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ANALYSIS OF AMBIENT AIR QUALITY DUE TO MOTOR VEHICLE EMISSIONS USING SYSTEM DYNAMICS MODELING ON JALAN KALIURANG, YOGYAKARTA

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Yusuf Wiryawan[1], Radjali Amin[2]
[1,2]Program Studi Magister Ilmu Lingkungan, Institut Teknologi Yogyakarta, Indonesia
Corresponding author: Yusuf Wiryawan
E-mail: yusufucup177@gmail.com

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Abstract:
The increase in motor vehicle activity in the Special Region of Yogyakarta has contributed to higher exhaust emissions, particularly carbon monoxide (CO), which may affect ambient air quality in densely travelled urban corridors. This study analyzes traffic characteristics, CO concentrations, estimated CO emission loads, and future traffic-emission scenarios along the Jalan Kaliurang segment from STA 0+000 to STA 1+330. Primary data were obtained through peak-hour traffic counts and direct ambient air measurements at three observation points, while supporting meteorological and spatial data were used to interpret pollutant dispersion. CO concentrations were compared with the ambient air quality standard stipulated in Government Regulation Number 22 of 2021. Emission load was estimated using an emission-factor approach, and traffic-emission trends were projected using a system dynamics scenario model. The results show that traffic volume reached 3,948 units/2 hours in the morning and 5,633 units/2 hours in the afternoon. The measured CO concentration ranged from 341.03 to 632.14 μg/m³ and remained below the national quality standard. Passenger cars contributed the largest estimated CO emission load because of their higher emission factor. The scenario model indicates that, without adequate intervention, traffic density and CO emission load may continue to increase over the next ten years. The recommended strategies include improving roadside vegetation, strengthening periodic vehicle emission testing, promoting smart driving practices, and evaluating traffic impact analysis obligations.

Keywords: Ambient Air Quality, Carbon Monoxide, Motor Vehicle Emissions, System Dynamics, Traffic Emission Load, Urban Road Corridor.

INTRODUCTION

Transportation is an essential activity in society because it supports mobility for work, education, shopping, recreation, and other social activities. However, increased transportation activity occurring at the same time and on the same road segment can lead to traffic density, reduced travel speed, increased travel time, and a decline in road service levels. If this condition continues over time, congestion may occur and contribute to higher fuel consumption and increased motor vehicle emissions.

The increasing number of motor vehicles in urban areas is one of the main factors contributing to the decline in ambient air quality. Motor vehicles produce exhaust emissions containing various pollutants that are harmful to human health and the environment. In several major cities in Indonesia, motor vehicle emissions are known to be a dominant contributor to nitrogen dioxide (NO_2) and carbon monoxide (CO) concentrations in the air, accounting for more than 50% of total concentrations (Simanjuntak, 2007). Air pollution sources can generally be classified into stationary

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sources, such as industries, power plants, and households, and mobile sources, which originate from motor vehicle traffic and other transportation activities (Simanjuntak, 2007).

The use of fuel oil in motor vehicles contributes to air pollution because the combustion process produces pollutant compounds such as CO, HC, NOx, SOx, and lead in the form of TEL compounds and similar substances (Departemen Perhubungan RI, 2006). One pollutant parameter that requires particular attention is carbon monoxide (CO). CO is hazardous because it has a much stronger ability to bind with hemoglobin in the blood than oxygen, thereby disrupting oxygen distribution in the human body (Wardhana, 2004). Therefore, examining CO concentrations in areas with high traffic volume is important as a basis for controlling ambient air pollution.

The Special Region of Yogyakarta is known as a center of education, culture, and tourism. These characteristics encourage high community mobility and have implications for the increasing number of motor vehicles. Based on data from the Transportation Agency of the Special Region of Yogyakarta, the growth rate of motor vehicles in Yogyakarta during the 2018–2020 period reached 5.89% per year (Dinas Perhubungan Provinsi DIY, 2021). This growth has the potential to increase pressure on road capacity, particularly on strategic road segments that serve as centers of educational and economic activities, as well as access routes to tourism areas.

One of the road segments experiencing traffic density in Sleman Regency is Jalan Kaliurang, particularly from STA 0+000 to STA 1+330. This road segment is located in a strategic area because it is adjacent to Universitas Gadjah Mada, serves as an access route to tourism areas, and is connected to the North Ring Road. The high traffic volume on this segment has the potential to increase motor vehicle emissions, especially CO, which may reduce ambient air quality and affect the health of communities around the research site.

Based on these conditions, an analytical approach is needed to describe the relationship between traffic volume, emission loads, meteorological conditions, and ambient air quality in a more integrated manner. Previous discussions on traffic-related air pollution have often emphasized measured concentration values, whereas fewer studies combine field measurement, emission-load estimation, spatial interpretation, and scenario-based system dynamics in a specific urban road segment. Therefore, this study aims to analyze traffic density, determine ambient air quality status based on CO parameters, estimate CO emission loads, project traffic volume and emission loads over the next ten years, and formulate environmental management strategies for the Jalan Kaliurang segment from STA 0+000 to STA 1+330.

Ambient Air Pollution. Air pollution refers to the introduction of substances, energy, or other components into ambient air as a result of human activities, causing a decline in air quality and preventing the air from functioning optimally. Air pollution may occur due to the presence of pollutants such as dust, gases, smoke, vapors, aerosols, or other particles entering the atmosphere in certain amounts and potentially endangering humans, animals, plants, materials, and environmental comfort (Wardhana, 2004; Soedomo, 2001). In terms of pollution sources, air pollution may originate from mobile sources, such as motor vehicles, trains, aircraft, ships, and heavy vehicles, as well as stationary sources, including industries, power plants, households, forest fires, and waste burning.

Air pollutants can be classified based on their physical form, namely particles, gases, and energy. Gaseous pollutants include carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), hydrocarbons (HC), and hydrogen sulfide (H_2S). Based on their formation process, air pollutants are divided into primary pollutants, which are emitted directly from their sources, and secondary pollutants, which are formed through chemical reactions in the atmosphere (Soedomo, 2001). This classification is important for understanding pollutant characteristics and determining appropriate control approaches.

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Motor Vehicle Emissions and Carbon Monoxide. Motor vehicles are one of the main sources of air pollution in urban areas. Vehicle emissions are produced through fuel combustion in engines, fuel evaporation, and other vehicle operational processes. The types and amounts of pollutants generated are influenced by engine characteristics, vehicle technology, fuel type, vehicle age, vehicle maintenance, and usage patterns (Kementerian Lingkungan Hidup, 2013). In mobile-source emission inventories, emission load calculation generally uses the emission factor approach, in which the number of vehicles is multiplied by road segment length and the emission factor of each vehicle type.

Carbon monoxide, or CO, is one of the main pollutants emitted by motor vehicles. This gas is colorless, odorless, tasteless, flammable, and toxic. CO may be generated from natural activities such as forest fires and volcanic activity; however, dominant anthropogenic sources include motor vehicles, fuel combustion, waste burning, and industrial activities (Kementerian Lingkungan Hidup, 2013). CO concentrations tend to increase under dense traffic conditions because vehicle combustion processes occur at higher intensity.

The health impacts of CO are severe because this gas can bind with hemoglobin and form carboxyhemoglobin. The bond between CO and hemoglobin is much stronger than that of oxygen, thereby inhibiting oxygen distribution to body tissues. Suma'mur (2009) stated that high CO levels can cause rapid death, while Wardhana (2004) explained that CO exposure at certain concentrations may cause dizziness, nausea, heart function disorders, breathing difficulties, fainting, and even death. Therefore, monitoring CO in high-traffic areas is essential for controlling urban air quality.

Emission Load and Traffic Projection. Emission load refers to the mass of air pollutants released from pollution sources within a certain period. In the context of traffic, emission load indicates the amount of pollutants generated by motor vehicles on a road segment. Emission load can be calculated by multiplying the number of vehicles, road segment length, and vehicle emission factor (Sengkey, 2011). This approach is used to estimate the contribution of motor vehicles to ambient air pollution.

Emission and traffic volume projections are needed to estimate future environmental conditions. One method that can be used is the arithmetic method, which is a projection approach based on the initial value, growth rate, and a specific time period (Handiyatmo et al., 2010). In studies of air quality affected by traffic, this projection is important for identifying the potential increase in vehicle volume and emission loads in the long term, allowing control strategies to be designed more anticipatively.

System Dynamics Modeling. System dynamics modeling is an approach used to understand the structure, causal relationships, and behavior of complex systems. A dynamic model describes relationships among variables through feedback loops, response delays, and system changes over time (Fuchs, 2006). In environmental studies, system dynamics modeling can help describe the interrelationships between vehicle volume, traffic growth, emission loads, and ambient air quality.

A model is a representation or abstraction of real conditions that is simplified for systematic analysis. A good model should be able to describe both direct and indirect relationships among variables and represent the system being studied (Soemarno, 2003). In system dynamics, model development is generally conducted through several stages, including conceptualization, causal loop diagram development, stock-flow diagram development, model validation, simulation, and scenario analysis. A causal loop diagram is used to illustrate causal relationships among variables, while a stock-flow diagram is used to visualize accumulation, flow, and changes in system variables (Muhammadi et al., 2001; Sterman, 2000).

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The system dynamics approach is relevant in air quality research because it is capable of projecting system changes continuously. Through simulation, the model can be used to estimate the impact of increasing vehicle numbers on emission loads and support the formulation of air pollution control strategies. Software such as Powersim can be used as a simulation tool to compare relationships among variables and calculate system dynamics numerically (Avianto, 2006).

Meteorological Factors and Vegetation in Pollutant Dispersion. Air pollutant dispersion is influenced by meteorological conditions, particularly wind direction and wind speed. Wind direction determines the orientation of pollutant dispersion from emission sources toward affected areas, while wind speed affects the dilution and distribution of pollutants in the atmosphere. A wind rose can be used to describe the frequency of wind direction and speed at a particular location over a certain period (Nevers, 2000). Meteorological information is important in pollutant dispersion analysis, particularly in road areas where the emission source is linear.

Vegetation also plays a role in reducing air pollution. Roadside green belts are part of urban green open spaces that function as shade providers, pollution absorbers, noise reducers, windbreaks, and separators between vehicle lanes and pedestrian areas. Vegetation selection should consider canopy density, number of leaves, and the combination of trees, shrubs, bushes, and ground cover plants. Vegetation can help reduce pollutants through diffusion and absorption processes, namely the dispersion of pollutants into a broader atmosphere and the absorption of gaseous pollutants through leaf stomata (Departemen Pekerjaan Umum, 1996; Departemen Pekerjaan Umum, 1999; Nasrullah, 2001).

Geographic Information Systems in Air Pollution Modeling. A Geographic Information System, or GIS, is a computer-based technology used to collect, store, process, analyze, and present data with spatial references. GIS can be used to map environmental phenomena based on geographical location, including the distribution of air pollutants (Ekadinata et al., 2008; Adam Suseno & R. A., 2012). In air quality studies, GIS helps connect pollutant concentration data with affected locations, allowing the results to be presented in the form of distribution maps.

The integration of air pollution modeling with GIS provides a spatial dimension in air quality analysis. GIS can be used to show the geographical distribution of pollutants, the extent of affected areas, pollution intensity, and the relationship between air quality and surrounding environmental conditions (Yerramilli, 2008). With the support of software such as ArcGIS, spatial and tabular data can be processed to produce map visualizations that support decision-making in air quality management (Wahana Komputer, 2014).

METHODS

This study employed a quantitative descriptive approach to analyze ambient air quality caused by motor vehicle emissions on the Jalan Kaliurang segment from STA 0+000 to STA 1+330, Sinduadi Subdistrict, Mlati District, Sleman Regency, Special Region of Yogyakarta. The research location was selected because this road segment has high traffic activity, is located near Universitas Gadjah Mada, serves as an access route to tourism areas, and is connected to the North Ring Road. Observations were conducted at three sampling points representing the beginning, middle, and end of the road segment. The observation points were determined using a Global Positioning System (GPS) to ensure that the data collection locations had clear spatial references. The use of three points was intended to provide an initial spatial representation of the corridor; therefore, the spatial results should be interpreted as an exploratory distribution pattern rather than a full-scale dispersion model.

Primary data in this study were obtained through traffic volume observations and direct measurements of ambient air quality, particularly the carbon monoxide (CO) parameter. Traffic observations were conducted during selected peak-hour periods on Saturday, from 07.00 to 09.00 WIB to represent the morning period and

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from 13.00 to 15.00 WIB to represent the afternoon period. Vehicle counting was carried out manually using traffic counting equipment and traffic recording forms. The observed vehicle types included motorcycles, passenger cars, buses, and trucks. This vehicle-counting technique referred to the mobile-source emission inventory approach, in which the number of vehicles serves as one of the main bases for calculating motor vehicle emission loads (Kementerian Lingkungan Hidup, 2013).

Ambient air quality measurements were conducted using carbon monoxide (CO) as the main parameter. Air samples were collected directly at the research site using a minivol air sampler. CO was selected because it is one of the main pollutants produced by motor vehicle emissions and has the potential to endanger human health. Measurement results were compared with the CO ambient air quality standard in Government Regulation Number 22 of 2021. In addition to CO data, this study considered wind direction and wind speed because both variables influence the dispersion pattern of air pollutants. The main observed environmental variable was CO concentration, while traffic volume by vehicle type and meteorological conditions were used as explanatory variables in interpreting emission load and pollutant distribution.

Secondary data were obtained from relevant institutions, including the Transportation Agency of the Special Region of Yogyakarta, the Transportation Agency of Sleman Regency, the Environmental Agency of Sleman Regency, the Regional Development Planning Agency of Sleman Regency, the Central Statistics Agency of Sleman Regency, and other supporting institutions. The secondary data included existing traffic conditions, ambient air quality references, map data, meteorological data, and supporting data on geographical and regional monographic conditions. Historical meteorological data were used to support the interpretation of dispersion direction, while the field traffic and CO measurements represented the primary condition of the research corridor.

Data analysis was conducted in several stages. Traffic volume data were analyzed descriptively to determine vehicle density based on vehicle type and observation time. CO concentration data were compared with the ambient air quality standard based on Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. CO emission load was estimated using the emission-factor approach, namely the number of vehicles multiplied by road length and the emission factor for each vehicle type. Wind direction and wind speed data were analyzed using WRPlot View to identify the dominant wind direction through windrose visualization. System dynamics modeling was conducted using Powersim to develop a scenario projection of traffic volume and CO emission loads over the next ten years. The model was interpreted as a scenario-based projection derived from observed traffic volume, growth assumptions, and emission factors, rather than as a deterministic prediction. Spatial analysis was performed using ArcGIS to visualize the exploratory distribution of CO concentrations at the research location. The results of all analytical stages were then used as the basis for formulating environmental management strategies for the Jalan Kaliurang segment from STA 0+000 to STA 1+330.

RESULT AND DISCUSSION

Traffic Volume Characteristics. The observation of traffic volume on the Jalan Kaliurang segment from STA 0+000 to STA 1+330 showed that vehicle activity at the research location was dominated by private vehicles, particularly motorcycles and passenger cars. During the morning period, the total number of vehicles passing through the segment was recorded at 3,948 units/2 hours, while during the afternoon period it increased to 5,633 units/2 hours. The morning traffic composition was dominated by motorcycles at 52.61%, followed by passenger cars at 46.96%, buses at 0.33%, and trucks at 0.10%. In the afternoon period, motorcycles remained the dominant vehicle type at 57.66%, followed by passenger cars at 41.33%, buses at 0.87%, and trucks at 0.14%. These findings indicate that the corridor is strongly influenced by private mobility patterns, which are relevant for emission-control planning.

Table 1. Traffic Volume by Vehicle Type

Vehicle Type	Morning (units/2 hours)	Morning Percentage (%)	Afternoon (units/2 hours)	Afternoon Percentage (%)
Motorcycle	2,077	52.61	3,248	57.66

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Passenger car	1,854	46.96	2,328	41.33
Bus	13	0.33	49	0.87
Truck	4	0.10	8	0.14
Total	3,948	100.00	5,633	100.00

Source: Primary field data processed by the researchers, 2026.

Ambient Air Quality Based on CO Concentration. Ambient air quality measurements were conducted at three observation points using carbon monoxide (CO) as the measured parameter. The results showed that CO concentrations in the morning ranged from 341.03 to 447.06 µg/m³, while those in the afternoon ranged from 430.09 to 632.14 µg/m³. The highest CO concentration was found at the third observation point in the afternoon, at 632.14 µg/m³, while the lowest concentration was found at the second observation point in the morning, at 341.03 µg/m³. All measurement results remained below the ambient air quality standard stipulated in Government Regulation Number 22 of 2021, namely 10,000 µg/m³ for the CO parameter. Nevertheless, lower-than-standard concentration values should be interpreted together with traffic growth and emission-load projections because cumulative exposure and future increases may still create environmental risks.

Table 2. CO Concentration Measurement Results

Point	Parameter	Morning (µg/m³)	Afternoon (µg/m³)	Quality Standard (µg/m³)	Coordinates
1	CO	447.06	498.17	10,000	7°45'56.99"S; 110°22'42.68"E
2	CO	341.03	430.09	10,000	7°45'46.68"S; 110°22'47.51"E
3	CO	422.26	632.14	10,000	7°45'18.29"S; 110°22'58.98"E

Source: Primary field data processed by the researchers, 2026.

CO Emission Load from Motor Vehicles. The CO emission load was calculated based on the number of vehicles, road segment length, and vehicle emission factors. The results showed that the total estimated CO emission load in the morning period was 134,439 g/day, while in the afternoon period it reached 180,958 g/day. Therefore, the total estimated emission load from transportation activities at the research location was 315,397 g/day. Based on vehicle type, passenger cars were the largest contributor to emissions, with a total of 217,464 g/day, followed by motorcycles at 96,915 g/day, buses at 887 g/day, and trucks at 131 g/day. This finding demonstrates that the number of vehicles alone does not fully explain emission contribution because emission factors differ across vehicle categories.

Table 3. CO Emission Load by Vehicle Type

Vehicle Type	Emission Factor (g/km)	Road Length (km)	Morning (units)	Afternoon (units)	Morning Emission Load (g/day)	Afternoon Emission Load (g/day)	Total (g/day)
Motorcycle	14	1.3	2,077	3,248	37,801	59,114	96,915
Passenger car	40	1.3	1,854	2,328	96,408	121,056	217,464
Bus	11	1.3	13	49	186	701	887
Truck	8	1.3	4	8	44	87	131
Total					134,439	180,958	315,397

Source: Primary field data processed by the researchers, 2026.

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Note: CO emission load was estimated using the emission-factor approach based on vehicle count, road length, and vehicle-specific emission factors; the values represent estimated loads for the observed traffic periods and should be interpreted as inventory estimates.

Meteorological Conditions and Vegetation. Meteorological data used as supporting information showed that wind direction generally moved toward the north and northeast. Based on processing using WRPlot View, wind direction in several months tended to move toward the northeast, southeast, north, and south; however, overall, the average windrose pattern tended to move toward the north and northeast. Monthly wind speed ranged from 1.60 to 2.32 m/s, while monthly rainfall ranged from 0.28 to 13.22 mm. These meteorological data were used to support the interpretation of CO dispersion tendencies and should not be treated as a substitute for real-time meteorological measurement during each air sampling event.

Table 4. Summary of Meteorological Conditions in 2021

Parameter	Minimum Value	Maximum Value	General Description
Wind direction	204.84°	251.61°	Dominantly toward the north and northeast
Wind speed	1.60 m/s	2.32 m/s	Relatively low to moderate
Rainfall	0.28 mm	13.22 mm	Varied across months

Source: Supporting meteorological data processed by the researchers.

Note: Meteorological data are used to support dispersion interpretation and are not intended to replace real-time meteorological measurements during each CO sampling event.

Vegetation conditions along the Jalan Kaliurang segment were dominated by plants placed in artificial cement pots and a small amount of vegetation growing around the sidewalks. In general, the vegetation at the research location did not meet the criteria for optimal pollutant-absorbing vegetation because it lacked dense canopy cover and was not composed of a combination of trees, shrubs, bushes, and ground cover plants. This condition was influenced by the limited available space along the Jalan Kaliurang segment from STA 0+000 to STA 1+330.

Dynamic System Modeling and Spatial Distribution of CO. System dynamics modeling was conducted to develop a ten-year scenario projection of traffic volume and emission load. Based on the model developed through causal loop diagrams and stock-flow diagrams, traffic volume in 2032 was projected to reach 17,158 passenger car units/day, while the CO emission load was projected to reach 564,827 g/day. These results indicate a potential increase in motor vehicle emissions if traffic control and environmental management are not implemented adequately. Because the model is based on traffic growth and emission-factor assumptions, the projection should be interpreted as a planning scenario that requires periodic updating and validation using future traffic and air-quality data.

Spatial analysis of CO distribution was conducted using the kriging method in ArcGIS. The mapping results showed that CO distribution tended to move toward the north and northeast, following the dominant wind direction pattern. The highest CO concentration was identified at a distance of approximately 0.094 km from the emission source and then decreased as the distance from the road segment increased. Considering that the spatial interpolation used only three observation points, the resulting map should be regarded as an exploratory visualization of concentration tendencies rather than a definitive pollutant dispersion map. A denser sampling network is recommended for future studies to improve spatial reliability.

The results showed that the Jalan Kaliurang segment from STA 0+000 to STA 1+330 was characterized by traffic dominated by private vehicles, particularly motorcycles and passenger cars. The dominance of motorcycles indicates that this segment is intensively used for daily mobility by residents, students, and road users traveling to educational areas, residential areas, and tourism destinations. However, although motorcycles had the highest number of units, the largest contribution to emissions came from passenger cars. It occurred because the emission factor of

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passenger cars is higher than that of motorcycles, resulting in greater emission loads despite their lower number of units.

These findings indicate that air pollution control on the Jalan Kaliurang segment should not focus solely on the number of vehicles but should also consider vehicle type and the characteristics of emission factors. Passenger cars contributed approximately 71.71% of CO emissions in the morning and 66.90% in the afternoon, while motorcycles contributed 28.12% in the morning and 32.67% in the afternoon. Buses and trucks contributed relatively little to total emissions because their numbers on this road segment were very limited.

The measured CO concentrations at the three observation points were still below the ambient air quality standard. However, this condition should not be interpreted as the absence of environmental risk, since the modeling results indicate the potential for increased traffic volume and emission loads in the long term. With traffic volume projected to reach 17,158 passenger car units/day and an emission load of 564,827 g/day in 2032, pressure on ambient air quality may increase if there is no policy intervention and transportation management. Therefore, actual measurements and scenario modeling should be interpreted complementarily: the measurements represent current field conditions, while the model indicates potential future risks under the assumed growth pattern.

Meteorological factors also play an important role in explaining the CO dispersion pattern at the research location. The dominant wind pattern toward the north and northeast caused the CO distribution to follow the same direction. It is consistent with the concept that wind direction and wind speed influence the distribution of pollutants in the atmosphere. In the context of urban air pollution, changes in meteorological parameters can influence the diffusion and dispersion of pollutants from emission sources to affected areas (Soedomo, 2001; Nevers, 2000). Thus, CO distribution mapping using GIS is important because it can identify areas that are potentially more affected by pollutant concentrations.

Vegetation conditions along the research location were not yet optimal as an air pollution control measure. Most of the existing vegetation was placed in cement pots and did not form a dense vegetation structure. In fact, roadside green belts can function as shade providers, pollution absorbers, noise reducers, and windbreaks. Effective vegetation for pollutant reduction should have dense canopy cover, numerous leaves, and consist of a combination of trees, shrubs, bushes, and ground cover plants (Departemen Pekerjaan Umum, 1996; Nasrullah, 2001). Therefore, vegetation enhancement strategies should be directed toward plant species with pollutant-absorbing capacity and adjusted to the limited space available along the Jalan Kaliurang corridor.

Based on these results, environmental management strategies that can be implemented include increasing vegetation along road spaces or available vacant land, implementing periodic vehicle emission testing, promoting smart driving practices, and evaluating the obligation to conduct Traffic Impact Analysis, or ANDALALIN. These strategies should not only aim to maintain current CO concentrations below the quality standard but also anticipate future increases in traffic volume and emission loads. In addition, transportation policies such as vehicle restrictions at certain times and in specific areas may be considered if vehicle growth continues to increase. The implementation of these strategies requires coordination among transportation, environmental, spatial planning, and local government stakeholders.

Study Limitations. This study has several methodological limitations that should be acknowledged. First, CO measurement was conducted at three observation points, so spatial interpolation should be interpreted cautiously. Second, meteorological data were used as supporting information and may not fully represent instantaneous conditions during each sampling period. Third, the system dynamics model provides a scenario projection based on available growth assumptions and emission factors; therefore, model accuracy needs to be improved through calibration and validation using longer time-series data. These limitations do not invalidate the findings, but they define the appropriate scope of interpretation and provide directions for future research.

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CONCLUSION

Based on the results of the study, the Jalan Kaliurang segment from STA 0+000 to STA 1+330 is characterized by relatively high traffic activity and is dominated by private vehicles, particularly motorcycles and passenger cars. Traffic volume reached 3,948 units/2 hours in the morning and 5,633 units/2 hours in the afternoon. CO concentrations ranged from 341.03 to 632.14 µg/m³ and remained below the ambient air quality standard stipulated in Government Regulation Number 22 of 2021. However, the emission-load estimation shows that passenger cars contributed the largest CO emission load because of their higher emission factor, while the system dynamics scenario indicates that traffic density and CO emission load may continue to increase within the next ten years. Spatial visualization also suggests that CO distribution tends to follow the dominant wind direction, although this result should be interpreted as exploratory because of the limited number of sampling points. Therefore, air quality management along the Jalan Kaliurang segment should be implemented continuously through vegetation improvement, periodic vehicle emission testing, smart driving campaigns, and evaluation of Traffic Impact Analysis (ANDALALIN) obligations. Future studies should strengthen model validation, expand the number of sampling points, and integrate real-time meteorological measurements to obtain more robust pollutant dispersion analysis.

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