustrates the types and number of motorized vehicles passing through the study location. The data reveal distinct patterns in vehicle activity based on the day of the week. On WD, the peak vehicle activity occurs during the morning hours. Motorcycles dominate the traffic, followed by light vehicles, with heavy vehicles constituting the smallest proportion, while the total number of vehicles passing through on WD ranges between 10,000-11,000 units. On WE, a significant decline in vehicle activity is observed, especially among motorcycles. This reduction highlights the lower traffic volume and reduced PM emissions during WE.

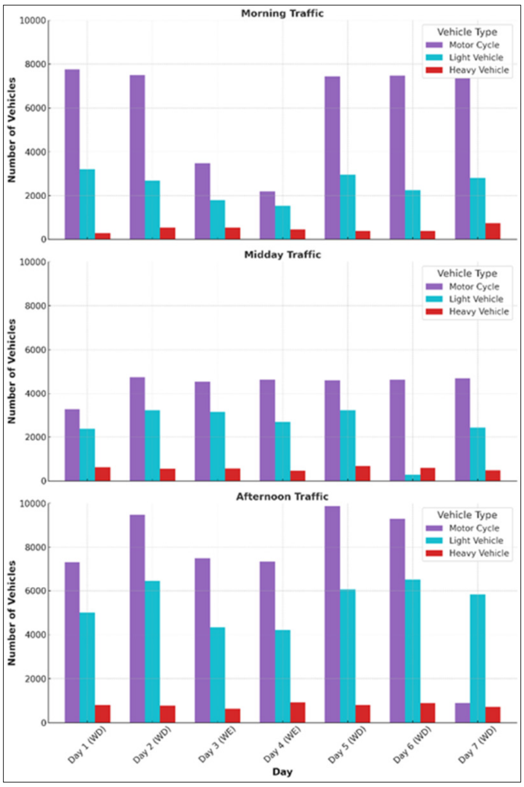

Fig. 3. Diagram of types and number of vehicles passing through Bypass Road II Padang City.

TABLE I. TRAFFIC SPEED AND TRAFFIC VOLUME ON BYPASS ROAD II PADANG CITY

Days	Traffic Speed (km/h)	Traffic Volume (pcu/h)
Day 1(WD)	46.94	2549.65
Day 2(WD)	59.14	2266.55
Day 3(WE)	56.73	1689.30
Day 4 (WE)	55.25	1305.73
Day 5 (WD)	44.79	2463.98
Day 6 (WD)	56.33	1950.60
Day 7 (WD)	57.67	2559.80
Average	**53.84**	**2112.23**
Day 1(WD)	47.74	2590.63
Day 2(WD)	54.85	2541.83
Day 3(WE)	52.04	2486.85
Day 4 (WE)	52.44	2204.70
Day 5 (WD)	44.66	1976.25
Day 6 (WD)	55.12	2350.43
Day 7 (WD)	51.63	2096.48
Average	**51.21**	**2321.02**
Day 1(WD)	48.55	4749.53
Day 2(WD)	57.00	4891.20
Day 3(WE)	52.17	3488.53
Day 4 (WE)	45.20	3579.30
Day 5 (WD)	48.55	3898.18
Day 6 (WD)	51.50	4958.35
Day 7 (WD)	57.80	4486.00
Average	**51.54**	**4293.01**

Table I presents the average traffic volume and speed at different times of the day. The highest average traffic volume was recorded in the afternoon at 4293.01 pcu/h, followed by midday at 2321.02 pcu/h, and the morning at 2112.23 pcu/h. During the morning, traffic volumes on WE were notably lower than on WD (1305.73 to 1689.30 pcu/h). However, traffic volumes during midday and afternoon periods on WE showed no significant differences compared to those on WD. The observed variations in traffic volume and speed are attributed to the mix of vehicle types and the timing of measurements at the sampling locations [19, 20]

Figure 4 portrays the relationship between the traffic volume and PM concentrations, PM_{10}, $PM_{2.5}$, and PM_1. A moderate correlation is observed, with the coefficients of determination (R^2) for PM_{10}, $PM_{2.5}$, and PM_1 being 0.591, 0.729, and 0.6625, respectively. These values indicate that 59.1%, 72.9%, and 66.25% of the variability in PM concentrations can be attributed to traffic volume [21]. Similar findings were reported in [22], which also identified a moderate correlation between the PM_{10}, $PM_{2.5}$, and PM_1 concentrations and traffic volume.

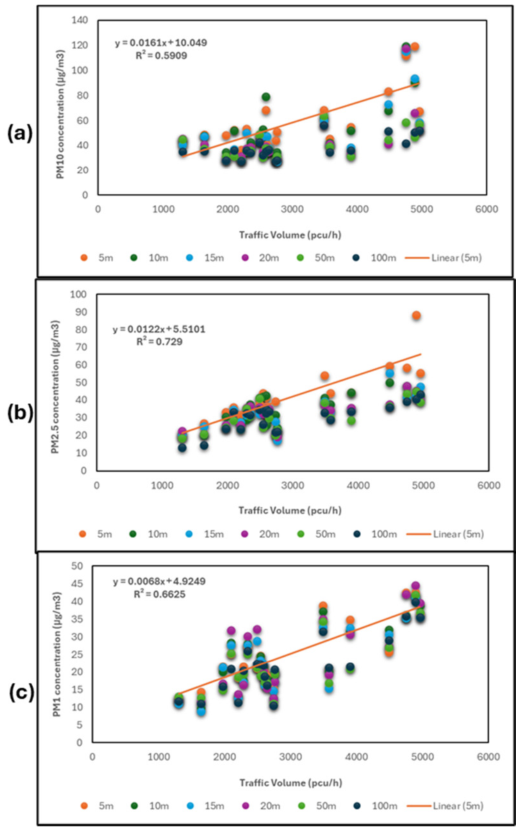

Fig. 4. Colleration between the traffic volume and PM concentrations. (a) PM_{10}, (b) $PM_{2.5}$, and (c) PM_1.

However, research suggests that the relationship between the traffic volume and PM concentrations varies significantly across regions, influenced by local environmental and meteorological conditions [23–27]. For instance, in Ulsan, Korea, high correlations were identified between the PM concentrations ($PM_{2.5}$, PM_{10}, TSP) and traffic volume, particularly with small and heavy-duty vehicles [23].

B. Characteristics of Meteorological Conditions and Relationship with PM_{10}, $PM_{2.5}$, and PM_1 Concentrations

Figure 5 depicts the meteorological conditions observed during the sampling period, including variations in temperature, relative humidity, wind speed, and atmospheric pressure over time. These factors are critical for understanding their potential influence on the PM concentrations.

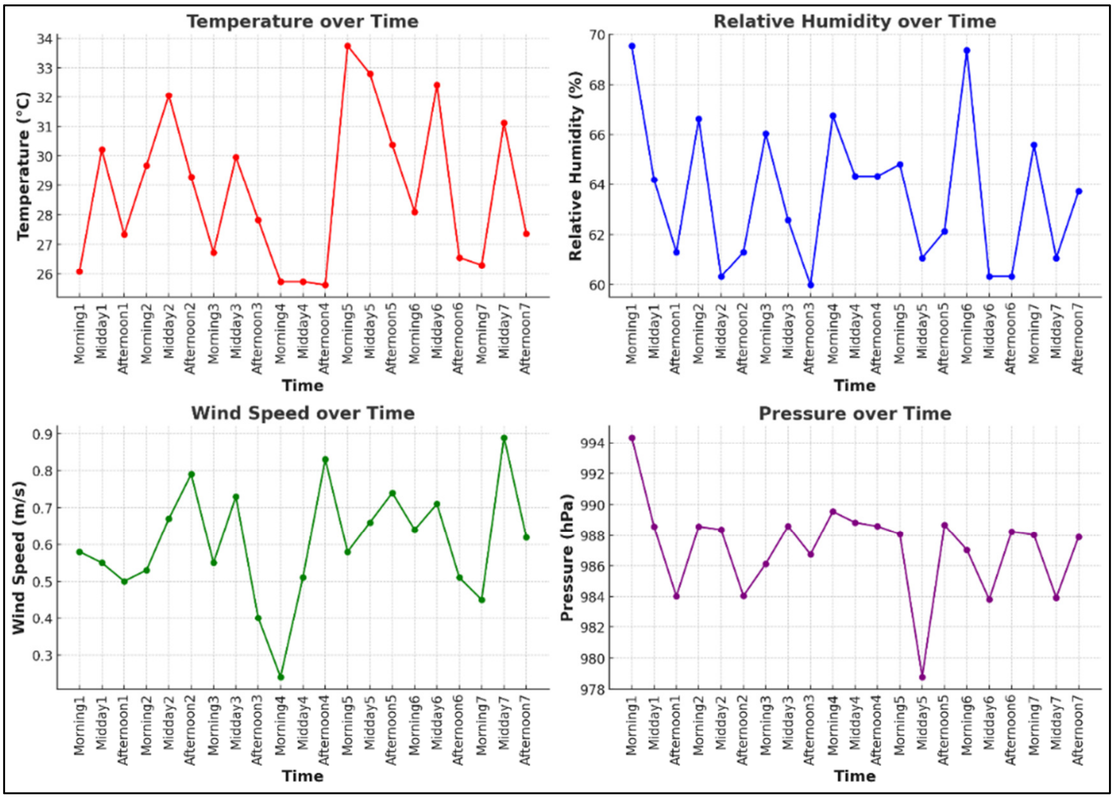

Fig. 5. Meteorological conditions of the sampling period.

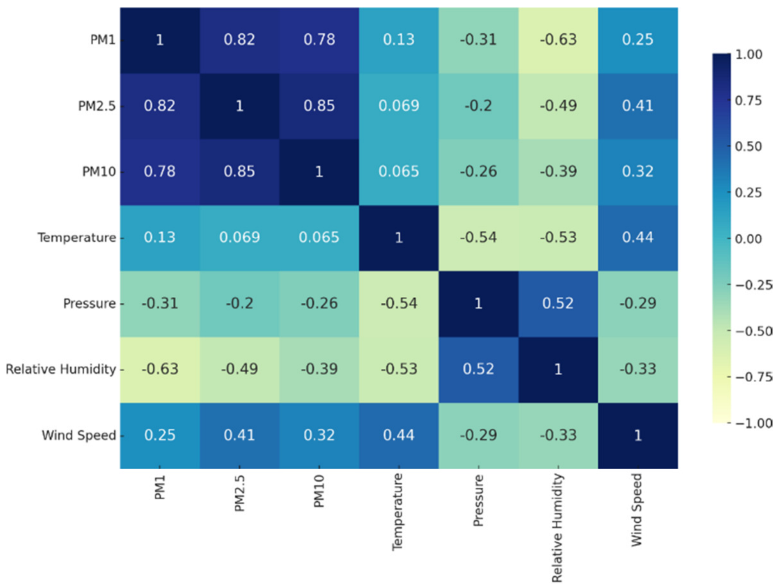

Fig. 6. Correlation between meteorological conditions and PM cocnectrations

Figure 6 displays the relationship between the PM_{10}, $PM_{2.5}$, and PM_1 concentrations and four meteorological factors: temperature, pressure, relative humidity, and wind speed. The performed analysis reveals a generally weak correlation between the PM concentrations and these meteorological variables, suggesting that local emissions, traffic, or other factors may have a more significant influence on the PM levels than meteorological conditions alone.

1) PM_{10} and Meteorological Factors

The low coefficient of determination (R^2) for PM_{10} and the meteorological factors indicate that none of these variables individually accounts for substantial variability in PM_{10} concentrations. This suggests that local sources, such as vehicle emissions, traffic, or other anthropogenic activities may play a more substantial role in determining the PM_{10} levels than meteorological conditions.

2) $PM_{2.5}$ and Meteorological Factors

The lack of a high correlation between the $PM_{2.5}$ and temperature indicate that this factor does not directly influence concentration levels, which is in accordance with [28]. Additionally, the very weak correlation with pressure suggests that the atmospheric pressure has an indirect effect, often related to broader weather pattern changes rather than directly altering. As for relative humidity, its negative correlation with $PM_{2.5}$ concentrations reveals that drier conditions are associated with higher PM2.5 levels. This phenomenon may result from reduced particle agglomeration and removal processes under lower humidity conditions. Similar research, such as [29], has demonstrated that lower humidity levels can increase PM concentrations by limiting particle settling and washout. Finally, the moderate correlation of $PM_{2.5}$ and windspeed suggests that higher wind speeds are associated with slightly increased concentrations. This is supported by [30], where it was found that increased windspeeds enhance the dispersion and dilution of pollutants, leading to lower PM levels.

3) PM_1 and Meteorological Factors

Temperature does not show a strong direct influence on PM_1 concentrations but may affect them through secondary mechanisms. Similarly, atmospheric pressure lacks a meaningful relationship with PM_1, suggesting that its effects are indirect and tied to its influence on meteorological patterns. A moderate negative correlation with relative humidity indicates that lower humidity levels may lead to higher PM concentrations by reducing particle mass and removal, as highlighted in [31]. Meanwhile, a slight positive correlation of the wind speed suggests that higher wind speeds are associated with slightly increased PM_1 concentrations at the measurement sites. This is in accordance with [30], where it was shown that higher wind speeds improve the scattering and diluting of pollutants, leading to reduced PM levels.

C. Spatial Profiles of PM_{10}, $PM_{2.5}$, and PM_1 Concentrations

The relationship between the PM concentrations and their distance from the road can be seen in Figures 7-9.

1) PM_{10} and Distance

Figure 7 illustrates the spatial variation of PM_{10} concentrations based on the distance from the road at different times of the day: morning, midday, and afternoon.

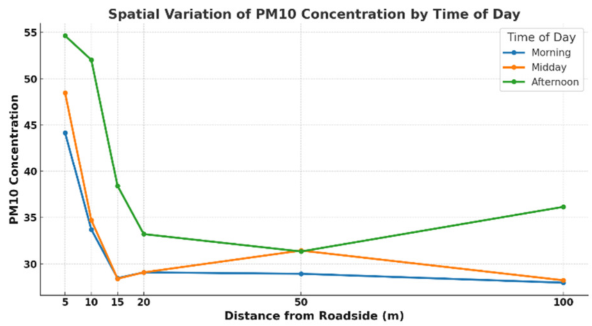

Fig. 7. Spatial profile of PM_{10} concentrations (5 m, 10 m, 15 m, 20 m, 50 m, and 100 m).

The afternoon measurements exhibit the highest PM_{10} concentrations, with a peak at 5 m from the road, followed by a gradual decrease over a distance reaching the lowest value at 50 m. At 100 m, however, PM_{10} levels, suggesting sustained particle presence farther from the road. This pattern aligns with the findings from a study carried out in Western UAE [32], which also observed peak PM_{10} levels in the afternoon. The midday readings exhibit notably lower concentrations, starting at around 48 μg/m^3 at 5 m from the road, decreasing with distance at 15 m, then increasing again at 50 m before finally decreasing to its lowest value at 100 m. The morning PM_{10} levels display a similar decreasing trend with midday readings within the first 15 m from the road, starting at approximately 44 μg/m^3 and reaching around 28 μg/m^3. Beyond 15 m, the concentration shows a flatter distribution, maintaining relatively constant levels up to 100 m.

2) $PM_{2.5}$ and Distance

Figure 8 displays the $PM_{2.5}$ concentrations at different distances from the road during morning, midday, and afternoon. The highest values of $PM_{2.5}$ concentrations were observed in the afternoon, with a peak of approximately 45 μg/m^3 at 5 m from the road. The concentration then gradually decreases to about 30 μg/m^{3}at 50 m, before rising again to 34 μg/m^3 at 100 m. This suggests that while $PM_{2.5}$ levels are highest near the road, they remain detectable even at a distance of 100 m, with some potential re-entrainment or local factors contributing to the increase at farther distances. Midday and morning reveal significantly lower $PM_{2.5}$ concentrations compared to the afternoon. Specifically, midday levels range from 25-35 μg/m³, gradually declining from 5 to 15 m and stabilizing beyond 20 m. Similarly, morning values exhibit a decreasing trend until 15 m, starting slightly higher than the midday levels. These patterns indicate a general decrease in $PM_{2.5}$ concentrations with distance from the road, except during the afternoon. This aligns with the findings in [33], which highlight lower traffic volumes during the early morning hours and enhanced atmospheric dispersion at midday due to increased mixing heights, contributing to reduced fine particle concentrations.

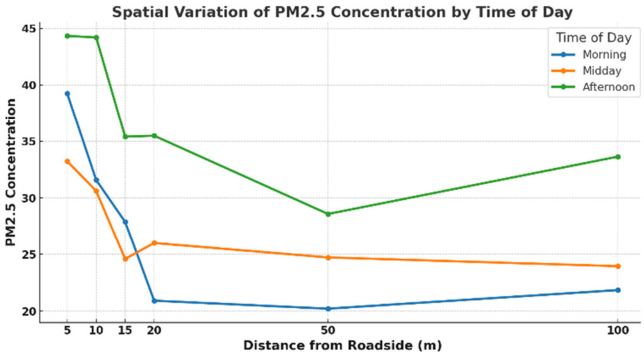

Fig. 8. Spatial profile of PM_{10} concentrations (5 m, 10 m, 15 m, 20 m, 50 m, and 100 m).

3) PM_1 and Distance

Figure 9 indicates the spatial variation of PM_1 concentrations as a function of distance from the roadside for three different times of the day: morning, midday, and afternoon.

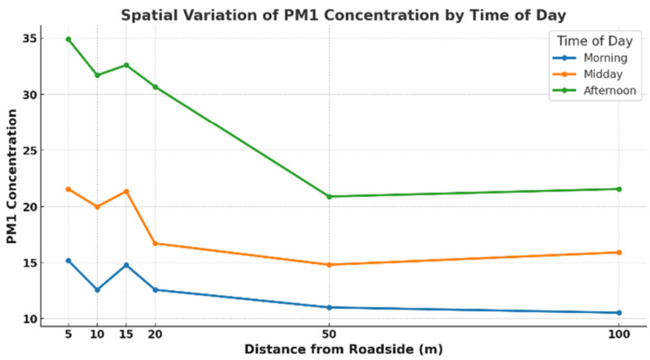

Fig. 9. Spatial profile of PM_1 concentrations (5 m, 10 m, 15 m, 20 m, 50 m, and 100 m).

The graph exhibits that the PM_1 concentrations are highest in the afternoon, with a clear decline as the distance from the road increases. The sharpest concentration decline is seen between 20m and 50m, particularly in the afternoon, indicating that particles disperse more effectively at further distances. Midday and morning readings are lower, with relatively stable trends beyond 20 m, demonstrating the combined effects of traffic volume and atmospheric conditions on particle dispersion. This pattern could be due to increased vehicle traffic in the afternoon, atmospheric stability, and meteorological conditions that limit dispersion. In a study on ultrafine particles [34], authors observed that particle number concentrations were highest within the closer distances of the road and decreased sharply at larger distances which is consistent with the current study.

D. Temporal Profiles of PM_{10}, $PM_{2.5}$, and PM_1 Concentrations

The relationships between PM_{10}, $PM_{2.5}$, PM_1, and their temporal time, morning, midday, and afternoon, can be seen in Figures 10-12.

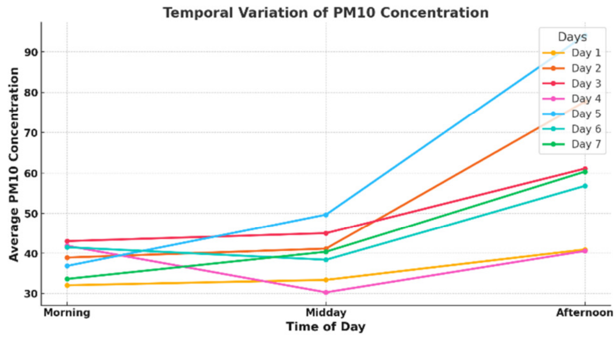

Fig. 10. Temporal profile of PM_{10} concentrations through the day: morning, midday, and afternoon of the sampling period.

Figure 10 shows distinct temporal and spatial variations in PM_{10} concentrations throughout the day. In the morning, PM_{10} concentrations are relatively low and stable, ranging between 30 and 45 µg/m³ across all distances from the road, with minimal differences, indicating weaker effects of proximity to the road at this time. During midday, PM_{10} concentrations exhibit a slight increase, particularly at 5 m from the road, likely due to increased vehicular emissions and human activity. However, the afternoon indicates the highest PM_{10} concentrations, with a sharp peak of over 100 µg/m^3 at 5 m from the road. At farther distances, such as 100 m, concentrations remain significantly lower, around 40-50 µg/m^3. This diurnal pattern suggests that PM_{10} levels are influenced by higher traffic volumes during peak hours and possibly meteorological factors, such as reduced atmospheric dispersion in the afternoon.

Figure 11 depicts the variation of $PM_{2.5}$ concentrations during morning, midday, and afternoon.

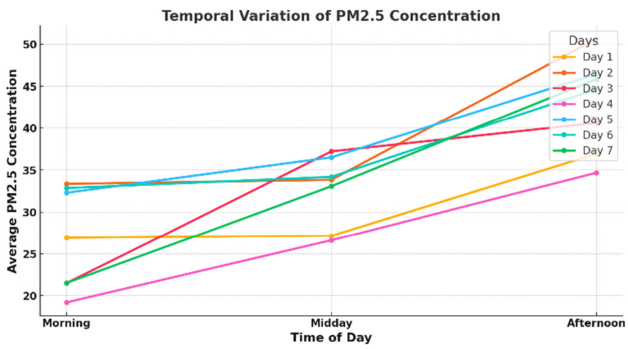

Fig. 11. Temporal profile of $PM_{2.5}$ concentrations through the day: morning, midday, and afternoon of the sampling period.

$PM_{2.5}$ concentrations exhibit a wide range in the morning, with the highest concentrations being observed at 5 m, approximately 40 µg/m³, and the lowest at 100 m, approximately 20 µg/m³. Durning midday, $PM_{2.5}$ concentrations generally decrease at closer distances, 10-20 m, while levels at further distances, from 20 to 100 m, remain relatively stable or increase slightly. Authors in [27] investigated the impact of traffic emissions on $PM_{2.5}$ levels and found that the concentrations were the highest near roadways during peak traffic hours. Similarly, the present study shows elevated PM2.5 levels at 5 m from the road during midday and afternoon, correlating with increased traffic volume.

Figure 12 presents the diurnal profile of PM_1 concentrations for each distance from the road.

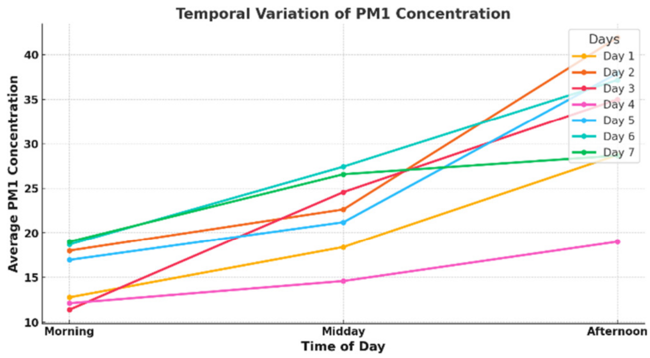

Fig. 12. Temporal profile of PM_1 concentrations through the day: morning, midday, and afternoon of the sampling period.

The PM_1 concentrations are the highest at 5m and 10m from the road, underscoring the significant impact of the proximity of the road on PM_1 exposure. The increase in concentrations from morning to afternoon suggests that activities contributing to PM_1, such as traffic and other human emissions, intensify as the day advances. At 100m from the road, PM_1 concentrations are the lowest throughout the day, highlighting the mitigating effect of distance on PM_1 exposure. These findings align with those of [35], where it is demonstrated that an increasing distance from the road significantly reduces the exposure to PM pollutants.

E. Comparative Analysis with Other Urban Regions

To situate the findings of this study within a broader framework, a comparison of the PM concentrations observed in Padang City with those reported in similar urban environments was conducted. In Beijing, diurnal variations in PM_{10} concentrations have been widely reported, with peaks being noted during morning and evening rush hours due to increased vehicular emissions [36]. This pattern is consistent with Padang, where traffic volume significantly influences PM levels, particularly during peak hours. Similarly, studies in metropolitan areas, such as Shanghai, have highlighted the impact of meteorological conditions, noting that high humidity can increase PM concentrations by strengthening the particle mass [28]. Despite the observed minimal direct influence of temperature and humidity on PM variability, Padang's tropical climate may still modulate PM behavior, as seen in other tropical cities. Comparatively, cities in Europe with strict traffic management policies report significantly lower PM concentrations [8], suggesting that similar interventions could benefit Padang. These comparisons underscore the challenges faced by rapidly developing cities, like Padang, and emphasize the importance of localized air quality management strategies tailored to specific environmental and socio-economic contexts.

IV. CONCLUSION

This study offers a comprehensive analysis of PM_{10}, $PM_{2.5}$, and PM_1 concentrations in Padang City, Indonesia, highlighting the significant impact of motor vehicle emissions in urban air quality. The findings indicate that Particulate Matter (PM) levels peak near major roadways, especially during high-traffic periods, emphasizing the significant influence of traffic volume and vehicle types on the PM pollution. Temporal trends show midday and afternoon as key periods for elevated PM levels, closely linked to atmospheric conditions and vehicular activity, underscoring the importance of targeted air quality management strategies. Addressing emissions during these peak hours could mitigate the health impacts of PM exposure and substantially improve urban air quality

Although the meteorological factors displayed a limited direct impact, the interplay between the local emissions and environmental conditions adds complexity to the PM behavior. The results align with the global findings, confirming that those urban areas with heavy traffic face significant air quality challenges. These insights underscore the urgency of implementing traffic management and emission control strategies, such as enhanced roadside air quality monitoring, stricter vehicle emission standards, and the promotion of alternative transportation modes, to reduce the PM levels and enhance the urban living conditions. The study also advocates for further research into seasonal variations and the specific contributions of different vehicle types to the PM dynamics. By addressing these gaps, policymakers can design more effective interventions tailored to Padang City's unique environmental and socio-economic context. Indonesia's tropical climate, characterized by high humidity and temperature, further complicates PM behavior, highlighting the need for localized studies to refine mitigation strategies.

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