Line source dispersion and spatial distribution of carbon monoxide concentration on Daan Mogot Street, Tangerang City, Jabodetabek Metropolitan Area

Muhardiyan Erawan1*, Mahawan Karuniasa1 and Haryoto Kusnoputranto1
1 School of Environmental Science, Universitas Indonesia, Central Jakarta, 10430, Indonesia

*muhardiyan.erawan81@ui.ac.id

Abstract. Air pollution is the most common problem in urban areas. Emissions from transport are hypothesized to be the main cause of this pollution. Therefore, studies on air pollution on a local scale must be carried out, especially on pollutants related to emissions from transportation, carbon monoxide. This study aims to provide an up-to-date study regarding the specific conditions of Carbon Monoxide concentration in the Daan Mogot Street area. This research uses the Gaussian Line Source and Geographic Information System (GIS) methods. This research shows that carbon monoxide concentrations around Daan Mogot Street ranged from 195.56 - 1482.50 µg/m³. This research findings are expected to anticipate the increase in the concentration of carbon monoxide in the research area, affecting the sustainability of people around the research area.

1. Introduction

Air pollution is a problem that often occurs and can impact human sustainability and the environment. Research results from World Health Organization (WHO) show that air pollution continues to increase by around 8% between 2008 and 2013 [1]. Due to air pollution, an estimated 7 million people die each year. Air pollution can cause various deadly diseases such as stroke, heart disease, respiratory problems, and cancer [2].

Air pollution will continue to increase in line with the development of the developing area's status to become an urban area [3]. Air pollution in urban areas is getting worse along with increasing population, use of vehicles and energy, and industrial growth [4]. These conditions can reduce air quality and be harmful to human health.

Air spatial variability is closely related to land use conditions around the air measurement and monitoring area. Land use can increase exhaust emissions of air pollutants into the atmosphere, therefore it is very important to regulate land use, especially in urban areas. A study in Lianyungan, Jiangsu Province, China concluded that several land uses such as residential areas and transportation are associated with higher emissions of air pollution [5].

A study in the industrial area of Mitrena, Portugal shows that industrial estates and warehousing also contribute to increasing the concentration of air pollution, especially through emissions released by vehicles passing in and around the area [6]. Another study states that in urban areas such as Salt Lake City (SLC), Utah, USA, which is generally filled not only by local residents but also commuters from
the surrounding area with the aim to work in office areas and other activities also contribute to increased air pollution depending on the mode of transportation used [7].

Based on the results of studies from several sources described earlier, the researcher chose a research area in one of the cities in the Greater Jakarta Metropolitan area that has similar land use characteristics and air pollution problems, namely Kota Tangerang. Air pollution indicated by carbon monoxide in Tangerang City is predicted to exceed air quality standards in Indonesia (>10,000 μg/Nm³) in 2034, and also several areas have been predicted to exceed quality standards in 2026 [8]. One of the predicted areas is the area around Jalan Daan Mogot.

Carbon Monoxide (CO) is a colorless, odorless, tasteless, and non-irritating, but deadly gas that results from the incomplete combustion of liquid, solid, and gaseous fuels. The most common source of CO in free air is from motorized vehicles. Another source can come from cigarette smoke, but only in small amounts [9]. CO levels in the blood will have different effects on the body, from psychological disorders to death [10].

This study aims to provide an up-to-date study regarding the specific conditions of Carbon Monoxide concentration in the Daan Mogot Street area. This research uses the Gaussian Line Source method approach and is combined with spatial analysis using a Geographic Information System (GIS). This research is expected to anticipate the increase in the concentration of carbon monoxide in the research area which can affect the sustainability of people around the research area.

2. Method

This method includes an explanation of the Study Area, Gaussian Line Source Dispersion Model, and Geographic Information System (GIS) Model. The data processing starts from Traffic Volume Counting to Spatial Interpolation [Figure 1]. Traffic Volume Counting was performed with a manual counter at 7-10 AM (morning) and 3-6 PM (evening). This time was chosen by considering the conditions of the densest human activities in the study area. The data processing and calculation of pollution discharge, average wind speed, atmospheric class, dispersion coefficient, and concentration of CO can be seen in the Gaussian Line Source Dispersion Model section. The data processing and calculation of mapping line source dispersion and spatial interpolation inverse distance weight (IDW) can be seen in Geographic Information System (GIS) Model section.

Figure 1. Data processing flow chart.

2.1. Study area

The city of Tangerang is one of regency/city in Banten Province, one of the provinces in Indonesia, located at 106°32'-106°44' east longitude and 6°6'-6°13' south latitude. The research location is on Jalan Daan Mogot in the Batuceper District area. Monitoring and research data collection was carried out on June 2, 2020, when the COVID-19 pandemic was occurring.

2.2. Gaussian Line Dispersion Model

Motorized vehicles are a direct source that emits pollutants into the atmosphere. The number of trips and vehicle distances per kilometer that determine the amount of emissions is more determined by urban
factors in the existing transportation system. Motor vehicle emissions on the road are caused by two factors, namely the total volume of motorized vehicles and motor vehicle characteristics [11]. Determining the emission rate released by motorized vehicles can be seen in following formula:

\[ Q = \sum d x n x EF \]  

Where \( Q \), \( n \), \( d \), \( EF \) is the amount of pollution discharged (g/km.hr), average traffic volume per hour (amount per hour), observed path length, emission factor for each type of vehicle (g/km). Determination of emission factors is obtained from local regulations in Indonesia based on the Regulation of the Minister of Environment Number 12 of 2010 concerning the Implementation of Air Pollution Control in Regions [12]. The emission factors can be seen in [Table 1].

| Vehicle Type | Motorcycle | Car | Bus | Truck |
|--------------|------------|-----|-----|-------|
| Emission Factor for CO (g/km) | 14 | 32.4 | 11 | 8.4 |

The basic Gaussian equation which is an equation in calculating the concentration from a point source, so that it can be applied in calculating the concentration from a line source, assumes that when the point source moves along the line continuously (the vehicle on the road) is the same as the source line [13]. The basic Gaussian equation is obtained by following several assumptions [14]. First, a state is in a stable condition which is assumed that the emission obtained from the source is always constant. Second, uniform flow which is considered to be constant wind speed based on both time and altitude. Third, pollutants are conservative and there is no drop due to gravity. Fourth, perfect reflection of puffs on the bottom surface, such as no absorption by soil. Fifth, turbulent diffusion towards \( x \) is negligible because it is relative to the advection towards transport \( x \) which means that the model can be applied to average wind speeds of more than 1 m/s. Sixth, the terrain underlying the plume is flat. Last, the coordinate system is directed with the \( x \)-axis in the direction of flow, and the \( v \) (lateral) and \( w \) (lateral) components of the average time of the wind vector are set to zero.

The number of limitations that arise due to these assumptions means that the equation can only be applied for a short distance of 10 km with a pollutant travel time of 2 hours. The Gaussian equation that can be used to get the CO gas concentration from transportation activities can be seen in the following formula:

\[ q = \frac{\sqrt{2 \frac{Q}{\pi}}}{u \sigma z} \exp \left[ \frac{-z^2}{2 \sigma_z^2} \right] \]  

Where \( q \), \( Q \), \( u \), \( z \), \( \sigma_z \) is the concentrations of pollutants along the road were observed, carbon monoxide-CO (g/m3), the amount of pollution discharged (g/ms), average wind speed (m/s), effective stack height (m), and dispersion coefficient in the \( z \) direction (m). The determination of the value of \( \sigma_z \) is obtained based on the empirical equation of the dispersion coefficient for a city which is shown in [Table 2], where \( x \) is the distance between road and wind speed measurement point (3 meters) [15].

| Atmospheric Stability | \( \sigma_z \) (m) |
|-----------------------|-----------------|
| A-B                   | 0.24 x (1 + 0.0001x)\(^{1/2} \) |
| C                     | 0.20x           |
| D                     | 0.14 x (1 + 0.0003x)\(^{1/2} \) |
| E-F                   | 0.08 x (1 + 0.0015x)\(^{1/2} \) |
Atmospheric stability is the tendency of the atmosphere to withstand vertical movements or suppress existing turbulence, which affects the atmosphere's ability to disperse pollutants emitted into the atmosphere. The determination of the atmospheric stability of a region can be seen in [Table 3].

**Table 3. Atmospheric stability classification.**

| Surface Wind Speed (m/s) | Day | Incoming Solar Radiation | Night Cloudiness |
|--------------------------|-----|--------------------------|-----------------|
| <2 A                     | A-B | B                        | E F             |
| 2-3 A-B                  | B   | C                        | E F             |
| 3-5 B                    | B-C | C                        | D E             |
| 5-6 C                    | C-D | D                        | D D             |
| >6 C                     | D   | D                        | D D             |

2.3. Geographic Information System (GIS) Model

Geographic Information System (GIS) is a computerized system that processes data starting from the data entry phase, data analysis, and data presentation devoted to location data and/or other georeferenced data [16]. This model uses the Inverse Distance Weight (IDW) interpolation method which is used to estimate spatial values based on the value of the known measurement location points. Spatial interpolation (or spatial prediction) aims to predict a target variable's values in the entire study area, which is presented in the form of an image or map [17]. The IDW method is a technique for averaging values by considering the magnitude of a point around it [Figure 2].

![Figure 2. Spatial interpolation Method Concept IDW [16].](image)

3. Results and discussion

3.1. Result

Observation and calculation of traffic volume were done manually using a manual counter in the morning (7-10 AM) and evening (3-6 PM). This time is determined based on the assumption that it is the time for the most traffic on the road. Observations were made for 3 hours, then the hourly average was calculated. The results of observations and calculations can be seen in [Table 4]. The types of vehicles that are mostly around Daan Mogot Street are sorted from the most to the least, namely Motorcycle, Car, Truck, and Bus. The Motorcycle is the type of vehicle that is most counted for several reasons. First, the COVID-19 pandemic condition has resulted in local regulations to use private vehicles more than public transportation. This condition also applies to cars and also causes the number of buses to seem very small. Second, the public perception that motorcycle is effective and efficient transportation around Tangerang City, especially for short distances. Finally, there is online motorcycle...
transportation with the name ojek which is widely available in the Jabodetabek Metropolitan Area, especially in Tangerang City in this research.

Table 4. Average traffic volume per hour.

| Road Name                                   | Morning (7-10 AM) | Evening (3-6 PM) |
|---------------------------------------------|-------------------|------------------|
|                                             | Mean Traffic Volume per Hour | Mean Traffic Volume per Hour |
|                                             | Motorcycle | Car | Bus | Truck | Motorcycle | Car | Bus | Truck |
| Daan Mogot (Segment 1) to Jakarta           | 2990       | 960 | 3   | 225   | 1948       | 671 | 4   | 179   |
| Daan Mogot (Segment 1) to Tangerang        | 2341       | 587 | 9   | 202   | 4101       | 781 | 10  | 231   |
| Daan Mogot (Segment 2) to Jakarta           | 2576       | 993 | 8   | 196   | 1324       | 561 | 9   | 158   |
| Daan Mogot (Segment 2) to Tangerang        | 1767       | 447 | 9   | 76    | 2631       | 628 | 15  | 202   |
| Daan Mogot (Segment 3) to Jakarta           | 4285       | 831 | 7   | 132   | 2872       | 647 | 10  | 137   |
| Daan Mogot (Segment 3) to Tangerang        | 2378       | 653 | 6   | 122   | 4137       | 722 | 13  | 103   |
| Pembangunan to North                       | 496        | 107 | 0   | 56    | 476        | 102 | 0   | 59    |
| Pembangunan to South/Daan Mogot            | 400        | 73  | 1   | 41    | 670        | 96  | 1   | 41    |
| Maulana Hasanudin to North/Daan Mogot      | 1369       | 553 | 1   | 205   | 1227       | 453 | 1   | 169   |
| Maulana Hasanudin to South                 | 1653       | 353 | 0   | 139   | 621        | 242 | 0   | 66    |
| Halim Perdanakusumah to North              | 969        | 157 | 0   | 42    | 954        | 166 | 0   | 42    |
| Halim Perdanakusumah to South/Daan Mogot  | 1004       | 118 | 0   | 38    | 719        | 107 | 1   | 31    |

The average traffic volume per hour is then multiplied by the emission factor for each type of vehicle according to [Table 1]. This is done to get the amount of pollution discharged (Q) on each road in units of g/km.hr. The value of Q is divided by 3.6 x 10^6 to convert the unit to g/ms. This is important to adjust to the Gaussian Line Source formula. The average value of wind speed in the observation area is carried out by recording the wind speed value that is read on the fan anemometer every 10 minutes for 3 hours in the morning and evening then calculating the average value. The effective stack height (z) has a value of 0.5 meters, assuming the vehicle exhaust point is at an altitude of 0.5 meters on the vehicle.

Table 5. Parameter and result of line source dispersion.

| Road Name                               | d (km) | Morning (7-10 AM) | Evening (3-6 PM) |
|-----------------------------------------|--------|-------------------|------------------|
|                                        | Q (g/ms) | u (m/s) | q (µg/m^3) | Q (g/ms) | u (m/s) | q (µg/m^3) |
| Daan Mogot (Segment 1) to Jakarta       | 1.370   | 0.015184 | 2.51 | 1049.27 | 0.010251 | 2.38 | 747.08    |
| Daan Mogot (Segment 1) to Tangerang     | 1.370   | 0.010865 | 2.51 | 750.81  | 0.017188 | 2.38 | 1252.64   |
| Daan Mogot (Segment 2) to Jakarta       | 2.084   | 0.009327 | 2.06 | 1194.62 | 0.005084 | 2.12 | 632.74    |
| Daan Mogot (Segment 2) to Tangerang     | 2.084   | 0.005326 | 2.06 | 682.16  | 0.007870 | 2.12 | 979.47    |
| Daan Mogot (Segment 3) to Jakarta       | 1.557   | 0.015718 | 2.09 | 1482.50 | 0.011138 | 2.00 | 1097.80   |
| Daan Mogot (Segment 3) to Tangerang     | 1.557   | 0.009909 | 2.09 | 934.60  | 0.014686 | 2.00 | 1447.50   |
| Pembangunan to North                    | 1.125   | 0.002687 | 2.81 | 136.20  | 0.002584 | 2.76 | 133.35    |
The diffusion coefficient value in the z-direction ($\sigma_z$) is obtained based on the atmosphere's stability, which is determined based on the average value of wind speed and incoming solar radiation. The average value of wind speed ranges from 2-3 m/s and the time of sun exposure in the research area is around 12 hours or about 50% so that incoming solar radiation is in the Moderate class. Based on these conditions, the research area's atmospheric stability is in class B and has the formula $0.24 x (1 + 0.0001x)^{1/2}$, where the x value is 3 meters. The diffusion coefficient value in the z-direction ($\sigma_z$) in this research is 0.720107992 meters. After obtaining the values of $Q$, $u$, $z$, and $\sigma_z$, the value of $q$ can be determined using the Gaussian Line Source formula, which results in the concentration of pollutants dispersed along the calculated road segment and has units of g/m². This value is multiplied by 10⁶ to get a value in µg/m³. Then the value is multiplied by the length of the road observed (d). The q value of each road section can be seen in Table 5.

The calculated q values varied from 104.11 µg/m³ to 1447.50 µg/m³. The distribution of these values can be seen in Figure 3. Daan Mogot Street in general has a high q value (> 600 µg/m³) compared to other roads. This is related to the hierarchy of road functions, where Daan Mogot Street is an arterial road, and the other roads are collector roads. CO concentrations on roads leading to Jakarta are generally higher in the morning [Figure 3a] on the contrary, CO concentrations on roads leading to Tangerang are generally higher in the evening [Figure 3b]. This happens because Jakarta is the center of human activities that is in line with its status as the capital and is the center of government and trade center in Indonesia so that the movement of people and vehicles will be congested towards the center in the morning and congested towards the outside of the center. In contrast to other roads, which generally have high CO concentration values on the sections leading to Daan Mogot Street in the morning. This occurs because of differences in the hierarchy of road functions where the movement of transportation and people will be congested towards higher road classes in the morning.

The CO concentration of each road section was then analyzed for its spatial distribution using the GIS Inverse Distance Weight (IDW) Interpolation method. This method estimates the distribution of CO concentration values based on calculated value points. This is related to the basis of the Gaussian Line Source dispersion theory which assumes that the dispersion source points are spread along the road so that the CO concentration values are spread along the road with the same segment. This study uses a point of distribution every 50 meters. The results of this spatial distribution can be seen in Figure 4. The spatial distribution in the northern region of the research location is generally higher in the morning [Figure 4a] and conversely, the spatial distribution in the southern region of the research location is generally higher in the afternoon [Figure 4b]. This phenomenon is in accordance with the causes of the variation in CO concentrations described previously. The spatial distribution value in the morning and evening is averaged to obtain a daily spatial distribution pattern. The pattern of daily spatial distribution in the research area shows that the closer to the arterial road, the higher the value of CO concentration.

3.2. Discussion

This research uses a lot of assumptions, so the validity of the results of this research needs to be studied further. The CO concentration used in this research is limited to only estimates based on calculation results based on Traffic Volume data and other parameters so that the validity of this value
is necessary. The COVID-19 pandemic condition resulting in government regulations to minimize human movement allows a lower traffic volume value than non-pandemic conditions (normal conditions).

The spatial distribution patterns in the north and southwest regions have invalid interpolation values because there are no data on CO concentration in those regions. This spatial distribution also ignores the possibility of other pollutant sources, absorption or loss of levels, the influence of wind direction, and building height resistance. The results in this research will be more accurate if the value of CO concentration is spread over each road segment. However, this is constrained by the large number of roads leading to Daan Mogot Street as arterial roads, therefore the researchers chose roads that have a hierarchical function below them, namely the collector road (Pembangunan Street, Maulana Hasanudin Street, and Halim Perdanakusumah Street).

Figure 3. (a) Map of line source dispersion of CO on Daan Mogot Street in the Morning; (b) Map of line source dispersion of CO on Daan Mogot Street in the Evening.
Figure 4. (a) Spatial Distribution of CO on Daan Mogot Street in the Morning; (b) Spatial Distribution of CO on Daan Mogot Street in the Evening; (c) Mean Value and Spatial Distribution of CO on Daan Mogot Street.
4. Conclusion
The calculated q values varied from 104.11-1447.50 µg/m³ depending on the path's direction and the hierarchy of the road function. A large number of model assumptions, the lack of a location for calculating traffic volumes, and the COVID-19 pandemic are thought to have an effect on lower CO concentrations in the research area compared to previous studies. Based on this research results, the condition of carbon monoxide pollution in the Daan Mogot Street area is classified as low and within the range of environmental quality standards. This research needs to be reviewed when the pandemic situation has ended to determine the pollution conditions under normal conditions.

Acknowledgements
This paper is supported and funded by the International Indexed Publication Grant for Student Final Project (PITMA B) with the contract of NKB-1026/UN2.R3.1/HKP.05.00/2019 by the Universitas Indonesia 2019.

References
[1] M. Li and L. Mallat 2018 Health Impacts of Air Pollution SCOR The Art & Science of Risk July pp 1–29
[2] WHO 2012 Air Pollution , Climate and Health
[3] US Department of Health and Human Services 2017 Rural and Urban Differences in Air Quality 2008–2012 and Community Drinking Water Quality 2010–2015 United States Morb. Mortal. Wkly. Rep. 66
[4] H. Mayer 1999 Air Pollution in Cities Atmos. Environ. 33 pp 4029–4037
[5] L. Chen, L. Li, X. Yang, Y. Zhang, L. Chen, and X. Ma 2019 Assessing the impact of land-use planning on the atmospheric environment through predicting the spatial variability of airborne pollutants Int. J. Environ. Res. Public Health 16 pp 1–18
[6] S. M. Garcia, G. Domingues, C. Gomes, A. V. Silva, and S. M. Almeida 2013 Impact of Road Traffic Emissions on Ambient Air Quality in an Industrialized Area J. Toxicol. Environ. Health 76 pp 429–439
[7] R. A. Chaney, C. D. Sloan, V.C. Cooper, D. R. Robinson, N. R. Hendrickson, T.A. McCord, and J. D. Johnston 2017 Personal exposure to fine particulate air pollution while commuting: An examination of six transport modes on an urban arterial roadway PLoS One 12 pp 1–15
[8] M. Erawan and M. Karuniasa 2020 Spatial Dynamics of Air Pollution in Tangerang City, Jabodetabek Metropolitan Area Int. Interdiscip. Stud. Semin.
[9] NHDES 2007 Carbon Monoxide : Health Information Summary Environmental Fact Sheet 20 (New Hampshire Department of Environmental Services) pp 1–3
[10] N. de Nevers 2000 Air Pollution Control Engineering, 2nd ed. (Illinois: Waveland Press, Inc.)
[11] X. Wang, M. Li, and B. Peng 2018 A Study on Vehicle Emission Factor Correction Based on Fuel Consumption Measurement IOP Conf. Ser. Earth Environ. Sci. 108
[12] Peraturan Menteri Negara Lingkungan Hidup Nomor 12 Tahun 2010 tentang Pelaksanaan Pengendalian Pencemaran Udara di Daerah. Regulation of the State Minister for the Environment of Indonesia Number 12 of 2010 concerning the Implementation of Air Pollution Control in Regions
[13] J. Colls 2002 Air Pollution, 2nd ed. (London: Spon Press)
[14] M. Khare 2007 A Formulation of Delhi Finite Line Source Model ( DFLSM ) Artif. Neural Networks Veh. Pollut. Model. 173 pp 163–173
[15] A. De Visscher 2014 Air Dispersion Modeling Foundations and Applications (New Jersey: John Wiley & Sons)
[16] R. A. de By, R.A. Knippers, Y. Sun, M. C. Ellis, M. J. Kraak, M. J. C. Weir, Y. Georgiadou, M. M. Radwan, C. J. van Westen, W. Kainz, E. J. Sides 2001 Principles of Geographic Information Systems (Enschede, The Netherlands: The International Institute for Aerospace Survey and Earth Sciences)
[17] T. Hengl 2009 *A Practical Guide to Geostastical Mapping* (Luxembourg: Office for Official Publications of the European Communities)