Sustinere
Journal of Environment and Sustainability
Volume 6 Number 3 (2022) 239-250

Print ISSN: 2549-1245 Online ISSN: 2549-1253
Website: https://sustinerejes.com E-mail: sustinere.jes@uinsaid.ac.id

RESEARCH PAPER

The effect of community mobility changes to air quality in Java-Bali during the early phase of COVID-19 pandemic

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Article history:
Received 28 October 2021 | Accepted 28 December 2022 | Available online 31 December 2022

Abstract. Previous studies found a reduction in pollution levels when travel was banned due to the COVID-19 pandemic. This study aims to identify the changes in community mobility and air quality, as well as to analyze the effect of community mobility changes on air quality during the early phase of the COVID-19 pandemic. This study used daily secondary data from Google Mobility Report and station data archive of Air Quality Monitoring System (AQMS) which records Air Pollutant Index Standard (ISPU). This study focused on the early phase of the pandemic (15th Feb – 15th June 2020) in six provinces in Java and Bali. This study used panel regression and GIS. The results show that there is 35-90% reduction in mobility and also some decreases in air quality pollutants. Furthermore, it was shown that there is a positive relationship between ISPU and mobility. Community mobility explains ISPU in Bali, the Special Region of Yogyakarta, the Special Capital Region of Jakarta, West Java, Central Java, and East Java by 24%, 53%, 13%, 3.7%, 20%, and 39% respectively. Meanwhile, the combined influence of the six provinces is 18.8%. The variable that has a significant effect is the community mobility changes on transit stations. Every 1% increase in the transit station's mobility is capable to increase ISPU by 0.4.

Keywords: Air quality; mobility changes; travel banned; COVID-19; panel regression

1. Introduction

COVID-19 has spread to practically every country in the world, causing tremendous anxiety. This virus is easily transmitted from human to human. Every government has its own ways to handle the pandemic. Lockdown was first implemented in Wuhan on January 23rd, 2020, with Hubei Province following a few days later (Muhammad et al., 2020). The Chinese government implemented a lockdown to all of their provinces to prevent the spread of the COVID-19 pandemic. Other countries in the world also adopted this strategy.

The first confirmed Corona Virus Disease 2019 (COVID-19) case in Indonesia was found on March 2nd, 2020. From the first verified case, Indonesia has faced a rapid increase of confirmed number. Based on the publication by the COVID-19 Indonesian Task Force (2020), almost all provinces in Indonesia have been infected. As a result, the quarantine implementation has secondary repercussion in various fields, including economic and environmental sectors. This

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DOI: https://doi.org/10.22515/sustinerejes.v6i3.219

quarantine has suppressed consumer's demand and caused several crises. However, there was a positive impact on the environment.

Travel bans resulted in a considerable reduction in some air pollutants (Dutheil et al., 2020). It can be seen from the number of pollutant concentrations in ambient air. Based on images released by the European Space Agency (ESA) (2020), NO_2 levels plummeted by up to 20-30% during the lockdown in several countries, such as Spain, France, and Italy, compared to the same period in the previous year. National Aeronautics and Space Administration (NASA) (2020) also proved that there was a 30% drop in NO_2 in the northeastern US compared to the previous year period. Also, according to Rahmawati & Ramadhani) (2020), there was a 14.4% decrease of $PM_{2,5}$ in Jakarta compared to the same period in the previous year. This significant decrease was not only found in Jakarta, but also in several regions of Indonesia, including Makassar, Banjarmasin, and Padang.

The air quality and climate problems have become global problems. one Point 13 of the Sustainable Development Goals (SDGs) lists it as one of the aims. The reduction of pollutants due to social restriction in other countries also need to also be researched in Indonesia. This study aims to identify community mobility and air quality changes, and analyze the effect of community mobility changes on air quality in Java and Bali during the early phase of the COVID-19 pandemic. This study demonstrated the significance of mobility in affecting air quality at specific periods.

2. Methods

2.1. Study area

This study used provinces as an analysis unit, including six provinces (Special Capital Region of Jakarta, Special Region of Yogyakarta, Bali, Central Java, West Java, and East Java). Each province is paired with the selected daily period, starting from February 15th – June 15th, 2020 (122 days).

These locations were chosen because they had the highest COVID-19 transmission in Indonesia. Moreover, the travel ban policy also focused on these six provinces in Java and Bali. Because these provinces are the center of the economic activities, it is important to observe the mobility changes during the particular periods mentioned. The early phase of COVID-19 pandemic time period was chosen. It was when the government strictly implemented the travel ban regulation.

2.2. Data and Variable

This study used four independent variables and one dependent variable. The independent variables include changes in mobility from and to several locations; retail & recreation, grocery & pharmacy, parks, and transit stations. Meanwhile, the dependent variable is represented by a critical parameter on the daily Air Pollutant Index Standard (*ISPU*).

These four independent variables were chosen because it could represent the comprehensive daily mobility. This data came from location changes that were recorded on smartphones of each individual in a province (Google Mobility Report, 2020). The "mobility changes" itself are measured from the baseline (average measurements on January 3rd – February 6th, 2020) which means before the pandemic reached Indonesia. The same mobility variables from Google were also used by Muhammad et al. (2020) to identify the mobility changes during pandemic in the several cities of China.

ISPU is recorded based on the Air Quality Monitoring System (AQMS) which is the official tool to measure air quality in a region by the Ministry of Environment and Forestry of Indonesia. Moreover, there are at least 26 AQMS spread all over Indonesia; and there are 9 AQMS in 6 focused provinces. AQMS records air quality based on several pollutants, including CO, SO_2, O_3, PM_{10}, and NO_2. In addition, meteorological parameters including wind direction and speed, temperature, air humidity, and rainfall data were all considered in real time and continuously. *ISPU* was chosen as a dependent variable because it explains specific values based on various emissions and meteorological parameters.

2.3. Research Method

The six researched areas were paired with the selected period (122 days) and paneled with both dependent and independent variables. In total, this study was based on more than a thousand data.

The values of independent variables show the mobility changes from the baseline (value of mobility before the pandemic). In most cases, each province has only one AQMS site for the dependent variable. However, in West Java and East Java, more than one monitoring tool was found. In total, there were nine AQMS in six provinces of the study area. Therefore, for the province with multiple monitoring grounds, an average was taken to represent an exact value for a province in a day. *ISPU* calculation is conducted in accordance with its regulation (Ministry of Environment and Forestry Regulation Number 14 Year 2020 about Standard of Air Pollution Index). In addition, the study also used Geographic Information System (GIS) for analysis techniques.

Panel data was also used because it can display a combination between cross-sections of households, countries, companies, and over a certain period. In addition, panel data can accommodate heterogeneity in a variable, improve variability, decrease collinearity, and increase efficiency (Hsiao, 2003). The linear regression taken in panel data becomes panel regression. The formula for the panel regression in this study, based on Baltagi's (2005), is presented in Equation (1).

$$y_{it} = \beta_{it} + \sum_{k=2}^{K} \beta_{kit}\, x_{kit} + \varepsilon_{it} \qquad (1)$$

i is unit of cross section, *t* is unit of time series, y_{it} is Value of dependent variable in related cross section and time series, x_{it} is Value of independent variable in related cross section and time series, β_{it} is measured parameter, ε_{it} is population disturbance, and K is unit of regression parameter measured.

There are three types of panel regression models that may be used to achieve this calculation; Common Effect Model, Fixed Effect Model, and Random Effect Model. The statistical data processor can define which model is the best with Chow Test, Haussman Test, and Breusch-Pagan (Baltagi, 2005). The first step is to choose the most appropriate model and continue with the statistical assumption test.

3. Results and Discussion

3.1 COVID-19 Government's Regulation

After the first case of COVID-19 was found, the Indonesian government formed a team for handling this pandemic. This team is known as the National COVID-19 Task Force, which is stated on the Presidential Decree of Republic Indonesia Number 7 of 2020. In March 2020, the Indonesian government focused on strategies to overcome the pandemic. Due to the uncontrollable daily cases, the government started implementing Work from Home (WFH) regulation on March 15th. Instead of using the phrase "lockdown," the government implemented local to large scale quarantine to minimize adverse consequences on the social economy; this regulation is known as *Pembatasan Sosial Berskala Besar* (PSBB).

Furthermore, on April 2020, the government focused on explaining in more detail about *PSBB* rules. In addition, not all provinces implemented *PSBB* to overcome the pandemic. The local governments should first consult with the national task force before implementing *PSBB*. The provinces that implemented *PSBB* were Special Capital Region of Jakarta, West Java, and East Java. In general, the guideline for *PSBB* was issued by the Ministry of Health through Ministry of Health Regulation No. 9 Year 2020 about *PSBB* Guidelines . Restrictions were placed on major activities, such as industrial and transportation sectors. In May and June, the government started to educate the public about the new normal.

3.2 Changes on Mobility

Based on Figures 1 and 2 below, since March 15th, 2020, the trend of mobility has declined in Jakarta. It is due to the WFH regulation implemented since March 16th, 2020. This is the highest mobility decline in Jakarta as a capital city. The mobility declined by up to 95% in Jakarta, especially for mobility changes in parks and transit stations. In general, the peak mobility reduction was found at the end of April until mid-May. On the other hand, the smallest reduction in mobility was found in Bali.

Different patterns were found in Central Java (Figure 3) and West Java (Figure 4). There was a significant increase in the new normal period. Some parameters have closed near, or even exceeded, the baseline in the green areas. Mobility in retail and recreation dominated the line close to the baseline, reflecting a less than 10% reduction. It was different from the other provinces that had a steady drop until the new normal period, such as the Special Capital Region of Jakarta, East Java (Figure 5), and the Special Region of Yogyakarta (Figure 6).

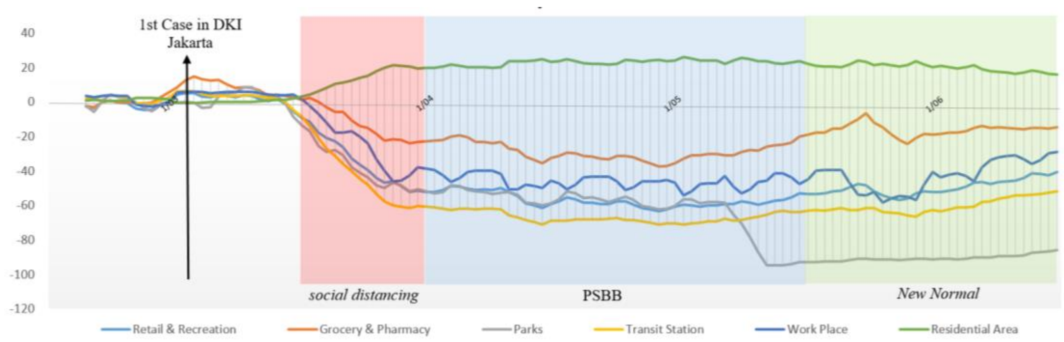

Figure 1. Community Mobility in the Special Capital Region of Jakarta from 15th February 2020 – 15th June 2020

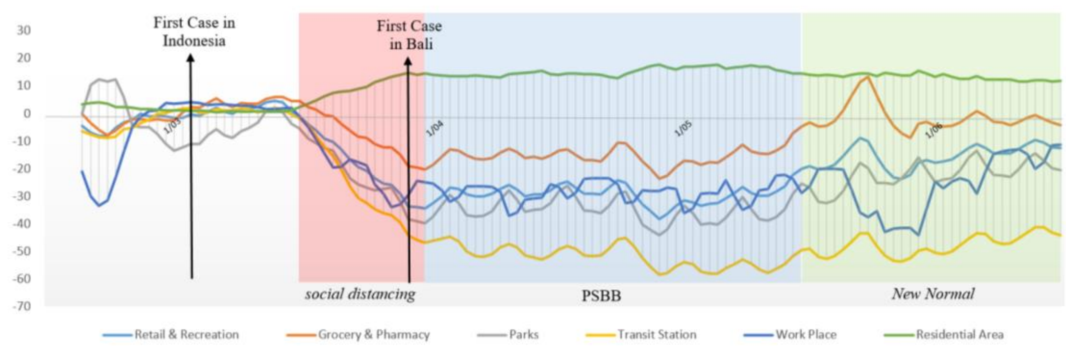

Figure 2. Community Mobility in Bali from 15th February 2020 – 15th June 2020

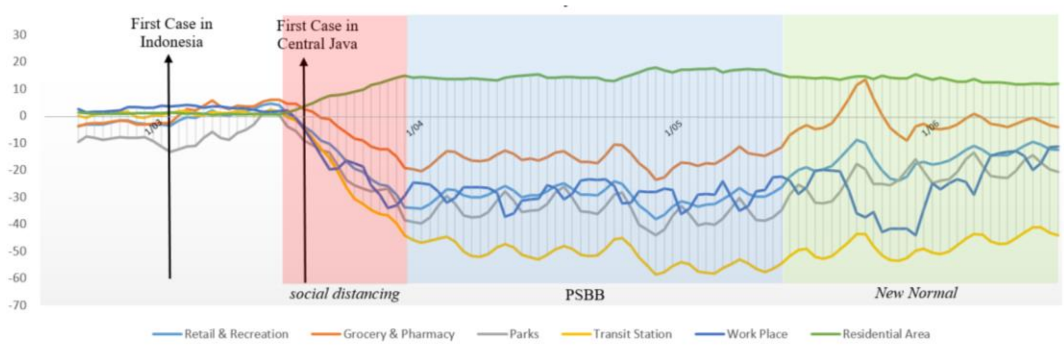

Figure 3. Community Mobility in Central Java from 15th February 2020 – 15th June 2020

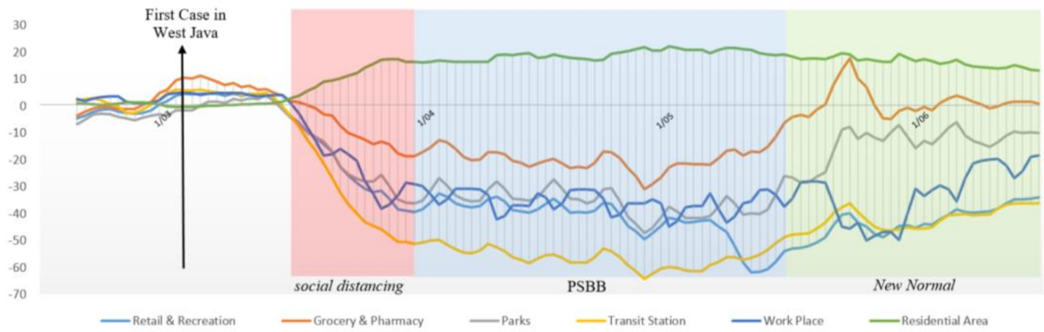

Figure 4. Community Mobility in West Java from 15th February 2020 – 15th June 2020

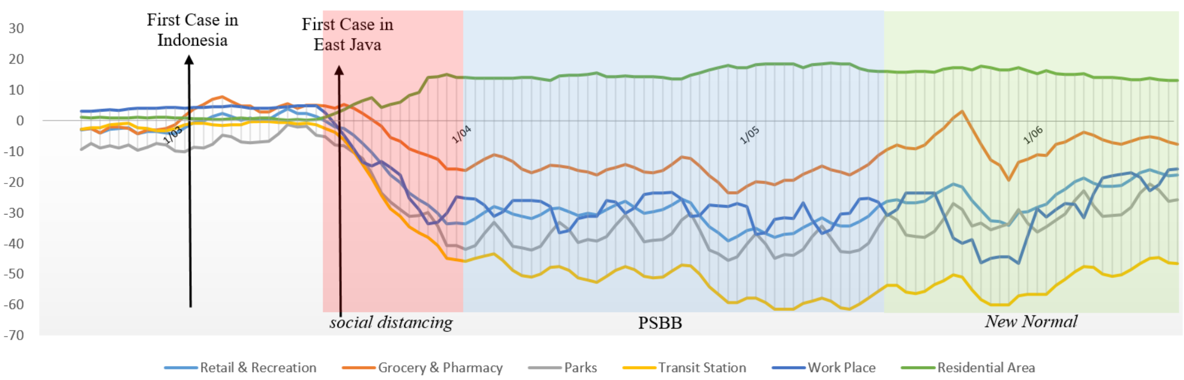

Figure 5. Community Mobility in East Java from 15th February 2020 – 15th June 2020

However, a deviation was found in residential mobility, which increased up to 20%. It was also found in every province. It is understandable that as result of WFH and *PSBB*, people only relocated locally to meet their needs of a place to stay. Then, residential mobility started to decline gradually during the new normal era. It was reflected that, after the new normal, people began to leave their homes. It was reported that family and settlements clusters contribute up to 85% of the total confirmed cases in Indonesia (BBC, 2020).

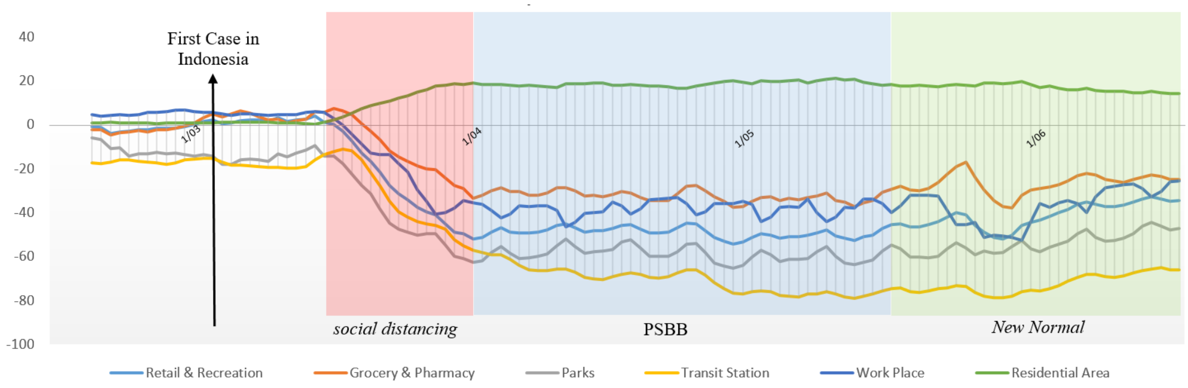

Figure 6. Community Mobility in the Special Region of Yogyakarta from 15th February 2020 – 15th June 2020

3.3 *ISPU* in 2019 and 2020

Before identifying the air quality trends in 2020, it is necessary to compare air quality in the same time last year. Comparing pollutants in 2020 to pollutants in 2015-2019 was also conducted in earlier study. Based on this study, the average concentration of NO_2 in April 2020 were generally lower than the average of those previous five years (Archer et al., 2020). Another study also compared air pollutants with the previous three years. The results show that the maximum concentration in April 2020 was the lowest compared to the same month in the previous three years (Mahato et al., 2020).

Figure 7 shows the *ISPU* comparison (SO_2 pollutants) for 2020 and 2019. *ISPU* was taken from air quality monitoring stations in GBK Stadium, Central Jakarta. Based on Figure 7, the SO_2 in 2020 was lower than that in 2019, especially during the *PSBB* period. Meanwhile, during the *PSBB*, the SO_2 index was still relatively at the same level. However, the index for SO_2 in 2020, starting from March, has slightly decreased until mid-May. Furthermore, the pattern has returned and shows that SO_2 in 2020 was lower than in 2019. Thus, these patterns are relevant to the previous studies. According to the previous study, the trend of pollutants ($PM_{2,5}$, PM_{10}, NO_2, CO, and O_3) in 2020 is lower compared to the previous year (Freitas et al., 2020). However, there are also some opposite patterns. It may have occurred due to other meteorological and climatological factors.

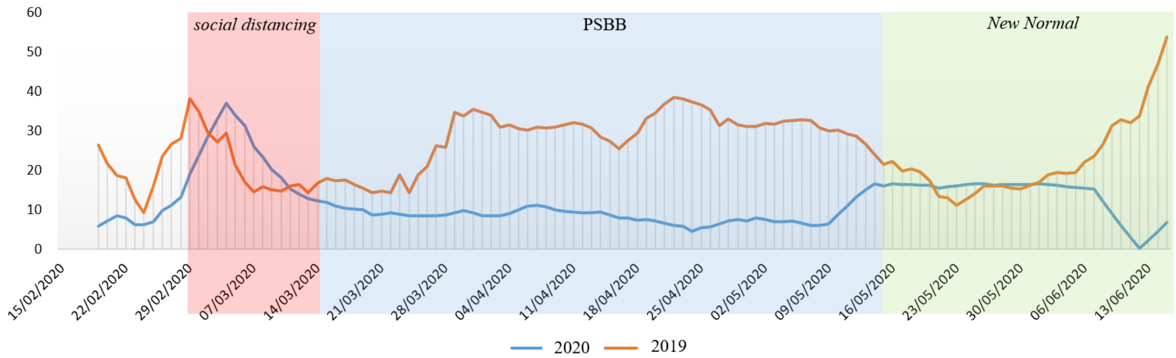

Figure 7. Comparison of SO_2 at GBK Stadium in Central Jakarta in Feb-Jun 2019 & 2020

The trend in Figure 7 shows that the work from home policy indirectly affects the air quality in an area. Moreover, the *ISPU* in Figure 7 was taken from the monitoring station in Jakarta, where the largest reduction of mobility occurred. The difference between the SO_2 index in 2019 and 2020 reaches up to 20-30% during the *PSBB* period. The pollution was reduced by 23% during the *PSBB* period compared to the same period in 2019 (Kerimray et al., 2020).

SO_2 is a type of gas that comes from various sources, mainly from the industrial sector. However, the transportation sector also contributes in small percentage. SO_2 is dominantly generated from stationary pollutant sources, such as factory and industrial activities. The pollutants concentration in ambient air comes from various complex sources and have interacted with other types of pollutants. SO_2 has been identified as the cause of asthmatic attacks and linked with the admission to hospital emergency rooms for asthmatic symptoms (Godish, 2003).

On the other hand, PM_{10} or particulate matter 10 is one of the important components in determining air quality in an area. These fine particles are produced from many activities, such as reactions in soil, bacteria, viruses, fungi, yeast, and seawater evaporation. In addition, these particles are also produced by human activities, such as motorcycles, industrial activities, and other household emissions. Figure 8 shows that the difference between *ISPU* of PM_{10} is not clear as a pattern. During the *PSBB* period, from March to May, there was no significant decrease in *ISPU* of PM_{10}. However, in some parts, especially in early March, in March & April for some parts, and mid of June, the *ISPU* of PM_{10} in 2020 is still lower compared to 2019.

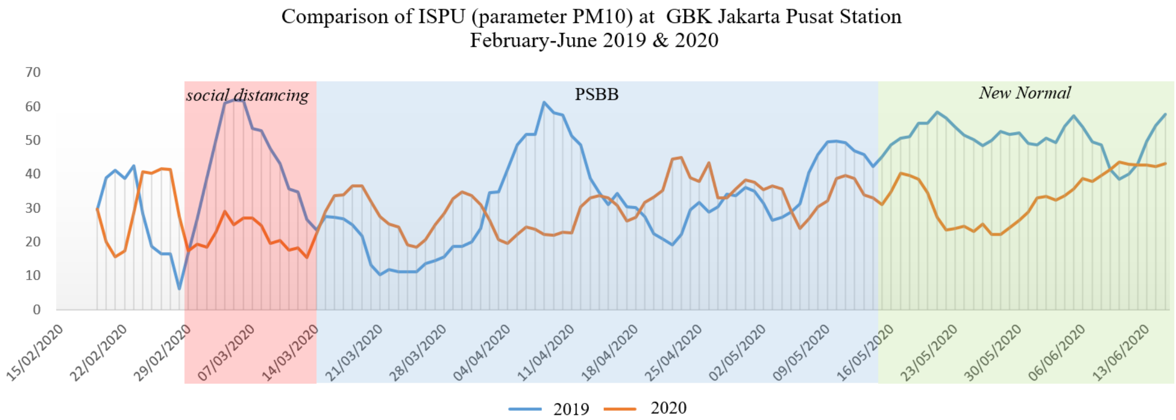

Figure 8. Comparison of PM_{10} at GBK Stadium in Central Jakarta from February-June 2019 & 2020

However, this sideways pattern is possible because non-transportation sector dominating the percentage of PM_{10} sources. It is in line with the measurement of PM_{10} in the United States which contributed 12.48 ppm (Godish, 2003). The most dominant sources are industrial activities. Moreover, the primary sources of PM_{10} were human activities including farming, industrial, and construction activities (Putri, 2017). It supports the results in Figure 8 above. PM_{10} was not directly affected by mobility sector, so that the major changes of mobility did not have a significant effect on PM_{10} concentration.

3.4 *ISPU* changes during PSBB

The changes of pollutants index or *ISPU* in an area were not as significant as changes in mobility. Certain pollutants have only decreased slightly. It shows that air quality problems were becoming serious. The monthly comparison of *ISPU* in the six provinces used in the study can be seen in Figure 10 below.

The changes of pollutant concentration during *PSBB* were not very clear, unlike mobility, where the decline was up to 95% in Jakarta. Based on Figure 9 below, it can be seen that in February, the air quality of six provinces was at a good and moderate level, but West Java showed an unhealthy level. Apart from the effect of mobility, the recorded *ISPU* is also dependent on the location of the monitoring station. On March 2020, when the *PSBB* was implemented for the first time, some provinces like West Java and Central Java, experienced an increase in pollutant levels. Furthermore, the *ISPU* in the next three months was showing an improvement to the Good class.

The increase of pollutant in March 2020 in West Java was possible because the *ISPU* of West Java was generated from the average *ISPU* at three monitoring stations, including Bandung Station, Depok Station, and Bekasi Station. Bekasi Station became an outlier because it recorded very high pollutants when compared to other stations. The number of monitoring stations was still limited in each province, so it is possible if there is a bias in the results obtained.

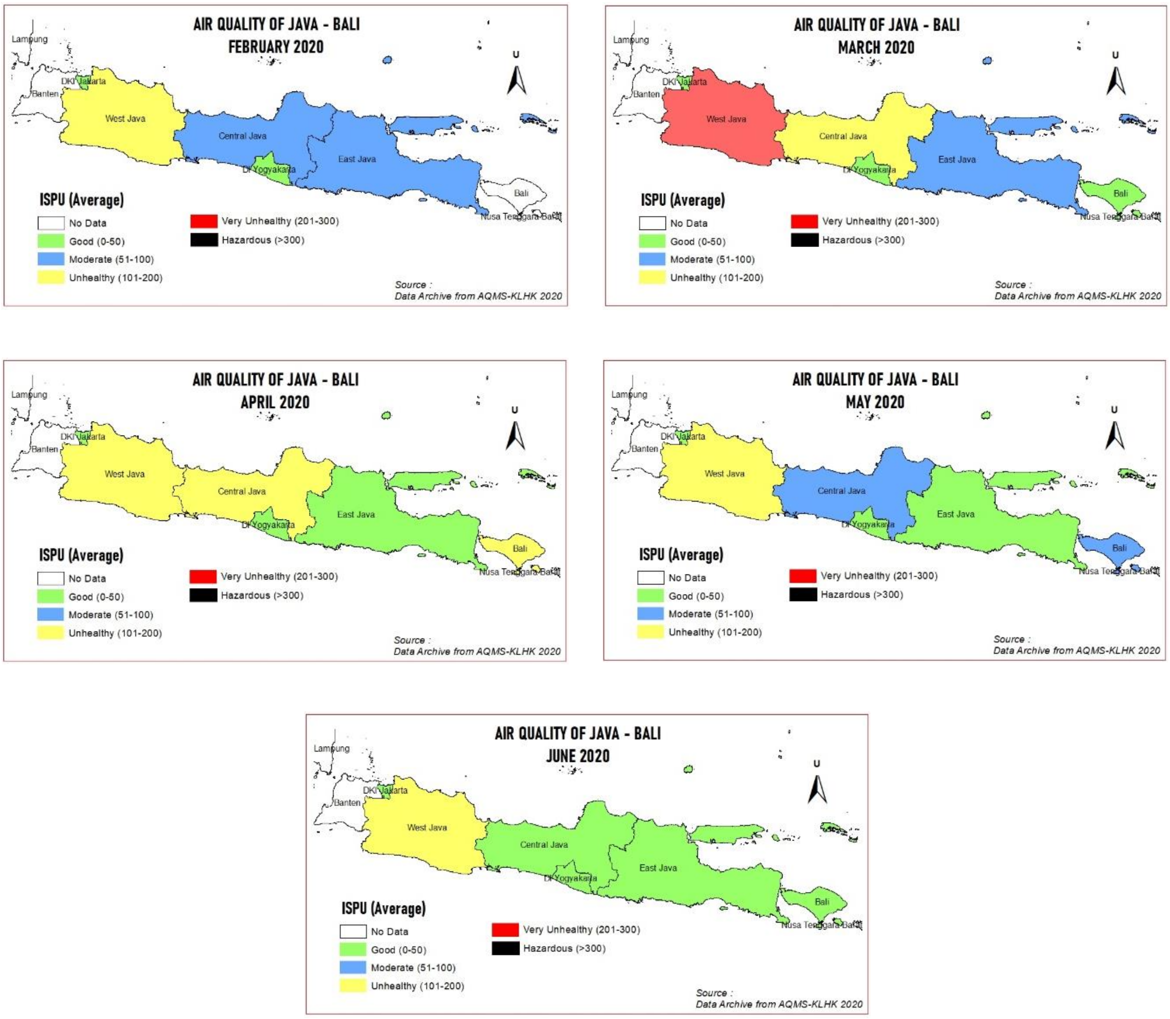

Figure 9. Monthly average of ISPU

3.5 Effect of Mobility Changes to Air Quality

3.5.1 Effect of Mobility Changes to Air Quality on Each Province

Table 1 shows the results of each linear regression for each province. It shows the mapping for the number of R Squared, classified into three classes. It can be seen that Jakarta and West Java are at the low class. It is indicated that more complex factors determined the air quality in Jakarta and West Java. More than 70% reduction of mobility in Jakarta and West Java only caused a small effect on pollutant levels, which is 13% for Jakarta and only 3.7% for West Java. It is possible because these two locations are classified as urbanized regions. Thus, the pollutant contributors are also becoming more diverse.

The population density in Jakarta is 15,900 people/km^2, while West Java is 1,394 people/km^2 (Indonesian Central Bureau of Statistics, 2019). These two regions are the most populous province in Indonesia. Household and individual activities can also contribute to a percentage of emission. Population growth stimulates economic activities while also increasing the number of pollutants. Industrial and household activities have a significant role in urban air quality. These two regions also contain an agglomeration of urban areas as well as peri-urban for Jakarta.

Table 1. Regression results and significant variable for each province

Effect Classification	Province	R Squared Value	Significant Variables of Mobility			
			Retail & Recreation	Grocery & Pharmacy	Parks	Transit Station
Low	West Java	3.7%	-	-	-	-
	Jakarta	13%	-	-	-	-
Medium	Bali	24%	v	-	-	-
	Central Java	20%	v	v	-	v
High	East Java	39%	-	-	-	v
	Yogyakarta	53%	v	-	v	v

Meanwhile, the next pattern is the urbanized class under Jakarta and West Java, located in the medium and low classification. Bali (24%) and Central Java (20%) fall under the medium of the effect classification. It is possible because Bali and Central Java are less urbanized than Jakarta. Pollutant-producing activities are scarcer. The activities in Bali and Central Java are less complex compared to Jakarta and West Java. It explains why their mobility *ISPU* has a larger percentage.

Based on Table 1, Yogyakarta and East Java are classified as having a high effect. These two areas have a lower urban level compared to the other provinces. The activities producing emissions are not as complex as those in West Java and Jakarta. Looking at their regional characteristics, it is obvious that mobility could explain why *ISPU* is substantially higher in East Java and Yogyakarta. It is because of their smaller built-up areas compared to other provinces. *ISPU* 39% and 53% for East Java and DI Yogyakarta, respectively, might be explained by mobility. Figure 10 depicts the spatial pattern of each effect of mobility changes on air quality.

3.5.2. Effect of Mobility Changes to Air Quality of All Provinces

Table 2 shows the panel regression results, representing the whole effect of mobility on air quality in six provinces. This panel regression used Fixed Effect Model (FEM) with Ordinary Least Square (OLS). This model was selected based on the results of the Chow, Haussman, and Breusch-Pagan test. In addition, this model was chosen because it could condition unused variables in the population.

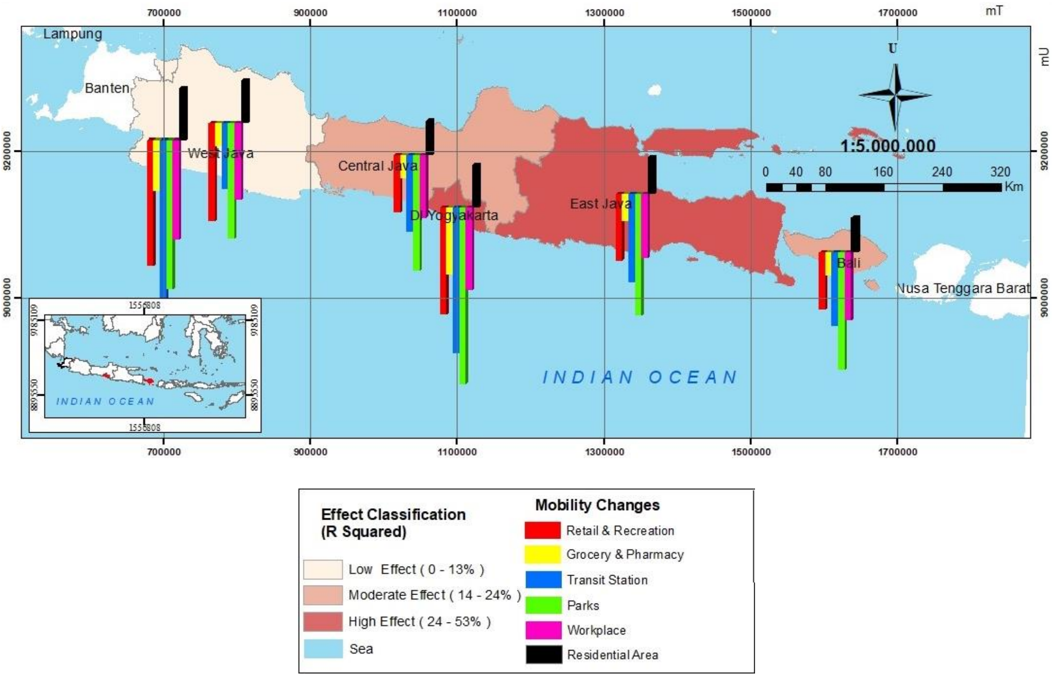

Figure 10. Effect map of mobility to air quality in Jawa and Bali during the early phase of the COVID-19 pandemic (Feb-Jun 2020)

Table 2. Panel Regression Results

Dependent Variable: Y_ISPU
Method: Panel Least Squares
Date: 04/21/21 Time: 19:39
Sample: 2/15/2020 6/15/2020
Periods included: 122
Cross-sections included: 6
Total panel (balanced) observations: 732

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	44.69014	3.846551	11.61824	0.0000
X1_RETAIL_REKREASI	0.560399	0.318561	1.759156	0.0790
X2_TOKO_MAKANAN	0.322754	0.280124	1.152182	0.2496
X3_TAMAN	0.138254	0.167860	0.823628	0.4104
X4_TRANSPORTASI	0.407186	0.187522	2.171406	0.0302

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.188906	Mean dependent var	50.71311
Adjusted R-squared	0.178795	S.D. dependent var	54.13177
S.E. of regression	49.05441	Akaike info criterion	10.63730
Sum squared resid	1737374.	Schwarz criterion	10.70009
Log likelihood	3883.253	Hannan-Quinn criter.	10.66152
F-statistic	18.68393	Durbin-Watson stat	0.593042
Prob(F-statistic)	0.000000		

Based on the table, there is only one significant variable, which is mobility changes in transit stations. It can be seen that transit station mobility is the only variable below the significant level. According to Google Mobility Report, transit stations include train stations, ports, taxi hubs, rest areas, and rental agencies. It is because the mobility in transit station, including train station and ports, has a probability to reflect the mobility changes in a long distance as well. Looking at the coefficient value, every 1% increase in mobility of transit station affects the *ISPU* by 0.4 positively. Meanwhile, the other three variables have no significant effect on the samples taken.

Furthermore, the whole effect of these four variables on explaining *ISPU* is 18.8%. Meanwhile, the other 81.2% could be explained by other factors not used in this study. These findings show that the decrease in mobility by up to 90% has not resulted in the same reduction in pollutants (*ISPU*). Although the R Squared number is relatively small, it is in line with the previous studies. A previous research shows that mobility can explain Air Quality Index (AQI) by 7.8% (Bao and Zang, 2020). In addition, another result shows that mobility restriction decreases pollutants by 19.47% (Zhu et al., 2020). Perhaps the 81.2% is affected by other meteorological factors such as temperature, wind, or weather. Based on Tosepu et al. (2020), from the six aspects of weather, temperature is responsible for 39.2% of the air quality in Jakarta.

4. Conclusion

The decrease in mobility significantly occurred in each province in Java and Bali. The decline began in March 2020 since the implementation of work-from-home policy and continued to decline until its peak in early April 2020. The decrease varies from 35-90%, compared to the baseline. The biggest declines were in the Special Capital Region of Jakarta and the Special Region of Yogyakarta. However, a deviation was found to increase by up to 20% in a residential area. Meanwhile, the changes of air quality were not as big as the changes that occurred in community mobility. Some pollutants such as PM_{10}, SO_2, CO, and O_3 slightly decreased starting in March 2020 and the following months.

The effect of mobility changes to air quality in the Special Capital Region of Jakarta is 13%, West Java is 3.7%, Central Java is 20%, the Special Region of Yogyakarta is 53%, East Java is 39%, and Bali is 24%. Meanwhile, the whole effect of changes in mobility that can explain *ISPU* is 18.8%, with only one significant variable (transit station mobility). The other 82% were explained by factors that were not used in the study.

Acknowledgement

The author would like to thank Drs. Joko Christanto, M.Sc. who has supervised this study from the beginning. Also, thanks to everyone who has supported and contributed to the writing process of this paper.

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