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Spatial Distribution of NO_2 and PM_{10} Concentrations from Transportation Emissions in Yogyakarta

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ABSTRACT

As a city center for education and culture, Yogyakarta has experienced an increase of anthropogenic activities related to transportation sector, leading to a deterioration in air quality. This study aims to comprehensively analyze emission loads through a line source inventory across 20 arterial roads. We monitored air quality using High-Volume Air Sampler (HVAS) and Impinger sampling methodologies, and we simulated pollutant dispersion using the AERMOD model. The results indicate that emissions from the transportation sector range between 0.41 - 1.82 gr/s for NO_x and 0.08 - 0.36 gr/s for PM_{10}. Based on observation using HVAS method, PM_{10} varied between 6.5 - 50.92 µg/m³, while NO_2 concentration is 0.89 - 1.5 µg/m³ in major roads. Our model using AERMOD showed a low error, indicating it is a reliable tool for simulating the dispersion of NO_2 and PM_{10}. Further, the findings suggest city development shall be supported by environmentally friendly transportation that minimize emission sources, and the enhancement of greening initiatives in susceptible areas.

KEYWORDS

AERMOD, emissions, HVAS, impinger, transportation

1. INTRODUCTION

Anthropogenic activities hves driven a sharp rise in transportation usage, making it a primary contributor to urban air pollution (Mubarak et al., 2024). Motor vehicles are major contributors to air pollution, accounting for 71% of nitrogen oxides (NOx), 15% of sulfur oxides (SOx), and 70% of particulate matter (PM_{10}) emissions (Ismiyati et al., 2014). Monitoring these specific pollutants is a matter of critical public health (Eguiluz-Gracia et al., 2020). A systematic epidemiological evidence demonstrates that even short-term exposures to PM_{10} and NO_2 are directly linked to increased mortality from cardiovascular and respiratory diseases, with long-term PM_{10} exposure elevating overall mortality risks (Lu et al., 2015).

Air quality, specifically NO_2 and PM_{10} in Yogyakarta City are assessed through monitoring stations. However, these stations are limited to specific locations including Malioboro, Kotagede, and Gondokusuman. The restricted distribution of these monitoring stations impedes the comprehensive assessment of air quality conditions and the impact of pollution across the entire city. To address this limitation, the AERMOD dispersion model has been employed to simulate the spatial distribution of NO_2 and PM_{10} pollutants, derived from line emission sources. The model has demonstrated commendable performance in areas characterized by mountainous topography (Perry et al., 2005) and industrial zones (Afzali et al., 2017), although it has occasionally under-predicted concentrations in regions with complex topography (ul Haq et al., 2019).

This study was conducted to address the deterioration of air quality in Yogyakarta City. The initial phase involved quantifying the emission load resulting from transportation activities on 20 arterial roads within the city. Subsequently, the concentration levels of NO_2 and PM_{10} were analyzed utilizing sampling tools alongside the AERMOD modeling approach. The model outputs were then compared with empirical measurement data to assess the validity of the model. A higher degree of model validity will facilitate the formulation of more effective regulatory measures (Askariyeh et al., 2017).

2. MATERIALS AND METHODS

2.1 Study Area

The study site focuses on the highlighted blue arterial roads in Yogyakarta City, as shown in Figure 1, which were selected based on the highest congestion levels observed in the central to northern parts of the city. These roads serve as major transportation corridors, experiencing heavy traffic flow that can contribute significantly to air pollution, particularly emissions of NOx and PM_{10}.

2.2 Line source emission inventory

The processing of data pertaining to the line source transportation emission inventory is performed to derive the emission load data for NO_2 and PM_{10} parameters. In accordance with the Technical Guidelines for Emission Inventory established by the Ministry of Environment and Forests in 2018, the main road network, which includes arterial and collector roads, is categorized as line sources. The analysis encompasses various vehicle types, including motorcycles, passenger cars, and buses, with fuel types comprising gasoline and diesel. The mathematical formula employed to calculate the total emission load from line sources is detailed as follows in Equations (1-2).

$$E_{j,i} = VKT_{j,i} \times FE_j \quad (1)$$

$$VKT_{j,i} = \sum_{i=1}^{n} Q_{j,i} \times FE_j \quad (2)$$

where $VKT_{j,line}$, Q_{ji}, l_i, EF, E_{cji}, and c each represent the VKT (vehicle kilometer travelled) of vehicle category j on road segment i which is calculated as a line source (km/year), vehicle volume in category j on road section i (vehicles/year). years), length of road section i (km), emission factor, pollutant emission c for road category j vehicles on road section i, and efficiency of emission control equipment (%). The emission factor applied in this analysis is derived from Minister of Environment Regulation No. 12/2010, which categorizes emissions based on the type of vehicle utilized and the fuel employed.

2.3 NO_2 and PM_{10} Sampling Methods

The measurement of PM_{10} concentrations was conducted on 20 arterial roads in Yogyakarta City using a High Volume Air Sampler (HVAS) in accordance with SNI 7119.15:2016, employing the gravimetric method. Meanwhile, NO_2 concentrations were measured using an Impinger with the Griess-Saltzman method, analyzed with a spectrophotometer, following SNI 19-7119.2.2005. Sampling was carried out for 24 hours for PM_{10} and 1 hour for NO_2. The measurement results were then compared with the ambient air quality standards outlined in Government Regulation No 22/2021.

2.4 Data Analysis

2.5 Simulation of NO_2 and PM_{10} concentrations dispersion in Yogyakarta City using the AERMOD model

The AERMOD dispersion model serves as a reputable regulatory instrument for simulating the transport and dispersion of air pollutants across diverse environments. This study employed AERMOD to simulate the spatial distribution of NO_2 and PM_{10} concentrations in Yogyakarta City, emphasizing emissions attributable to transportation sources. The model integrates meteorological data, terrain characteristics, and emission source parameters to estimate NO_2 and PM_{10} concentrations throughout the designated study area.

The simulation process encompasses three pivotal stages: preprocessing meteorological data through AERMET, preparing terrain and receptor data with AERMAP, and conducting dispersion modeling using AERMOD. These interrelated stages are essential for generating accurate spatial distribution maps of NO_2 and PM_{10}.

2.6 Model validation test

Model validation was performed to evaluate the accuracy of the AERMOD simulation results by statistically comparing the predicted pollutant concentrations with observed air quality monitoring data (Sharma et al., 2021). To quantify the discrepancy between the simulated and measured values, the Root Mean Square Error (RMSE) was utilized as the primary statistical metric. A lower RMSE value signifies a minimal deviation between the two datasets, thereby demonstrating that the model exhibits high performance and precision in replicating real-world pollutant dispersion. The RMSE formula can be described as follows in Equation (3), where $\hat{y}_i$ is predicted value, y_i is observed value, while n is number of observations.

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}} \quad (3)$$

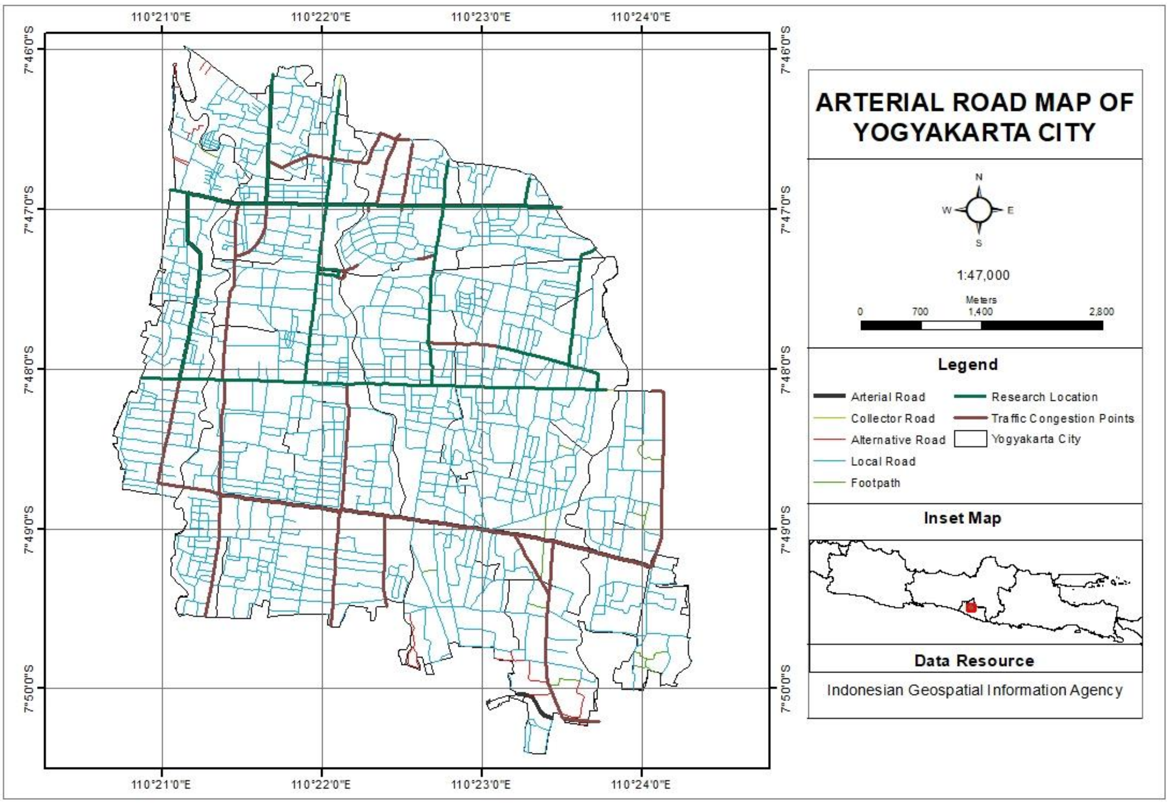

Figure 1. Selected arterial road segments within the study area.

3. RESULTS AND DISCUSSION

3.1 Traffic Emission Loads and Ambient Pollutant Concentrations

The emission load attributable to the transportation sector in Yogyakarta is assessed by evaluating the volume of vehicles traversing 20 arterial roads situated in the northern region leading to the city center. This analysis encompasses various vehicle types, including motorcycles, cars, buses, and light goods vehicles such as pickups, which operate on diesel and gasoline. The methodology employed follows a top-down approach, utilizing Tier 2 emission factors in accordance with the guidelines established by the Ministry of Environment and Forestry (KLHK).

Emission calculations are executed by considering vehicle volume, specific emission factors associated with each vehicle type, and local traffic conditions on each analyzed road segment. The vehicle volume is recorded during peak rush hour for one hour and is subsequently utilized as a representation of daily traffic activity (Irwandi et al., 2025). This approach is implemented due to the limitations concerning resources, costs, and time associated with conducting exhaustive traffic surveys.

Based on Table 1, the total emission loads of NO_x and PM_{10} across the 20 arterial roads are 19.22 g/s and 3.75 g/s, respectively, with NOx consistently exceeding PM10. The highest NO_x and PM_{10} emissions occur on Magelang and Dr. Supomo Streets, respectively, while Gejayan Street exhibits the lowest levels. This spatial variation is driven by differences in traffic volume, vehicle composition, fuel types, specific emission factors, and street characteristics. As a primary intercity highway, Magelang Street carries high-density traffic connecting Yogyakarta to northern regions (Magelang and Semarang). Conversely, Gejayan Street runs through a predominantly educational and residential area dominated by private vehicles and motorcycles, whereas Dr. Supomo Street serves as a vital corridor linking commercial, office, and educational zones.

These variations suggest that transportation emissions in Yogyakarta are concentrated along specific arterial corridors. High-emission segments correspond to intensive traffic activity, longer road links, or a higher proportion of vehicles with elevated emission factors. Furthermore, the predominance of NOx over PM_{10} reflects the dominance of fuel combustion from gasoline and diesel vehicles. However, emission loads do not directly represent receptor-level ambient air quality, as concentrations are heavily modulated by meteorology, atmospheric dispersion, deposition, and surrounding land use. Consequently, field measurements of NO_2 and PM_{10} were conducted to evaluate how these calculated source loads translate into actual ambient conditions.

Table 1. Emission load of NO_2 and PM_{10} from 20 artery line sources.

Street	NO_x emission (g/s)	PM_{10} emission (g/s)
Magelang Street	1,8202	0,2844
A.M Sangaji/ P Mangkubumi Street	0,9994	0,1866
Kyai Mojo Street	0,9884	0,1403
HOS Cokroaminoto Street	0,7350	0,1291
Parangtritis Street	1,4741	0,2859
Diponegoro Street	0,8571	0,1349
Jendral Sudirman Street	0,9956	0,1907
Prof. DR. ir. Yohanes Street	0,5139	0,0900
Urip Sumoharjo Street	0,6750	0,1234
Adi Sucipto Street	0,8138	0,1371
Gejayan Street	0,4131	0,0831
Malioboro Street	0,4581	0,0837
K.H Ahmad Dahlan Street	1,1282	0,2932
Senopati Street	0,7872	0,1736
Dr. Wahidin Sudirohusodo Street	0,5868	0,0944
Dr. Supomo Street	1,5781	0,3639
Sultan Agung Street	1,4386	0,3323
Kusumanegara Street	1,2476	0,2700
Kenari Street	1,1885	0,2335
Ipda Tut Harsono Street	0,5215	0,1176
Total	**19,220**	**3,7477**

Following the emission load assessment, ambient air quality measurements were conducted to provide empirical evidence of pollutant concentrations at receptor locations. The concentration of NO_2 and PM_{10} were measured at three road segments with the highest Volume-to-Capacity (V/C) ratio in Yogyakarta City, namely AM Sangaji Street, Parangtritis Street, and Adisucipto Street. These locations were selected because high V/C ratios indicate intensive traffic activity and potential pollutant accumulation near road corridors. The measurements were carried out using an Impinger for NO_2 and HVAS for PM_{10}, allowing the calculated emission loads to be compared with actual ambient air quality conditions. Sampling was carried out in December, during the rainy season, which significantly affected the measurement results. During this month, the intensity of solar radiation tends to be low, and cloud cover is higher, which may reduce the photodissociation process of NO_2 by UV light (Rahman et al., 2022). On the other hand, PM_{10} concentrations are greatly influenced by rainfall. Higher rainfall intensity can enhance the scavenging effect on airborne particles, causing PM_{10} concentrations to decrease through wet deposition, where suspended particles are carried down to the ground surface by raindrops.

The results of the measurements indicate that the concentrations of NO_2 and PM_{10} remain below the ambient air quality standards established in Government Regulation No. 22 of 2021, which stipulate limits of 200 µg/m³ for NO_2 and 75 µg/m³ for PM_{10}. The observed higher concentration of PM_{10} relative to NO_2 in this study can be attributed to the distinct physicochemical characteristics and atmospheric residence times of each pollutant. PM_{10}, being particulate matter, exhibits a longer residence time, contingent upon meteorological conditions and deposition processes. In contrast, NO_2 possesses a shorter lifetime, around several hours to one day, due to its higher reactivity and propensity for chemical transformation within the atmosphere (Pommier, 2023). Furthermore, the distribution of these pollutants along arterial roads is significantly influenced by meteorological factors, including wind speed, temperature, and humidity, which dictate the dispersion and accumulation of pollutants in specific locations. Consequently, the differences in atmospheric dynamics and emission sources elucidate the variations in concentrations between PM_{10} and NO_2.

The measured data reveal distinct variations among the three sampling locations based on the differing behaviors of PM_{10} and NO_2. PM_{10} concentrations peaked at Parangtritis Street, followed by Adisucipto Street and AM Sangaji Street. This variation indicates that particulate levels were driven not only by atmospheric residence time but also by local roadside factors, including road dust resuspens-ion, traffic turbulence, vehicle composition, and nearby

Table 2. Sampling test results of meteorological parameters and ambient air quality using HVAS (PM_{10}) and Impinger (NO_2) instruments**.**

No	Parameters	Unit	Result
AM Sangaji Street (07⁰46'13.9" S 110⁰22'07" E)			
1	Temperature	^0C	24,9 ±1,23
2	Relative humidity	%	87,8 ± 2,30
3	Wind speed	m/s	0,07
4	Pressure level	mmHg	744 ± 1,68
5	Concentration of NO_2	μg/m^3	1,72 ± 0,22
6	Concentration of PM_{10}	μg/m^3	7,21 ± 0,71
Parangtritis Street (07⁰49'37.4" S 110⁰22'3.4" E)			
1	Temperature	^0C	26,2 ±1,23
2	Relative humidity	%	82,9 ± 2,30
3	Wind speed	m/s	0,97
4	Pressure level	mmHg	744 ± 1,68
5	Concentration of NO_2	μg/m^3	1,65 ± 0,20
6	Concentration of PM_{10}	μg/m^3	56,2 ± 5,28
Adisucipto Street (07⁰46'59.5" S 110⁰24'27.5" E)			
1	Temperature	^0C	26,2 ±1,23
2	Relative humidity	%	82,9 ± 2,30
3	Wind speed	m/s	0,97
4	Pressure level	mmHg	744 ± 1,68
5	Concentration of NO_2	μg/m^3	1,01 ± 0,12
6	Concentration of PM_{10}	μg/m^3	43,2 ± 4,06

activities. Conversely, NO_2 levels varied minimally across locations due to the pollutant's high reactivity and short atmospheric lifespan. Additionally, December's rainy season, a conditions with high humidity, more rainy days that enhancing wet deposition, and low solar radiation may suppressed the photochemical production of NO_2, maintaining low overall concentrations (Yoo et al., 2014).

3.2 AERMOD Simulation of and Spatial Dispersion

Wind direction and speed represent critical meteorological factors that significantly affect the distribution of atmospheric pollutants (Afzali et al., 2017). The direction of the wind delineates the primary trajectory of pollutant transport from the source of emission, while the wind speed influences the extent of mixing and dispersion of these pollutants within the atmosphere. Under conditions of low wind speed, pollutants are prone to accumulate in proximity to their emission sources due to reduced transport capacity, thereby heightening the risk of localized exposure. Conversely, increased wind speeds can expedite the dispersion of pollutants, resulting in a more uniform distribution and a broader geographical region affected by the pollution (Ibrahim et al., 2022).

Wind rose analysis provides a critical meteorological baseline for interpreting the spatial dispersion of and in Yogyakarta City. The prevailing wind blows from the northwest to the southeast, indicating that road corridor emissions are primarily transported toward the southeastern region. Concurrently, the meteorology is dominated by low wind speeds, with 55.4% of the period falling within the 0.50–2.10 m/s range (Figure 3). These low-velocity conditions restrict atmospheric mixing and pollutant dilution, facilitating localized accumulation and hotspot formation near dense arterial road networks. Consequently, integrating wind vector analysis is indispensable for validating the dispersion model's spatial patterns.

Following this meteorological interpretation, the AERMOD dispersion model was employed to simulate the distribution of NO_2 and PM_{10} concentrations in Yogyakarta City. By incorporating emissions loads, meteorology, terrain features, and receptor locations, the model provides a more comprehensive spatial analysis than field observations alone, mapping contaminant distribution across areas without direct monitoring. Consequently, these AERMOD outputs help pinpoint potential high-concentration zones and facilitate urban-scale air quality management.

The model was used to estimate the spatial distribution of traffic-related pollutants by incorporate-ing emission load data, meteorological conditions, terrain characteristics, and receptor locations. The simulation results offer a more comprehensive spatial interpretation than field observations, as they depict the distribution of contaminants over the extensive

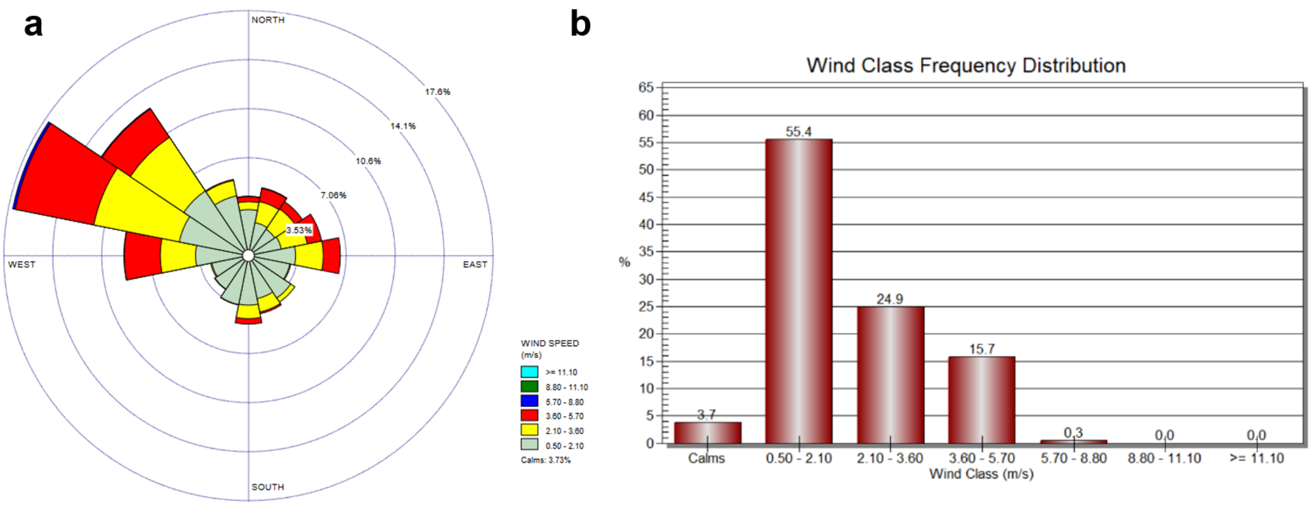

Figure 3. Meteorological characteristics during December in Yogyakarta City: (a) wind rose plot showing prevailing directions and speed classes, and (b) wind class frequency distribution.

research region, including sites where direct monitoring was absent. Consequently, the AERMOD output can be utilized to pinpoint probable concentration zones and facilitate air quality management at the urban scale

The spatial distribution maps show that both NO_2 and PM_{10} concentrations were generally concentrated around major arterial roads and decreased with increasing distance from the emission sources. This pattern indicates that transportation activity is the dominant factor controlling the spatial distribution of pollutants in the study area. According to Figure 4, the highest concentration zones were observed around Sultan Agung Street and its surrounding road network. This area is likely influenced by the combination of relatively high emission loads, dense traffic activity, and limited atmospheric dispersion during the sampling period. The low wind speed condition may have restricted pollutant transport, allowing concentrations to accumulate around road corridors rather than being rapidly dispersed to wider areas.

The simulated maximum concentrations reached approximately 66 µg/m³ for NO_2 and 60 µg/m³ for PM_{10}, remaining below the standards set by Government Regulation No. 22 of 2021. However, localized concentration zones demonstrate that regulatory compliance does not equate to uniform air quality across the city. Certain road corridors face higher exposure driven by emission intensity, traffic density, low wind speeds, and local land-use features. Thus, urban air quality management must account for these spatial patterns, especially near sensitive receptors like schools, residential zones, and markets. Furthermore, the dispersion differences highlight distinct atmospheric behaviours, while particulate matter is heavily influenced by physical factors. NO_2 acts as a reactive gas primarily tied to vehicle combustion and atmospheric chemical transformation.

Consequently, its spatial distribution is strongly driven by traffic emission intensity and atmospheric reactivity. In contrast, PM_{10} originates from both exhaust emissions and non-exhaust sources—such as road dust resuspension, tire and brake wear, and roadside activities. Its distribution is therefore shaped by a broader range of local factors, including road surface conditions, rainfall, traffic turbulence, and surrounding land use. This explains why PM_{10} concentration patterns do not always align directly with NO_2 distribution, despite both pollutants sharing a strong link to transportation sources.

The model output also suggests that meteo-rological conditions during December played an important role in reducing and redistributing pollutant concentrations. The rainy season may contribute to lower PM_{10} levels through wet deposition, in which suspended particles are removed from the atmosphere by rainfall. However, low wind speed during the same period may counteract this effect by limiting dispersion and promoting local accumulation near road corridors. This indicates that air quality conditions in Yogyakarta may vary seasonally, and pollutant concentrations during the dry season could potentially be higher due to lower rainfall and weaker particle scavenging. Therefore, future modeling and monitoring should include both rainy and dry season conditions to provide a more representative assessment of annual air quality patterns.

The AERMOD simulation demonstrates that the spatial distribution of NO_2 and PM_{10} in Yogyakarta City is controlled by the interaction between transportation

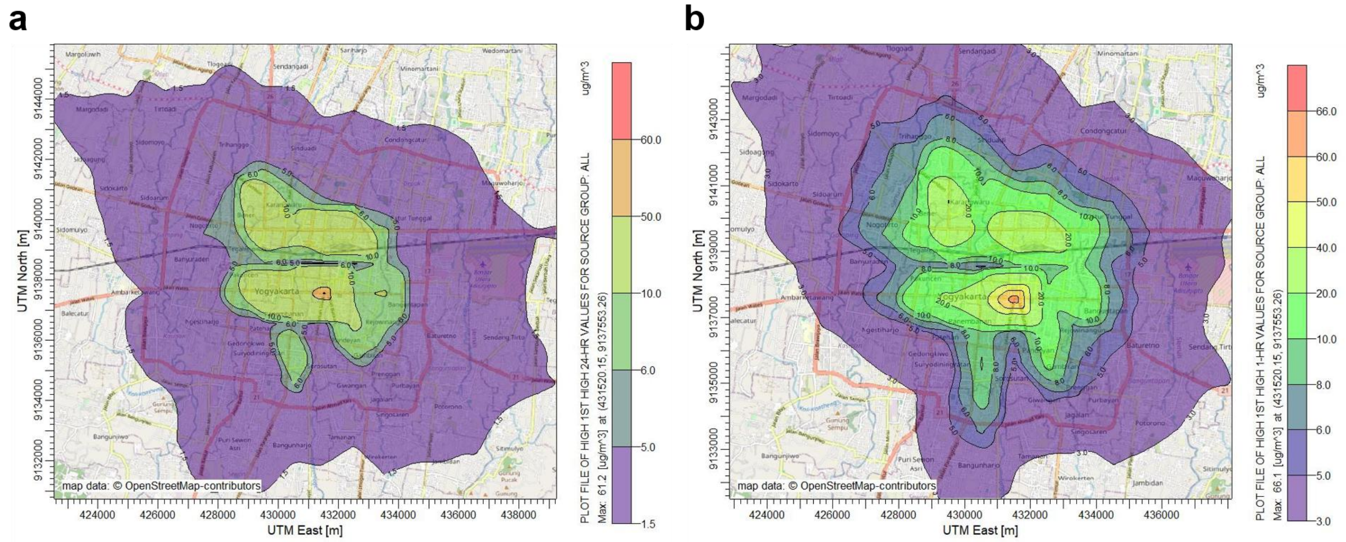

Figure 4. A spatial distribution of (a) PM_{10} (24-hr average) and (b) NO_2 (1-hr average) concentrations

emission loads, road network characteristics, meteorological conditions, and local environmental factors (Pratama & Sofyan, 2020). Despite the simulated concentrations being below national ambient air quality standards, identifying localized concentration zones is crucial for proactive air quality management. These findings indicate that mitigation strategies should be prioritized in areas with higher modeled concentrations, especially along arterial roads with dense traffic and limited dispersion. Practical measures may include traffic flow management, improvement of public transportation, reduction of vehicle emissions, control of road dust, and development of roadside green infrastructure. In this context, AERMOD can serve as a useful decision-support tool for identifying potential pollution hotspots and designing targeted air quality management policies in Yogyakarta City.

3.3 Validation and Air Quality Management

The validation performance of the AERMOD simulation against field measurements across the three monitored road segments namely Parangtritis, AM Sangaji, and Adisucipto Streets is summarized in Table 3. The evaluation reveals distinct, pollutant-specific predictive behaviors between gaseous and particulate matter.

The validation results indicate that the model exhibited different predictive characteristics for NO_2 and PM_{10}. For NO_2, the AERMOD simulation tended to overpredict the measured concentrations at all sampling locations. The measured NO_2 concentrations ranged from 0.89 to 1.50 μg/m³, while the simulated values ranged from 7.44 to 10.17 μg/m³. This overprediction may be associated with the simplified representation of NO_x emissions and the chemical transformation of nitrogen oxides in the atmosphere. In real atmospheric conditions, NO_2 is a reactive pollutant that can undergo photolysis, oxidation, and conversion into other nitrogen-containing compounds. Therefore, the measured NO_2 concentration at receptor points may be lower than the modeled concentration, especially when the model does not fully represent short-term chemical transformation processes, traffic fluctuation, and local-scale dispersion near road corridors. In contrast, the model tended to underpredict PM_{10} concentrations, particularly at Parangtritis Street and Adisucipto Street. The measured PM_{10} concentrations at these locations were 50.92 μg/m³ and 39.14 μg/m³, respectively, whereas the simulated values were 8.83 μg/m³ and 2.95 μg/m³.

This underprediction suggests that the PM_{10} concentration measured in the field was not only influenced by exhaust emissions from motor vehicles, but also by non-exhaust and local particulate sources. These sources may include road dust resuspension, tire and brake wear, roadside commercial activity, construction dust, and traffic-induced turbulence. Meanwhile, the lower RMSE value for PM_{10} at AM Sangaji Street indicates that the model performance was better at locations where local particulate sources were less dominant or where measured concentrations were closer to the estimated line-source contribution.

These findings indicate that while AERMOD reasonably captures the spatial trends of traffic-related pollutant dispersion, its performance depends heavily on emission inventory completeness, meteorological representativeness, and local roadside complexity. Consequently, the overprediction of and under-prediction of should not be viewed as a model failure, but rather as evidence that gaseous and particulate pollutants demand distinct modeling considerations.

Table 3. RMSE value for AERMOD's simulation result

No	Street	Measurement (µg/m³)		AERMOD Simulation (µg/m³)		RMSE	
		NO_2	PM_{10}	NO_2	PM_{10}	NO_2	PM_{10}
1	Parangtritis Street	1.45	50.92	10.17	8.83	5.03	24.3
2	AM Sangaji Street	1.5	6.5	9.34	4.75	4.5	1.01
3	Adisucipto Street	0.89	39.14	7.44	2.95	3.78	18.3

Specifically, simulations require enhanced representations of atmospheric chemistry and temporal traffic variability. Conversely, modeling must incorporate non-exhaust sources and localized dust resuspension. As demonstrated by the location- and pollutant-specific deviations in Table 3, these variations highlight the necessity for pollutant-specific modifications to improve future simulation accuracy.

From a policy perspective, the validation results demonstrate that AERMOD is useful as a screening and decision-support tool for identifying potential air pollution hotspots in Yogyakarta City. Although the model may not perfectly simulate measured concentrations at every receptor point, it can provide spatial information that cannot be obtained from limited field measurements. This is particularly important for urban air quality management because direct monitoring stations are often limited in number and cannot represent the spatial variability of traffic-related pollution across all arterial roads. Therefore, the integration of emission inventory, field measurement, and dispersion modeling can help local authorities identify priority road segments for monitoring, mitigation, and regulatory intervention.

The findings also suggest that air quality policy should not rely only on compliance with ambient air quality standards. Although both measured and simulated concentrations remained below the regulatory thresholds, the presence of localized concentration zones and pollutant-specific model deviations indicates that preventive management is still needed. For NO_2, mitigation should focus on reducing combustion-related emissions through traffic flow improvement, vehicle emission testing, public transport optimization, and gradual transition toward low-emission vehicles. For PM_{10}, mitigation should include not only vehicle emission control, but also road dust management, regular street cleaning, control of construction-related dust, improvement of road surface conditions, and roadside vegetation development.

In practical terms, the model can be used by local government to evaluate several future air quality management scenarios. For example, AERMOD can be applied to estimate the potential impact of traffic diversion, road capacity changes, public transportation improvement, low-emission zones, parking restriction policies, or increased roadside greening. By comparing the predicted pollutant concentrations under different scenarios, policymakers can prioritize interventions that provide the greatest air quality benefit. This approach is particularly relevant for Yogyakarta City, where transportation activity is closely related to education, tourism, commerce, and daily commuting.

The validation results indicate that AERMOD possesses the capability to facilitate evidence-based air quality management in Yogyakarta City, especially when integrated with field measurement data. The model provides an important basis for identifying spatial pollution patterns, evaluating emission reduction strategies, and supporting preventive policy development. Future applications should improve the emission inventory by including more detailed traffic activity data, vehicle composition, temporal traffic variation, non-exhaust PM_{10} sources, and seasonal meteorological conditions. Strengthening these input data will improve model accuracy and increase the usefulness of AERMOD as a planning tool for sustainable urban air quality management.

4. CONCLUSION

This study aims to evaluate the distribution of NO_2 and PM_{10} pollutants emitted by the transportation sector along 20 arterial roads in the northern to-center region of Yogyakarta City, integrating a direct measurement approach in the field and the dispersion modeling techniques using AERMOD. The findings generated from this analysis can inform strategies for enhancing or maintaining air quality within the study area. It is essential to consider that the validity of the model must accurately represent real-world conditions.

The results showed that air quality levels were relatively good, with concentrations of NO_2 and PM_{10} remaining below the ambient air quality standards established in Government Regulation No. 22 of 2021. Several factors contribute to the observed low pollutant concentrations, including the meteorological conditions prevalent during December (the rainy season), the volume of vehicular traffic on each roadway segment, and the analysis of emission loads from the 20 selected arterial roads. The modeling results obtained through AERMOD demonstrated a high level of correlation with the direct field measurements, as evidenced by the low error values calculated using the RMSE formula for Parangtritis Street, AM Sangaji Street, and Adisucipto Street with the concentration of pollutants is overpredicted for NO_2 and underpredicted for PM_{10}. This establishes the AERMOD dispersion model as a reliable instrument for conducting air quality assessments in Yogyakarta City, particularly concerning emissions from the transport-ation sector, and serves as a viable alternative when direct field measurement resources are constrained.

However, this study has several limitations that should be considered when interpreting the results. First, direct measurements of NO_2 and PM_{10} concentrations were conducted only at three sampling locations, namely AM Sangaji Street, Parangtritis Street, and Adisucipto Street, which may not fully represent the spatial variability of air quality across all arterial roads in Yogyakarta City. Although these locations were selected based on high traffic conditions, pollutant concentrations may differ in other road segments due to variations in traffic volume, vehicle composition, road geometry, surrounding land use, and local activities. Second, the sampling was conducted during December, which represents the rainy season. Seasonal meteorological conditions, particularly rainfall, humidity, cloud cover, and relatively low wind speed, may influence pollutant dispersion, wet deposition, and atmospheric transformation processes. Therefore, the measured concentrations during this period may be lower than those that could occur during the dry season, when rainfall scavenging is limited and road dust resuspension may increase. These limitations indicate that the results should be interpreted as a representative assessment of transportation-related NO_2 and PM_{10} dispersion under the specific sampling and meteorological conditions of the study period.

For future research, it is recommended to expand the number of sampling locations to include more arterial, collector, and local roads, and to conduct repeated measurements across different seasons. The inclusion of both rainy and dry season data, longer monitoring periods, and more detailed traffic activity information would improve the representativeness of the emission inventory, field measurements, and AERMOD simulation. These improvements would strengthen the use of dispersion modeling as a decision-support tool for urban air quality management in Yogyakarta City.

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