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Empirical evidence shows that air quality changes during COVID-19 pandemic lockdown in Jakarta, Indonesia are due to seasonal variation, not restricted movements

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ABSTRACT

Implementing a lockdown or activity restriction to reduce the spread of COVID-19 cases is assumed to improve air quality in highly populated cities. The effect of lockdown on air quality is often quantified by comparing pre- and during-lockdown air quality parameters without considering confounding meteorological factors. We demonstrated that rainfall can explain changes in PM10 and PM2.5 parameters in the city of Jakarta during lockdown. This article shows that comparing air quality pre- and during lockdown is misleading. Variables affecting air quality such as meteorological variables should be taken into account. The air quality in Jakarta as measured by PM10 and PM2.5 did not change significantly during the lockdown period after removing the seasonal effect.

The global COVID-19 pandemic has highlighted the close connection between human health and the environment (Coccia, 2021a; Marquès and Domingo, 2021). The governments of each country have carried out various lockdown strategies to contain the spread of COVID-19. Restrictions on human activities during the lockdown purportedly have contributed to the reduction of global carbon emissions. Le Quéré et al. (2020) estimated that the world's CO_2 emissions were decreased by 17% due to the COVID-19 lockdowns. These lockdowns offered real-world data to quantify the effect of reduced human activities on air quality. During lockdowns, the decrease in human mobility and economic activities was assumed to reduce air pollutants due to less traffic and less industrial activities. As there is a correlation between outdoor air pollution and the incidence and severity of COVID-19 (Marquès and Domingo, 2021), there is a large number of studies were published within a short period demonstrating the effect of lockdown on improved air quality (e.g., Coccia, 2021b; Chen et al., 2021a, 2021b; Dabbour et al., 2021; Mahato and Ghosh, 2020). According to the Scopus database with keywords: "COVID", "lockdown", and "air quality", as of October 2021, 190 papers were published in 2020 and 526 papers in 2021. However, many of these studies, including some published in *Environmental Research* are based on short term (1–2 months) comparisons of air quality before and during lockdowns, such as Shukla et al. (2021) in India, and Anugerah et al. (2021) in Jakarta, Indonesia.

Air quality is highly affected by seasonal variation and meteorological variables, and thus comparing pre- and during-lockdown air quality parameters might just highlight seasonal differences. Thus, conflicting results on the effect of lockdown air quality were reported. For example, Wibowo (2021) and Santoso et al. (2021) reported a decrease in PM2.5 concentration in Jakarta during the lockdown, while Anugerah et al. (2021) observed that the PM10 concentration in Jakarta increased by 10.9% compared with the pre-lockdown period.

A large number of papers were published rapidly in the wake of the novelty of the pandemic, and thus many of the studies suffered from a lack of a deeper analysis considering temporal variation and drivers of air pollutant concentrations such as meteorological variables. For example, the study of Collivignarelli et al. (2020) compared air quality in the city of Milan, Italy before and during the lockdown in 2020 and showed a significant reduction of air pollutants concentration. This highly cited paper (more than 200 citations according to Scopus in October 2021) did not analyze the confounding meteorological factors. Fig. 1 shows PM2.5 data (expressed as Air Quality Index/AQI) for an air monitoring station in Milan, Italy (Milano Pascal Citta Studi, downloaded from https://aqicn.org/) highlighting the period of pre-lockdown (or control, CTRL, February 7, 2020 to February 20, 2020), partial lockdown (PL, March 9, 2020 to March 22, 2020) and total lockdown (TL, March 23, 2020 to April 5, 2020) as defined by Collivignarelli et al. (2020). The figure shows a decline in PM2.5 from February (CTRL) to March and April or the lockdown period. However, this trend of decreasing air pollution is just a natural seasonal pattern as rainfall in Milan increased from February to April (average monthly rainfall: 61, 72, 103 mm, respectively). Etchie et al. (2021) recently highlighted that air quality changes in Nigeria during the lockdown period were due to seasonal variation not caused by the lockdown itself. Gkatzelis et al. (2021) acknowledged the need to correct meteorological corrections for investigating change but did not show the effect of seasonal variation.

This article highlights that reported changes in air quality due to COVID-19 lockdowns could be due to the short-term monitoring that do not take into account the seasonal variability of air quality in the analysis. We demonstrate the case of Anugerah et al. (2021) on the air quality of Jakarta, but our results are relevant to other studies. This article is presented as follows. First, long-term data of air quality is shown to vary seasonally within a year and between years. Second, the calculation of changes using pre and during lockdown values is shown to

; PM2.5, Particulate Matter less than 2.5 microns; PM10, Particulate Matter less than 10 microns; COVID-19, **Co**rona**vir**us**d**isease of 20**19**.

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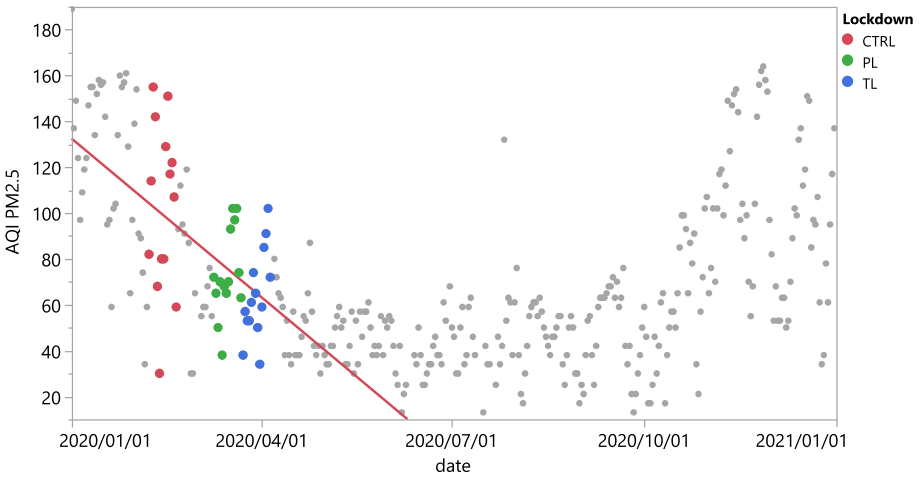

Fig. 1. PM2.5 data of Milano Pascal Citta Studi in 2020. The red dots represent the control period, the green period was partial lockdown (PL) and the blue dots were total lockdown (TL). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

be misleading. Third, the importance of taking meteorology into account by using long-term data is discussed. Finally, the letter provides some implications and recommendations for future work.

1. Air pollution and seasonal variation

The air quality in Jakarta is analyzed similarly to Anugerah et al. (2021). Unfortunately, we do not have access to all of the Anugerah et al. data, but we have a subset of PM2.5 and PM10 data. Jakarta is one of the most populated and polluted cities in the world. According to the Köppen classification, the climate of Jakarta is tropical monsoon with an annual rainfall between 1800 and 2100 mm. The daily PM2.5 and PM10 data were downloaded from Air Quality Historical Data Platform (https://aqicn.org/). The data were from stations of Central and South Jakarta USA consulates. The two stations' daily data were averaged and used for analysis. Note that the data from AQICN reported PM2.5 as Air Quality Index (AQI). PM2.5 values were not available and were already converted to AQI using the US EPA standard. AQI values range fom 0 to 500, the higher the AQI value, the greater the level of air pollution. AQI values above 100 indicate that the air quality is unhealthy. All data analysis were carried out using JMP Pro 14.2.0 (SAS Institute Inc.).

Fig. 2 shows that PM2.5 and PM10 varied annually, and within each year also varied monthly. The particulate pollutants (PM) were seasonal, lower in the rainy season (Dec–March) and peaked in the dry season (June–July). In particular, there were many data gaps or unrecorded PM10 data prior to mid-2019.

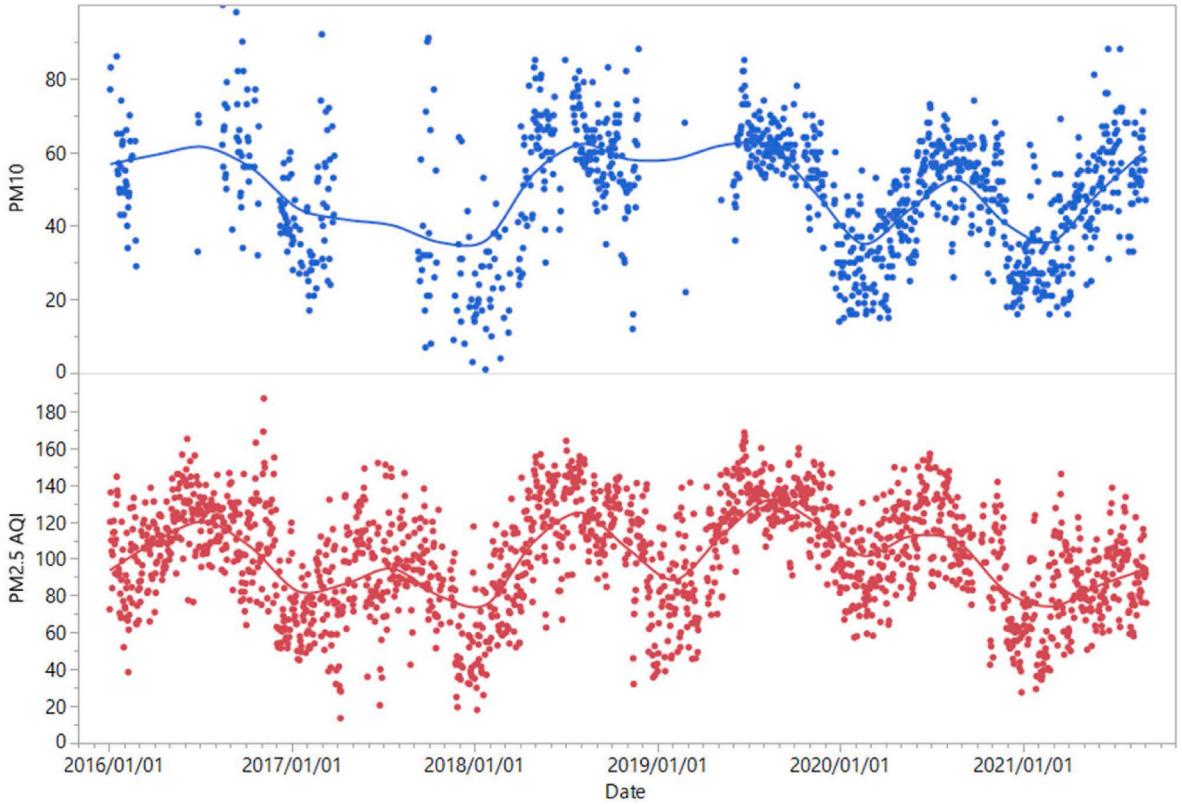

Fig. 2. Daily PM2.5 and PM10 data in Jakarta from January 1, 2016 until December 31, 2020.

2. Calculating changes using pre and during lockdown values

In Indonesia, the large-scale COVID-19 lockdown was implemented from April 10 until June 4, 2020, a period of 56 days. In this letter, the pre-lockdown period was defined as 56 days before the lockdown started to allow a fair comparison. Fig. 3 shows the PM2.5 and PM10 concentrations in 2020, highlighting 56 days before and during the lockdown period. Indeed an increase of PM2.5 and PM10 was observed during lockdown compared to before lockdown, as shown by Anugerah et al. (2021). The mean of PM2.5 pre-lockdown was 93.72 (St. dev = 19.24) and during lockdown it increased to 112.03 (std. dev = 17.23). While for PM10, pre-lockdown was 29.79 (std.dev. = 10.15), and at lockdown 41.31 (std.dev. = 8.43). One would assume that lockdown caused an increase in pollutant levels. Such a trend was reported by Rodríguez-Urrego and Rodríguez-Urrego (2020), who concluded that air quality in Jakarta worsened due to the lockdown. Benchrif et al. (2021) noted that a remarkable increase in PM2.5 concentration despite the lockdown measure. They attributed the increase due to the mobility of vehicles that remained in operation during the pandemic and to using private vehicles instead of public transportation. A close inspection of Fig. 3 shows that this decrease in air quality (increase PM concentrations) was a natural seasonal variation as the city was entering the dry season in June.

3. Addressing seasonal variation of meteorological variable

Fig. 4 presents monthly rainfall and average monthly PM values. The PM2.5 and PM10 data were inversely related to precipitation patterns, with the highest rainfall in January and decreasing each month until it reached the driest month in August (Fig. 4). This observation explained why Anugerah et al. (2021) and other authors observed that lockdown caused an increase in PM concentrations in Jakarta. The rainfall in February 2020 was 1043, March: 220 mm, April: 183 mm and May: 50 mm, respectively. The increase in PM10 and PM2.5 was mainly due to lower precipitation during the lockdown period. The estimation using the paired *t*-test by Anugerah et al. (2021) suffered from confounding meteorological variables that directly affecting air quality. Thus, reported air quality changes were not due to lockdown but a pure seasonal variation.

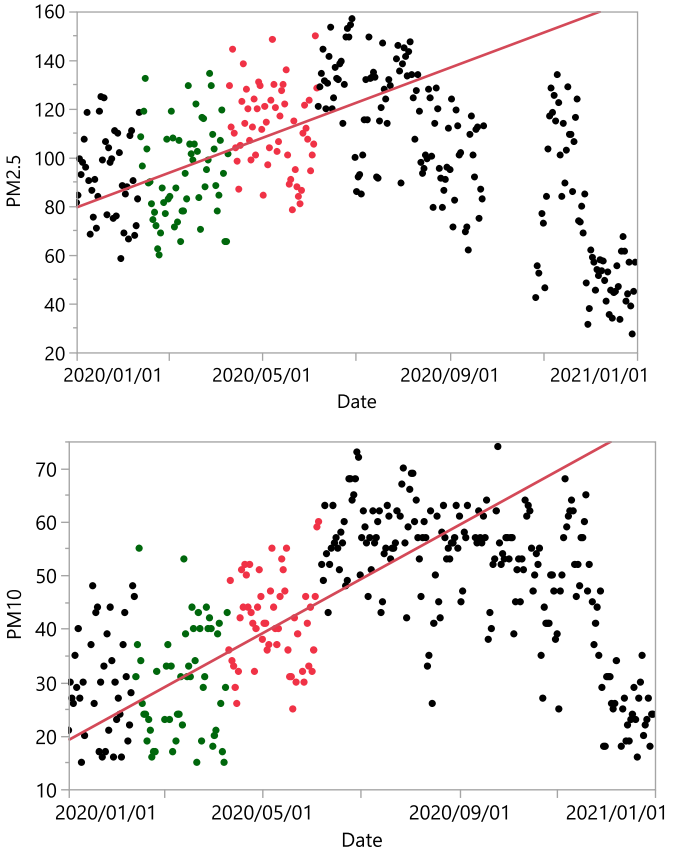

Fig. 3. Daily PM2.5 and PM10 of Jakarta in 2020. The green dots represent the pre-lockdown period and the red dots represent the pre-lockdown period. The line represents a linear trend between pre and during lockdown period. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

To control for these effects, the air quality could be compared based on long-term averages pre-COVID-19 period as a comparison or removing the effect of meteorological variables. Table 1 shows PM10 and PM2.5 values during the lockdown and pre-lockdown period from 2016 to 2020. For PM10 data, there were only data for 2018–2020. The table shows that the PM10 and PM2.5 values during the lockdown period in 2020 were not statistically different from previous years. In this example, the air quality data at the same period over the past years were assumed to represent a long-term mean. Nevertheless, the climate also varies annually and is affected by global circulation, such as El-Nino. Studies such as Kolluru et al. (2021) and Rudke et al. (2021) compared air quality values during lockdown with the corresponding period in 2019. As shown in the example, comparing 1–2 previous years could also present some uncertainty. The meteorological data that were available in Jakarta were monthly rainfall, wind speed, temperature, humidity, and sunshine hours. Rainfall had a significant negative correlation coefficient to PM10 and PM2.5 concentrations ($r = -0.52$, -0.43, respectively, $P < 0.001$), and humidity ($r = -0.27$, -0.31, $P < 0.05$) While wind speed is reported to control air quality (Coccia 2021a, 2021b), and had a negative correlation with PM concentrations, ($r = -0.20$, -0.14), it is not statistically significant. In tropical humid countries, rainfall is the main driver of air quality parameters. Future work requires daily data taken together with the PM concentrations to take into account these factors when estimating changes.

4. Conclusion and recommendation

This letter pointed to limitations of past studies and comparing air quality pre- and during lockdown is misleading. Variables such as air quality vary seasonally, and meteorological variables, in the case of Jakarta was rainfall, should be taken into account. The air quality in Jakarta as measured by PM10 and PM2.5 did not change significantly during the lockdown period. The same was observed in the State of São Paulo, Brazil (Rudke et al., 2021).

Future studies need to take into account confounding meteorological factors in the model. Machine learning approaches such as Ryan et al. (2021) can be used to calculate baseline time series of air pollutants based on long-term (10–15 years) historical data to detrend the time series. Opportunities in big data and machine learning considering all environment and meteorology factors may be beneficial in analyzing such data (Ryan et al., 2021; Dickshit et al., 2021; Padarian et al., 2020; Lovrić et al., 2021; Ma et al., 2019).

We discussed our results based on the paper of Anugerah et al. (2021), but this example is not a single case, as many studies compared air quality between pre- and during lockdown. Based on this example, we conclude that air quality changes during lockdowns were not as large and as significant as reported by many studies. The empirical evidence suggests that the lockdown itself cannot significantly decrease air pollution in highly-populated and polluted cities such as Jakarta as fossil fuel usage and industrial activities were not significantly reduced. In addition, there are also many studies that link the incidence of COVID-19 cases with air quality parameters and meteorological variables without considering the seasonal effect (Kolluru et al., 2021). Those studies need careful interpretation as well as needing interdisciplinary approaches (Bontempi, 2020).

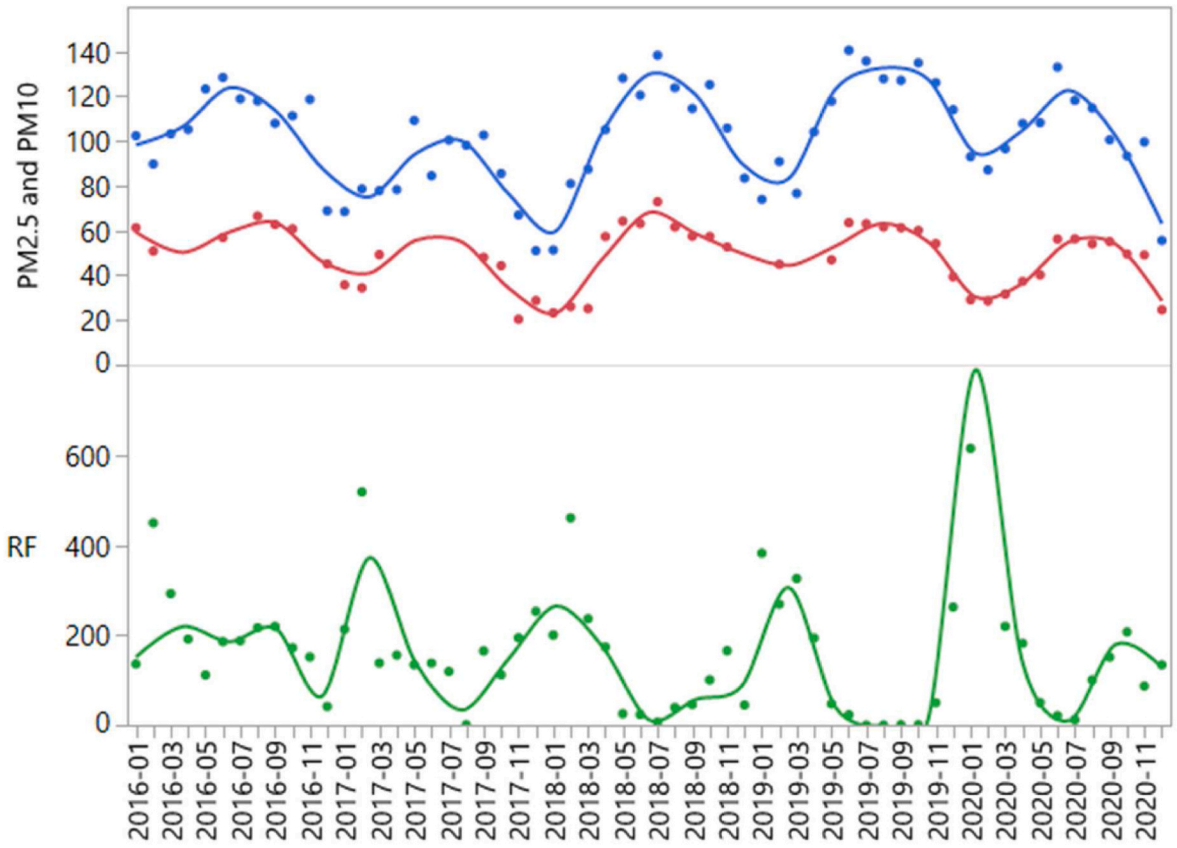

Fig. 4. Monthly PM2.5 and PM10 values and rainfall from January 2016 to December 2020.

Table 1
Air quality in Jakarta during lockdown and pre-lockdown period based on Julian days for 2016 to 2020. Means with the same letter are not significantly different according to *t*-test (p = 0.05).

	Lockdown period			Pre-lockdown period		
	Mean	Std. dev.		Mean	Std. dev.	
PM10, 2018	63.0	13.6	a	39.0	40.4	ab
PM10, 2019	50.0	2.6	bc	45.0	32.5	ab
PM10, 2020	40.7	7.7	c	29.5	10.2	b
PM2.5, 2016	117.7	16.3	ab	101.5	19.4	a
PM2.5, 2017	102.3	23.9	c	75.3	26.4	d
PM2.5, 2018	122.8	21.8	a	84.8	22.0	bc
PM2.5, 2019	113.9	21.9	b	84.8	25.7	bc
PM2.5, 2020	110.7	18.3	b	92.7	19.0	b

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Alana Jakob*
BioEnvirometrics Research, Suite 110, Jl. Pangeran Jayakarta No. 70, Jakarta Pusat, Daerah Khusus Ibukota Jakarta, 11110, Indonesia

Saberina Hasibuan
Environmental Quality Laboratory Department of Aquaculture Faculty of Fisheries and Marine Sciences, University of Riau, Pekanbaru, Indonesia

Dian Fiantis
Department of Soil Science, Faculty of Agriculture, Andalas University, Kampus Limau Manis, Padang, 25163, Indonesia

* Corresponding author.
E-mail address: alana.jakob@protonmail.com (A. Jakob).