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# Dispersion of Carbon Monoxide Pollutant and The Effect of Health (Case Study on Frontage Road Surabaya by Gaussian Line Source Equation Model)

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**Abstract**

Air pollution was being a very important problem and danger for human life. This was related to diseases that arise due to motor vehicle emissions, especially carbon monoxide. Simulation of air dispersion models is the one way to study about air quality that is needed in this regard. This study aims to determine the distribution of carbon monoxide pollutants in Ahmad Yani's frontage and to anticipate the dangers of these pollutants to the health of the people living around the research location. This research discussed about the mathematical model of the dispersion of CO that emitted from cars that passed through the frontage road on the Ahmad Yani Street, Surabaya. The method used is direct observation in the field and numerical simulation using a mathematical model, Gaussian Line Source Equation Model (GLSEM). GLSEM had prepared based on the mechanism of transport of pollutants in dispersion, diffusion and advection. With GLSEM we calculated CO gas concentration values for certain heights downwind. We validated the model by comparing numerical results and measurements of CO concentration. We used the $R^2$ test and we got an $R^2$ close to one. We simulated GLSEM by used Fortran programming language and visualized it with Surfer. The results of the visualization in June showed that the pattern of CO gas dispersion was influenced by the direction and speed of the wind. The results obtained are that the distribution of CO pollutants in the Ahmad Yani frontage is horizontal/downwind. CO concentrations at night are higher than during the daytime. From the CO dispersion pattern, we had known that there were dangerous of air around the frontage for people health. We conclude that around the frontage road of the Ahmad Yani highway there is sufficient open air space so that the danger of CO pollutants being emitted can be minimized so that the health of the community, namely pedestrians, motorcycle drivers and the community around the location can be protected.

**Keywords:** CO pollutant; GLSEM; health; public health

***Original Research Article***

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## *Dispersi Polutan Karbon Monoksida dan Pengaruhnya Terhadap Kesehatan (Studi Kasus pada Frontage Road Surabaya dengan Model Persamaan Gaussian Line Source)*

*Abstrak*

*Pencemaran udara menjadi masalah dan bahaya yang sangat penting bagi kehidupan manusia. Hal ini terkait dengan penyakit yang muncul akibat emisi kendaraan bermotor, terutama karbon monoksida. Simulasi model dispersi udara merupakan salah satu cara untuk mempelajari kualitas udara yang diperlukan dalam hal ini. Penelitian ini bertujuan untuk mengetahui sebaran pencemar karbon monoksida di depan Ahmad Yani dan mengantisipasi bahaya pencemar tersebut bagi kesehatan masyarakat yang tinggal di sekitar lokasi penelitian. Penelitian ini membahas tentang model matematis dispersi CO yang dipancarkan dari mobil yang melewati frontage road di Jalan Ahmad Yani Surabaya. Metode yang digunakan adalah observasi langsung di lapangan dan simulasi numerik menggunakan model matematika Gaussian Line Source Equation Model (GLSEM). GLSEM disusun berdasarkan mekanisme pengangkutan polutan secara dispersi, difusi dan adveksi. Dengan GLSEM kami menghitung nilai konsentrasi gas CO untuk ketinggian tertentu melawan arah angin. Kami memvalidasi model dengan membandingkan hasil numerik dan pengukuran konsentrasi CO. Kami menggunakan tes R2 dan kami mendapatkan R2 mendekati satu. Kami mensimulasikan GLSEM dengan menggunakan bahasa pemrograman Fortran dan memvisualisasikannya dengan Surfer. Hasil visualisasi pada bulan Juni menunjukkan bahwa pola penyebaran gas CO dipengaruhi oleh arah dan kecepatan angin. Hasil yang diperoleh adalah sebaran polutan CO di tambak Ahmad Yani adalah horizontal/downwind. Konsentrasi CO pada malam hari lebih tinggi dari pada siang hari. Dari pola penyebaran CO, kita telah mengetahui bahwa ada udara yang berbahaya bagi kesehatan masyarakat. Disimpulkan bahwa di sekitar bagian depan jalan raya Ahmad Yani terdapat ruang terbuka yang cukup luas sehingga bahaya pencemar CO yang dipancarkan dapat diminimalisir sehingga kesehatan masyarakat yaitu pejalan kaki, pengendara sepeda motor dan masyarakat sekitar lokasi dapat dilindungi.*

***Kata kunci****: polutan CO, GLSEM, kesehatan, kesehatan masyarakat*

## INTRODUCTION

The city of Surabaya is the capital city of East Java Province. The area of the city of Surabaya is approximately 326.36 km$^2$. Surabaya has two seasons, namely the rainy season from November to April and the dry season from May to October. It has an average rainfall of 172 mm, with temperatures ranging between a maximum of 30°C and a minimum of 25°C. Surabaya has an average wind speed of 6.4 knots to 20.3 knots. Surabaya has three patterns of development space (Emanuel, 2017). First, vertical residential areas spread almost throughout the city of Surabaya, while residential areas are directed towards the development of the west, east, and south of the city. Second, the area for service and trade activities centered in the city center and sub-district centers as well as development units. Third, areas for industrial and warehousing activities are concentrated in the northern and southern coastal areas.

With the development of the city of Surabaya, the number of vehicles in this city is increasing. The number of vehicles in the city of Surabaya in 2009 was 1,483,271, but we know that the number of vehicles in 2015 was 2,126,168 consisting of motorcycles, cars, goods vehicles, and large buses. The increase in the number of vehicles was offset by the construction of a frontage as an additional road section on the left and right sides of the main route, such as Jl. Ahmad Yani. The addition of roads due to the construction of the frontage provides advantages and disadvantages for each community (Morakinyo et al., 2016; Dash et al., 2017; Vicente et al., 2018). On the one hand, with the construction of road infrastructure, the community will be facilitated. But on the other hand, public health will be threatened due to pollutants that are naturally generated from motor vehicle exhaust emissions (Butland et al., 2017; Sarrat et al., 2017; Vicente et al., 2018). This of course affects the quality of the ambient air at the front.

Pollutants from motor vehicle exhaust emissions are a source of air pollution originating from mobile sources, namely the production of CO, NO2, Hydrocarbons, SO2 and tetraethyl lead which are tin metals added to low-quality gasoline to increase the octane value so that there is no explosion in the engine (Soedomo, 2001). This source of pollution is not as perfect as in industrial activities so that it contributes 70% of the total air pollution. Air pollution can increase morbidity and can reduce lung function which will make it easier for microbiologists to infect the respiratory tract (Firdaus & Sulistyorini, 2016). So that, air pollution was being dangerous thing for live. Air pollution causes death in many parts of the world. A total of 7 million people die annually, with a proportion of 4.2 million deaths due to ambient air pollution and 2.8 million deaths due to household air pollution due to cooking with polluting fuels and technologies (Shorshani et al., 2014). In Indonesia, cases of poisoning and even deaths from air pollution have not been specifically reported. Statistical data for the 10 most common diseases in the city of Surabaya as of 2019 shows that as many as 26.40% are diseases of the respiratory system. Beside of cigarettes of tobacco producing the smoke, this incident can occur due to air pollution.

One of the steps in controlling air pollution is knowing the pattern of pollutant dispersion using the Gaussian Line Source Equation Model (GLSEM). GLSEM is a method in modeling the dispersion of pollutants that is used as an assessment of the risk and environmental impact of pollution sources. In this study, GLSEM is discussed to determine the dispersion of CO pollutants on the Ahmad Yani Surabaya frontage road, with the wind direction perpendicular to the line source. Ahmad Yani road has been choosen because it is the one of the main road that so many people were living near the road. GLSEM is used with the consideration that only this model is appropriate and close to reality. The advantage of GLSEM is that it can predict where the actual source of pollutant with high emission levels is and so it can predict the impact that can be caused to health. This study aims to determine the distribution of carbon monoxide pollutants in Ahmad Yani's frontage and to anticipate the dangers of these pollutants to the health of the people living around the research location.

## MATERIAL AND METHODS

This research was carried out in the following stages:

a. Data collection of the major emission sources by determining the number of vehicles that pass at the study site based on the type at the specified time and the average speed of the vehicle
b. Secondary data collection (meteorological data from BMKG) to determine the model to be used
c. The use of mathematical models that have been determined based on data-data that had collected
d. The completion of the mathematical model was followed by the use of a computer program for the completion of the mathematical model
e. Verification of mathematical models
f. Primary data collection in the form of CO concentrations in ambient air and field meteorological data
g. Model validation with primary data obtained from the field
h. Simulation of CO pollutant dispersion patterns
i. Documentation of results

The specificity of the study area selection because there is relatively no influence from the industry around the location and no influence from other pollutant sources, the Gaussian model can be applied for this study. The data needed in this study includes the number of vehicles that passed by type on the frontage road is taken between 06:00 - 21:00, types of vehicles (diesel or gasoline), the height of the source of emissions (exhaust), the average speed of the vehicle were carried out by the two-person observer method, which is to place two people at a point on a road segment 20 m away. When a vehicle passes, the first observer gives a "signal" and the second observer begins to press the stopwatch. The second observer stops the stopwatch as the vehicle passes and records the time. This recording is done at the time of sampling. In this research, we also needed meteorological data from BMKG Tanjung Perak Surabaya which includes wind speed and direction, temperature, dan wind rose for June 2021.

The mathematical model used to determine the pattern of CO pollutant dispersion at the frontage road is the Gaussian Line Source Equation model. This model had prepared by modifying the Gaussian plume model. The model had counted to input data in the form of average meteorological condition data over a period of time. Completion of this model has done using the Fortran program language.The assumptions used in the preparation of this model are the direction and speed of the wind between the source and receiver areas were not various, and the wind direction was crosswind. The source line was straight and no pollutants were lost from the puff, also changing due to chemical reactions had ignored. If the puff touched the ground, it has considered to be reflected back. The chemical properties of compounds released were stable and did not change in the air. In the system, the plumes rise occurs at a constant and continuous rate. There was no effect of other chemical compounds around the study location. There were not other sources of pollutants affected the concentration of CO pollutants in the study area.

We took the primary data to validate the mathematical models. We used the inpanger as the instrument to measure CO levels in ambient air in this study. The sample air had sucked by the inpanger through the suction hose for 30 minutes. After these samples entered the inpanger, CO had absorbed by 2% KI solution. After that, the solution will be stored and analyzed in the laboratory. The primary data were CO concentrations in ambient air in the receiving area. In addition, meteorological data had needed in the field, includes wind direction and speed, temperature and humidity of the air, and weather at the time of sampling to estimate cloud cover. Sampling had carried out at the location of the study area by considering the location of the emission source. Sampling had carried out in June 2021. Sampling locations had determined on the frontage road in Ahmad Yani highway, Surabaya, in the downwind area of the emission source based on the prediction of the dominant wind direction in the study area during sampling, namely the direction of the wind from west to east. In addition, to obtain a representative sampling location, the sampling location were in the open air, more than 10 m away from buildings and trees, to avoid reducing levels of pollutants by trees and tall buildings.

There were several positions to put inpanger done randomly in that position. Sampling had collected between 06.00 - 21.00 WIB. The determination of the sampling time were andomly for 30 minutes. This sample had analyzed in the laboratory. The 2% KI solution that absorbs CO will be decomposed with 2.5% I2O5 solution then the values of CO-concentration will be obtained. Data analysis had carried for several stages: the mathematical model testing to determine whether there is a close relationship between the results of calculations from the Gaussian model line source with the results of sampling in the field. The two values above had compared using the R2 test and we got that the R2 value is getting closer to one, then the Gaussian line source model is valid. Modification of the Gauss equation had obtained,

$$C(0,\bar{u}) = \frac{2q}{(2\pi)^{\frac{1}{2}}\bar{u}\,\sigma_z}\,\mathbf{exp}\left(-\frac{1}{2}\frac{h^2}{\sigma_z^2}\right) \quad (4)$$

where

$C(0, \bar{u})$ = concentration of pollutant ( $\mu$g /m$^3$)

q = power of the source of pollutant ( g/s)

$\bar{u}$ = windspeed average to the X-direction( m/s )

h = height of the emission source ( m )

$\sigma_z$ = the coefficient of dispersion to Z-direction

## RESULT

The observation was held in day of 22$^{th}$, 23$^{th}$, 24$^{th}$, 25$^{th}$,26$^{th}$ two sessions of each, in day of 27$^{th}$ only one session and three sessions in day of 28$^{th}$. The greatest average speed was held in day 23$^{th}$ (3 m/s) and the smallest was 0.1m/s, held on 22$^{th}$ and 23$^{th}$. During the observation, the wind direction was west. The stability was mainly B-level.

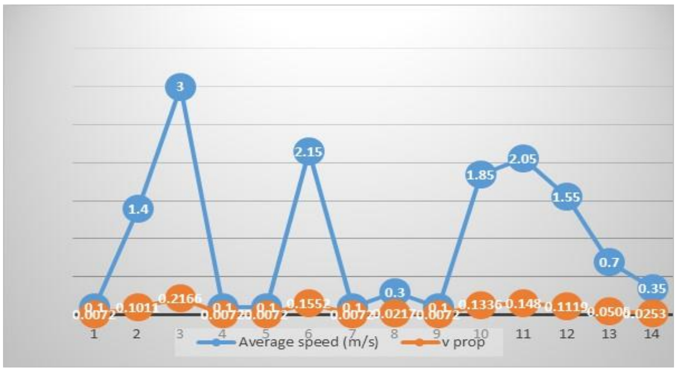


**Figure 1.** Data of average speed and v-proportion of vehicles

Figure 1 shows that the average speed of the vehicle between 0.1 m/s to 3 m/s. The vehicles were very slow because of there are a lot of speed bump at the road and maximum speed is 40 km/h. It means that the CO will be emitted much than other segment. The proportion of the wind speed lied on 0.0072 to 0.1552. And after all data has been entered, the calculated data is then hybridized and plotted. Because the results of the calculation of the concentration in units of µg / m$^3$, while the concentration measured from field observations for each receptor position is in ppm, the calculation results are converted into units of ppm. By using (4) we displayed the value of each $C_{observer}$(C1), $C_{counted}$(C2), $C^2_{observer}$(C3), $C^2_{counted}$(C4).

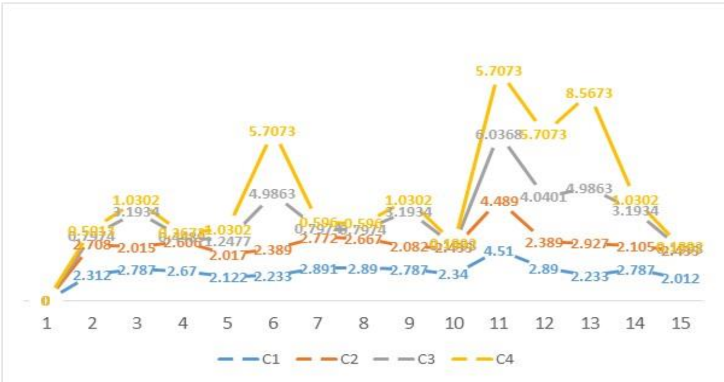


**Figure 2.** Graph of $C_{observer}$(C1), $C_{counted}$(C2), $C^2_{observer}$(C3), $C^2_{counted}$(C4)

The results showed in Figure 2. The greatest value of $C_{observer}$(C1) was in 26$^{th}$ (second session), that was 4.510 ppm and the smallest value of $C_{observer}$(C1) were in 28$^{th}$ (third session), that was 2.012 ppm. The greatest value of $C_{counted}$ (C2) was in 28$^{th}$ (first session), that was 4.489 ppm and the smallest value was in 22$^{th}$ (second session), that was 2.015 ppm. By used (4), we found that the value of $R^2$ test = 0.946, it could be said that the GLSEM can be used to calculate CO concentrations at the downwind ground level is valid.

Plotting simulation for CO dispersion is shown in Figure 3. It showed that along the frontage road, the average concentration of CO was around 4500 ppm and the minimum concentration was around 2000 ppm. It means that dispersion model predictions of CO at frontage road were small, as has been observed in other analyses.

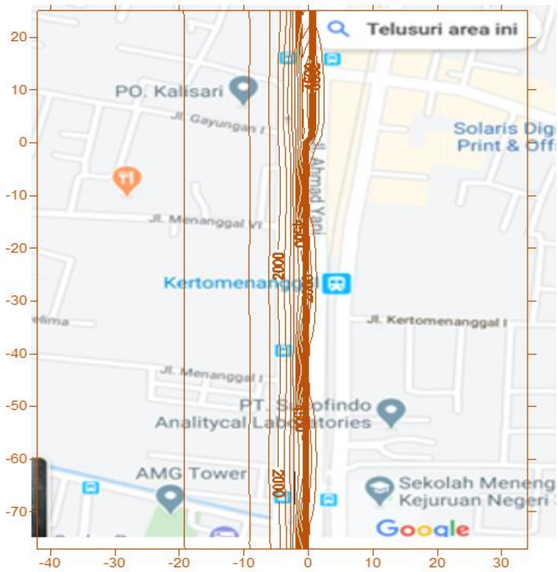


**Figure 3.** Location where case study was being investigated at frontage road Ahmad Yani Surabaya City Indonesia

## DISCUSSION

Ahmad Yani street is one of the main traffic lanes passed by motorized vehicles entering or leaving the city of Surabaya. Every day this road is passed by tens of thousands of vehicles of various types, two-wheeled and four-wheeled. In general, this motor vehicle is fueled by oil which is a producer of carbon monoxide gas in its combustion(Zong & Zhang, 2014; Dash et al., 2017; Morakinyo et al., 2016; Emanuel, 2017). Carbon monoxide gas is very harmful to the human body (Coudon et al., 2018; Gallagher & Lago, 2019; Iodice et al., 2017; Irwin et al., 2018; Moreira & dos Santos, 2019; Mylläri et al., 2016; Seto et al., 2014; Zhunussova et al., 2017). Monoxide gas produced by motorized vehicles at medium speeds is different from those at high speeds. The results showed that on the Akhmad Yani road the speed of motorized vehicles was in the interval 0.1 m/s to 3 m/s. This is agreed with because on this route a lot of two-wheeled vehicles pass and there is a lot of space for changing lanes from the main road to the frontage(Gallagher & Lago, 2019; Jeanjean et al., 2017; Morakinyo et al., 2016; Emanuel, 2017). In this study, a simulation model is needed to provide an overview of the distribution of carbon monoxide pollutants produced by motorized vehicles in the Ahmad Yani frontage so that the dangers of the gas can be anticipated and as a material for consideration in taking the next steps by policy makers regarding this matter. In addition to vehicle speed, wind speed and wind direction are also influential in this study (Gallagher & Lago, 2019; Kiesewetter et al., 2014; Izzah et al., 2019). Wind speeds are low enough to cause the carbon monoxide pollutant produced to not leave the road immediately (Izzah et al., 2019). This can result in adverse effects for road users who inhale it. The CO content in the air around the study site or ambient air is sampled to indicate the concentration of pollutants in this condition that is called $C_{Observer}$ (Emanuel, 2017).

Laboratory results will be compared with the results of calculations using the formula ($C_{Counted}$). Calculations using the formula will be converted to units of ppm (parts per million). The results of observations on the $26^{th}$ in the second session showed that the largest CO concentration was 4,510 ppm ($C_{Observed}$) which was almost the same as the simulation results, which was 4,489 ppm ($C_{Counted}$). The second session on that date took place in the afternoon. June 26 is a Saturday and most people from out of town go to Surabaya for entertainment and they cross the frontage using four-wheeled motorized vehicles. Although the situation was during COVID-19 restrictions, but the people still went to Surabaya. This causes high concentrations of CO produced by the motorized vehicles they use (Jeanjean et al., 2017). The high concentration of CO produced is very dangerous for the health of the people living near of the location. Users of two-wheeled motorized vehicles are at risk of inhaling the CO gas produced. Even though they wear safety helmets, they can still breathe CO gas freely. This is very dangerous for their health in the future. The CO content in the body is large enough to interfere with body health and can even be fatal. In addition, other road users, namely pedestrians, also have a very large health risk from inhaling CO gas.

Based on the results in Figure 2, it is known that the highest CO concentration occurs at during day where in these conditions, there are still many private vehicles such as cars, motorcycles, trucks passing by. Coupled with the wind speed that can affect the amount of CO distribution in the Frontage. When associated with high CO concentrations, CO has a negative impact on the environment and health. CO in the environment can lead to a decrease in environmental quality which has an impact on living things and plants. In excess levels in the atmosphere, CO can increase the greenhouse effect (Dash et al., 2017). While the effect of CO on health causes the accumulation of CO in the body and an increase in HbCO levels (Tomasi et al., 2015). This is influenced by how much CO concentration and duration of exposure. As the population grows and the number of vehicles continues to increase, the presence of CO in the air needs to be monitored. Moreover, targets at risk of being exposed to high CO are motorcyclists and people working around the frontage (Sarrat et al., 2017). If motorized vehicle users can leave the location immediately, they reduced CO gas for a longer time. This of course can further increase the CO content in their bodies, which can directly increase the adverse effects of CO gas on the human body (Seprianto & Sainab, 2015). Communities living in the vicinity of the location also have a great health risk from this condition. The lowest observed CO concentration was 2,015 ppm which was achieved on the $22^{th}$ in the second session and was not significantly different from the calculated results. This low CO concentration also reduces the risk to health. Statistical calculation that is $R^2$ of 0.946 indicates that this model is valid, namely GLSEM can be used to calculate CO concentration at the downwing ground level. GLSEM can be used to predict the concentration of CO so that it can be minimized until it is eliminated so that its negative impact on human health is significantly reduced (Emanuel, 2017). This model can be used as a predictor that at certain times it is necessary to have special handling or special policies so that there is no large increase in CO concentration at the Ahmad Yani frontage so that the health hazard to road users and the community around the location can be minimized.

CO in the air can enter the body through the respiratory system by being inhaled by the nose, absorbed by the lungs, and circulated throughout the body. The respiratory system is one of the main routes for toxic substances to enter the body. Unlike the skin, the tissues of the respiratory system (the lungs in particular) are not protective against chemical exposure. The main function of the lungs is to exchange oxygen and carbon dioxide. If the incoming air flow is not only oxygen but various types of other chemicals, it can cause systematic damage to the lungs. Very thin lung tissue can be injured and interfere with its vital function as a supplier of oxygen. In addition, exposure to CO can cause antibody-forming cells to decrease which causes the body to experience allergies, lung and respiratory infections, and other symptoms.

CO in the body can reduce the amount of oxygen that enters the body and tissues. CO that enters the body can mix with hemoglobin (Hb) in the blood and form carbon monoxide hemoglobin (COHb). In a person's body there is already 0.5% COHb obtained from the metabolism of heme breakdown (which is a component of hemoglobin), the rest can come from exposure to CO gas from outside the body. There has been no effect on health if COHb is still at a concentration <2%. Health problems in the form of disturbances in the central nervous system and the five senses if the COHb concentration is 2-5%. Then if the concentration of COHb in the blood has exceeded 5%, it will cause poisoning in the blood and even disturbances or changes in heart and lung function, so that the flow of oxygen in human blood is also disrupted (Gallagher & Lago, 2019).

The health risks to the community due to exposure to CO gas, CO poisoning comes from inhaling fumes from combustion and exhaust gases from motor vehicles, vehicles, generators, engines, and industries that use fuel (Seto et al., 2014). CO exposure often occurs in confined or confined spaces. If a chemical is not carried in the air (air borne), it cannot enter the lungs through the inhalation route, and vice versa. The effects of CO exposure on human health vary widely depending on the amount of exposure, duration of exposure, and the health status of the person exposed.

The amount and duration of CO exposure is related to the length of time humans are in a place where CO exposure is present. The longer a person is exposed to CO gas, the greater the concentration of CO gas in their blood. This is in line with research that the concentration and duration of CO exposure that exceeds normal limits can cause disturbances in the cardiology, hematology, neurology, and respiratory systems. In addition, groups of people at high risk for exposure are people who are very vulnerable, namely the elderly and children. Especially if the person has respiratory, lung, and heart diseases (Coudon et al., 2018; Vicente et al., 2018).

Research related to the effects of CO pollutant in health showed there was a relationship between the length of exposure and the concentration of COHb in the respondent's blood, where there were 20 respondents with 8 hours of work/day or 80 days/year of exposure did not meet the requirements (Seprianto & Sainab, 2015). This matter because the respondent inhaled exhaust fumes from vehicles that produce incomplete combustion so that it will produce CO gas. This is also in accordance with the theory which states that the longer a person is exposed to CO gas, the greater the concentration of CO gas in their blood. Based on the dangerous of the CO gas effect, we should have more attention to them. The public should be aware of the effects of CO gas, where inhaling carbon monoxide gas can cause headaches, dizziness, vomiting, and nausea. If inhaled carbon monoxide levels are high enough, it can cause fainting and even death. Exposure to moderate and high levels of carbon monoxide over a long period of time can also increase the risk of heart disease. The knowledge of the people living around Ahmad Yani's frontage regarding the impact of CO gas on health needs to be increased. Public awareness needs to be increased related to CO pollutant sources which do not only come from motor vehicle exhaust gases, but also from household activities. The use of fuel oil for household activities should be reduced or replaced with other energy sources. This is intended so that the CO gas pollutant produced can be reduced significantly. In addition, people need to be aware of environmental hygiene and health. A clean and fresh environment can make residents who live will feel comfortable and healthy. The use of plants that can absorb CO gas can also be applied to reduce the impact of CO gas on environmental and human health. Suggestion of further research is to reduce the impact of CO gas pollution on human health and the environment so that the world remains fresh and clean so that it can be felt by future generations.

## CONCLUSION

From this research there are several conclusions, namely the Gaussian Line Source Equation Model (GLSEM) can be used to determine the concentration of CO pollutants on the frontage road Ahmad Yani Surabaya and from the visualization results, it is found that CO concentrations during the day. The results of the visualization in June showed that the pattern of CO gas dispersion was influenced by the direction and speed of the wind. The results obtained are that the distribution of CO pollutants in the Ahmad Yani frontage is horizontal/downwind. CO concentrations at night are higher than during the daytime. From the CO dispersion pattern, we had known that there were poor condition of ambient air for people health around the frontage Ahmad Yani. High concentrations of CO can have health effects depending on the amount of exposure, duration of exposure, and the health status of the person exposed. The research on the dispersion of pollutants in this study should be able to inspire other researchers to conduct further research not only to the dispersion of CO pollutants at the ground downwind level and also in other months. In addition, members provide input to the government of Surabaya City to provide solutions about the rapid growth of motorized vehicles, so that the danger arising from CO pollutants emitted from emission sources can be minimized. We conclude that around the frontage road of the Ahmad Yani highway need more sufficient open-air space so that the danger of CO pollutants being emitted can be minimized so that the health of the community, namely pedestrians, motorcycle drivers and the community around the location can be protected.

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