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Study of air pollution from vehicle emissions at R.T.A. Milono – Willem A. S. intersections Palangka Raya City

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ABSTRACT

The intersection of R.T.A. Milono Road and Willem A. Samad Road is one of the busiest three-arm signalized intersections in Palangka Raya. There is a significant amount of traffic at this intersection, particularly during rush hour when people are commuting to work, school, and college. Exhaust emissions from the high volume of traffic are generated by numerous vehicle movements. These vehicle exhaust emissions negatively impact the environment and human health. To compare the quantity of exhaust emissions at the intersection with national ambient air quality standards based on government regulations, this study first calculates the amount of exhaust emissions from motor vehicles. The study employs an empirical calculation formula and a survey of vehicle speed and traffic volume. Based on the analysis of vehicle emissions compared with national air quality standards, it was found that Willem A. Samad Road meets the permitted quality standards for all types of pollutants. Meanwhile, R.T.A. Milono (A) Road and R.T.A. Milono (B) Road meet the standards for NO_2 pollutants (below 200 μg/m^3) and PM_{10} pollutants (below 72 μg/m^3) but exceed the permitted standards for CO pollutants (above 4,000 μg/m^3) and HC pollutants (above 160 μg/m^3).

1. Introduction

The development of Palangka Raya, the capital of Central Kalimantan Province, has rapidly accelerated due to population growth and increased socio-economic activity across various sectors. According to the Palangka Raya City Central Statistics Agency [1], the city's population in 2023 was 306,104, with a growth rate of 1.51%. Additionally, the number of registered vehicles in 2023 reached 391,562, including 46,852 passenger cars, 13,313 pickup trucks, 6,115 trucks, 36 buses, and 325,246 motorcycles. This high vehicle count contributes to increased traffic congestion and air pollution in the city.

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Urban air pollution, primarily from motor vehicle emissions, poses significant risks to public health and the environment. Haryanto [2] highlights the respiratory and cardiovascular health impacts of urban air pollution in Indonesia, driven by climate change and vehicle emissions. Similarly, Luo et al. [3] and Zhang & Batterman [4] link vehicular emissions, particularly nitrogen oxides (NOx) and particulate matter (PM), to higher mortality and morbidity rates in urban areas. Studies consistently show that vehicle emissions at traffic-dense intersections elevate concentrations of pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), hydrocarbons (HC), and PM [3, 5, 6, 7]. In Indonesia, localized studies by Warsiti and Risman [8] and Nurmaningsih [5] confirm high CO levels at busy intersections, posing health risks to nearby populations. Another study [9] establishes a direct correlation between vehicle-related pollution and respiratory diseases in developing urban centers.

Intersections are critical hotspots for emissions due to stop-and-go traffic patterns. Research by Zhao et al. [10], Wang et al. [11], and Li et al. [12] demonstrates that vehicle idling and acceleration at signalized intersections significantly increase CO and NOx emissions. The intersection of R.T.A. Milono Road and Willem A. Samad Road, a busy three-arm signalized intersection in Palangka Raya, exemplifies this issue. R.T.A. Milono Road, a primary arterial road, hosts commercial areas and the Muhammadiyah University campus, while Willem A. Samad Road, a primary collector road, is home to provincial offices. High vehicle movement, especially during peak commuting hours, exacerbates emissions at this location.

Based on this background, this research aims to:

(1) Quantify motor vehicle exhaust emissions at the R.T.A. Milono Road–Willem A. Samad Road intersection.
(2) Compare these emissions with national air quality standards.

Given the intersection's proximity to office and commercial areas, assessing motor vehicle emissions is critical. This study seeks to quantify emissions to provide potential solutions if levels exceed regulatory thresholds and to provide data for government policymaking.

2. Literature review

Advanced models are essential for accurate emission estimation. Zhong et al. [13] provide a comprehensive review of various prediction models, including empirical, statistical, and simulation-based methods. Ye et al. [14] discuss how driving behavior affects CO_2 emissions, while studies such as Cappiello et al. [15] and Afotey et al. [16] offer insights into vehicle-specific emission factor modeling. Predictive tools using real-time data, such as those incorporating GPS and LiDAR, improve emission quantification at micro levels, such as intersections [11], [17].

The Design Manual for Roads and Bridges (DMRB) uses an empirical formula that links vehicle volume, pollutant factors, and speed conversion factors to calculate exhaust emissions from light and heavy vehicles [18]. The calculated emissions include major pollutants such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM).

In urban areas, such as Pertokoan Coyudan Surakarta [5], the empirical DMRB method is used to calculate CO, HC, NOx, and PM emissions based on directly measured vehicle volume and speed data. The results show that the emissions produced remain within the permitted air quality standards. Conversely, the DMRB method, applied in research on Tambun Bungai Street, Palangka Raya [19], indicates that each type of pollutant exceeded permissible air quality standards.

Additional localized investigations in Indonesia contribute to this theme. Sasmita et al. [20], Purnomoasri et al. [21], and Iqbal and Muammar [22] examined CO and CO_2 levels at urban intersections, confirming the contribution of vehicle density and signal timing to pollution peaks. Comparative studies have analyzed control types—signalized intersections versus roundabouts. Meneguzzer et al. [23, 24] and Ramadan et al. [25] found that roundabouts generally reduce stop delays, which in turn lower pollutant emissions. Šarić et al. [26] further emphasize the role of intersection geometry in pollution management, noting the potential for emission mitigation through design optimization.

3. Material and method

This research was conducted at the intersection of R.T.A. Milono Road – Willem A. Samad Road in Palangka Raya City which has three signalized intersection arms. The study location is on Fig. 1.

Fig. 1. Top-down view of the intersection of Jl. R.T.A. Milono and Jl. Willem A. Samad in Palangkaraya, near the University of Muhammadiyah Palangkaraya.

3.1. Data collection

The data collection method utilized both primary and secondary data. Primary data collection was divided into two stages: the first stage involved recording traffic volume, and the second stage involved measuring travel speed data. Secondary data included road network maps.

3.1.1. Traffic volume data

Traffic volume data were collected through field surveys using video recordings, followed by manual traffic enumeration. Surveyors documented vehicle flow and directional movements across all approaches. Observations were conducted on a Monday (a representative workday with high traffic demand) during morning peak hours from 06.00 to 09.00 WIB (*Western Indonesia Time, GMT+7*). This timeframe was selected to capture typical congested conditions. Vehicle classification followed three categories: light vehicles (passenger cars, minibuses, pick-ups, and jeeps), heavy vehicles (trucks and buses), and motorcycles.

3.1.2. Travel speed data

Travel speed data is collected at 100 m (0.1 km). The tools used in this survey are a stopwatch and roll meter, where travel time is measured over 100 m by recording 10 samples of light vehicle and heavy vehicle units.

3.2. Vehicle emission analysis

The results obtained from the field survey will be analyzed using empirical calculations to quantify motor vehicle exhaust emissions (CO, HC, NOx, and PM). These calculations will determine both individual pollutant levels and total vehicular emissions, which will then be compared against permissible limits specified in the National Air Quality Standards. The empirical calculations will be performed using the methodology outlined in the Design Manual for Roads and Bridges (DMRB) [18], with Eqs. (1)-(3):

$$Ekr = Vr \ x \ FPKr/1000 \ x \ FKKKr \quad (1)$$

$$Ekb = Vb \ x \ FPKb/1000 \ x \ FKKKb \quad (2)$$

$$Etotal = EKr + EKb \quad (3)$$

where Ekr denotes light vehicle traffic emissions, Ekb denotes heavy vehicle traffic emissions, Vr denotes the volume of light vehicle traffic (vehicles/hour), Vb denotes the volume of heavy vehicle traffic (vehicles/hour), $FPKr$ denotes the pollution factor for light vehicles for each pollutant category, $FPKb$ denotes the pollution factor for heavy vehicles for each pollutant category, $FKKKr$ denotes the conversion factor for light vehicle speed for each type of pollutant, and $FKKKb$ denotes the conversion factor for heavy vehicle speed for each type of pollutant. The pollutant value factor, used to estimate the volume of traffic exhaust gas emissions on the road, is provided in Table 1 and Table 2. The vehicle speed conversion factors are provided in Table 3 and Table 4.

Table 1
Pollutant levels by distance per 1000 vph (light vehicles).

Distance pollutant (m)	CO (ppm)	HC (ppb)	NOx (ppb)	PM (μg/m^3)
5	0.505	98.5	200.4	6.56
10	0.478	93.2	189.1	6.18
15	0.41	80	162.2	5.34
20	0.35	68.4	138.7	4.58
25	0.301	58.7	119.3	3.96
30	0.26	50.7	103.2	3.44
35	0.226	44.1	89	2.98
40	0.198	38.4	78.4	2.64
45	0.173	33.7	68.8	2.32
50	0.152	29.6	60.6	2.05

Table 2
Pollutant levels by distance per 1000 vph (heavy vehicles).

Distance pollutant (m)	CO (ppm)	HC (ppb)	NOx (ppb)	PM (μg/m^3)
5	0.37	46.39	909.8	177.8
10	0.35	43.90	858.8	167.5
15	0.30	37.68	736.4	144.7
20	0.356	32.22	629.7	124.1
25	0.22	27.65	541.6	107.3
30	0.19	23.88	468.5	93.2
35	0.165	20.77	407.7	80.8
40	0.145	18.09	355.9	71.5
45	0.127	15.87	312.4	32.9
50	0.111	13.94	275.1	55.6

Table 3
Air quality assessment speed conversion factors (light vehicles).

Speed (kph)	CO (ppm)	HC (ppb)	NOx (ppb)	PM (μg/m^3)
5	20.53	15.45	3.51	2.21
10	11.57	9.29	1.99	1.72
15	8.30	6.99	1.46	1.50
20	6.48	5.66	1.19	1.36
25	5.25	4.74	1.02	1.26
30	4.34	4.04	0.91	1.17
35	3.63	3.48	0.83	1.10
40	3.05	3.00	0.77	1.04
45	2.57	2.61	0.74	1.00
50	2.17	2.26	0.71	0.96

Table 4
Air quality assessment speed conversion factors (heavy vehicles).

Speed (kph)	CO (ppm)	HC (ppb)	NOx (ppb)	PM (μg/m^3)
5	4.05	15.01	2.15	2.94
10	3.45	7.85	1.88	2.10
15	2.93	5.38	1.65	1.71
20	2.49	4.09	1.44	1.46
25	2.12	3.28	1.26	1.28
30	1.8	2.72	1.10	1.14
35	1.63	2.30	1.06	1.03
40	1.43	1.98	0.99	0.95
45	1.24	1.72	0.92	0.87
50	1.06	1.52	0.85	0.82

Table 5
National ambient air quality standards.

No	Parameter	Measurement time	Quality standards
1	Sulfur dioxide (SO_2)	1 hour	150 μg/m³
		24 hours	75 μg/m³
		1 year	45 μg/m³
2	Carbon monoxide (CO)	1 hour	10000 μg/m³
		8 hours	4000 μg/m³
3	Nitrogen dioxide (NO_2)	1 hour	200 μg/m³
		24 hours	65 μg/m³
		1 year	50 μg/m³
4	Ozone (O_3)	1 hour	150 μg/m³
		8 hours	100 μg/m³
		1 year	35 μg/m³
5	Non-Methane Hydrocarbon (NMHC)	3 hours	160 μg/m³
6	Dust particulates < 100 μm (TSP)	24 hours	230 μg/m³
	Dust particulates < 10 μm (PM_{10})	24 hours	75 μg/m³
		1 year	40 μg/m³
	Dust particulates < 2,5 μm ($PM_{2,5}$)	24 hours	55 μg/m³
		1 year	15 μg/m³
7	Lead (Pb)	24 hours	2 μg/m³

Table 6
Traffic volume of Willem A. Samad road.

Time	Motorcycles	Light vehicle	Heavy vehicle	Vehicle/hour
06.00 - 07.00	159	38	1	198
06.15 - 07.15	200	58	0	258
06.30 - 07.30	236	82	0	318
06.45 - 07.45	273	103	0	376
07.00 - 08.00	306	115	0	421
07.15 - 08.15	327	136	0	463
07.30 - 08.30	338	145	2	485
07.45 - 08.45	332	155	2	489
08.00 - 09.00	321	166	2	489
06.00 - 09.00	786	319	3	1108

Table 7
Traffic volume of R.T.A. Milono (A) road.

Time	Motorcycles	Light vehicle	Heavy vehicle	Vehicle/hour
06.00 - 07.00	965	453	4	1422
06.15 - 07.15	944	478	3	1425
06.30 - 07.30	903	455	1	1359
06.45 - 07.45	905	439	2	1346
07.00 - 08.00	913	455	1	1369
07.15 - 08.15	919	442	1	1362
07.30 - 08.30	900	436	2	1338
07.45 - 08.45	830	402	1	1233
08.00 - 09.00	791	368	3	1162
06.00 - 09.00	2669	1276	8	3953

3.3. National Ambient Air Quality Standards

Air pollutant parameters are based on ambient air quality standards as outlined in Government Regulation Number 22 of 2021 [27]. These include sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), hydrocarbons (HC), and lead (Pb). These six pollutants are considered to have a direct and significant impact on human health. Each parameter has a distinct maximum allowable concentration, typically expressed in micrograms per cubic meter (μg/m³) under standard conditions (i.e., a temperature of 25°C and a pressure of 1 atmosphere). Ambient air quality is considered good if pollutant concentrations remain below the established quality standards. Table 5 presents the national ambience air quality standards.

Table 8
Traffic volume of R.T.A. Milono (B) road.

Time	Motorcycles	Light vehicle	Heavy vehicle	Vehicle/hour
06.00 - 07.00	1370	475	1	1846
06.15 - 07.15	1263	458	1	1722
06.30 - 07.30	1178	464	3	1645
06.45 - 07.45	1073	403	2	1478
07.00 - 08.00	1001	390	3	1394
07.15 - 08.15	944	408	3	1355
07.30 - 08.30	892	379	1	1272
07.45 - 08.45	848	381	1	1230
08.00 - 09.00	777	372	0	1149
06.00 - 09.00	3148	1237	4	4389

Table 9
Travel speed data from vehicles on Willem A.Samad road, R.T.A. Milono (A) road, R.T.A. Milono (B) road.

No	Willem A.Samad road				R.T.A. Milono (A) road				R.T.A. Milono (B) road			
	Light vehicle		Heavy vehicle		Light vehicle		Heavy vehicle		Light vehicle		Heavy vehicle	
	sec	kph	sec	kph	sec	kph	sec	kph	sec	kph	sec	kph
1	10.0	36.00	12.0	30.00	7.5	8.80	8.8	40.91	9.2	39.13	10.8	33.33
2	10.5	34.29	12.5	28.80	7.8	9.00	9.0	40.00	9.0	40.00	11.0	32.73
3	9.8	36.73	12.3	29.27	8.0	9.20	9.2	39.13	8.8	40.91	10.5	34.29
4	10.2	35.29	13.0	27.69	7.7	9.50	9.5	37.89	9.0	40.00	10.8	33.33
5	11.0	32.73	12.0	30.00	8.2	8.50	8.5	42.35	8.7	41.38	9.7	37.11
6	10.4	34.62	12.5	28.80	8.0	9.20	9.2	39.13	9.2	39.13	9.8	36.73
7	10.2	35.29	12.7	28.35	8.5	9.50	9.5	37.89	8.8	40.91	9.8	36.73
8	9.8	36.73	11.5	31.30	7.5	8.50	8.5	42.35	9.0	40.00	10.2	35.29
9	10.0	36.00	11.0	32.73	8.5	9.00	9.0	40.00	9.2	39.13	10.5	34.29
10	11.0	32.73	11.0	32.73	8.2	8.70	8.7	41.38	9.0	40.00	10.2	35.29
Average		35.04		29.97		45.14		40.10		40.06		34.91

4. Results and discussion

4.1. Traffic volume data

Based on the traffic survey conducted, hourly traffic volume data for each section are presented in Table 6, Table 7, and Table 8. Table 6 indicates that the peak traffic volume on the Willem A. Samad road section, from 08:00 to 09:00, is 489 vehicles/hour, comprising 321 motorcycles, 166 light vehicles, and 2 heavy vehicles. Table 7 shows that the peak traffic volume on the R.T.A. Milono (A) road section, from 06:15 to 07:15, is 1,425 vehicles/hour, consisting of 965 motorcycles, 453 light vehicles, and 3 heavy vehicles. Table 8 reveals that the peak traffic volume on the R.T.A. Milono (B) road section, from 06:00 to 07:00, is 1,846 vehicles/hour, including 1,370 motorcycles, 475 light vehicles, and 1 heavy vehicle.

4.2. Lane width

It can be observed that Willem A. Samad road spans a width of 7.0 meters, while RTA Milono (A) road measures 9.5 meters wide, and RTA Milono (B) road extends to 9.0 meters in width. These dimensions highlight the distinct characteristics of each roadway, facilitating efficient urban planning and traffic management.

4.3. Travel speed data

According to Table 9, the average travel speeds for light vehicles are 35 km/h on Willem A. Samad Road, 45 km/h on RTA Milono (A) Road, and 40 km/h on RTA Milono (B) Road. For heavy vehicles, the average speeds are 30 km/h on Willem A. Samad Road, 40 km/h on RTA Milono (A) Road, and 35 km/h on RTA Milono (B) Road.

Table 10
Vehicle emissions of Willem A. Samad road.

Time	CO (ppm)	HC (ppb)	NOx (ppb)	PM (μg/m³)
06.00 - 07.00	0.070	13.152	7.321	0.477
06.15 - 07.15	0.106	19.881	9.647	0.419
06.30 - 07.30	0.150	28.108	13.639	0.592
06.45 - 07.45	0.189	35.306	17.132	0.743
07.00 - 08.00	0.211	39.420	19.128	0.830
07.15 - 08.15	0.249	46.618	22.621	0.981
07.30 - 08.30	0.267	49.955	26.120	1.452
07.45 - 08.45	0.285	53.383	27.783	1.524
08.00 - 09.00	0.306	57.154	29.613	1.603
06.00 - 09.00	0.587	109.725	56.062	2.910

Table 11
Vehicle emissions of R.T.A. Milono (A) road.

Time	CO (ppm)	HC (ppb)	NOx (ppb)	PM (μg/m³)
06.00 - 07.00	0.588	116.827	70.781	3.647
06.15 - 07.15	0.620	123.162	73.588	3.642
06.30 - 07.30	0.591	117.066	68.375	3.154
06.45 - 07.45	0.570	113.044	66.903	3.218
07.00 - 08.00	0.591	117.066	68.375	3.154
07.15 - 08.15	0.574	113.723	66.448	3.068
07.30 - 08.30	0.566	112.273	66.458	3.198
07.45 - 08.45	0.522	103.440	60.516	2.806
08.00 - 09.00	0.478	94.883	57.275	2.921
06.00 - 09.00	1.654	327,563	194,037	9,358

4.4. Vehicle emissions

To assess vehicle-related air pollution, a structured analysis of emissions from both light vehicles (LV) and heavy vehicles (HV) is conducted, followed by the calculation of total emissions for key pollutants: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). The process is streamlined into three clear steps, ensuring precision and clarity in determining the environmental impact.

First, emissions from light vehicles are calculated. The pollution factors ($FPKr$) for light vehicles are retrieved from Table 1: CO at 0.505 ppm, HC at 98.5 ppb, NOx at 200.4 ppb, and PM at 6.56 μg/m³. Next, speed conversion factors ($FKKKr$) for each pollutant are obtained from Table 3: CO at 3.63 ppm, HC at 3.48 ppb, NOx at 0.83 ppb, and PM at 1.10 μg/m³. Using Eq. (1), light vehicle emissions (Ekr) are computed by multiplying the factor 166/1000 by the respective pollution and speed conversion factors, yielding: CO = 0.304 ppm, HC = 56.901 ppb, NOx = 27.611 ppb, and PM = 1.198 μg/m³.

Next, the analysis shifts to heavy vehicle emissions. Pollution factors ($FPKb$) for heavy vehicles are sourced from Table 2: CO at 0.37 ppm, HC at 46.39 ppb, NOx at 909.80 ppb, and PM at 177.8 μg/m³. Speed conversion factors ($FKKKb$) are drawn from Table 4: CO at 1.8 ppm, HC at 2.72 ppb, NOx at 1.10 ppb, and PM at 1.14 μg/m³. Using Eq. (2), heavy vehicle emissions (Ekb) are calculated with the factor 2/1000, resulting in: CO = 0.002 ppm, HC = 0.252 ppb, NOx = 2.002 ppb, and PM = 0.405 μg/m³.

Finally, total vehicle emissions (E total) for each pollutant are determined using Eq. (3), which sums the emissions from light and heavy vehicles. The results are: CO = 0.306 ppm, HC = 57.153 ppb, NOx = 29.613 ppb, and PM = 1.603 μg/m³. This comprehensive approach provides a clear and accurate assessment of vehicle-related pollutant levels.

Using the same methodology as the previous calculation, vehicle emission values for each road section are presented in Table 10, Table 11, and Table 12. Based on Table 10, the maximum vehicle emissions on the Willem A. Samad road section from 08:00 to 09:00 are 0.306 ppm CO, 57.154 ppb HC, 29.613 ppb NO_2, and 1.603 μg/m³ PM. Table 11 shows that the maximum vehicle emissions on the R.T.A. Milono (A) road section from 06:15 to 07:15 reach 0.620 ppm CO, 123.162 ppb HC, 73.588 ppb NO_2, and 3.642 μg/m³ PM. Meanwhile, Table 12 indicates that the maximum vehicle emissions on the R.T.A. Milono (B) road section from 06:00 to 07:00 are 0.732 ppm CO, 140.469 ppb HC, 74.261 ppb NO_2, and 3.424 μg/m³ PM.

Table 12
Vehicle emissions of R.T.A. Milono (B) road.

Time	CO (ppm)	HC (ppb)	NOx (ppb)	PM (μg/m³)
06.00 - 07.00	0.732	140.469	74.261	3.424
06.15 - 07.15	0.706	135.446	71.637	3.308
06.30 - 07.30	0.716	137.432	74.492	3.715
06.45 - 07.45	0.622	119.300	64.115	3.116
07.00 - 08.00	0.603	115.565	63.073	3.210
07.15 - 08.15	0.630	120.884	65.851	3.333
07.30 - 08.30	0.584	112.101	59.447	2.769
07.45 - 08.45	0.587	112.692	59.756	2.782
08.00 - 09.00	0.573	109.926	57.403	2.538
06.00 - 09.00	1.902	364.860	192.345	8.785

Table 13
Maximum total vehicle emissions.

No	Intersection approach	Parameter						
		CO (ppm)		HC (ppb)		NOx (ppb)	PM (μg/m³)	
		1 hour	8 hours	1 hour	3 hours	1 hour	1 hour	24 hours
1	Willem A.Samad	0.306	1.565	57.154	109.725	29.613	1.603	23.280
2	R.T.A. Milono (A)	0.620	4.411	123.162	327.563	73.588	3.647	74.862
3	R.T.A. Milono (B)	0.732	5.072	140.469	364.860	74.492	3.715	70.281

Table 14
Conversion factors for air pollutants.

No	Air pollutant	Conversion factor
1	Carbon monoxide (CO)	1 ppb = 1.15 μg/m³
2	Nitrogen dioxide (NO_2)	1 ppb = 1.88 μg/m³
3	Ozone (O_3)	1 ppb = 1.96 μg/m³
4	Sulfur dioxide (SO_2)	1 ppb = 2.62 μg/m³
5	Methane (CH_4)	1 ppb = 0.656 μg/m³
6	Ethane (C_2H_6)	1 ppb = 1.23 μg/m³
7	Propane (C_3H_8)	1 ppb = 1.8 μg/m³
8	Benzene (C_6H_6)	1 ppb = 3.19 μg/m³

4.5. Total emissions compared with national air quality standards

The maximum total vehicle emissions for each road section and pollutant type are presented in Table 13. As the field survey was conducted over only three hours, the collected data were converted to represent 8-hour and 24-hour emission levels using the equation: Emission (desired time) = (Existing emission data / Survey time) × Desired time. For instance, the calculation for CO emissions on Willem A. Samad Road yields the following results: for 3 hours, CO is 0.587 ppm, and for 8 hours, it is calculated as (0.587 / 3) × 8 = 1.565 ppm. The pollutant values in Table 13 were then converted from parts per billion (ppb) to micrograms per cubic meter (μg/m³) using the formula: Concentration (μg/m³) = Concentration (ppb) × Conversion factor. Table 14 show the conversion factors from several pollutans. An example calculation for HC emissions (3 hours) on Willem A. Samad Road shows HC at 109.725 ppb, resulting in 109.725 × 0.656 = 71.980 μg/m³.

The total vehicle emissions, now expressed in μg/m³, were compared with national air quality standards, as shown in Table 15. The analysis reveals that CO levels at 1 hour for all roads remain below 10,000 μg/m³, but at 8 hours, R.T.A. Milono (A) and R.T.A. Milono (B) roads exceed 4,000 μg/m³. For HC, the 3-hour levels on Willem A. Samad Road are below 160 μg/m³, whereas R.T.A. Milono (A) and R.T.A. Milono (B) roads surpass 160 μg/m³. NO_2 levels at 1 hour for all roads are below 200 μg/m³, and PM_{10} levels at 24 hours for all roads are below 75 μg/m³. Despite Willem A. Samad Road having a narrower width and lower travel speeds, it exhibits lower pollution levels compared to R.T.A. Milono (A) and R.T.A. Milono (B) roads, which experience higher pollution due to greater volumes of vehicle traffic, including both light and heavy vehicles.

Table 15
Total vehicle emissions compared to national air quality standards

No	Intersection approach	Parameter				
		CO (μg/m³)		HC (μg/m³)	NO_2 (μg/m³)	PM_{10} (μg/m³)
		1 hour	8 hours	3 hours	1 hour	24 hours
1	Willem A. Samad	351.480	1799.437	71.980	55.672	23.280
2	R.T.A. Milono (A)	713.430	5072.389	214.881	138.345	74.862
3	R.T.A. Milono (B)	842.055	5832.416	239.348	140.045	70.281
	Permitted quality standards	10000	4000	160	200	75

Control measures and urban policy interventions are essential for mitigating emissions. Xu and Qin [28] evaluated emission control policies in Hainan, China, and reported significant pollutant reductions following regulatory changes. Stewart et al. [29] introduced updated NOx/NO_2 emission curves, enhancing the accuracy of emissions inventories and informing policymaking. Signal optimization techniques, such as adaptive signal control based on CO emissions [30] and simulation-based strategies using PTV VISSIM [31], demonstrate potential for real-time pollution control at intersections. Additionally, Wallington et al. [32] highlight the historical impact of emission reduction technologies, such as catalytic converters and improved fuel quality standards, as critical advancements in pollution control.

5. Conclusions

Based on the analysis of vehicle emissions compared to national air quality standards, Willem A. Samad Road recorded levels of all pollutants below the permitted thresholds. In contrast, R.T.A. Milono (A) Road and R.T.A. Milono (B) Road met the standards for NO_2 (below 200 μg/m³) and PM_{10} (below 72 μg/m³) but exceeded the limits for CO (above 4,000 μg/m³) and HC (above 160 μg/m³), failing to comply with the permitted standards. The government should prioritize addressing vehicle emissions on R.T.A. Milono Road and implement effective solutions to mitigate this issue. Additionally, the community is encouraged to remain vigilant about environmental conditions and maintain motorized vehicles to prevent excessive exhaust emissions from traffic. For future research, investigating the specific sources of elevated CO and HC emissions on R.T.A. Milono Road, such as vehicle types, traffic patterns, or industrial contributions, could provide valuable insights for developing targeted emission reduction strategies.

Declaration statement

Ari Widya Permana: Methodology, Data Analysis, Writing-Original Draft. **Gusti Iqbal Tawaqal**: Conceptualization, Collecting Data, Writing-Review & Editing.

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Disclosure statement

The author declares that this manuscript is free from conflict of interest and is processed by applicable journal provisions and policies to avoid deviations from publication ethics in various forms.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

AI Usage Statement

Generative AI and AI-assisted tools were used to enhance the language and readability of this manuscript. The authors have reviewed and revised all AI-generated content to ensure its accuracy and alignment with the research. The authors remain fully responsible for the work's scientific content, conclusions, and integrity, and disclose the use of AI to ensure transparency and adherence to publisher guidelines.

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