



Changes in air quality during and after large-scale social restriction periods in Jakarta city, Indonesia

Muhammad Rendana¹ · Wan Mohd Razi Idris² · Sahibin Abdul Rahim³

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Abstract

COVID-19 outbreak has constrained human activities in Jakarta, Indonesia during the large-scale social restriction (LSSR) period. The objective of this study was to evaluate the changes in the spatial variation of air pollutants over Jakarta during and after the LSSR periods. This study used satellite retrievals such as OMI, AIRS, and MERRA-2 satellite data to assess spatial variations of NO₂, CO, O₃, SO₂, and PM_{2.5} from May to June 2020 (during the LSSR period) and from July to August 2020 (after the LSSR period) over Jakarta. The satellite images were processed using GIS software to increase the clarity of the images. The relationship between air pollutants and meteorological data was analyzed using Pearson correlation. The results showed the levels of NO₂, PM_{2.5}, O₃, and CO increased by 59.4%, 21.2%, 16.2%, and 1.0%, respectively, while SO₂ decreased by 19.1% after the LSSR period. The temperature value was inversely correlated with PM_{2.5}, NO₂, and SO₂ concentrations. Furthermore, the backward trajectory analysis revealed that air pollutants from outland areas such as the east and southeast carried more particulate matter and gases pollutants, which contributed to the air pollution during and after the LSSR periods. As a whole, the COVID-19 outbreak had bad impacts on human health, but the increase in air pollutants levels after loosening the LSSR policy could also lead to a higher risk of severe respiratory diseases. This study provides new insight into air pollutant distribution during and after LSSR periods and recommends an effective method of mitigating the air pollution issues in Jakarta.

Keywords Air quality · Backward trajectory · COVID-19 · Jakarta · LSSR

Introduction

An infectious disease which is known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) or COVID-19 has been discovered in Wuhan, Hubei Province, China around the end of December 2019 (Du et al. 2020). In

January 2020, it was quickly transmitted to several cities and outside China region (Li et al. 2021). In Indonesia, the first case of this virus was discovered in Jakarta city on March 2, 2020 (Ministry of Health of Indonesia 2020). Then, the cases increased rapidly with a total number of five thousand cases has been reported on May 17, 2020. Therefore, the Indonesian government implemented the large-scale social restriction (LSSR) policy to manage the COVID-19 spread. This policy aimed to decrease the large social activities to control the virus transmission. Due to the effect of this policy, all social, and commercial activities have been restricted including the closure of offices, schools, transportation systems, malls, cafes, and others. However, some places have been partially operated such as pharmacies, grocery stores, banks, and health clinics.

While as we know the cost of this control measure has declined the economic growth of countries. Several studies revealed that decreasing human activities during the COVID-19 period had an important role in improving air quality (Dentener et al. 2020; Singh et al. 2020). But, Wang

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✉ Muhammad Rendana
muhrendana@ft.unsri.ac.id

- ¹ Department of Chemical Engineering, Faculty of Engineering, Universitas Sriwijaya, Indralaya, South Sumatera 30662, Indonesia
- ² Department of Earth Science and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
- ³ Department of Environmental Science, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia

et al. (2020) assumed that during heavy pollution, the reduction of human activities (i.e. transportation and industrial activities) could not stop the pollution when meteorological factors were not in favorable condition. NO_2 , CO , SO_2 , O_3 , and $\text{PM}_{2.5}$ are mainly ambient air pollutants in urban areas and many studies have investigated severe health issues like respiratory and cardiovascular diseases, lung cancer, and pneumonia related to these pollutants (Kinney 2018; Mo et al. 2018). Even the World Health Organization reported that around 4.2 million deaths per year were due to acute and chronic respiratory diseases. For instance, many studies have revealed a strong relationship between the increased $\text{PM}_{2.5}$ levels and acute health issues (Zhang et al. 2017; Neira et al. 2019). The $\text{PM}_{2.5}$ levels and respiratory health issues, such as death rate, hospital admissions, and others showed a positive correlation (Cao et al. 2018; Lee et al. 2019; Rendana et al. 2021; Sipra et al. 2020).

Anthropogenic activities were a substantial source of air pollution all over the world and specifically in Jakarta. Several studies have reported the combustion of fossil fuels such as coal-fired power plants has majorly contributed to SO_2 and NO_2 pollution (Rendana 2021; Xu 2019; Zhao et al. 2018). In 2014, there were about 5.5 million motorized vehicles in Jakarta that they have emitted more than one million tons of nitrogen oxides. Moreover, Zhu et al. (2020) found positive correlations of PM_{10} , $\text{PM}_{2.5}$, NO_2 , O_3 , and CO with COVID-19 cases. High levels of those pollutants could exacerbate and increase the risk of death of COVID-19 patients because of cardiovascular and pneumonia diseases (Barnett-Itzhaki and Levi 2021; Rendana and Idris 2021).

Therefore, in this study, we analyzed the changes in air pollutants levels ($\text{PM}_{2.5}$, SO_2 , NO_2 , CO , and O_3) during the COVID-19 period (during and after the LSSR periods). Because under the LSSR situation the emissions from usual sources have been diminished and it was important to identify the remaining pollutants came from and also their pathways. The association between the air pollutants such as SO_2 , $\text{PM}_{2.5}$, CO , O_3 , and NO_2 and meteorological factors were also prominent to be studied since severe air pollution generally occurred in favorable meteorological conditions. It would give a new insight into the mechanisms of air pollutants in distinct meteorological situations. Furthermore, the study in changes air pollutants during the two different periods will assist to ensure the emissions sources that lead to the changes in air pollutant levels. There are many studies on air pollution during the lockdown period investigated around the world (Kumar 2020; Patel et al. 2020; Tobias et al. 2020; Kumari and Toshniwal 2020). In Jakarta, previous studies such as Pramana et al. (2020) and Pardamean et al. (2021) have analyzed the air pollutants concentration, but, they concentrated on the before and the lockdown phases. They also did not elaborate on the spatial variations of the diverse air pollutants. Thus, this current study is a

preliminary investigation to analyze the association between the meteorological factors and air pollutants levels during and after the LSSR periods in Jakarta. These outputs could be used to arrange effective control strategies in solving the air pollution issue in Jakarta and other neighboring cities.

Materials and methods

Study area

Our study location is Jakarta city, it is the capital and populous city in Indonesia. It lies on the northwest coast of Java island and expands approximately 664.01 km² (Fig. 1). Jakarta is the core of the culture, entertainment, politic, and economy of Indonesia. The current population of the city is around 10,562,088. Since the COVID-19 outbreak spread in Indonesia on March 2, 2020, Jakarta becomes an epicenter of COVID-19. This city has the greatest number of COVID-19 cases with more than a total of 7000 cases as reported by the Indonesian Ministry of Health on May 31, 2020. Therefore, as a control measure, the local government has implemented a large-scale social restriction policy to control the spread of COVID-19 in the city. The restriction policy has a good impact on suppressing the COVID-19 cases even though it will lead to socio-economic setbacks.

Data sources

The satellite-based observation data for nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and $\text{PM}_{2.5}$ over Jakarta city were obtained from the website (<https://giovanni.gsfc.nasa.gov/giovanni/>). The NO_2 data was measured by the Ozone Monitoring Instrument (OMI) aboard the NASA Aura satellite with spatial resolution $0.25^\circ \times 0.25^\circ$. The SO_2 and $\text{PM}_{2.5}$ data were measured by the MERRA-2 satellite with spatial resolution $0.5^\circ \times 0.625^\circ$. While the CO and O_3 data were assessed by the Atmospheric Infrared Sounder (AIRS) on the NASA Aqua satellite with spatial resolution $1^\circ \times 1^\circ$. A total of four satellite data were obtained for each pollutant that was divided into four months (May–June during LSSR and July–August after LSSR period). All air pollutants data have been available in the form of raster data. The raster data were then processed using ArcGIS software to improve the clarity of the raster images. The air pollutants data from the satellite were compared with the air quality monitoring station around the study area. A good accuracy result has been acquired with $R^2 = 0.88$, $\text{RMSE} = 0.12$ and $\text{MAE} = 0.08$. This indicated that the satellite data could be used to evaluate the changes in air pollutant levels. In addition, the data on meteorology were collected from the Meteorology, Climatology, and Geophysical Agency of Indonesia. The data included

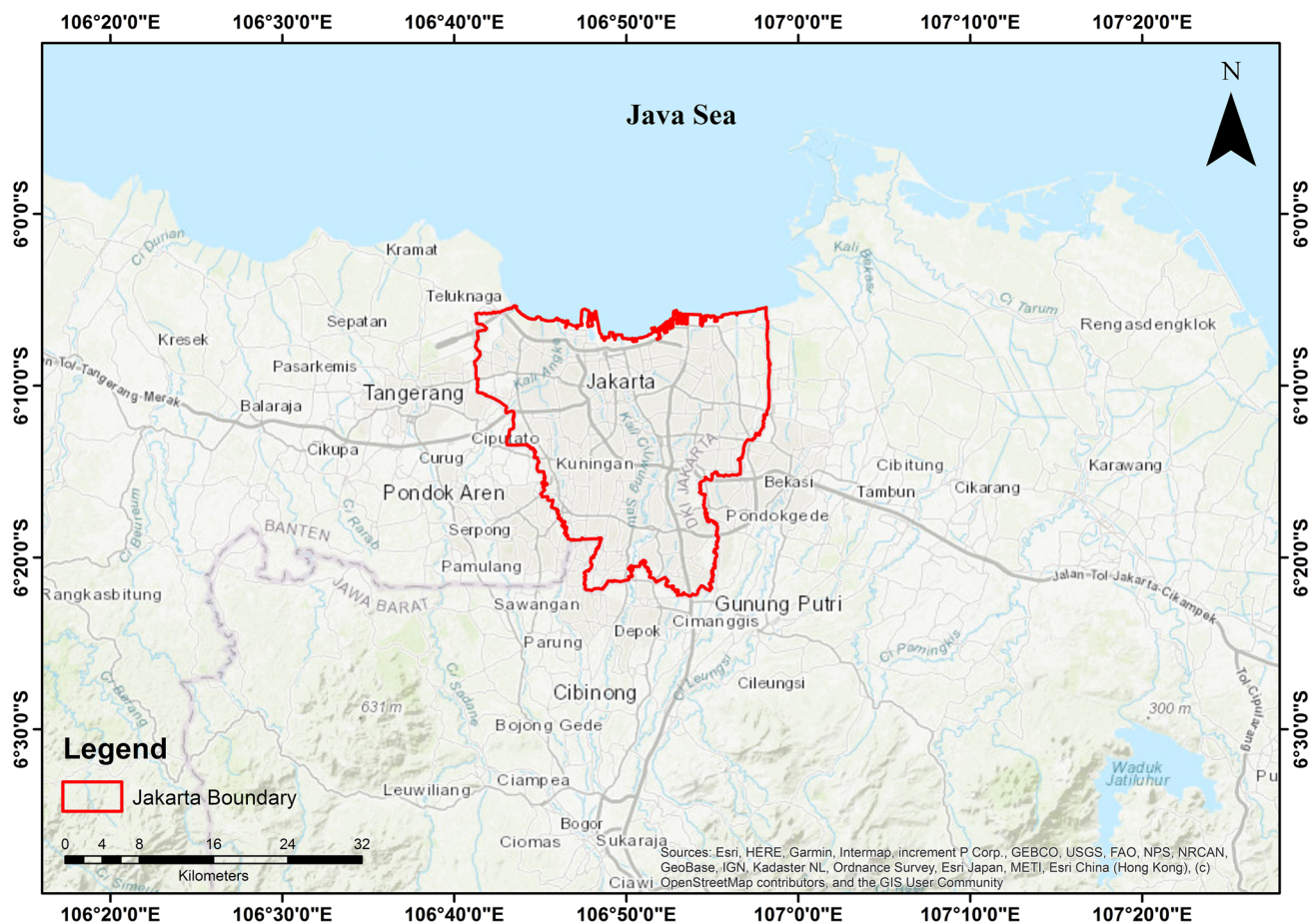


Fig. 1 Location map of the Jakarta city

temperature, humidity, rainfall, sunshine hour, and wind speed that all provided in daily data. The meteorological data retrieval time was adjusted for air pollutant data during and after LSSR periods. This was important to link meteorological and air pollutant data.

Correlation between air pollutants and meteorological factors

The Pearson correlation test was carried out to analyze the association between the five air pollutants (NO_2 , $\text{PM}_{2.5}$, O_3 , CO , and SO_2) and the five meteorological factors (humidity, temperature, rainfall, sunshine hour, and wind speed) using the IBM SPSS Statistic 21 application.

Backward trajectory model

The backward trajectory model of air pollutants was analyzed using the HYSPLIT model ver.5.1.0. This study applied the Global Data Assimilation System (GDAS) one-degree archive tool for analysis and it set the backward

trajectories for 48 h with different altitudes (100 m, 500 m, and 1000 m) which used the vertical velocity model method with 6 h interval.

Results and discussion

Changes in NO_2 , O_3 , CO , SO_2 , and $\text{PM}_{2.5}$ concentrations

Globally, fossil fuel and biomass burning activities were the major sources of particulate matter while the gaseous pollutants were primarily produced by power plants (Zhang et al. 2017). The local government has implemented a lockdown (known as the large-scale social restriction) as a control measure to mitigate the COVID-19 spread in Jakarta. One of the restricted actions was socio-economic activity. During the socio-economic restriction, every business on large, medium, and small scales were deferred, local transport, offices, universities, schools, amusement places, restaurants, market, shopping centers were all shut. However, pharmacies, daily stores, and banks remained open with

tight health protocols. These all situations directly contributed to the socio-economic decline. But besides that, it had good effects on air pollution, energy storage, and certainly less COVID-19 spread. Several studies have reported the COVID-19 lockdown had a beneficial impact in decreasing various air pollutants and greenhouse gaseous most of the time as they were co-emitted from the same activities (Ali et al. 2021; Lu et al. 2021).

In this study, a significant increase was recorded after the LSSR period in mean concentrations of O₃, PM_{2.5}, NO₂, and CO were 59.4%, 21.2%, 16.2%, and 1.0%, respectively (Table 1). This result was in line with a previous study by Ikhlasse et al. (2021) that found an increase in NO₂ (42%) and O₃ (21%) concentrations after the lockdown period in France. In contrast, our study observed a reduction in the mean concentration of SO₂ that was 19.1% after the LSSR period. We run the back trajectory analysis to know the cause of the reduction, we found the pollutants transported from east and central Java areas where these areas were implementing the lockdown, many industries were closed, only vital power plants that operated during this period thus it leads to the reduction of SO₂ emissions from the areas. The SO₂ value in our study was significantly higher than the value of SO₂ in France during the same period with a value of 3.4% (Ikhlasse et al. 2021). In the Republic of Korea, Hu et al. (2021) found a similar result where they found a reduction of SO₂ with a value of 12.1%. Contrarily, in Wuhan, China, the SO₂ levels were found to increase after lockdown with a value of 3.8%. The increased SO₂ was estimated because urban areas and industries in China were mainly burning without emission control tools such as uncontrolled metal processing plants which burned sulfide ores to produce metal oxides (Hu et al. 2021). By using spatial analysis, we found a notable increase in the mean concentration of NO₂ (2.12 to 3.38 NO₂ × 10¹⁵ molecule cm⁻²) and O₃ (24.92 to 28.98 ppbv) over the south of Jakarta from during to after the LSSR period. While a significant decrease in the mean

concentration of SO₂ (19.57 to 15.82 µg/m³) was observed in the northeast and southeast of Jakarta (Fig. 2). A substantial decrease could result from the shutting down of the essential sectors such as thermal power plants and other industries in the area.

The spatial distribution of PM_{2.5} concentration during the LSSR period was higher in the northeastern part of Jakarta with the mean concentration was 33 µg/m³, then it increased to 48 µg/m³ after the LSSR period (Fig. 3). In contrast, another study in France reported that PM_{2.5} levels decreased after the lockdown period with a value of 37.9% (Ikhlasse et al. 2021). A similar result was also shown in several cities in India (Roy and Singha 2021). According to Chauhan and Singh (2020) that the alteration of the level of PM_{2.5} relied on some factors such as dust events, seasonal distribution, traffic, and other human activities.

A substantial increase in PM_{2.5} could be caused by the increase in levels of NO₂ and CO emitted from vehicles and power plants (Carslaw et al. 2019). Additionally, because of the high population density in eastern Jakarta city, the emission from the residential sectors could also be a major source of high PM_{2.5} concentrations. Overall, the mean concentration of PM_{2.5} has increased by 21% (Table 1). Several studies revealed the increase in PM_{2.5} had a direct association with the application of lockdown policy (Mo et al. 2021; Das et al. 2021), we also believed, the increased emission scenario could be resulted from loosening LSSR policy such as movement control and other industrial activities. In Jakarta, the location of industries concentrated in the northern part of Jakarta has shown the areas with the highest PM_{2.5} levels. The recorded PM_{2.5} values from the districts in the Jakarta city after the LSSR period showed significantly higher than the lockdown period for all of the districts (Fig. 2). The reasons for such high PM_{2.5} values in this area were emissions from construction sites, fields, unpaved roads, smokestacks, or fires.

Association between air pollutants and meteorological factors

Table 2 showed the relationship between the level of air pollutants and meteorological factors analyzed by the Pearson correlation test. The level of SO₂, PM_{2.5}, and CO were positively correlated with temperature during the COVID-19 period. The SO₂ showed the greatest correlation coefficient followed by CO and PM_{2.5} (Table 2). However, NO₂ and O₃ were negatively correlated with temperature. These results were consistent with another study by Sulaymon et al. (2021) in Wuhan, China during the lockdown period.

The correlation between NO₂, PM_{2.5}, O₃, and CO was strong while the SO₂ had moderate correlations with humidity. During the COVID-19 period, only PM_{2.5} and NO₂ had a strong correlation with rainfall, while other pollutants

Table 1 The mean concentrations of air pollutants in Jakarta during LSSR (May–June 2020) and after LSSR (July–August 2020) periods

Variables	During LSSR (May–June 2020)		After LSSR (July–August 2020)		% change
	Mean	Std. deviation	Mean	Std. deviation	
NO ₂ × 10 ¹⁵ (molecule cm ⁻²)	2.12	0.17	3.38	0.44	+59.43
SO ₂ (µg/m ³)	19.57	2.25	15.82	1.97	-19.16
CO (ppbv)	88.07	0.20	88.97	0.36	+1.02
O ₃ (ppbv)	24.92	0.03	28.98	0.01	+16.29
PM _{2.5} (µg/m ³)	33	0.01	40	0.01	+21.21

Fig. 2 Satellite-retrieved average levels of **a** SO₂, **b** NO₂, **c** CO, **d** O₃, **e** PM2.5 for the months May–June 2020, **f** SO₂, **g** NO₂, **h** CO, **i** O₃, and **j** PM2.5 for the months July–August 2020 in Jakarta

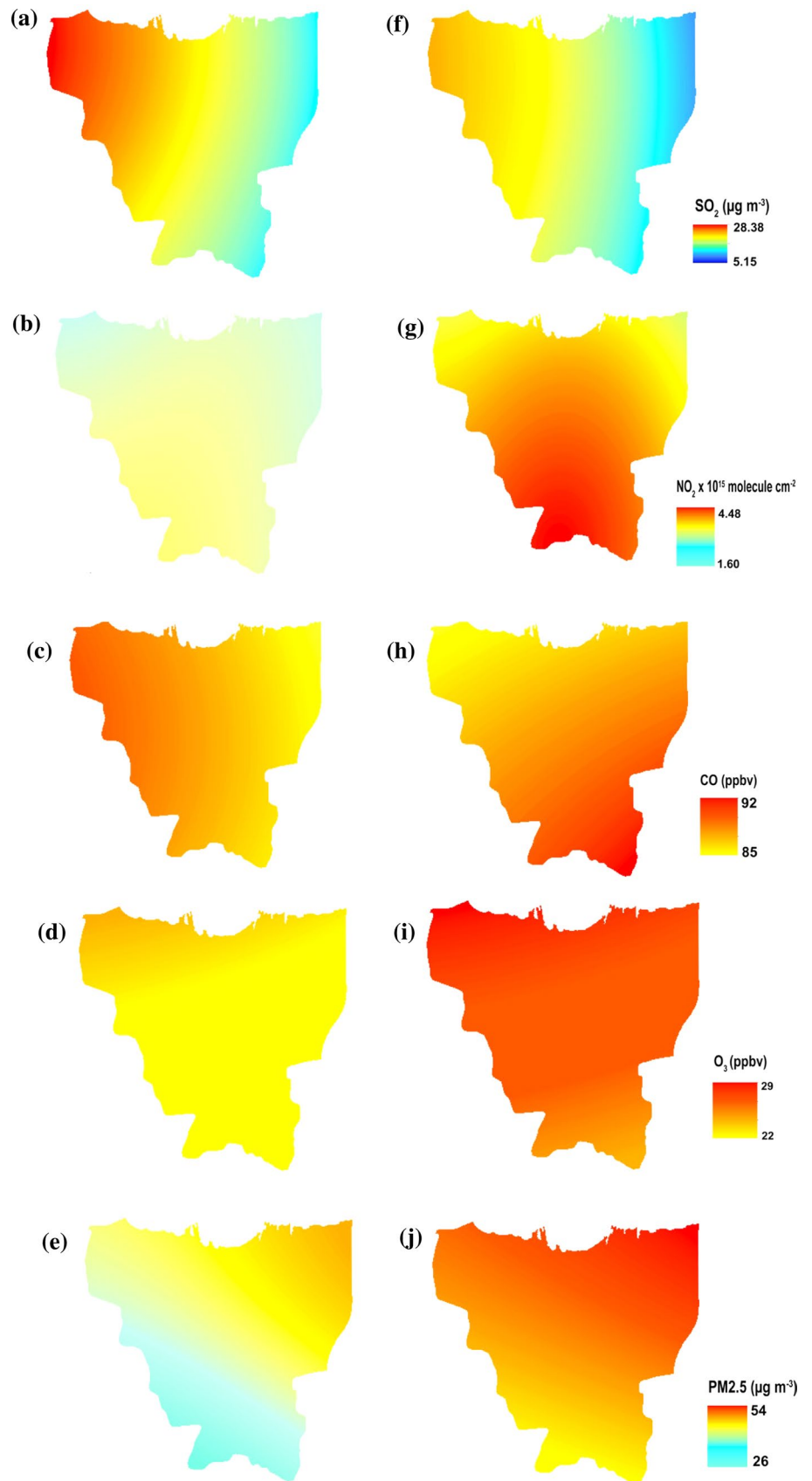


Fig. 3 The 48 h backward trajectory of air transport pathway **a** during the LSSR and **b** after the LSSR periods in Jakarta. AGL: Above Ground Level

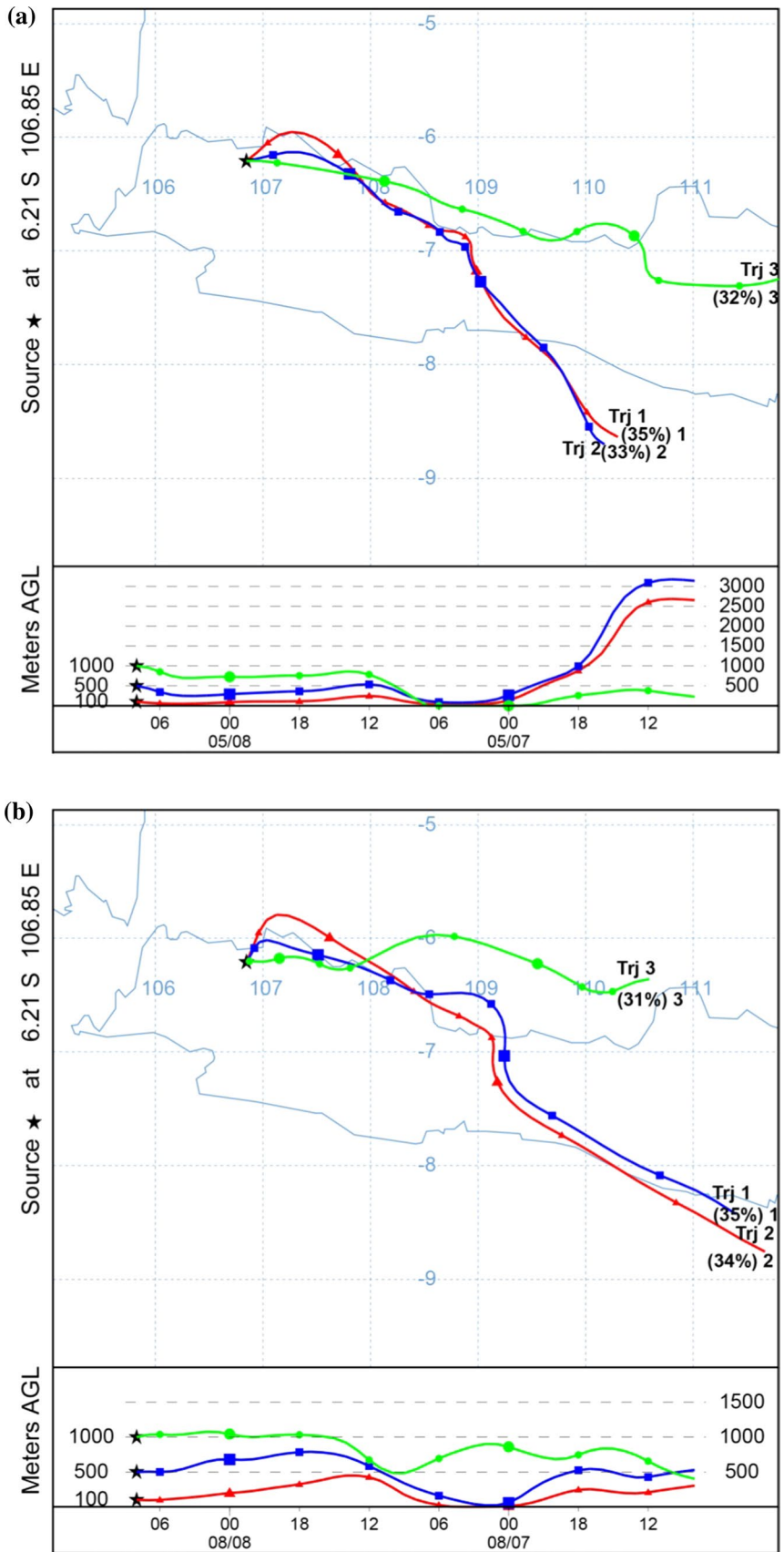


Table 2 The correlation between the mean values of each meteorological variable and each air pollutant concentration during LSSR (May–June 2020) and after LSSR (July–August 2020) periods

Meteorological variable	Period	PM2.5	NO ₂	SO ₂	CO	O ₃
Temperature	During LSSR	0.707	−0.848	0.956*	0.889	−0.856
	After LSSR	−0.963*	−0.951*	−0.980*	0.968*	0.978*
Humidity	During LSSR	0.863	−0.985*	0.299	0.665	−0.713
	After LSSR	0.441	−0.041	−0.456	−0.427	−0.390
Rainfall	During LSSR	0.629	−0.910*	0.024	0.417	−0.463
	After LSSR	0.021	−0.430	−0.641	−0.021	0.007
Sunshine hour	During LSSR	0.007	−0.420	−0.668	−0.302	0.239
	After LSSR	−0.267	−0.693	−0.932*	0.281	0.319
Wind speed	During LSSR	0.222	−0.595	−0.610	−0.240	0.173
	After LSSR	−0.347	−0.725	−0.941*	0.363	0.401

*The correlation is significant at 0.05 level (2-tailed)

showed a weak correlation. Furthermore, SO₂ and NO₂ showed a high negative correlation between sunshine and wind speed. PM2.5, CO, and O₃ showed a weak correlation with wind speed. The wind condition could govern the pollutant distribution. The air pollutants would be more congested when the area had lower wind speed (Coccia 2021).

Furthermore, all pollutants had a strong relationship with temperature during and after the LSSR periods. The wind speed was strongly related to NO₂ and SO₂ but weakly related to PM2.5, CO, and O₃ (Table 2). The association between humidity and all air pollutants after the LSSR period varied from weak to moderate correlation. Only SO₂ and NO₂ showed a high negative correlation with rainfall and sunshine, while other pollutants showed a weak correlation after the LSSR period.

Backward trajectory analysis

This study used the central coordinate of Jakarta (6.2088° S, 106.8456° E) to estimate the backward trajectory of air pollutants during and after LSSR periods from May to August 2020. Our study used the Global Data Assimilation System (GDAS) one-degree horizontal resolution dataset for analysis and it set the backward trajectories for 48 h with different altitudes (100 m, 500 m, and 1000 m) which used the vertical velocity model method with 6 h interval. Another study by Su et al. (2015) found a significant difference between trajectories resulted from GDAS1 (one-degree horizontal and temporal resolution of 3 h) and GDAS0P5 (0.5° horizontal resolution and temporal resolution of 3 h) datasets. It can be caused by the difference in vertical motion calculations and the lack of vertical velocity in GDAS0P5.

Figure 3 showed the 48 h of average backward trajectories of the air pollutant transport in Jakarta. The air mass of trajectory (Trj) 1, 2, and 3 were all from short-distance transport from the southeast, with the transport trajectory ratio of 35%, 33%, and 32%, respectively. Overall, the transport trajectory ratio was not much different during and after

LSSR periods. For instance, trajectory 3 that was from the east of Java, transported from southeast to Jakarta, had the lowest portion of all trajectories. The height altered during the pollution transport of trajectory 3 was low and hold below 1000 m. However, trajectories 1 and 2 slowly raised from a vertical height of 100 m to 3000 m. The transport trajectory of pollutants at the height of 100 m was the same as 500 m. If we compared the air trajectory transport during LSSR with after LSSR periods, the air transport pathway indicated almost the same pattern. Only after LSSR, air transport pathway differed in the height of all trajectories (1, 2, and 3) tended to be lower and maintained below 1000 m.

The source of air mass during and after the LSSR periods was not so scattered, with more than 30% of air mass coming from east Java, bringing the lower number of pollutants to Jakarta along the course. Trajectory 1 and 2 transported a higher number of pollutants originating from areas in central Java and other surrounding areas (68%). The ratio of this air mass was high enough, it largely traversed through dense areas with many factories, industries, and other emission origins. These activities contributed to more pollutants being carried to Jakarta along the pathway that aggravated the air quality in Jakarta. The air mass after LSSR mostly came from central Java had the highest proportion (69%) and had the longest distance. Meanwhile, the air mass of trajectory 3 passed over the Java Sea and most of the particles reacted with water vapor through dilution process.

According to Fig. 2, NO₂, O₃, and PM2.5 tended to exhibit a same pattern. In contrast, SO₂ and CO showed a slight distinct pattern. There were several possible factors that could affect this occasion. Firstly, the characteristic of air pollutant, high level of SO₂ was mainly observed in industrialized areas, such as Jakarta city, as well as in other neighbor cities. As for CO, the main sources were originated from the combustion process, high CO levels were usually same as SO₂, which was found in densely urbanized areas.

Renuka et al. (2020) explained the concentrations of SO₂ and CO in the lower atmosphere were not in abundance,

accounting for the season and region, both could not be maintain for long period. This interval was too concise for these gaseous to disseminate globally. Thus, in neighboring areas, where both high and medium emissions of SO₂ and CO were observed, a significant difference in the levels of SO₂ and CO could occur in the atmosphere. Furthermore, SO₂ and CO usually emitted in developed industrial areas, and also had a short distance transport from those areas with heavier air pollutants to neighbor areas, as presented by the backward trajectory analysis. Unlike SO₂, high particulate matter (PM) concentration was mainly found in similar areas where NO₂ and O₃ had high concentrations, but due to the much longer residence time of aerosol particles in the atmosphere, they tended to be carried over long distances thus their concentrations were higher than other gaseous like SO₂ and CO.

Conclusions

The impact of LSSR on air pollution due to the COVID-19 pandemic in Jakarta was assessed by comparing the levels of air pollutants from May to August 2020 using satellite-based data. During the implementation of the LSSR policy, the spatial variation of air pollutant concentrations in Jakarta was low. The restriction policy has helped to reduce emissions of greenhouse gases and aerosols caused by human activities. After the LSSR period, the spatial variation of NO₂, PM_{2.5}, O₃, and CO levels raised by 59.4%, 21.2%, 16.2%, and 1.0%, respectively over Jakarta. The air transport pathway were all from short-distance transport from the southeast to Jakarta, it was mainly from east and central Java areas. The increase in NO₂, PM_{2.5}, O₃, and CO levels quickly after the LSSR was an obvious hint that control measures must be carried out to improve air quality. Otherwise, we would revert to the same situation before the pandemic.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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