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Understanding Roadside Air Quality in a Traffic-Dominated Urban Corridor: A Case Study of Sangkuriang Road, Cimahi Utara, Indonesia

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ABSTRACT
Traffic emissions and local dispersion conditions exert a considerable influence on urban roadside air quality. This study aims to assess the ambient air quality and pollutant dispersion, resulting from the daily traffic on Sangkuriang Road in Cimahi Utara-Indonesia by integrating traffic characteristics, roadside field measurements, and CALINE4 dispersion modelling to evaluate near-road pollutant behaviour. Traffic characteristics were analyzed using volume, composition, speed and volume-to-capacity ratio (VCR) while ambient concentrations were measured and compared with national air quality standards. Traffic and meteorological conditions were used to simulate the dispersion patterns using the CALINE4 line-source model. The motorcycles dominated the flow of traffic, with VCR values indicating stable conditions. Concentrations of pollutants at monitoring site were lower than the national limits, but dispersion modelling indicated higher concentrations close to the road that decreased rapidly with distance from traffic. The combined influence of motorcycle-dominated traffic and low wind speed conditions (0.28 m/s) likely reduced pollutant dispersion and enhanced near-road pollutant accumulation. CALINE4 was able to reasonably capture the observed roadside pollution patterns and near-road dispersion behaviour. The results underscore the need for a combined monitoring and modelling approach in order to better understand spatial heterogeneity and exposure risks of near-road environments.

1. INTRODUCTION

Air pollution is a major environmental and public health issue in rapidly growing cities around the world, where human activities increase the release of pollutants. Nevertheless, rapid urbanization and anthropogenic activities have caused an enhanced accumulation of pollutants that deteriorate air quality and pose health risks (World Health Organization, 2021), even at low concentrations (Dirgawati et al., 2019). It is well known that transport sector represents a key contributor to air pollution in urban locations. Vehicle exhaust emissions contain many types of pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons, sulfur dioxide (SO_2) and particulate matter including PM_{10}, $PM_{2.5}$ (U.S. EPA, 2023). The pollutants are often elevated in near-road environments. Therefore, populations living or traveling near road corridors may experience higher exposure levels. These pollutants are especially increased in near-road environments where the population are closest to and most exposed to traffic emissions. Various past investigations indicate that pollutant concentrations over distances of tens of meters from major roadways can be highly variable. This was because large spatial variations associated with the combination of traffic intensity and atmospheric dispersion processes (Karner et al., 2010; Health Effects Institute, 2010). Larger traffic volume and heavy congestion which are complemented by higher levels of pollutants could lead to negative effects on respiratory health (Iriani & Pribadi, 2023; Serpa et al., 2022; Tavares et al., 2025).

In addition to the emission magnitude, ambient concentrations of pollutants depend on atmospheric dispersion processes that are affected by meteorological conditions as well as traffic features and roadway geometry. Assessment of urban air quality is not only about measuring pollutant concentrations, but also understanding their spatial distribution and dispersion dynamics. Atmospheric dispersion modeling is a robust method to represent these processes with line sources including roadways in particular. The CALINE4 model is a Gaussian line-source dispersion model. Model parameters comprise traffic volume, emission factors of the vehicle fleet, geometry of roadway and meteorological inputs (wind speed and direction) (Benson, 1989). CALINE4 has previously been shown to be able to predict near-road pollutant dispersion across a range of traffic and meteorological conditions (Nath et al., 2024). In this study the model pollutants selected were carbon monoxide (CO) and particulate matter with diamater less than 10 micrometers (PM10). CO is a primary pollutant released by the incomplete combustion of fuels and so can be used as an indicator of traffic emissions. PM_{10} emissions were mainly attributed to both combustion exhaust and non-exhaust such as the resuscitation of road dust from the mechanical action of vehicles on the roadway surface (Alshetty & Nagendra, 2022).

While many air quality studies have been conducted in urban Indonesia, most have focused largely on pollutant concentrations and regulatory compliance (e.g., the exceedance of ground level air quality standards), fewer studies have integrated traffic characteristics and roadside dispersion processes to better understand near-road pollution dynamics. In addition, the application of line-source dispersion models such as CALINE4 in medium-sized Indonesian urban areas remains relatively limited.

Consequently, current knowledge on the interaction between traffic activity, meteorological conditions and spatial characteristics in accounting for pollutant levels within roadside environments is limited by this information gap. This study therefore aims to examine traffic characteristics and road performance parameters as drivers of vehicular emission intensity, evaluate roadside ambient air pollutant concentrations and their compliance with the national air quality standards, and simulate the spatial dispersion of pollutants using the CALINE4 model. This study addresses a traffic-dominated urban corridor, defined as a roadway with high traffic volume, great proportion of motorcycles and relatively low velocity thus associated with higher emission intensity and complex dispersion conditions.

2. METHOD

2.1 Study Location

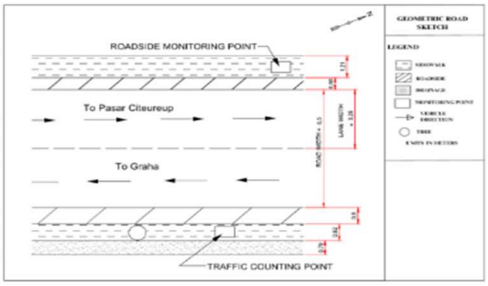
The study was located in North Cimahi District, Cimahi City, West Java Province, an area with elevated population density and transportation activities (BPS Kota Cimahi, 2025).

The roadside environment in the urban area of North Cimahi has a high potential for exposure to traffic related air pollution. One monitoring site was chosen on the Sangkuriang Road section in Cipageran Village which represents a secondary arterial road as the main corridor that connects residential areas, education and urban activity. This road section is representative for evaluating the roadside ambient air quality and transportation emissions dispersion characteristics, which are characterized by a high- density traffic. The study area is a two-way urban lane in the Graha and Pasar Citeureup directions. The flow in all lanes is unidirectional, with at least four lanes in total, as shown by **Figure 1**.

(a)

TC: location of traffic counting; RSC: location of road site monitoring

(b)



(c)

Figure 1. (a) North Cimahi Districts, (b) monitoring site (Sangkuriang Road) and (c) Sangkuriang road geometry

The total width of the road is about 6.50 m, and it comprises a single lane of approximately 3.25 m. The roadside monitoring point is set about 5 m from the road edge, representing typical near-road exposure conditions while traffic counting takes place next door. The observed geometry is used as input information to the CALINE4 model to specify the locations of the line source and receptors with coordinates, enabling realistic pollutant dispersion simulation

2.2 Sampling Design

In this study, roadside ambient air quality measurement, analysis of traffic characteristics and pollutant dispersion modeling using CALINE4 models are combined to evaluate the ambient air quality conditions in the roadside environment and investigate how pollutants form from transport activities disperse. This study consists of primary and secondary data used as input for traffic characteristics analysis and pollutant dispersion modelling. Traffic characteristics obtained through traffic counting activities, including vehicle volume based on vehicle type and speed on the study road. We collected road geometry data (the road width, the number of lanes, and the physical characteristics of the road). Meteorological and road-side ambient air quality data were also measured.

2.2.1 Roadside Ambient Air Quality Monitoring

Ambient roadside air quality measurements were conducted through short-term field monitoring on June 11, 2024. The measurements represent short-term roadside conditions during active traffic periods and were intended to support dispersion modelling and near-road exposure assessment rather than long-term compliance evaluation. All the measured parameters included carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), non-methane hydrocarbons NMHC, total suspended particle (TSP), particulate matter <10 um (PM_{10}) and <2.5 um ($PM_{2.5}$), and lead (Pb). The reference methods for measuing each parameter is summarized in **Table 1**.

Table 1. Reference Methods dor Ambient Air Quality Measurement

No.	Parameter	Measurement Method
1	Sulfur Dioxide (SO_2)	SNI 7119-7:2017
2	Carbon Monoxide (CO)	NDIR / Direct Reading
3	Nitrogen Dioxide (NO_2)	SNI 7119-2:2017
4	Photochemical Oxidants as Ozone (O_3)	SNI 7119-8:2017
5	Non-Methane Hydrocarbons (NMHC)	Direct Reading
6	Total Suspended Particles (TSP, <100 μm)	SNI 7119-3:2017
7	Particulate Matter (PM_{10})	SNI 7119-15:2017
8	Particulate Matter ($PM_{2.5}$)	SNI 7119-14:2017
9	Lead (Pb)	SNI 7119-4:2017

Measurements and laboratory analyses were conducted using standardized national monitoring and analytical procedures (SNI-19-7119. 9–2005 on the Location Determination of Samples for Roadside Air Quality Monitoring Test) to ensure the quality, consistency, and comparability of the data. Direct-reading instruments (NDIR) were used to measure gaseous pollutants (CO and NMHC), meanwhile particulate matter and other parameters utilized SNI-based laboratory methods. Such standardized measurement approaches provide a sound basis to estimate ambient air quality and can allow the integration between observational data and results from dispersion modelling.

2.2.2 Traffic Characteristics Monitoring

Traffic characteristics were collected through classified traffic counts, where vehicles were categorized into motorcycles, light-duty vehicles, trucks, and buses to evaluate traffic composition and potential emission intensity. Hourly traffic observations were conducted in both traffic directions along Sangkuriang Road using a traffic counter application and supported by DSLR-based recording for verification and data consistency. We collected data during three representative periods. First, during morning peak (06:00–09:00), secondly during off-peak midday (11:00–14:00), and finally during evening peak (16:00–19:00) to capture daily traffic patterns in North Cimahi. Traffic parameters derived from data were volume, road capacity, V/C ratio, Level of secrvice (LOS) and spot mean speed. They were utilised to describe the traffic performance, as wellas quantify emission-generating activity through the roadside space.

2.2.3 Emission Estimation and CALINE4 Modelling

Pollutant dispersion from traffic emissions along Sangkuriang Road was simulated using the CALINE4 model, which represents the roadway as a line source. The model incorporates traffic characteristics, road geometry, and site-specific meteorological conditions (wind speed and direction) to estimate pollutant concentrations at receptor locations. Traffic counting data and emission factors in accordance with PerMen LH No. 12/2010 (**Table 2**) were used to calculate vehicle emission loads.

Table 2. Vehicle Emission Factors by Vehicle Category (g/km) (adapted from PerMen LH No. 12/2010)

Air Quality Parameter	Vehicle Category			
	Motorcycle	Light Vehicle	Bus	Truck
CO	14.0	40.0	11.0	8.4
HC	5.9	4.0	1.3	1.8
NOx	0.29	2.00	11.9	17.7
PM_{10}	0.24	0.01	1.4	1.4
CO_2	3180	3180	3172	3172
SO_2	0.008	0.026	0.93	0.82

Traffic emissions were estimated using vehicle-specific emission factors adapted from internationally recognized emission inventory methodologies, including the EMEP/EEA Guidebook for road transport emissions. Some of the key inputs to the model include traffic volume, emission factors, road geometry, meteorological data (wind speed and direction), and coordinates of receptors. The model calculates the dispersion of pollutants along the road to nearby receptors.

2.2.4 Determination and Characteristics of Receptors

Receptors were defined to account for spatial gradients in pollutant exposure along the road corridor, with distance from the emission source, land use and position relative to prevailing wind direction. Ten receptors were selected, including commercial, transportation, residential, industrial and background locations for comparison. The receptor distances were from 5 to 114 m, capturing the near-road concentration gradient. Geographic coordinates based on WGS 84 system were used as inputs in CALINE4 model. The receptors in the simulation are points that receive a measure of concentration from the line source giving spatial analysis for dispersion and exposure along distance. Receptor features are shown in **Figure 2** and **Table 3**.

Figure 2. Spatial distribution of selected receptors and their relative positions along Sangkuriang Road used dor CALINE4 dispersion modeling

Table 3. Vehicle Emission Factors by Vehicle Category (adapted from PerMen LH No. 12/2010)

ID	Location Name	Latitude (°) Longitude (°)	Distance from Source (m)	Category
RS1	Pasar Citeureup	6°51'42.52"S 107°32'37.32"E	33	High-intensity commercial area
RS2	Terminal Citeureup	6°51'42.82"S 107°32'36.14"E	17	Public transport facility
RS3	Residential Area 1	6°51'44.22"S 107°32'38.16"E	90	Residential area
RS4	Car Workshop	6°51'43.71"S 107°32'35.46"E	26	Low-intensity commercial area
RS5	Heimat Studio	6°51'44.91"S 107°32'34.84"E	41	Low-intensity commercial area
RS6	PT. Ahera	6°51'46.09"S 107°32'36.98"E	114	Industrial area
RS7	Residential Area 2	6°51'46.40"S 107°32'32.59"E	37	Upwind
RS8	Secretary Driver	6°51'40.30"S 107°32'36.59"E	21	Upwind
RS9	Cooperative	6°51'41.80"S 107°32'35.45"E	19	Upwind
TS	Sampling Point	6°51'41.46"S 107°32'36.70"E	5	Observation point

3. RESULTS AND DISCUSSION

3.1 Traffic Characteristics

Traffic characteristics on the Sangkuriang Road section were analyzed to determine road operational conditions that have the potential to affect vehicle emission levels and ambient air quality in the roadside environment. The results of the traffic performance analysis on the Jalan Sangkuriang section show that the road capacity in each direction of travel is 1322 units/hour. The total traffic volume during the observation period was recorded at 4582 in the direction of Graha and 5091 in the direction of Citeureup Market. **Figure 3** shows hourly traffic volume variation on the monitoring site.

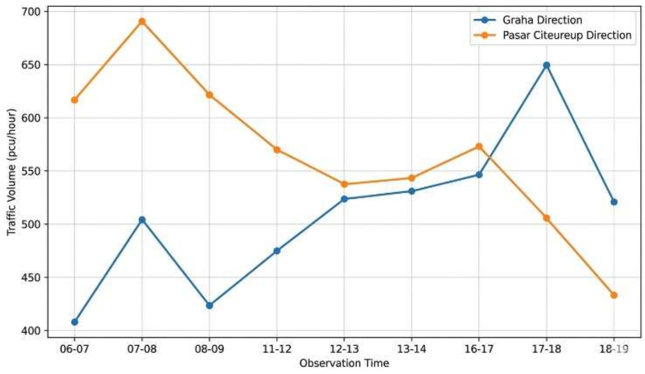


Figure 3. Hourly Traffic Volume Variation on Monitoring Site (Sangkuriang Road)

The variation in traffic volume per hour shows a clear pattern of commuter movement on the Jalan Sangkuriang corridor. In the direction of Citeureup Market, the highest volume occurred at 07.00–08.00 (690 units/hour), while in the direction of Graha it occurred at 17.00–18.00 (649 units/hour). This pattern reflects typical work and school commuting activities, which influence directional traffic flow dynamics along the corridor. Generally, the direction to Citeureup Market has a higher traffic volume in the morning-noon while Graha towards is increasing at noon-afternoon.

The results of hourly variation of traffic volume, V/C ratio and vehicle speed is provided in **Table 4.** The value of VCR ranges from 0.31 – 0.49 in the direction of Graha and 0.33 – 0.52 in the direction of Citeureup Market. Based on this value, traffic flow conditions along the study corridor were classified as LOS A, which shows that the traffic flow condition is still relatively stable and does not experience significant congestion. This is characteristic of traffic-dominated corridors often found in urban areas, where increased density and low speeds contribute to a high emission intensity.

Table 4. Hourly Variation of Traffic Volume, V/C Ratio and Vehicle Speed

Time	V/C Ratio		Mean Speed (km/h)	
	Graha	Citeureup	Graha	Citeureup
06:00–07:00	0.31	0.47	37	32
07:00–08:00	0.38	0.52	38	32
08:00–09:00	0.32	0.47	35	27
11:00–12:00	0.36	0.43	32	23
12:00–13:00	0.40	0.41	35	23
13:00–14:00	0.40	0.41	33	22
16:00–17:00	0.41	0.43	32	24
17:00–18:00	0.49	0.38	34	22
18:00–19:00	0.39	0.33	39	20

Analysis of vehicle composition showed that motorcycles consistently dominated the vehicle throughout the observation period, contributing about ±75–86% of the total traffic volume, as seen in **Figure 4**. This dominance is relatively consistent throughout the day, with increases in the morning and evening periods that coincide with peak hours. Light vehicles contribute ±14–22% with more volatile variations, while heavy vehicles (buses and trucks) have a very small proportion (<3%).

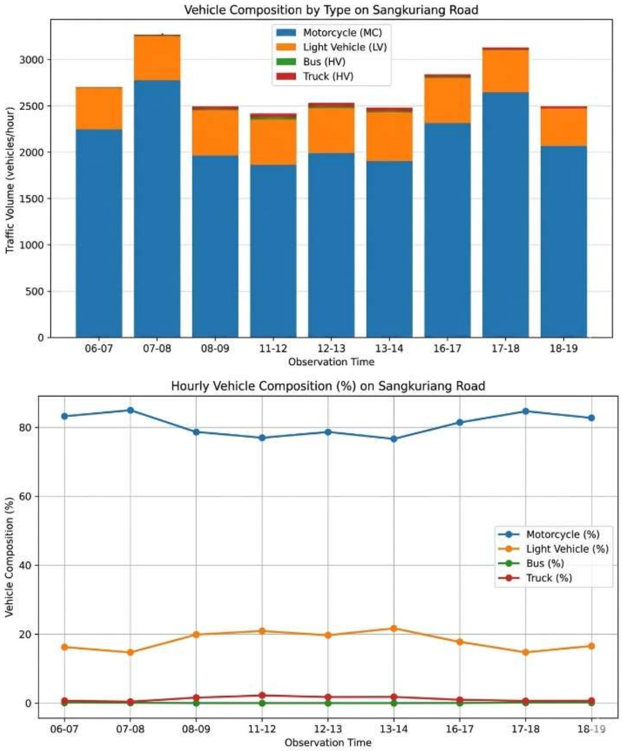


Figure 4. Hourly Vehicle Composition on monitoring Site

Traffic characteristics have direct impact on roadside ambient air quality. Higher volumes as well as dominant motor vehicle characteristics can increase emissions of other pollutants like carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons and particulates. Previous studies have demonstrated that air pollutant concentrations are typically higher in near-road environments because of its direct emission of air pollutants (Nishitateno, 2024). Heavy vehicles are a smaller fraction of total traffic volume but could be responsible for larger roadside emissions in part due to their relatively high emission factors, especially NOx and particulate matter. Overall, this composition shows the contribution of light vehicles and motorcycles on the emissions at the study site are dominant.

Vehicle also affects the amount of emissions. In heavy traffic or low-speed conditions, combustion efficiency decreases so pollutant emissions increase. This often occur in the roadside environment of urban areas with very high traffic activity. Furthermore, the Volume to Capacity ratio (V/C ratio) indicates how well road capacities are used. A high V/C value reflects saturation conditions, which could result in vehicle slowdown and elevated emissions. Therefore, traffic parameters considering volume, composition, and speed along with the V/C ratio are key indicators of any possibility of vehicle emissions and its effects on ambient air quality. Our results confirm studies reporting that those living near the road will experience higher exposures to pollutants such as CO, NOx and particulate matter due to direct emission from vehicle compare to residents further away (Karner et al., 2010; HEI, 2010). Therefore, the analysis of traffic characteristics is an important basis for understanding the relationship between vehicle activity and the distribution of pollutant concentrations in the roadside environment on the Sangkuriang Road section.

3.2 Roadside Ambient Air Quality and Meteorology

The measurement results showed that traffic pollutant concentrations were generally higher in areas adjacent to roads, especially for primary pollutants and traffic-sensitive particulate matter as well as local dispersion conditions (Park, 2021). As shown in **Table 5**, meteorological conditions during measurements showed limited dispersion potential of pollutants. Low wind speeds (0.28 m/s) indicate poor atmospheric ventilation. This condition promotes pollutants from vehicle emissions tend to accumulate in roadside environments due to reduced advection processes and atmospheric mixing (Seinfeld & Pandis, 2016).

The dominant wind direction from the east is one of main factors in the spatial distribution of pollutants, where receptors in the downwind location have the potential to receive higher concentrations than upwinds. This is consistent with the concept of atmospheric dispersion at the source line, where the wind direction is the main factor in determining the distribution pattern of pollutants. High air temperatures (33.01 °C) could trigger the increase in photochemical activity in the atmosphere, especially O_3 formation, and humidity (50.28%) shows moderate atmospheric condition. The combination of high temperatures and stable atmospheric conditions can worsen urban air quality through increased chemical reactions and accumulation of pollutants (Jacob, 1999). Air pressure is relatively stable (694.05 mmHg), which produces stagnant atmospheric conditions and inhibition of vertical mixing, leading to the accumulation of a larger amount of pollutants near the surface. In general, low wind speeds, warm temperatures and stable atmospheric conditions prevailing at the time of measurement are likely to contribute to high concentrations of road side pollutants. This plays an important role in the interpretation of air pollutant measurement and CALINE4 results.

Table 5. Temporal Variation of Traffic Volume, V/C Ratio and Vehicle Speed

Parameter		**Value**	**Unit**
Metorology	Temperature	33.01	°C
	Wind Speed	0.28	m/s
	Wind Direction	East	-
	Relative Humidity	50.28	%
	Pressure	694.05	mmHg
Air Pollutant	SO_2	38.23	µg/m³
	CO	6,068	µg/m³
	NO_2	20.66	µg/m³
	O_3	56.55	µg/m³
	NMHC	39.60	µg/m³
	Pb	0.24	µg/m³
	PM_{10}	62.70	µg/m³
	TSP	113.50	µg/m³

The maximum limit of air pollutants concentrations in ambient air followed the national standard, i.e. PP No. 22 of 2021 (SO_2, 1 hour: 150 µg/m^3; CO, 1 hour: 10,000 µg/m^3, NO_2, 1 hour: 200 µg/m^3), O_3, 1 hour: 150 µg/m^3; NMHC, 3 hours: 160 µg/m^3; TSP, 24 hours: 230 µg/m^3; PM_{10}, 24 hours: 75 µg/m^3; and Pb, 24 hour: 2 µg/m^3) (Indonesia, 2021).

High CO concentration (6.068 µg/m^3) at the monitoring site added evidence that CO is a primary pollutant resulted from incomplete combustion in motor vehicles. In urban corridors predominantly light vehicles and motorcycles, CO is prevalent as a strong indicator of vehicle emission contribution, especially when traffic flows are high and atmospheric dispersion is not optimal. Model studies and near-road measurements show that CO and traffic particulate matter are two groups of pollutants that are highly responsive to changes in vehicle flow and micro-meteorological conditions around the road (Chang et al., 2022).

The PM_{10} concentration of 62.7 µg/m^3 and TSP of 113.5 µg/m^3 showed that the particulate fraction at the study site was quite pronounced, although still below the 24-hour quality standard. For roadside environments, this value is scientifically important because coarse particles come not only from exhaust gas emissions, but also from tire abrasion, road surface wear, and especially dust resuspension due to vehicle turbulence. Field studies show that traffic on urban roads can increase the concentration and variability of *roadside particulates*, with the coarse fraction likely to be influenced more by local sources near the road than by the background of the area (Xie et al., 2024; Liu et al 2025).

Other gas parameters such as SO_2, NO_2, O_3, and NMHC are also all below the comparative values on the chart. A relatively low NO_2 concentration (20.66 µg/m^3) may indicate that at the time of measurement there is no high accumulation of nitrogen oxide emissions, or that the dispersion process is still sufficiently effective to prevent an increase in concentration at the receptor point. Meanwhile, O_3 of 56.55 µg/m^3 needs to be interpreted carefully because ozone is not a primary traffic pollutant, but rather a secondary pollutant formed through precursor photochemical reactions such as NOx and hydrocarbons under solar radiation. Therefore, the O_3 value in the road corridor does not always increase in the direction of traffic intensity, and is often influenced by regional photochemical dynamics as well as the interaction of ozone titration by NO near the source of the emission.

The Pb concentration of 0.24 µg/m^3 is also still far below the quality standard used in the graph. In general, low Pb in *roadside* ambient air is in line with the decline in the use of leaded additives in vehicle fuels in many countries, so the contribution of lead from modern traffic tends to decrease significantly compared to previous periods. Thus, from the perspective of current sources of traffic pollutants, the more relevant parameters to analyze as dominant indicators are CO and particulates, in particular PM_{10}, since they both more directly represent primary emissions and road dust resuspension.

When compared to other studies, the pattern of results on Jalan Sangkuriang is still consistent with the general character of the urban roadside environment, namely primary transportation pollutants are still clearly detected but the magnitude is highly dependent on traffic intensity, meteorology, and location configuration. A review of *roadside* stations in various cities shows that concentrations near roads are often higher than in urban backgrounds, but these differences can be weakened when wind speeds are sufficient to accelerate dilution or when vehicle volumes are not saturated. Conversely, field studies and modelling also show that the concentration of CO and PM near roads can increase sharply in low wind conditions, proximity of receptors close to the source, or the presence of dispersion disturbances by local land use (Chang et al., 2022).

In this study, ambient air quality results need to be read together with traffic characteristics and meteorological conditions. Jalan Sangkuriang has a fairly active traffic flow, with a dominance of motorcycles and light vehicles, while meteorological data shows low wind speed. The combination theoretically supports the presence of primary pollutant concentrations in the roadside environment, but the actual magnitude of the concentration at the receptor point remains determined by the dispersion process in the atmosphere. Therefore, the results of the concentration measurements in this subchapter are an important basis to be linked to the CALINE4 dispersion simulation in the next subchapter, especially to explain how traffic, wind direction, and receptor position together control the distribution of pollutant concentrations around the study corridor.

3.3 Predicted Pollutant Concentrations and Dispersion Pattern

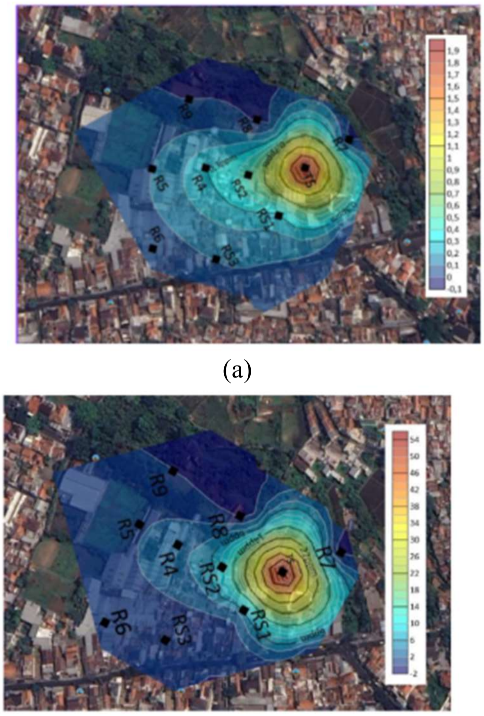
Model results demonstrate a pronounced near-road gradient, with pollutant concentrations decreasing sharply with distance from the roadway (**Table 6**). The receptor distance of 5 m (TS) shows the highest concentrations of PM_{10} with 64.0 µg/m^3 and CO with 2.2 ppm (2,520 µg/m^3). At 17 m (RS2), PM_{10} reduces to 7.3 µg/m^3 (−88.6%); CO, to 0.5 ppm (573 µg/m^3, −77.3%). Beyond 90 m (RS3–RS6), concentrations reach background levels ($PM_{10} \leq 0.5$ µg/m^3; CO $\geq$ 0.1 ppm (115 µg/m^3)) suggesting that pollution exposure is localized, confined within the first few tens of meters from road source and are consistent with reported near-road dissipation gradients (Apte et al., 2017; Park et al., 2021).

Table 6. Estimated PM_{10} and CO concentrations at selected receptors along Sangkuriang Road based on CALINE4 modeling results.

Receptors ID	**Receptors Category**	**PM_{10} (µg/m^3)**	**CO (µg/m^3)**
RS1	High-intensity commercial area	3.6	344
RS2	Public transport facility	7.3	573
RS3	Residential area	0.5	115
RS4	Low-intensity commercial area	4.1	344
RS5	Low-intensity commercial area	1.1	115
RS6	Low-intensity commercial area	0.1	0
RS7	Upwind	0.0	0
RS8	Upwind	0.0	0
RS9	Upwind	0.0	0
TS	Observation Point	54.0	2,520

Note: CO concentrations were converted using the relationship of 1 ppm CO ≈ 1145 µg/m^3 under standard conditions (25°C and 1 atm).

Figure 5 shows the pattern of concentration decrease differs between pollutants. CO concentrations decreased more rapidly with distance from the roadway because CO is a primary gaseous pollutant directly emitted from vehicle exhaust and is more readily dispersed under ambient atmospheric conditions. In contrast, PM_{10} decreases more slowly. The non-exhaust influences road dust resuspension (Apicella et al., 2026). This was indicated by the predicted PM10 levels found at intermediate distances (4.1 µg/m³ at 26 m).



(a)

(b)

Figure 5. Spatial Dispersion of (a) CO and (b) PM_{10} Predicted concentrations by CALINE4

Meteorological conditions are also exacerbating this spatial variations. Also, low wind speed (0.28 m/s) would limit the horizontal transport and turbulent mixing for pollutants to disperse away from the source area, leading them to accumulate in its vicinity. Differences in plume transport are driven by wind direction, with most upwind receptors (RS7–RS9) near zero concentration. . Conversely, higher concentrations are seen at downwind locations. Similar findings have shown that weak wind conditions significantly enhance pollutant accumulation in roadside environment.

3.4 Dispersion Pattern and Meteorological Influence

Traffic characteristics define the emission intensity driving this pattern. Peak-hour traffic reaches 690.2 pcu/h and 649.1 pcu/h for the two directions, with motorcycles dominating the fleet composition. The V/C ratios remain within stable conditions (0.31–0.52). However, it was observed increasing traffic density reduces vehicle speed to 20–24 km/h during peak periods. The speed reduction worsens emissions due to inefficient combustion performance, which particularly increases CO concentration, as reported in other studies (Chen et al, 2020).

High emissions intensity, combined with poor dispersion due to meteorological conditions and the pollutant characteristics lead to higher concentrations closer to the source. Importantly, pollutant-specific behavior is evident. CO is mainly from exhaust emissions and has a fast decay rate. . PM10, on the other hand, is indicative of mixed sources and shows greater spatial pattern.

The good agreements between the modelled and observed concentrations support that the CALINE4 model is likely capable of representing roadside dispersion patterns under the monitoring conditions. All other differences are likely attributed to local meteorological variability, interpolated data resolution, and model steady-state assumptions. Although the results of field measurements suggest compliance with air quality standards, the model predicts fine-scaled concentration gradients characterized by elevated concentrations near roadways. This illustrates the problem of bias in micro-scale environments where fixed monitoring points can underestimate exposure. The consistency between observed and modelled trends suggests that CALINE4 was able to reasonably represent the general roadside dispersion patterns under the observed traffic conditions. However, the model performance is influenced by low wind speed conditions, which tend to limit dispersion and increase near-road accumulation. Those findings illustrate that CALINE4 is a suitable tool in interpreting the spatial heterogeneity and exposure risk with minimal data in an urban environment.

This study has several limitations that should be acknowledged. Firstly, the study relied on one-off roadside monitoring at a single location that will not capture spatial heterogeneity across the greater urban area.. Second, the temporal resolution and availability of field data may limit capturing short-term variability and episodic events. Third, the CALINE4 model is based on steady-state assumption and has simplified input parameters in complicated urban dispersion processes. This may yield inconsistent results with higher deviation under extremely variable meteorological conditions. Furthermore, traffic and emission input data uncertainties can impact on the model accuracy. Therefore, the findings should be interpreted within the context of a data-limited environment, and future studies are encouraged to incorporate multi-site monitoring and more detailed emission characterization to improve robustness.

4. CONCLUSION

Using integrated monitoring and CALINE4 modelling, this study aims to assess the contribution of specific traffic characteristics and dispersion processes to roadside air quality in a road segment on Sangkuriang Road. Although measured pollutant concentrations remained below national air quality standards, clear near-road concentration gradients were still observed.

CO exhibited a steeper decrease with distance due to its direct exhaust origin and atmospheric dispersion characteristics whilst traffic emissions and non-exhaust sources like resuspension influence PM_{10}. Low wind speed and high traffic intensity further limit dispersion and enhance near-road accumulation.

These results emphasize that point-based measurements can underestimate local exposures in near road environments and they further illustrate the utility of integrating monitoring with modelling to capture spatial variability. These findings highlight the importance of integrating roadside monitoring and dispersion modelling in urban air quality management.

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