A spatial analysis of the dispersion of transportation induced carbon monoxide using the Gaussian line source method

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Abstract. The Purpose of this study is to model the spatial distribution of transportation induced carbon monoxide (CO) from a street, i.e. Jl. Singamangaraja, in Medan City using the gaussian line source method with GIS. It is observed that the traffic volume on the Jl. Singamangaraja is 7,591 units/hour in the morning and 7,433 units/hour in the afternoon. The amount emission rate is 49,171.7 µg/m.s in the morning and 46,943.1 µg/m.s in the afternoon. Based on the gaussian line source method, the highest CO concentration is found at the roadside, i.e. 20,340 µg/Nm3 in the morning and 18,340 µg/Nm3 in the afternoon, which are fairly in agreement with those measured in situ. Using GIS, the CO spatial distribution can visually be modeled to observe the affected area.

1. Introduction

The gaussian line source model is a development of gaussian plume source models with the assumption that the line source is a point source series in which each point is interdependent (mutually dependent) and capable of producing a cloud of pollutants. Thus, the concentration at a locality on the side of the road is calculated as the summation of the concentrations of the points [1].

Previous researches [2, 3, 4, and 5] illustrated that modeling the spatial distribution of pollutants could help estimate the concentration of pollutants in areas with no air pollution monitoring stations and then determine areas where pollutant concentrations (e.g. CO) exceed air pollution standards. Furthermore, spatial modeling of pollutant distribution can be utilized for exposure assessment and epidemiological studies.

Integrating the model with GIS generates a geographical dimension of air quality information by linking the actual concentration of pollution to the relevant geospatial attributes in a pile of database based map layers. GIS spatial analysis tools can then demonstrate the relationship between poor air quality with public facilities and environmental health [6].

2. Method

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2.1 Data Collection

The data required are the volume of traffic, emission factors, wind direction and speed, intensity of solar radiation, the map of Medan, as well as the CO concentration in the field of direct measurements. Traffic volume is obtained from direct observation in the field using manual counter. Types of vehicles that are counted are motorcycles, passenger cars, buses, and trucks. Emission factor is derived from national emission factor [7]. Wind direction and speed obtained from [8], Medan city map obtained from [9]. While CO concentration obtained by doing direct measurement in field by method of NDIR Analyzer [10].

The calculation of traffic volume and measurement of CO concentration in the field was done on Saturday, October 15, 2016. The sampling observation was conducted for 1 hour in the morning and 1 hour in the afternoon. The location of the CO measurement in the field was on the roadside, at a distance of 300 m, 500 m, and 600 m to the south from the identified centre of the line source.

2.2 Data processing

In order to estimate the emission rate q, the traffic volume data is multiplied by the related emission factor. Next the emission rate q is submitted to the gaussian line source equation as follows [1,11]:

$$C = \frac{K}{\sqrt{2\pi}} (G_2 - G_1) \quad (1)$$

$$K = \frac{q}{u\sigma_z}\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_Z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_Z^2}\right]\right\} \quad (2)$$

$$G_2 - G_1 = \int_{B1}^{B} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-B^2}{2}\right) dB^2 \quad (3)$$

$$B_2 = \frac{y_2}{\sigma_y} ; B_1 = \frac{y_1}{\sigma_y} \quad (4)$$

where C = concentration (μg/Nm^3), q = the emission rate of pollutant sources gram.m/second, ū = wind speed at position x (m/second), σ_z = the dispersion parameter of the constant at position z (m), σ_y= the dispersion parameter of the constant at the y position (m), z = position z direction on Cartesian coordinates (m), H = effective altitude of emission sources (m), and B = the ratio of the length of the road segment to the dispersion parameter σ_y

The validation used to compare the results with direct measurements in the field refers to [1,12,13]. The validation parameters include *Wilmott's Index of Agreement* (d), *Normalized Mean Square Error* (NMSE), Pearson Correlation (R), *Friction Bias* (FB), and Factor of 2 (Fa_2). Research results can be accepted if the following criteria are satisfied: 1) NMSE about 0.5, 2) FB in the range of -2 to 2, 3) The values of R and d close to 1, and 4) Fa_2 about 50%. Concentration data obtained from both calculations and from direct measurements in the field overlap with the Medan City map to obtain spatial conditions of CO spreading.

3. Result and Discussion

3.1 Traffic Volume And Percentage Of Emissions Rate

Sisingamangaraja street is a road that connects Medan City with other cities in North Sumatera Province and national road status causing traffic in this road is relatively solid. The total number of vehicles passing during the morning is 7,591 units / hour, and the total number of vehicles passing during the day is 7,433 units / hour, the amount is not much different from the traffic volume data of Sisingamangaraja street obtained from [14] 8,208 vehicles / hour. The percentage of emission rates donated for each measurement time can be seen in Figure 1 and 2.

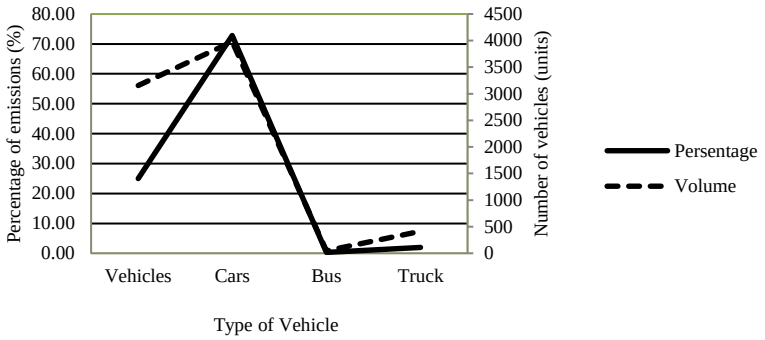

Figure 1. Percentage of Emission Rate at Morning

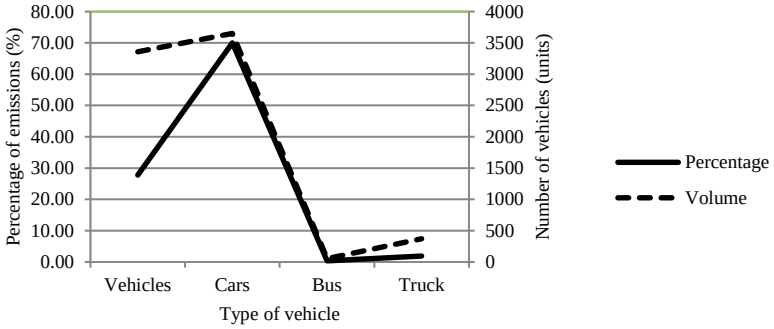

Figure 2. Percentage of Emissions Rate at Noon

The large number of private passenger vehicles such as cars, motorcycles, which pass through this road due to the activity of residents around the District of Medan Amplas to get and return from the city center. The bus that passes this road is the inter-provincial bus and Kuala Namu Airport bus. The number of buses that pass through this road is influenced by the activities of the people of Medan City go home and go out of town. While the goods carriers such as trucks also crossed this road because of the large number of goods transfer in and out of Medan. The variation in the amount of emissions donated by each vehicle type is influenced by the variation in the number and emission factors

3.2 Analysis of Gaussian Line Source Modeling Results

The calculation using the gaussian line source method uses Equation 1 to Equation 4. In this study calculated the concentration at a distance of ±7 m from the source up to ±2,000 m from the source. The concentration results for a distance of 7 meters to 2,000 m from the emission source can be seen in Figures 3 and 4 below.

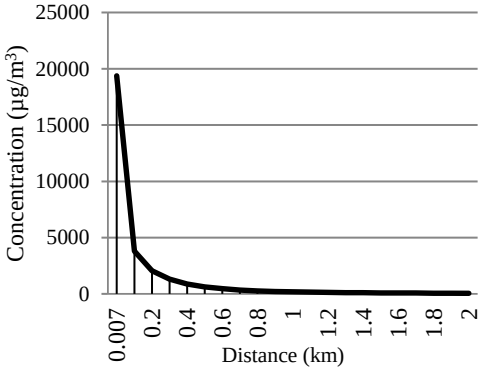

Figure 3. CO concentration Result of Gaussian Line Source Morning Modeling

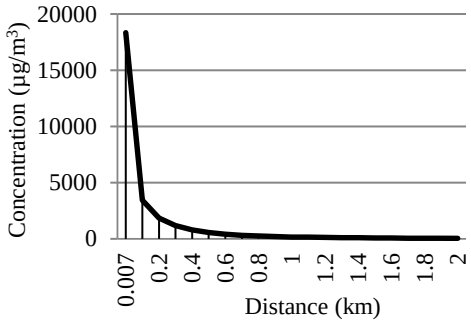

Figure 4. Concentration of CO Result of Gaussian Line Source Day Modeling

Based on Fig. 3 and Fig. 4 the further the distance from the source the pollutant concentration decreases. This proves that distances affect the spread of pollutants. The highest concentration in the morning is at a distance of 0.007 km or 7 m from the emission source of 20,340 µg/Nm^3. While in day time with the same distance CO concentration is as much as 18,340 µg/Nm^3. In the morning the lowest concentration is at 2 km or 2,000 m from a source with a concentration of 49.497 µg/Nm^3 and in the morning and 44.629 µg/Nm^3 during the day.

On the morning measurement the weather is bright and wind speed is 2.45 m/sec. While at the time of measuring the weather is brighter with a higher wind speed of 2.58 m/sec. The weather is getting brighter indicating the intensity of solar exposure is getting bigger. Based on the Pasquill table, the atmosphere conditions in the morning in class B, and the atmospheric conditions during the day in class A-B. This means that the atmosphere in the morning is more stable than during the day. When the atmosphere is more stable then the air will tend to move downwards and slow down the dispersion process so that the concentration of pollutants on the surface of the earth is greater. This results in concentration in the morning greater than the concentration during the day.

3.3 Concentration Comparison of Calculation Result, Field Measurement and Quality Standard
Figures 5 and 6 show comparison of CO concentration of modeled results, CO concentration of measurement results and quality standards of national ambient air according to[15].

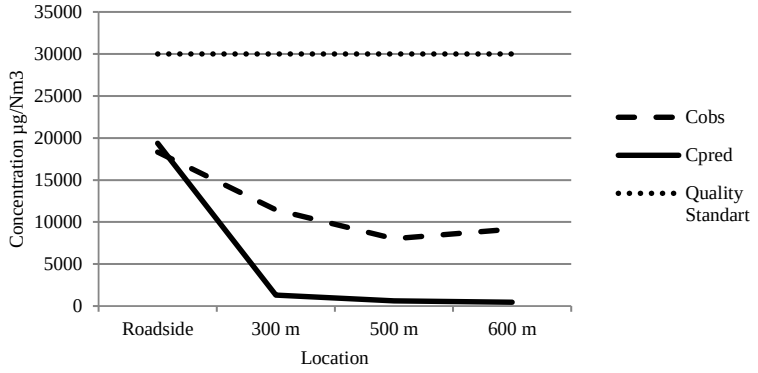

Figure 5. Comparison of CO Concentration of Calculation Results, Measurement Results and Quality Standards of Morning Measurement Results

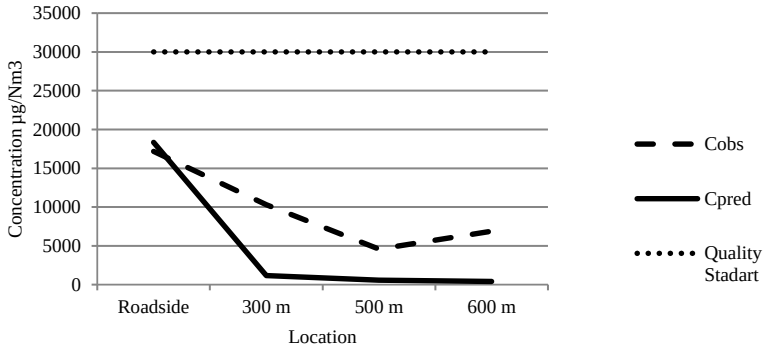

Figure 6. Comparison of CO Concentration of Calculation Result, Measurement Results, and Quality Standard of Day Measurement Results

The CO concentration of measurement results is still below the ambient air quality standard [15]. The highest CO concentration is on roadside for morning sampling of 18,323 µg/Nm^3 and 17,177 µg/Nm^3 for day sampling. At the next location the concentration of CO tends to drop in because the distance from the emission source is further away. But at point 600 m CO concentration tends to rise due to the influence of other sources of emissions in the form of transportation sources. Measurement at point 600 m is done adjacent to the road on the residential complex of residents.

Validation of CO modeling results with measurement results in the field can be seen in Table 1 and Table 2 below.

Table 1. Statistical Validation of Modeling Results of Morning CO

NO	Location	Cobs	Cpred	d[a]	NMSE[b]	R[c]	FB[d]	Fa_2[e] (%)
1	*Roadside*	18323,11	20340,75	0,69	0,04	0,96	-1,02	33
2	300 m	11451,94	1293,501					
3	500 m	8016,36	616,1519					
4	600 m	9161,554	454,0679					
	Average	11738,24	5676,118					
	Standard Deviation	3997,942	8472,483					

Information:

a. *Willmot's index of agreement*
b. *Normalize Mean Square Error*
c. *Pearson correlation coefficient*
d. *Fraction Bias*
e. *Percentage in range 0,5≤ Cobs/Cpred ≤ 2*

Table 2 Validasi Statistik Hasil Pemodelan CO Siang

NO	Location	Cobs	Cpred	d[a]	NMSE[b]	R[c]	FB[d]	Fa_2[e] (%)
1	*Roadside*	17177,91	18340,031					
2	300 m	10306,75	1166,272					
3	500 m	4580,777	555,547	0,84	0,02	0,93	-1,41	34
4	600 m	6871,166	409,4057					
	Average	9734,151	5117,814					
	Standard Deviation	4756,349	7639,127					

Source: Survey and Analysis, 2016

Information:

f. *Willmot's index of agreement*
g. *Normalize Mean Square Error*
h. *Pearson correlation coefficient*
i. *Fraction Bias*
j. *Percentage in range 0,5≤ Cobs/Cpred ≤ 2*

Based on Tables 1 and 2 it can be seen that the d value for the morning measurement is 0.69 and for the day measurement is 0.84. A value of d close to 1 indicates a high degree of compatibility between modeling results and field measurements. NMSE values less than 0.5 and Fa2 less than 50% for morning and day measurements indicate error and bias values in small data of 0.5. The value of R close to 1 indicates the modeling results have a linear relationship with the measurement results. FB values of -1.41 and -1.02 are still within the allowed range.

According to [1,16,17] the Gaussian pitch formula for surface emission sources when compared with observations has a 10% -20% accuracy. Based on 50% of Fa_2 the accuracy of this study is 16.5% -17% and still within the range of these criteria.

The linear relationship between the modeling results and the field size measurements is evidenced by Figures 7 and 8 showing that the trend of calculated concentration and direct measurement results in the field is the same for the roadside sampling point, 300 m from the road and 500 m from the road. The result proves that the match between the calculation result and the direct measurement in the field is also proved by the value of Pearson (R) correlation coefficient very close to 1.

3.4 Spatial Analysis with Geographic Information System Application

Figure 7 to Figure 10 shows the results of spatial analysis using Geographic Information System. The area affected by CO distribution is Harjosari 2 to the border area of Deli Serdang Regency. Based on the calculation, the maximum concentration is in the area close to the road and the distance from the concentration source will be smaller, whereas based on the measurement the maximum concentration is also located in the area close to the road, but at a distance of 600 meters the CO concentration is greater than Distance of 500 meters.

According to data from [18] the population of Medan Amplas Sub-district is 121,362 people with an area of 11.19 km^2 and a density ratio of 10.846 residents per km^2. The impact of CO on humans is the occurrence of the bond between CO and hemoglobin form COHb, symptoms that are directly felt by the population is a disease of respiratory infection and lung disorders. Number of incidence of disease Data from [18] mentions mild ISPA in Kecamatan Medan Amplas is as many as 15,209, bronchitis as much as 276. The relationship between disease incidence and CO distribution needs to be studied further. According to [1,19] in Indonesia rarely performed HbCO

examinations in patients, resulting in these symptoms known after the patient is in acute condition when taken to a health care center.

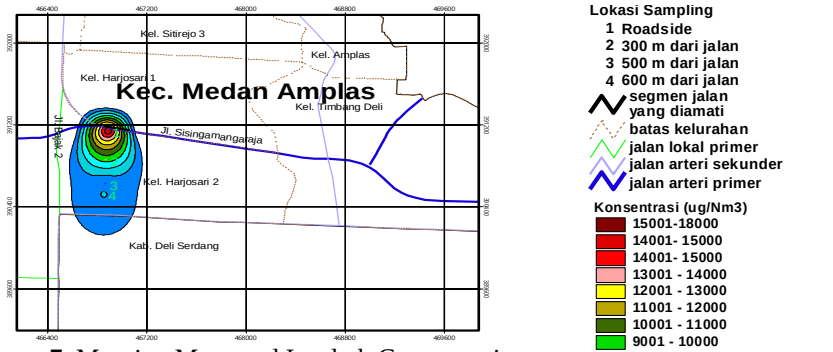

Figure 7. Morning Measured Isopleth Concentration

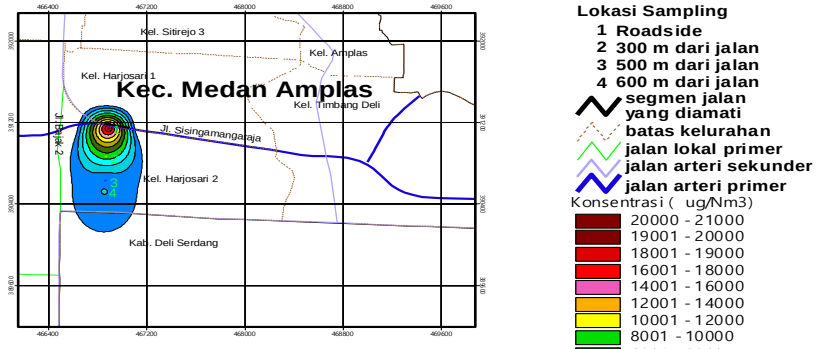

Figure 8. Day Measured Isopleth Concentration

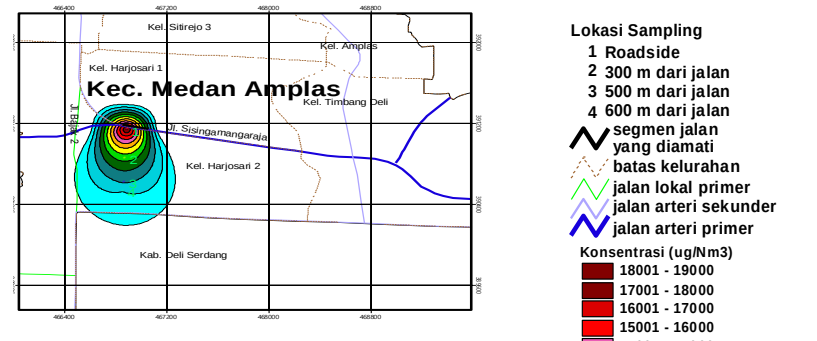

Figure 9. Morning Modelled Isopleth Concentration

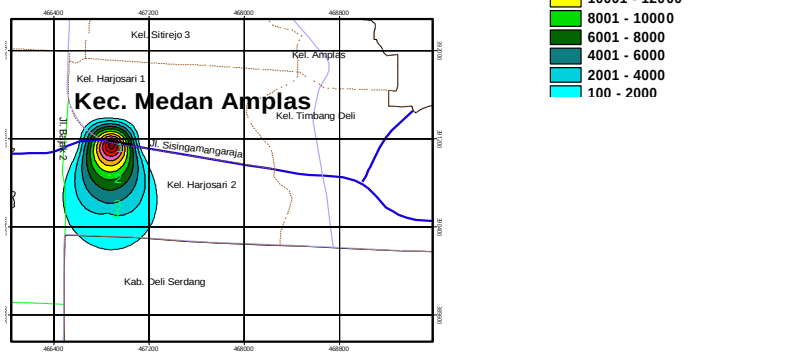

Figure 10. Day Modelled Isopleth Concentration

4. Conclution

Traffic volume at Jl. Sisingamangaraja is 7,591 units/hour during morning observation and 7,433 units/hour during afternoon observation. The transportation contributes emission rates of 49,171.7 μg/m.s in the morning and 46,943.1 μg/m.s in the afternoon. Based on the gaussian line source model, the highest CO concentration is on the roadside, i.e. 20,340 μg/Nm^3 in the morning and 18,340 μg/Nm^3 in the afternoon which are in relative agreement with the measured concentration.

The comparison of modelling results and field measurements is supported with the statistical parameters. GIS has help this study to visualize and analyse the modelling versus the measured results.

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