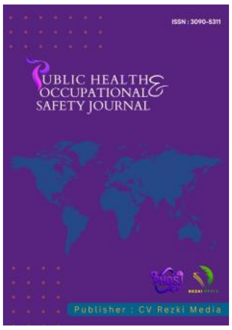

Impact of large-scale social restrictions on air quality (NO_2, CO, O_3) during COVID-19: Surabaya case study, Indonesia

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ABSTRACT

Background: The COVID-19 pandemic galvanized the world at the end of 2019. It was identified as an attack on humans and spread very quickly almost all over the world. As the person in charge of protecting the community, the government makes a policy that can suppress the spread of the COVID-19 virus.

Objectives: This study aims to determine whether implementing large-scale social restrictions (PSBB) in the COVID-19 period (2020 to 2021) impacts air quality in Surabaya City, East Java.

Methods: This quantitative research uses an Analysis of Secondary Data (ADS) approach by utilizing secondary data as the primary source. This research was conducted at the Surabaya City Environmental Service, East Java Province, in July - August 2021, with the total population being all the results of NO2, O3, and CO air quality measurements in 2020-2021 during the COVID-19 pandemic in January 2020 to December 2021 at monitoring stations in Surabaya City. This study uses Wilcoxon test analysis.

Results: The results showed that implementing the first phase of large-scale social restrictions had no significant impact on NO_2 air quality in Surabaya City ($p = 0.068$). Implementing the transitional PSBB (second stage) had no significant impact on NO_2 air quality in Surabaya City ($p = 0.068$). Implementing the first and second phases of the PSBB has no significant impact on NO_2 air quality in Surabaya City ($p = 0.173$).

Conclusions: The implementation of PSBB Phase One and PSBB Phase Two (transition period) did not significantly impact the air quality of NO2, CO, or O3 gases in Surabaya City. This finding challenges the common assumption that lockdowns automatically improve air quality and emphasizes the need for more comprehensive environmental policies.

Keywords: air quality, CO, COVID-19, NO_2, O_3, social distancing.

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INTRODUCTION

The COVID-19 pandemic is an event that has taken the world by storm. This pandemic is caused by a virus part of a family of viruses that cause diseases ranging from flu to more severe diseases such as MERS and SARS. COVID-19 is a new type discovered in 2019 in Wuhan, China, and has not been identified as attacking humans. At the end of 2019, it was only identified as attacking humans and unthinkingly spread quickly almost worldwide (Irawan, 2021).

In Indonesia, COVID-19 was first identified in March 2020, when two people were still exposed to COVID-19. Then, over time, many people were infected by this virus. So, the government issued Government Regulation Number 21 of 2020 concerning Large-Scale Social Restrictions (PSBB) to accelerate the handling of COVID-19. Implementing this large-scale social restriction policy includes the cessation of teaching and learning activities, restrictions on work activities, religious activities, activities in public places, socio-cultural activities, and the movement of people and goods using transportation (Suryani, 2020).

Implementing large-scale social restriction policies impacts transportation volumes, especially land transportation. The direct impact is a decrease in air pollution sources due to fewer exhaust emissions released by motorized vehicles. This is proven by several researchers who examined social restriction policies affecting air quality. According to Nakada's research in Brazil, one of them is that there was a very drastic decrease in air quality compared to the monthly average of five years and four weeks before the partial lockdown. Overall, there was a drastic decrease in NO (up to -77.3%), NO2 (up to -54.3%), and CO concentrations (up to -64.8%). Conversely, an increase of about 30% in ozone concentrations was observed in urban areas which are heavily influenced by vehicle traffic (Nakada & Urban, 2020).

Meanwhile, according to research by Zangari et al., the COVID-19 pandemic has caused changes in air quality in New York City, United States. During the COVID-19 pandemic, New York took action to stop COVID-19 (lockdown). During the lockdown period, there was a decrease in PM2.5 (delicate particulate matter) concentration by 36% and also a decrease in NO2 by 51% obtained from monitoring at 15 central monitoring stations in New York City, USA (Zangari et al., 2020). Meanwhile, Wuhan City, the source of the coronavirus, has also experienced a decline in air quality due to lockdown measures during the pandemic. The decrease was 33.9% from the average value of the monthly air quality index (AQI) in Wuhan, which was 59.7 and fine particles decreased by 36.9%, nitrogen dioxide also decreased by 53.3%, and the ozone layer increased by 116.6% (Lian et al., 2020).

Not much different from other countries, in Indonesia itself, the policy of large-scale social restrictions also affects air quality, one of which is in the capital city of Indonesia itself, initially the air quality before the implementation of social restrictions on air quality in the city of Jakarta was categorized as unfavorable around 6.10-8 mg/m3 to 8. 10-8 mg/m3. There was a significant decrease after the implementation of social restrictions, reaching 2x1-8 mg/m3 to 4.10-8 mg/m3 (Anugerah et al., 2020). Apart from Jakarta, there are also several cities in Indonesia that have experienced improvements in air quality due to social restrictions, namely Bandung City, which experienced a significant decrease from 8x1-8 mg/m3 to 1x1-8 mg/m3 to 3x1-8 mg/m3. Then there is also Medan City, which also experienced a decrease in air quality from 8x10-8 mg/m3 for the last 3 years to 1x10-8 mg/m3 to

3x10-8 mg/m3 in 2020, indicating that air quality in Medan City is improving. This also happened in other cities, such as Makassar, Semarang, and Palembang (Nugroho, 2020).

According to the Surabaya City Government report, Surabaya is the second largest city in Indonesia after Jakarta, with a population of 3 million. The large number of people causes a decrease in air quality in the city of Surabaya due to the large number of motorized vehicles and also from several industries in the city of Surabaya. According to the Head of the Environmental Quality Monitoring and Control Section of the Surabaya City Environmental Service, the largest source of emissions affecting air quality on the streets is transportation (motorized vehicles). However, during the COVID-19 pandemic, Surabaya City imposed a system where restrictions on arrivals from various cities in Indonesia and also stay at home. This causes a reduction in the volume of motorized vehicles, and it can affect air quality in Surabaya City. This is evidenced by the air quality report, which stated that in 2018, the air quality in Surabaya City was categorized as good as 81 and increased to 143 in 2019.

This, of course, becomes an interesting study to analyze to find out whether the implementation of large-scale social restrictions in the COVID-19 period (2020 to 2021) impacts air quality in Surabaya City, East Java. If it affects, this research can be used as an evaluation to determine an action plan to maintain air quality even though it is not during the COVID-19 pandemic, to know that implementing a large-scale social restriction policy impacts air quality in Surabaya City.

This study fills a gap in the literature by investigating the impact of PSBB on air quality in Surabaya City, which has not been explored much before. International studies such as Nakada & Urban (2020) in Brazil and Zangari et al. (2020) in New York showed significant decreases in NO_2 and CO concentrations during lockdown, while Lian et al. (2020) reported an increase in O_3 in Wuhan. However, these findings are inconsistent across regions, as shown by Tobías et al. (2020), who found variations in lockdown impacts depending on local factors such as industrial activity and population mobility. This study provides a unique perspective by revealing that PSBB in Surabaya did not significantly impact air quality, possibly due to less stringent restrictions on economic activity and transportation compared to other cities. This finding enriches our understanding of the complex relationship between social distancing policies and air quality. It confirms the importance of local context in evaluating the effectiveness of environmental policies during the pandemic.

This study is the first to reveal that PSBB does not significantly affect air quality in Surabaya, which differs from the findings in Jakarta and Wuhan. This difference may be due to differences in compliance levels, industrial activities, and urban traffic patterns.

METHODS

Study Design and Participants

This type of quantitative research uses an Analysis of Secondary Data (ADS) approach by utilizing secondary data as the primary data source and using appropriate statistical tests to obtain the desired information from mature data obtained from certain agencies or institutions (such as BPS, departments or educational institutions or health institutions). This research was conducted at the Surabaya City Environmental Service, East Java Province, in July - August 2021, with the total population being all the results of NO_2, O_3, and CO air quality measurements in 2020-2021 during the COVID-19 pandemic in January 2020 to December 2021 at monitoring stations in Surabaya City. The monitoring station in Kebonsari Village was chosen because it represents a densely populated urban area with high traffic and industrial activities. Data were collected from official monitoring stations that the Surabaya Environment Agency regularly calibrates.

Ethical approval statement

This research uses secondary data obtained from official sources of the Surabaya City Environmental Agency and is public. Therefore, no formal ethical approval was required. However, the principles of research ethics were upheld, including respect for data integrity and transparency of data sources.

Research Instruments

The instruments in this study are secondary data obtained from the Surabaya City Environmental Agency in the form of measurement results of air quality parameters nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3) collected through monitoring stations in Kebonsari Village, Jambangan District, Surabaya. The data covers January 2020 to December 2021 and is grouped into three-time categories: before large-scale social restrictions (PSBB), during the first phase of PSBB implementation, and during the transition period (PSBB second phase).

Data Analysis

Data analysis was performed using a Shapiro-Wilk normality test to determine data distribution. Some data were not normally distributed based on the test results, so the Wilcoxon Signed Ranks Test was used as an alternative to the parametric test. This test determines whether there is a significant difference in air quality between the PSBB periods set in Surabaya City.

RESULTS

Our study aimed to determine the general changes in air quality in Surabaya City during the COVID-19 pandemic. We conducted a monthly average recapitulation of NO_2, CO, and O_3 gas concentrations obtained from air quality monitoring station data to achieve this. The data covers the period before the implementation of the PSBB, during the implementation of the first phase of the PSBB, and the transition period of the second phase of the PSBB. The data summary is presented in Table 1 below.

The sampling used is all the results of daily measurements of NO_2, CO, and O_3 air quality calculated monthly from January 2020 until December 2021. These measurements are particularly significant as they capture the impact of large-scale social restrictions on air quality, providing valuable insights for public health policies.

Figure 1 shows fluctuations in NO_2, CO, and O_3 gas concentrations during the two years of the pandemic (2020-2021) in Surabaya City, reflecting the dynamics of community activities during and after the implementation of PSBB.

Table 2 is the result of the normality test to determine whether the data to be calculated is usually distributed. The normality test uses the Shapiro-Wilk test because the amount of data is below 30.

Table 1. Average Results Per Month of Surabaya City Air Quality in 2020 - 2021

Category	Parameters		
	NO_2	CO	O_3
Before Social Distancing (PBB)	33,366	0,824	0,000
	40,821	0,751	0,000
	30,018	0,807	0,000
	22,543	0,686	11,155
When Social Restrictions are in Place	35,610	0,702	0,000
	44,650	0,710	0,000
	44,068	0,540	0,000
	43,275	0,527	0,000
	42,204	0,469	23,002
	46,146	0,417	24,882
When Large-Scale Social Restrictions are Enforced Transition	41,956	0,390	28,163
	4,717	0,514	27,745
	41,252	0,475	14,698
	24,260	0,828	11,625
	17,806	0,572	10,978
	12,563	0,333	11,672
	14,535	0,624	11,007
	23,527	0,575	10,957
	12,420	0,524	12,197
	6,701	0,578	13,068
	14,626	0,567	16,098
	20,166	0,140	13,258
	25,016	0,313	12,985
	25,662	0,373	12,770
	20,500	0,239	28,762
	13,221	0,758	46,342

Source: DLH Surabaya City 2020-2021

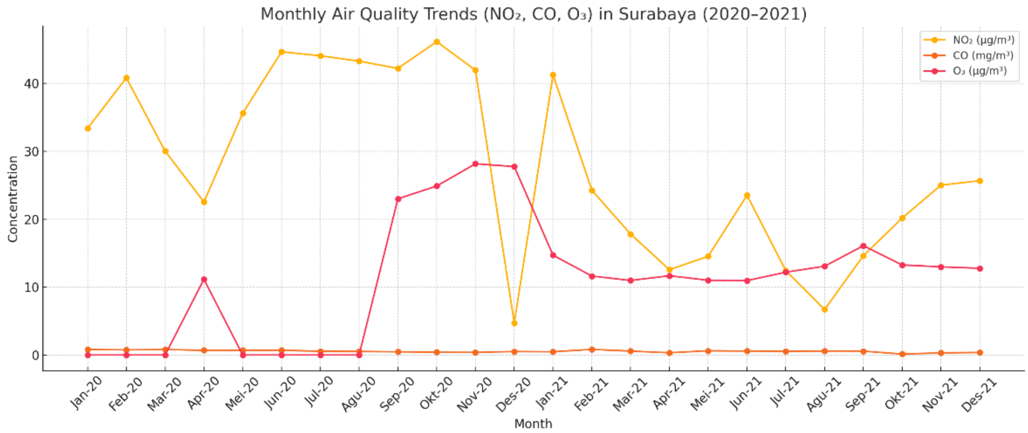

Figure 1. Monthly Trend of Air Quality in Surabaya (2020-2021)

Table 2. Data Normality Test Results

Parameters	Before Social Distancing (PBB)	When Social Restrictions are in Place	When Large-Scale Social Restrictions are Enforced Transition
Nitrogen Dioxide (NO_2)	0,989	0,038	0,061
Carbon Monoxide (CO)	0,594	0,072	0,265
Ozone (O_3)	0,001	0,002	0,142

Source: SPSS data processed by researchers

Table 2 shows that the significance value of the NO_2 gas variable before the implementation of social restrictions is 0.989, which is greater than 0.05, which means that the data is usually distributed. For the variable during the implementation of social restrictions, the significance value is 0.038, smaller than 0.05, meaning that the data is not normally distributed. For the NO_2 gas variable during the implementation of the second stage of social restrictions, the significance value is 0.061, greater than 0.05, which means that the data is usually distributed. From the above results, the significance value of the CO gas variable before the implementation of social restrictions is 0.594, which is greater than 0.05, which means that the data is usually distributed. For variables when social restrictions are imposed, the significance value is 0.072, greater than 0.05, which means the data is usually distributed. For the CO gas variable during the implementation of the second stage of social restrictions, the significance value is 0.0265, greater than 0.05, which means that the data is usually distributed. From the above results, the significance value of the O_3 gas variable before the implementation of social restrictions is 0.001, which is smaller than 0.05, which means that the data is not normally distributed. For variables when social restrictions are imposed, the significance value is 0.002, smaller than 0.05, which means the data is not normally distributed. For the O_3 gas variable, when the second stage of social restrictions is imposed, the significance value is 0.142, greater than 0.05, meaning the data is usually distributed.

In this study, data analysis used the paired-sample t-test to determine if the data was normally distributed. However, because there was data that was not normally distributed, the paired-sample t-test could not be carried out, so an alternative test was carried out to calculate the data, namely using the Wilcoxon alternative test. The Wilcoxon test results are said to have a difference if the two2-tailed asymp-sig probability value is smaller than 0.05; on the other hand, if the result is greater than 0.05, then the data is declared to have no difference.

Table 3. Wilcoxon Signed Ranks Test of Nitrogen Dioxide Gas Air Quality in Surabaya City

Category	Z count	Significant Value
NO^2 before PSBB – NO^2 PSBB	-1,826	,068
NO^2 before PSBB – NO^2 Transition	-1,826	,068
NO^2 Transition – NO^2 PSBB	-1,363	,173

Source: SPSS data processed by researchers

The following results were obtained based on the meticulous and comprehensive analysis conducted by our team of dedicated researchers refer to Table 3.

a) These findings are important, as they indicate that implementing the first phase of large-scale social restrictions does not impact NO2 air quality in Surabaya City.
b) For the category before the implementation of the PSBB (a large-scale social restriction in Indonesia) and during the implementation of the transition period or the second phase of the PSBB, the result is 0.068, which is greater than 0.05, indicating that the implementation of the transition period or the second phase of the PSBB has no impact on NO_2 air quality in Surabaya City.
c) For the category when the first phase of the PSBB and the second phase of the PSBB or PSBB transition period, the test result is 0.173, which is greater than 0.05, which means that the implementation of the first and second phases of social restrictions has no impact on NO_2 air quality in Surabaya City.

Table 4. Wilcoxon Signed Ranks Test of Carbon Monoxide Gas Air Quality in Surabaya City

Category	Z count	Significant Value
CO before PSBB – CO PSBB	-1,826	,068
CO before PSBB – CO Transition	-1,461	,144
CO Transition – CO PSBB	-,524	,600

Source: SPSS data processed by researchers

The following results were obtained based on the analysis conducted by the researcher refer to Table 4.

a) For the category before the implementation of social restrictions and after the implementation of the first phase of large-scale social restrictions with test results that have a significance value of 0.068 greater than 0.05, which means that the implementation of the first phase of social restrictions has no impact on CO air quality in Surabaya City.
b) For the category before the implementation of large-scale social restrictions and during the implementation of large-scale social restrictions during the transition period or the second stage of PSBB with a result of 0.144 greater than 0.05, which means that the implementation of transitional social restrictions has no impact on air quality in Surabaya City.
c) For the category during the implementation of large-scale social restrictions and during the implementation of large-scale social restrictions during the transition period with a result of 0.600 greater than 0.05, which means that the implementation of large-scale social restrictions and large-scale social restrictions during the transition period has no impact on air quality in Surabaya City.

Table 5. Wilcoxon Signed Ranks Test of Ozone Gas Air Quality in Surabaya City

Category	Z count	Significant Value
O_3 before PSBB – O_3 PSBB	-1,000	,317
O_3 before PSBB – O_3 Transition	-1,826	,068
O_3 Transition – O_3 PSBB	-1,153	,249

Source: SPSS data processed by researchers

The following results were obtained based on research conducted by researchers refer to Table 5.

a) For the category before the implementation of social restrictions and after the implementation of the first phase of large-scale social restrictions, the significance value is 0.317, greater than 0.05, which means that the implementation of the first phase of social restrictions has no impact on O_3 gas concentrations in Surabaya City.
b) For the category before the implementation of large-scale social restrictions and during the implementation of large-scale social restrictions during the transition period or the second stage of PSBB with a result of 0.068 greater than 0.05, which means that the implementation of transitional social restrictions has no impact on air quality in Surabaya City.
c) For the category during the implementation of the PSBB and the transition period (or the second phase of PSBB), the result was 0.249, which is greater than 0.05. This indicates no significant impact of large-scale social restrictions' first and second phases on the concentration of O_3 gas in Surabaya City.

DISCUSSION

This study aims to determine the impact of large-scale social restrictions (PSBB) during the COVID-19 pandemic in 2020-2021 on air quality in Surabaya City, especially nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3) levels. The results showed that the implementation of PSBB in both the first and second stages did not significantly affect the level of air pollution in the city. This is evidenced by the Wilcoxon test, which produces a significance value above 0.05 for all parameters. NO_2 obtained a value of 0.068 before and during PSBB and 0.173 for the transition period. CO parameters showed values of 0.068, 0.144, and 0.600, while O_3 recorded figures of 0.317, 0.068, and 0.249. These findings reveal that the social distancing policy did not effectively change the concentration of air pollutants in Surabaya during the pandemic.

Nitrogen dioxide (NO_2) is a gas found in free air (atmosphere), which consists mainly of nitric oxide (NO) and nitrogen dioxide (NO_2), and various types of oxides are found in smaller quantities. Nitrogen dioxide is soluble in water, brownish red, causing odor, pale yellow, and is a strong oxidizer. Nitrogen dioxide gas comes from natural sources and also human activities. Naturally, nitrogen dioxide gas comes from the displacement of NO gas in the stratosphere, volcanic activity, bacterial activity, and lightning, but its presence is in very low concentrations; in large quantities, NO_2 gas is produced from fossil fuel combustion and motor vehicle engine emissions (Angelia, Akili, & Maddusa, 2019).

The findings report that implementing large-scale social restrictions in Surabaya City does not impact NO_2 gas. This is not by research conducted by other researchers who state that the implementation of social restrictions has an impact on changing NO_2 gas concentrations for the better (Azizah et al., 20221; Keller et al., 2020; Togatorop et al., 2023). This can happen because the Surabaya City community is not maximally implementing social restrictions, and it can also happen because of policies that allow workers to come to work even though only half of the office and industrial workers cause the operation of industries in Surabaya City. Referring to Figure 1, there is a sharp decrease in December 2020 (4.71 $\mu g/m^3$) compared to the previous months, which may be due to a decrease in community mobility towards the end of the year or the extension of the PSBB. However, overall, there is no consistent pattern of decline during the PSBB, suggesting that activity restrictions may not be fully effective in reducing motor vehicle and industrial emissions.

Nitrogen dioxide gas itself has high toxicity; this gas can cause swelling of the lungs, resulting in difficulty breathing and leading to death. Low concentrations can cause eye irritation, but long-term exposure can lead to increased respiratory disorders or chronic bronchitis. In addition to the impact on health, nitrogen dioxide gas can also have an impact on the environment as well as SO_2 gas NO_2 gas can also cause acid rain, which will cause damage to environmental ecosystems, death of flora and fauna, and damage to buildings (Pandey & Singh, 2021), so that if the air is polluted by nitrogen dioxide gas, it will be very dangerous for people who breathe air polluted by the gas.

Carbon Monoxide is a compound that has colorless, tasteless, odorless properties and can be liquid at temperatures below -1920C. Carbon Monoxide is one of the pollutants that contribute most to air pollution. Carbon monoxide can be formed scientifically, such as forest fires, metal oxides in the atmosphere, oceans, and natural electrical storms. At the same time, artificial carbon monoxide sources come from motor vehicles (Sacchi et al., 2022).

The findings report that implementing large-scale social restrictions in Surabaya City has no impact on CO gas. This is not the case in research conducted by Indriyaningtyas (2021), which states that there are differences in CO air quality before and after the implementation of social restrictions, which means that the implementation of social restrictions has an impact on CO quality. This can happen because many people still do not maximally implement social restrictions, so many motorbikes and factory operations are some of the most significant sources of CO gas from motor vehicle emissions and factory smoke.

Carbon monoxide is a hazardous and toxic gas for the community. Carbon monoxide can cause death because carbon monoxide can bind to hemoglobin (Hb), which functions to deliver fresh oxygen throughout the body, causing Hb's function to carry oxygen throughout the body to be disrupted, the reduction in oxygen supply throughout the body is what causes shortness of breath and can cause death if it does not immediately get oxygen (Hale, Singhal, & Hsia, 2018). In addition to impacting human health, carbon monoxide can cause the greenhouse effect when it transforms into CO_2 gas (Romansyah, 2019).

Ozone is a colorless gas that condenses to form a blue liquid at -1110C and can form a blue-black solid at -1920C. Ozone is a highly toxic substance that is even more dangerous than cyanide (KCN or NaCN), striking, and carbon monoxide (Bocci, 2010). Ozone is a highly reactive allotrope compared to ordinary atmospheric oxygen because ozone consists of three oxygen atoms instead of two. Ozone is located within the stratosphere at altitudes between 10 and 50 km, which can help protect life on Earth from exposure to ultraviolet radiation (El-Sayed, Van Dijken, & Gonzalez-Rodas, 1996).

The findings also reported that implementing large-scale social restrictions in Surabaya City had no impact on O_3 gas. This is not the case in research conducted by other researchers who state that the implementation of social restrictions has an impact on changing O_3 gas concentrations for the better (Keller et al., 2020; Togarotop et al., 2023). There is no change in O3 air quality in Surabaya City because the community is not maximized in implementing social restrictions, which causes no change in the concentration of NO_2 gas and CO, which causes changes in O_3 gas.

O_3 gas is very beneficial for humans in the atmosphere as a protector of the community from UV rays. Otherwise, if O_3 gas is near the ground, it will be hazardous for people who breathe it because O_3 is a very toxic substance. Ozone can cause disturbances in humans and plants; in humans, ozone can cause throat irritation at 300 ppb and can also cause asthma attacks at 150 ppb. While in plants, it can cause growth slowdown at 30 ppb (Barnes et al., 2023).

The findings of this study indicate that large-scale social restrictions (PSBB) during the COVID-19 pandemic did not significantly impact air quality in Surabaya City, especially on the parameters NO_2, CO, and O_3. This contrasts research results in other cities such as Jakarta, New York, and Wuhan, which reported significant decreases in air pollutant concentrations during lockdown. The main contribution of this study is that it provides evidence that the effectiveness of PSBB in improving air quality is highly dependent on the local context, including the level of community compliance and industrial activities that continue to run during social restrictions.

Limitations of the study

However, this study has limitations. This study did not consider meteorological factors such as rainfall, wind speed, humidity, and air temperature, which significantly affect the dispersion and concentration of air pollutants. The data only came from one air monitoring station in Kebonsari Village, so it does not represent the air quality conditions in the entire Surabaya City area, which is very heterogeneous (e.g., industrial areas, heavy traffic areas, and residential areas). Only three air gas parameters were analyzed (NO_2, CO, and O_3). Other important parameters, such as PM2.5, PM10, and SO_2, have not been analyzed. Based on this, future research suggestions are to include weather and climate factors in order to analyze environmental influences on air quality changes more accurately, include other parameters such as PM2.5, PM10, SO_2, and VOCs to provide a more complete picture of air quality, and the use of atmospheric modeling models (such as WRF-Chem or CALPUFF) will provide a more accurate simulation of pollutant distribution over a specific period.

CONCLUSIONS

Based on the results of the discussion above, it can be concluded that the implementation of the first phase of the PSBB and the second phase of the PSBB (transition period) did not significantly affect the air quality of NO_2, CO, O_3 gases in Surabaya City. This is because, during the social restriction period, many people still carry out activities outside the home or company, causing motorcycle use and factory production to exist, causing no difference in the concentration of NO2 and CO in Surabaya city. After all, the most significant source of NO_2, CO gas, is from motor vehicle emissions and factory smoke. For O_3 gas, because there has been no decrease in the concentration of NO_2 and CO gas in Surabaya City, the concentration of O3 is still stable and has not increased. It is recommended that local governments prioritize emission control for industry and encourage public transportation to improve air quality outside of pandemic conditions.

ACKNOWLEDGMENTS

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DATA AVAILABILITY

The datasets generated and/or analyzed during this study are not publicly available due to institutional data-sharing policies but are available from the corresponding author upon reasonable request. The data was obtained from the Surabaya City Environmental Agency from January 2020 to December 2021, including air quality measurements of NO_2, CO, and O_3.

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CONFLICT OF INTEREST

The author officially certifies that there are no conflicts of interest with any party with respect to this research.

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