



COVID-19 Restriction Movement Control Order (MCO) Impacted Emissions of Peninsular Malaysia Using Sentinel-2a and Sentinel-5p Satellite

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Abstract

The unprecedented outbreak of Coronavirus Disease 2019 (COVID-19) has impacted the whole world in every aspect including health, social life, economic activity, education, and the environment. The pandemic has led to an improvement in air quality all around the world, including in Malaysia. Lockdowns have resulted in industry shutting down and road travel decreasing which can reduce the emission of Greenhouse Gases (GHG) and air pollution. This research assesses the impact of the COVID-19 lockdown on emissions using the Air Pollution Index (API), aerosols, and GHG which is Nitrogen Dioxide (NO₂) in Malaysia. The data used is from Sentinel-5p and Sentinel-2A which monitor the air quality based on Ozone (O₃) and NO₂ concentration. Using an interpolated API Index Map comparing 2019, before the implementation of a Movement Control Order (MCO), and 2020, after the MCO period we examine the impact on pollution during and after the COVID-19 lockdown. Data used Sentinel-5p, Sentinel-2A, and Air Pollution Index of Malaysia (APIMS) to monitor the air quality that contains NO₂ concentration. The result has shown the recovery in air quality during the MCO implementation which indirectly shows anthropogenic activities towards the environmental condition. The study will help to enhance and support the policy and scope for air pollution management strategies as well as raise public awareness of the main causes that contribute to air pollution.

Keywords COVID-19 · Air pollution · Lockdown · Sentinel · Satellite remote sensing

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1 Introduction

Since December 2019, the world has been shocked by an ongoing pandemic of a new coronavirus disease (COVID-19) that is caused by a novel coronavirus officially known as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). This virus is a new addition to the coronavirus family along with SARS-CoV in 2002–03 and Middle East respiratory syndrome coronavirus (MERS-CoV) which occurred in 2012 (Čiviljak et al. 2020). The outbreaks of this pandemic started in mid-December 2019 in the city of Wuhan in the province of Hubei, China with a population of 11 million people (Li et al. 2020; Al-Kindi et al. 2020). The aggressive virus spread across China in just 30 days (Wu and McGoogan 2020) and infected almost 72 countries worldwide in less than 3 months (Chinazzi et al. 2020). Due to the fact that the number of cases was increasing worldwide, the World Health Organization (WHO) declared COVID-19 as a pandemic on 12th March 2020. As of 8th May 2020, there were 3,759, 967 confirmed cases with 259,474 deaths worldwide (WHO 2020). With the advancement of technology in the medical field, COVID-19 is currently under control.

Based on the report from the Ministry of Health Malaysia (2020), the earliest COVID-19 cases detected in Malaysia were on 25th January 2020 and the cases escalated with new clusters detected from time to time (Talib et al. 2021). To break the chain of the outbreak, the Malaysian government decided to implement a Movement Control Order (MCO) starting with Phase 1 on 18th March 2020 reaching Phase 4. The first 3 phases of the MCO implementation were very strict, involving the restriction of several activities and only allowing essential services to operate Malaysian National Security Council (NSC 2020). Despite the significant restrictions on people's lives the MCO implementation was considered to have had some benefits in terms of reducing industrial emissions and traffic congestion. It is, therefore, believed that the environment in Malaysia was positively affected by the MCO implementation. Hence, this study seeks to assess the effect of global emissions on Malaysia during MCO Phases 1–4 using Sentinel Satellite Imagery. The reference of the date of MCO can be seen in Table 1 where the date of MCO is within two weeks, to reduce the movement.

Table 1 Date of MCO complete lockdown in Malaysia

| | Date of MCO |
|-------|----------------------|
| MCO 1 | 18th–31st March 2020 |
| MCO 2 | 1st–14th April 2020 |
| MCO 3 | 15th–28th April 2020 |
| MCO 4 | 29th–12th May 2020 |

Numerous epidemiological studies have shown that exposure to particulate matter of 2.5 microns or less in diameter (PM_{2.5}) both over short- and long-term periods are closely related to emissions such as air pollution (Liu et al. 2017). Several recent studies and reports have proven that the current COVID-19 pandemic is a global crisis and needs immediate proactive measures in order to tackle the issue (Lauri 2020; WHO 2020). However, while the world is tackling the increased risk of COVID-19, with many countries declaring lockdowns and restricting the movement of people within and between countries, a number of reports have identified cleaner air and reduced pollution as positive impacts of the implementation of these controls. Air quality in Malaysia was affected by COVID-19 lockdowns and has been further impacted by changes in global emissions. Sicard et al. (2020) show that observed decreases in particulate matter (PM) were due to the reduction in transport and fuel combustion in institutional and industrial buildings, but these were partially offset by increases in PM pollution from home activities in some cities. Good air quality is very important to the environment and the planet as a whole. In addition, air pollution which is also caused by road traffic is mainly due to human activities regardless of the implementation of the MCO. Thus, limited movement and human activities will not just lead to a less polluted environment but also contribute to a reduction in GHG emissions, and thus affect the earth's temperature. According to a report by Lauri (2020), the carbon emission in China fell by 25% in February 2020 compared to February 2019.

Malaysia has pledged to achieve net-zero GHG emissions 4as early as 2050. In addition, Malaysia's Prime Minister, Datuk Seri Ismail Sabri Yaakob targeted to reduce the intensity of greenhouse gas emissions across the economy by 45% based on the Gross Domestic Product (GDP) by 2030. According to the country's aspiration to ac, A local study assessed the air quality status before and during the 2020 MCO period in Malaysia using Air Pollution Index (API) data from the Department of Environment Malaysia (Abdullah et al. 2020). The data were examined on an hourly basis to track changes in PM_{2.5} at 68 air quality monitoring stations. It was found that the 2020 MCO period resulted in a reduction (up to 58.4%) in PM_{2.5} concentrations in Malaysia. Bernama online report's headline on 2020, April 19 stated "MCO breathes new life into the environment" it showed that it is not only bringing a new life for the people and society but also to the environment. Further, the second highest contributor of carbon dioxide (CO₂) in Malaysia was 23% had fallen gradually due to the 2020 MCO which ended up in lesser vehicle smoke and industrial activities. The API index had been utilized in Malaysia, which consists of concentrations of six air pollutants: NO₂, SO₂, PM_{2.5}, PM10, carbon monoxide (CO) and O₃. In a comparison of the air quality index (AQI) that had been specified by US EPA Standard

with API Index, both use the same six pollutants and the most dominant pollutant (Chloe 2021).

Most of the related studies have reported and analyzed the impact of MCO on the pollutants concentrations such as found by Abdullah et al. (2020). However, the overview of MCO impacted pollutant concentrations globally is still vague. With the potential imaging and mapping from remote sensing satellite images like Copernicus Sentinel-5P such as found in Dutta et al. (2021) and Vîrghileanu et al. (2020), more realistic pollutants distribution can be demonstrated; thus, the overview of pollutant's condition before and during MCO such as NO₂ and aerosols at the local area can be more significant to be revealed and justified. In this study, the use of a machine learning approach for data extraction from satellite images also brings more sophisticated, value-added, and meaningful outcomes, where the detailed time-based pollutant concentrations can be acquired and analyzed. Thus, the impact of MCO on pollutant concentrations can be more informative and monitored continuously.

Thus, the 2020 MCO period had some effect in reducing carbon emissions and PM2.5 air pollution. Here, we

examine API data for the period before and after the MCO was enforced and its effect on air pollution. To strengthen the new knowledge about the research on the impact of the COVID -19 pandemic, this study examines the effects of global emission on Malaysia during the MCO using Sentinel Satellite Imagery.

2 Methodology

2.1 Study Area

The study area is in the Selangor and Wilayah Persekutuan District, Malaysia located at coordinates 3.0738° N and 101.5183°E, as shown in Fig. 1. This area is located in the western part of Malaysia and has a large amount of industrial development which is suitable for air pollution research. Controlling and improving the development environment is the foundation for implementing and promoting the area around Selangor and Kuala Lumpur, Malaysia as a center for urbanization and tourism.

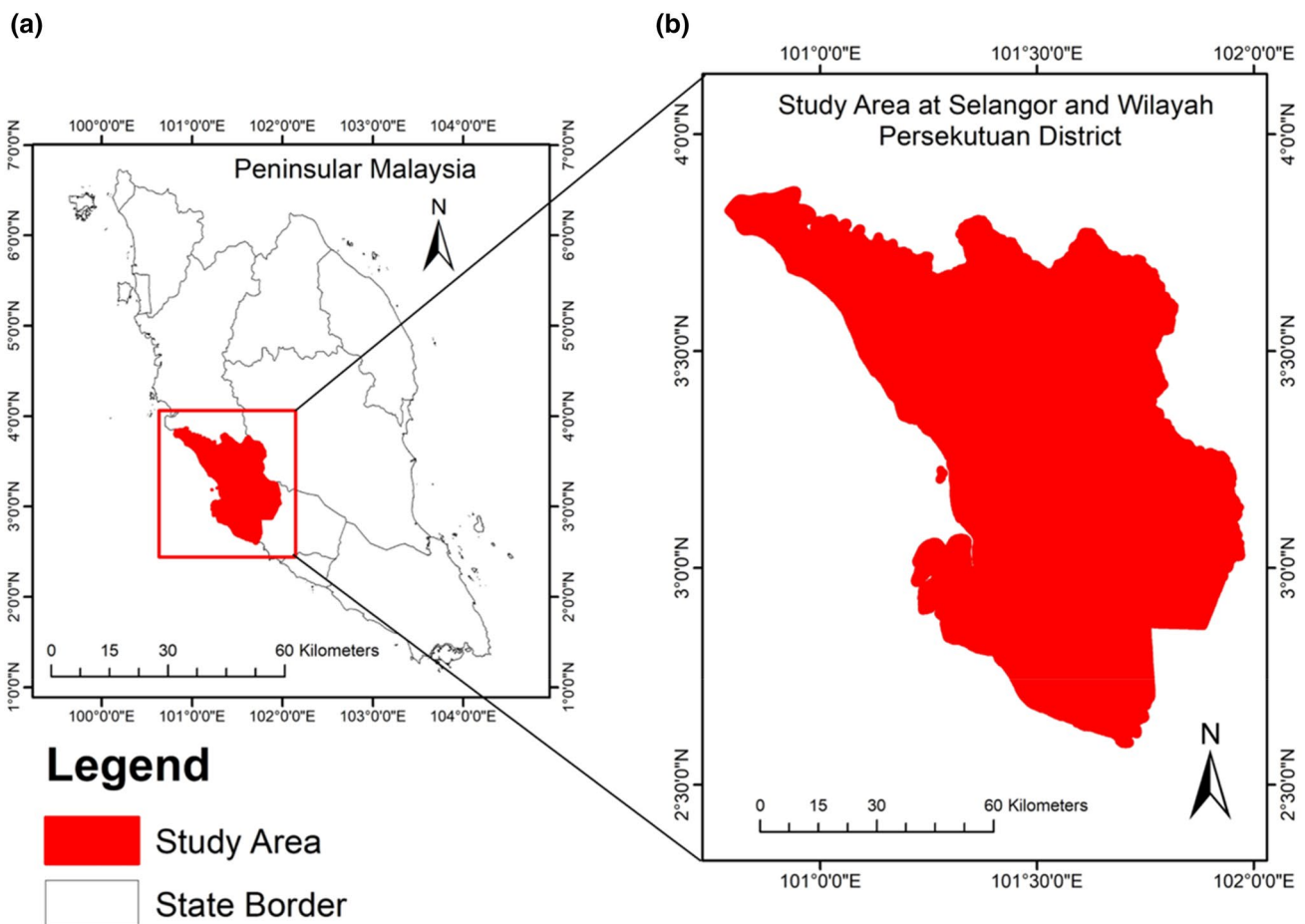


Fig. 1 Geographical description of the study area; a Peninsular Malaysia, b Selangor District (Sentinel-2A)

Therefore, Selangor and Kuala Lumpur were chosen as research areas being suitable for air pollution research before and after the MCO lockdown.

2.2 Data Preparation and Management

2.2.1 Data Acquisition

Sentinel-2A and Sentinel-5p were used in this research. Sentinel-2A that had been used has 10 m spatial resolution operated by European Space Agency (ESA). The data that were downloaded are from the different months, which are December 2019, January 2020, March 2020, and May 2020. The acquired data can be in two formats which are JPEG2000 format and GeoTIFF format. Sentinel-5p products are only accessible through the Sentinel-5p Pre-Operations Data Hub. The data were downloaded in Copernicus Open Access Hub where this project targeted the production of a study area map. The Copernicus Sentinel Satellite constellation provided Copernicus Sentinel-5 Precursor to monitor the atmosphere. The specification of Sentinel-5p is illustrated in Table 2.

2.2.2 Data Preparation

Data preparation involved data extraction identification for pollution emission monitoring in the study area that including Sentinel-2A and Sentinel-5p imagery. The data around Selangor and Wilayah Persekutuan District were extracted for the year 2019, before the implementation of the MCO and for 2020 which was taken during and after the lockdown period to compare the emission of pollutants and to monitor the distribution of nitrogen dioxide and aerosols. Based on the studies, the location of urban areas like Selangor and Wilayah Persekutuan District is relatively related to the issue of air pollution emission.

2.2.3 Data Collection

The data collection involving air quality monitoring for this project was accessed from Sentinel satellites that provide free data including Sentinel-2A and Sentinel-5p. Thus, these data were obtained from different sources like USGS Earth Explorer and Copernicus Sentinel Satellite Constellation based on a certain period time following the lockdown order. Due to the difference in monitoring stations at different times, the images taken markedly influence the interpolation results.

For this study, the Sentinel-2A data were downloaded from the USGS Earth Explorer to extract the image of the study areas. The data that had been downloaded were from different months such as December 2019, January 2020, March 2020 and May 2020. The purpose of the selection for these four month is because, between December 2019 and January 2020, the COVID-19 cases just started and no MCO, while on March 2020, the MCO was started, when the cases increased. During May 2020, the cases lower down, therefore there is no MCO was done. The acquired data was obtained in two formats, JPEG2000 and GeoTIFF. Thus, to derive the findings of this study, GeoTIFF format L1C_T47NQD_A023610_20191230T033757 was downloaded as presented in Fig. 2.

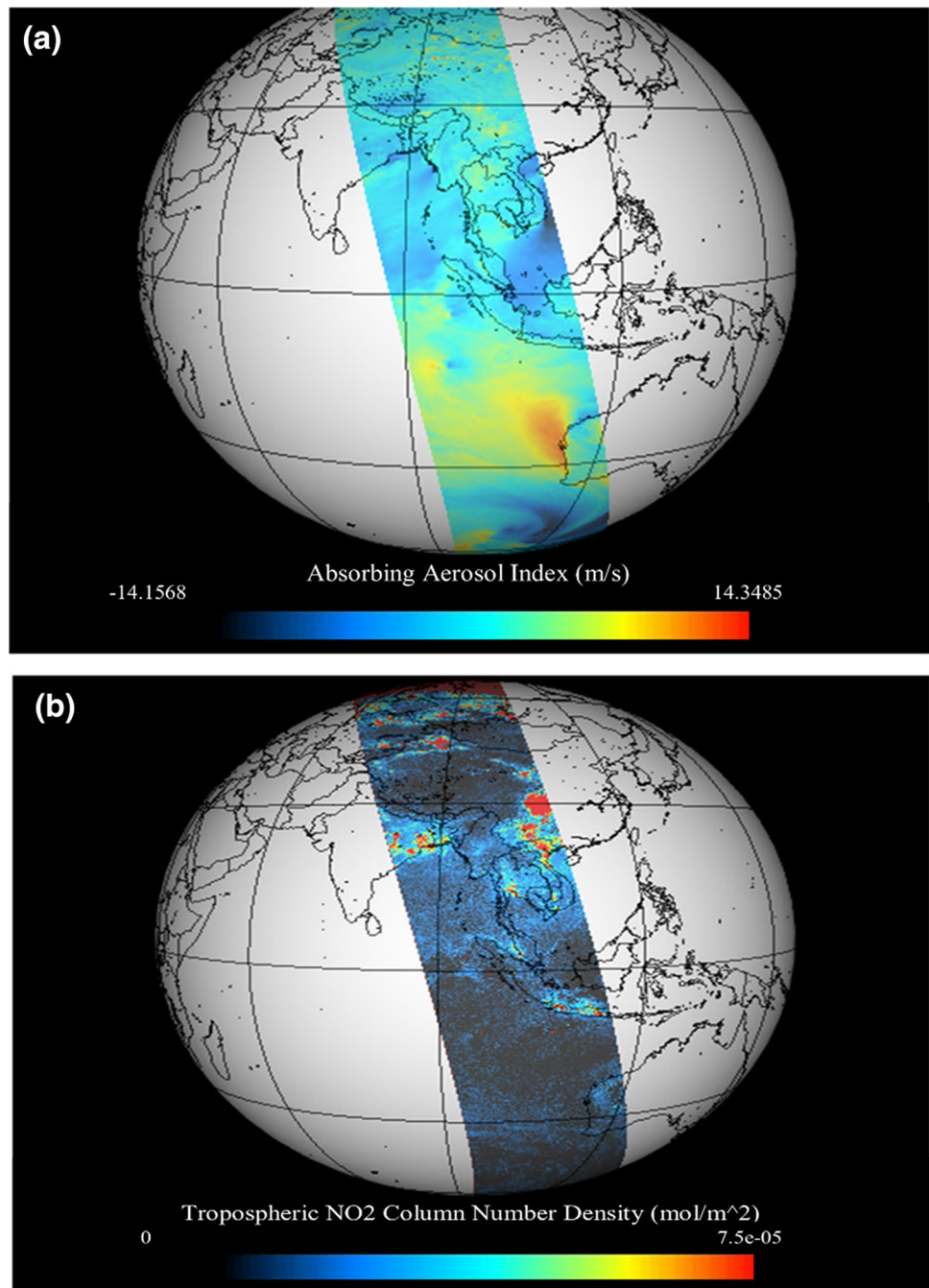
The Copernicus Sentinel Satellite constellation provided Copernicus Sentinel-5 Precursor to monitor the atmosphere. It also performs atmospheric measurements with a high spatio-temporal resolution for an air quality index and pollution emissions. This is obtained from the Sentinel-5P Pre-operations Data Hub for the sensing period from 1/12/2019 to 31/1/2020, from 1/3/2020 to 31/3/2020, and from 1/5/2020 to 31/5/2020 for the nitrogen dioxide (NO₂) and aerosol (AER) product types to measure the spread of polluted air during the lockdown period.

The air pollutant index is determined based on the average of the most dominant pollutants, including PM_{2.5}, PM₁₀ and ozone over a period of 24 h. The best practice is

Table 2 Data of API interpolation

| Bil | Latitude | Longitude | Location | Average 2019 | Average 2020 |
|-----|----------|------------|------------------------------|--------------|--------------|
| 1 | 3.213959 | 101.685665 | Batu Muda | 55 | 51.25 |
| 2 | 3.107113 | 101.724916 | Cheras | 58 | 48.75 |
| 3 | 2.926018 | 101.695243 | Putrajaya | 60 | 50.25 |
| 4 | 3.338375 | 101.245568 | Kuala Selangor | 56 | 46.75 |
| 5 | 3.128038 | 101.588607 | Petaling Jaya | 80 | 51.25 |
| 6 | 3.082356 | 101.544102 | Shah Alam | 78 | 49.25 |
| 7 | 3.046378 | 101.439283 | Klang | 61 | 56.75 |
| 8 | 2.811533 | 101.496162 | Banting | 55 | 48.75 |
| 9 | 2.974044 | 101.472180 | Johan Setia Klang (MCAQM) | 65 | 52.00 |

Fig. 2 A 3D visualization created from wplot in VISAN window application; **a** absorbing aerosol index average, **b** PM 2.5 nitrate dioxide monthly average



to track air quality in real time using hourly data. Hence, to measure and analyze the API before, during, and after the MCO period during COVID-19, the data were acquired from <https://aqicn.org/city/kuala-lumpur/>. The API at each of the study areas was completely recorded in Microsoft Excel and its average was computed.

2.2.4 Data Processing

To proceed with the data processing, it requires the images from the satellite need to be processed accurately using the

correct information. Furthermore, data processing is also required to improve the data and eliminate unnecessary

Table 3 Data and parameter

| | Check mission | Product type | Processing level | Timeless |
|------------------|---------------|--------------|------------------|----------|
| Aerosol | Sentinel-5p | L2_AER_AI | L2 | Offline |
| Nitrogen Dioxide | Sentinel-5p | L2_NO2 | L2 | Offline |

Fig. 3 Temporal pattern of air pollution index (API) average at Selangor and Wilayah Persekutuan District

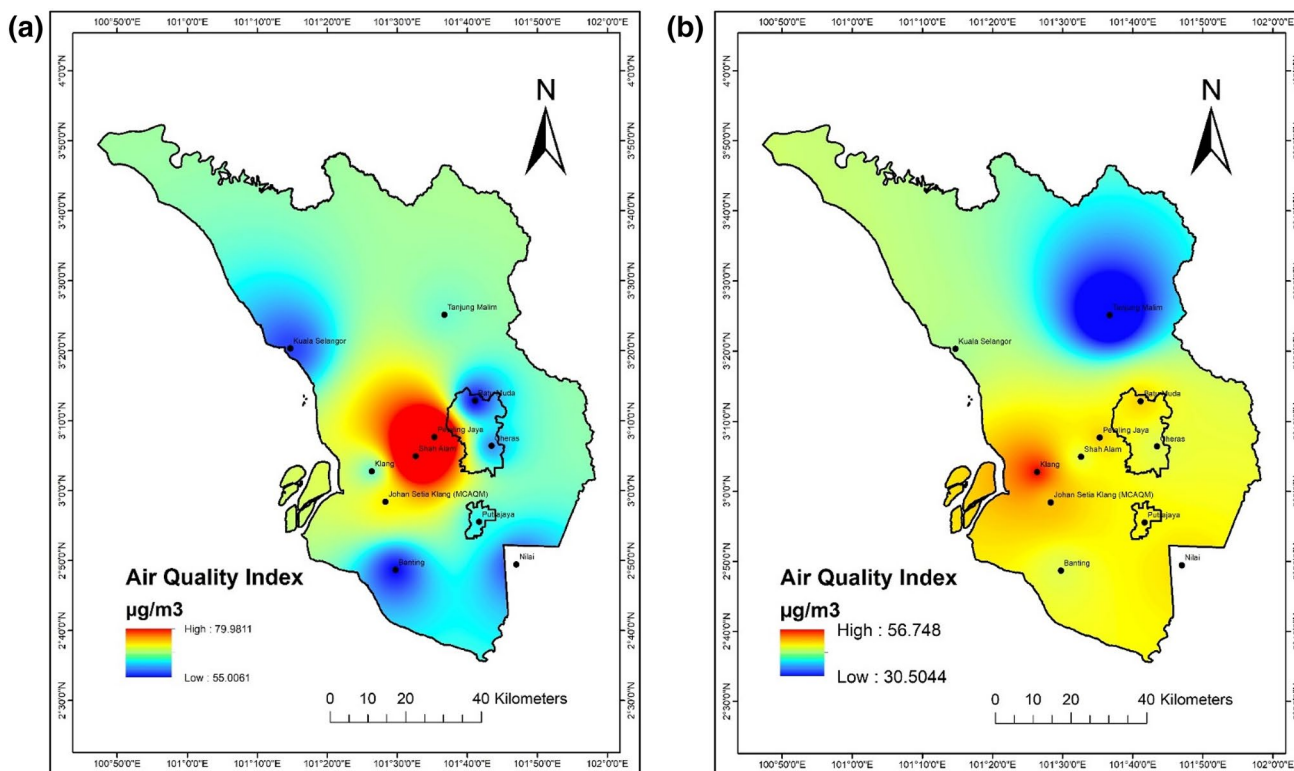
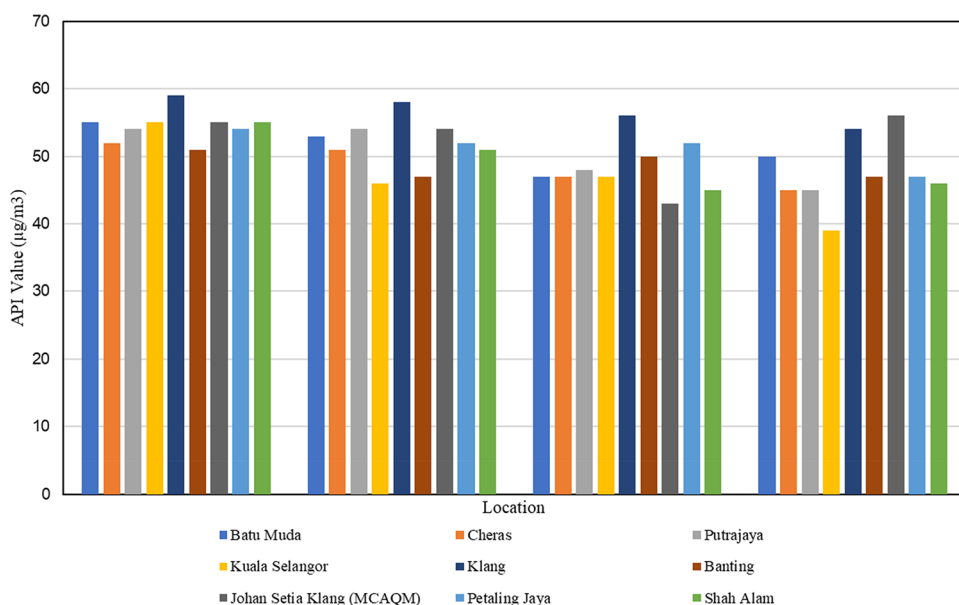


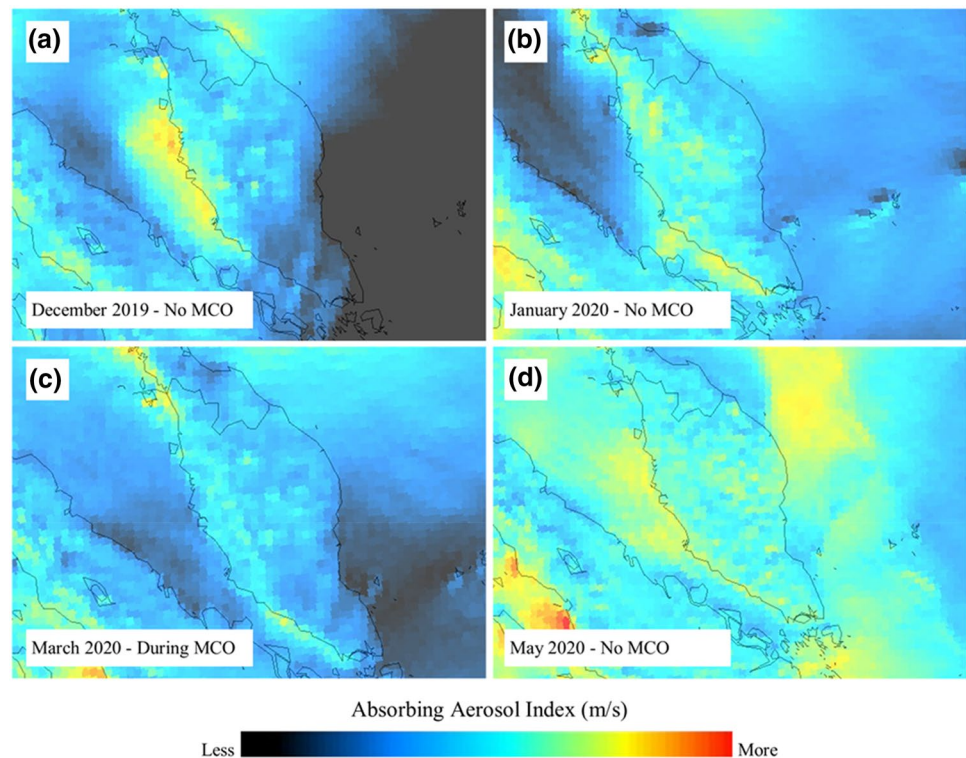
Fig. 4 Interpolation pattern of air pollution index at Selangor and Wilayah Persekutuan District based on year; **a** year 2019 before MCO, **b** year 2020 after MCO

information. In this project, all the data projections are used the WGS 1984 coordinate system.

Geoprocessing of inverse distance weighted interpolation in ArcGIS: The interpolation was made for the interpretation of the average air pollution index especially for the year

2019 before the implementation of MCO and in the year 2020, after the MCO period. In this study, in the aspect of geoprocessing, ArcMap 10.5 software was used for further processing. In Arc Toolbox, spatial analyst tools were chosen and involved the selection of interpolation tools. Then,

Fig. 5 Extrapolation of the effect of pollution absorbing aerosol index (AAI) during COVID-19 lockdown using Sentinel-5P **a** December 2019, **b** January 2020, **c** March 2020, **d** May 2020



the inverse distance weighted (IDW) interpolation method was used because this method provided a more accurate result and presented the nearest value to the minimum and maximum combination from the sample data (Hofstra et al. 2008). For the sample points, air pollution index (API) and average API were used for interpolation before, during and after the lockdown as shown in Table 3. To illustrate clearly, the measurement of the API starts from average API 2019 and average API 2020 and the interpolation of API map was produced to monitor the spreading of harmful air in the atmosphere.

2.2.5 Extrapolate Image in VISAN Application

To monitor the effects of pollution emissions during the COVID-19 lockdown, data from Sentinel-5p are used to visualize and analyze the quality of air from industrial activities in the VISAN application. VISAN is a cross-platform visualization and analysis application for atmospheric data. Air quality monitoring with Sentinel-5p was processed using two types of products—Nitrogen Dioxide (NO_2) and Aerosol (AER_AI)—accessed through the Sentinel-5p

Pre-Operations Data Hub. The data were downloaded via the Copernicus Open Access Hub.

In addition, to analyze the Sentinel-5p data and run the analysis, Basic Envisat Atmospheric Toolbox (BEAT) is used. The main components used are VISAN, Common Data Access toolbox (CODA), and HARP (Harmonization toolset for scientific earth observation data processing). These applications used Python as the means to provide commands to the application. The Python interfaces for CODA and HARP include ingesting product data from VISAN. CODA allows direct reading access to local product files, supporting a wide range of product formats, while HARP is a toolkit for reading, processing and inter-comparing satellite remote sensing data, model data, in situ data, and ground-based remote sensing data. The Sentinel-5P product was navigated to access metadata that contains data as 2D arrays by using aerosol index and nitrogen dioxide tropospheric column for nitrogen dioxide. After visualizing data as an array and 2D graphs, 3D visualization was created using the HARP Import and Python command in the main VISAN window. The data collected are displayed in the form of poles with the properties in the plot window and the changed parameters for

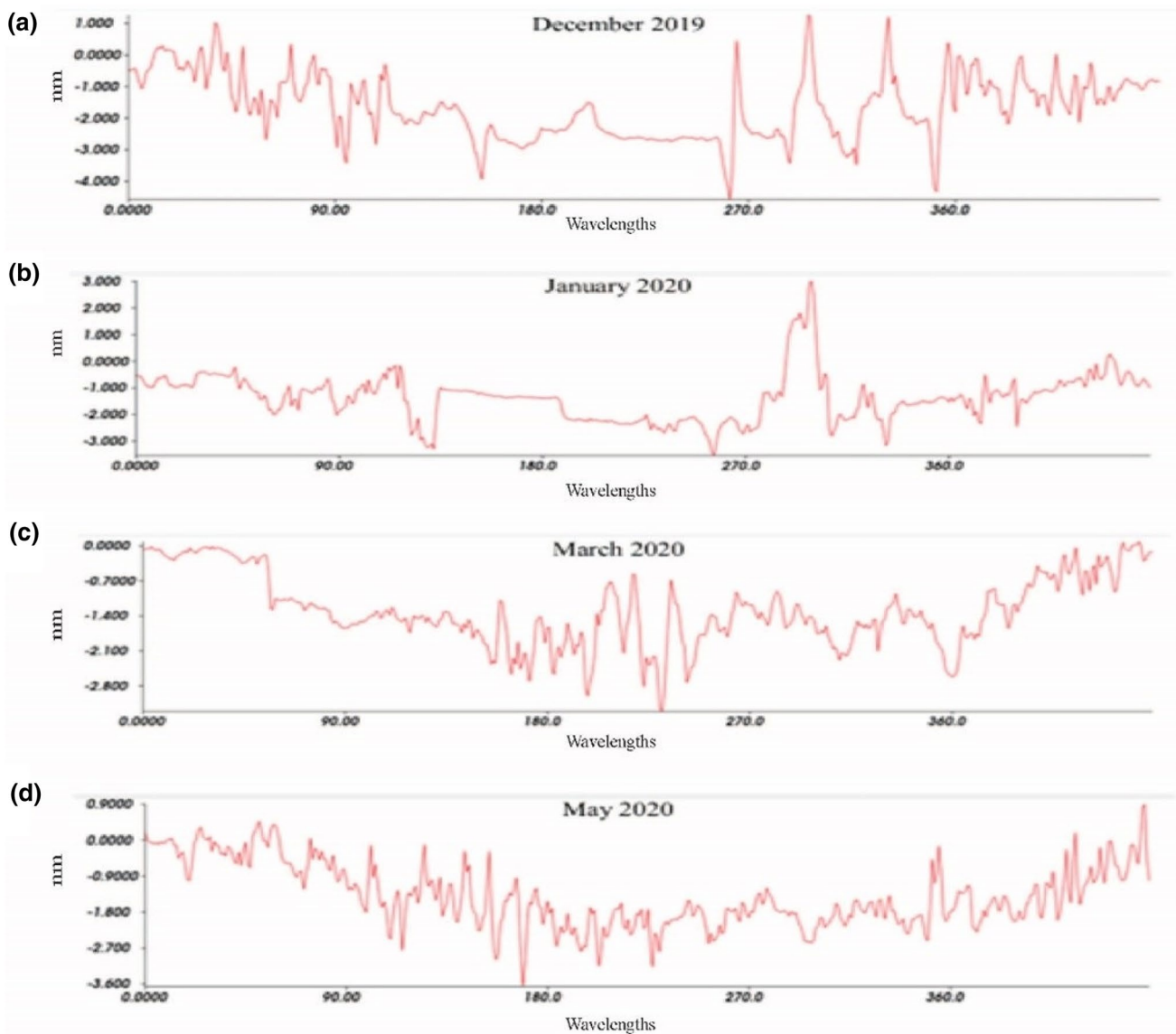


Fig. 6 Absorbing aerosol index in graph bar 2D plot from December to May 2020. **a** December 2019, **b** January 2020, **c** March 2020, **d** May 2020

minimum/maximum data and followed by the color bar from 0 to 0.000075 for nitrogen dioxide (Fig. 2a) and absorbing aerosol index average (Fig. 2b).

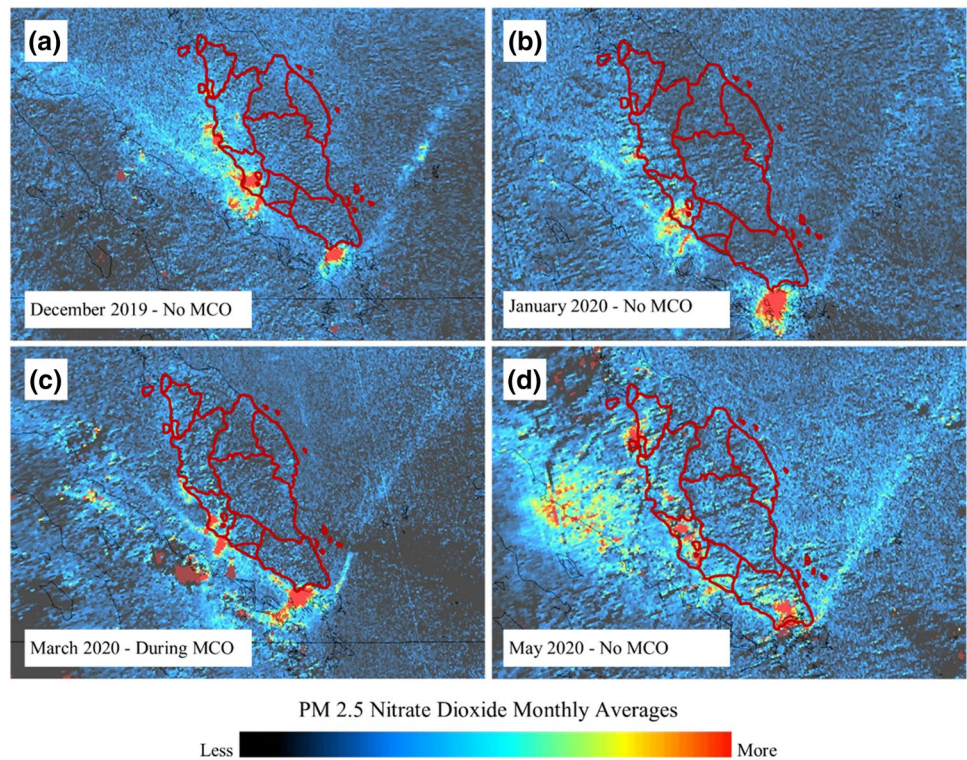
2.2.6 Monitoring Pollution Emission

In this segment, the capabilities of monitoring air pollution emissions in Selangor and Wilayah Persekutuan District using the aerosol and nitrogen dioxide index level 2 product were explored, taking advantage of the Sentinel-5p temporal resolution. Comparing the data before and after the MCO, it is evident that without the implementation of the MCO, the

pollution emissions at Selangor and Wilayah Persekutuan District were becoming the most destructive and polluted environments for residents there.

Extrapolated image data in lockdown air pollution are used to monitor if there is a significant difference between the four months in which involving the implementation and non-implementation of MCO. In this case, it is used to measure different concentrations of harmful gases that affect the quality of air. The method for monitoring air pollution was processed through VISAN application in measuring the concentration of aerosol and nitrogen dioxide throughout the interest.

Fig. 7 Extrapolation of the effect of pollution nitrate dioxide during COVID-19 lockdown using Sentinel-5P. **a** December 2019, **b** January 2020, **c** March 2020, **d** May 2020



3 Results

3.1 Interpolation for Air Pollution Index (API)

As mentioned before, the average API index from the sample data points using ArcMap 10.5 software is collected for the periods before, during, and after the MCO at Selangor and Wilayah Persekutuan District. Figure 3 shows the graph bar of the Air Pollution Index average at Selangor and Wilayah Persekutuan District between these two months. There were 9 sub-districts involved and the highest API was found in Klang.

Figure 4a, b illustrates the air pollution patterns based on IDW interpolation on API at Selangor and Wilayah Persekutuan District during MCO in 2019 and post-MCO in 2020, respectively. The range of API concentration levels in 2019 was computed between 55.006 and 79.981 $\mu\text{g}/\text{m}^3$. However, the range was reduced from 30.504 to 56.748 $\mu\text{g}/\text{m}^3$. It shows that the level of $\text{PM}_{2.5}$, PM_{10} , and O_3 increased during the post-MCO period as the factories start to operate, road traffic starts to increase, and people resume their activities.

3.2 Monitoring of Air Pollution for Aerosol (AER_AI)

To monitor the effect of air pollution during pre-MCO, MCO and post-MCO in Selangor and Wilayah Persekutuan District, the Absorbing Aerosol Index (AAI) was extrapolated in the

VISAN application using Sentinel-5p as shown in Fig. 5a–d, respectively. The differences between the four images show that the concentration of aerosols is reduced in March 2020 (during the MCO) because there was no industrial activity during the MCO. However, in May 2020, the concentration increases again as people resumed their normal routine causing an increase in the AAI as the air became polluted again. Details AAI trends before, during and after the MCO period in December 2019, January 2020, March 2020, and May 2020 were also depicted in Fig. 6a–c, respectively. It is found that the approximate maximum index values were 3 (January 2020) and 0 (March 2020) before MCO and during the MCO period, respectively. While the AAI only increase to 0.9 during post-MCO.

3.3 Monitoring of Air Pollution for Nitrogen Dioxide (NO_2)

Figure 7 shows the impact of air pollution on nitrogen dioxide levels during the COVID-19 lockdown in the Selangor and Wilayah Persekutuan Districts. The differences in the four images shown indicate the lowest levels of nitrogen dioxide in March 2020—during MCO—due to the absence of industrial and other economic activity. However, in May 2020, Selangor and Wilayah Persekutuan District experienced a high level of air pollution again as this activity resumed.

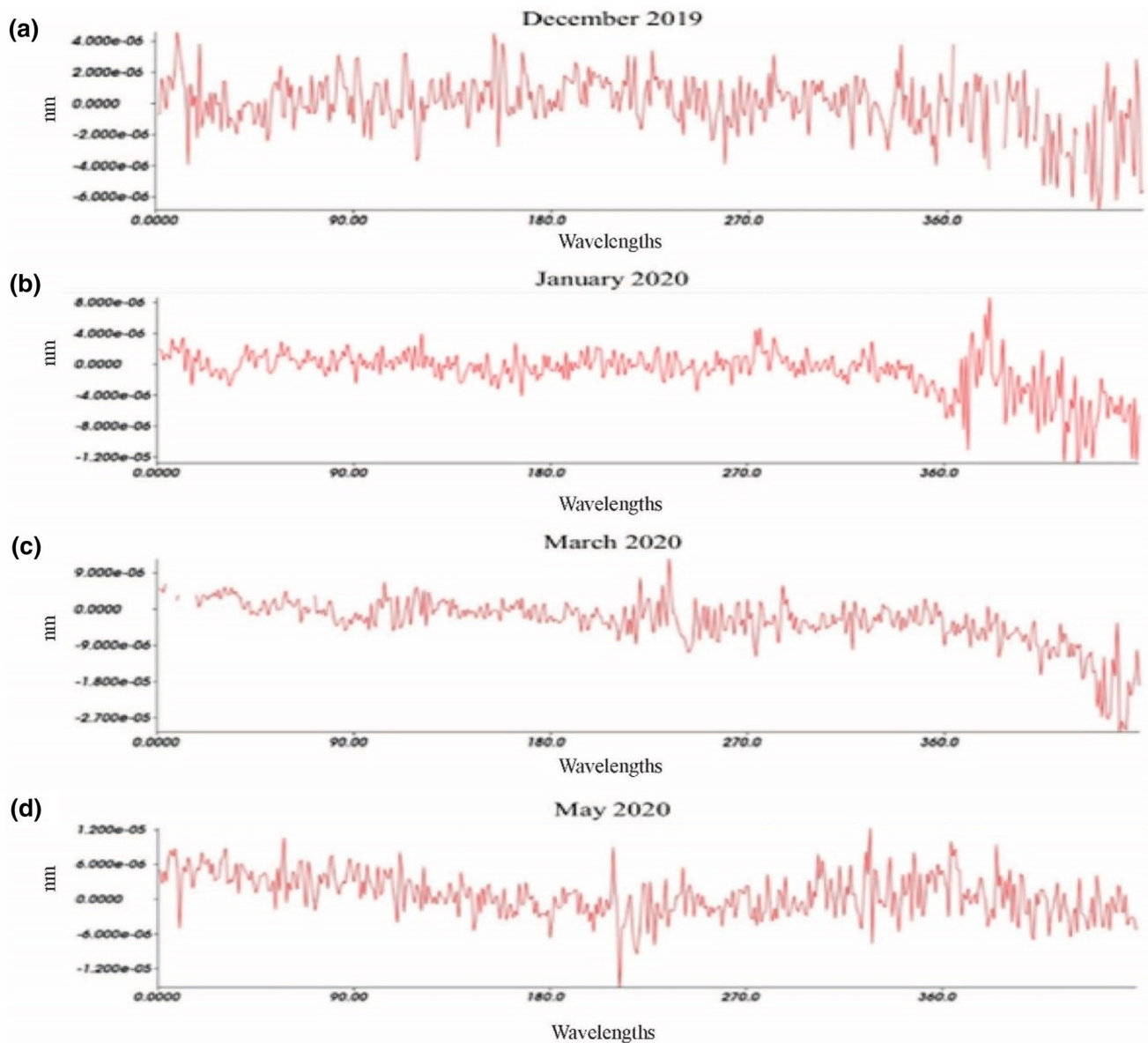


Fig. 8 PM 2.5 nitrate dioxide monthly averages. **a** December 2019, **b** January 2020, **c** March 2020, **d** May 2020

The NO_2 monthly average trends then were depicted in the pre-MCO, during MCO and post-MCO in Fig. 8a–c also for December 2019, January 2020, March 2020, and May 2020, respectively. The NO_2 average trend also was found highest before MCO in January 2020 (Fig. 8b) and the values dropped during MCO period in March 2020 (Fig. 8c).

4 Discussion

As demonstrated by results from several countries, the COVID-19 lockdown resulted in an improvement in air quality during the pandemic. (Hernández-Paniagua et al.

2021; Marco 2020; Nigam et al. 2021). In China, levels of PM2.5 nitrate fell in China's Hubei province after the government-imposed travel restrictions during the lockdown. In addition, a similar pattern was identified across the industrial belt of northern Italy which often experiences high levels of air pollution, where the rate of PM2.5 nitrate decreased during the nationwide lockdown from March 9, 2020 (Hernández-Paniagua et al. 2021). PM2.5 nitrate declined from January 2020 until March 2020 in this country, demonstrating the impact of people's movement on air quality.

Interpolation of an API index map which shows monthly changes and demonstrates that the quality of air

improved in March 2020. However, significant changes in the air pollution quality index also occurred in May 2020 when air pollution increased again. In addition, this study has also proven that the interpolation of the API index showed better results for monitoring air pollution during the period before and after MCO.

The value of the AAI and PM_{2.5} nitrate dioxide monthly average using Sentinel-5p by cross-platform visualization and analysis in VISAN application was used to monitor air pollution before, during, and after lockdown. By comparison, the previous studies also used concentration in the troposphere from the surface. The Sentinel-5p space-borne satellite was used in operating and managing the Copernicus Sentinel satellite constellation. The results from this project were said to be successful from the result of measuring it from a 2D graph bar. That means the results from the AAI and PM_{2.5} nitrate dioxide monthly averages are significant and show a strong relationship to each other.

The results from the interpolation of the API index map for 2019 (before the MCO) and 2020 (after the MCO) indicated that during the lockdown period (March 2020), the air quality improved by an average of 48.3 µg/m³. The final result clearly showed the concentration of aerosols and nitrogen dioxide had decreased in March 2020, measuring <0.00 µg/m³. Consequently, the 2D graph bar provided the measurement value for each according to human daily activities. This demonstrated the improvement in air quality during the lockdown represents a positive impact on the environment.

5 Conclusion

In conclusion, there is a good impact of COVID-19 MCO on global emissions when human activities were restricted by authority due to the outbreak of COVID-19. The integrated satellite remote sensing technology and geographical information system applications can help to monitor and measure the condition of the air quality periodically. The estimation of temporal air pollutants concentrations was able to be mapped and analyzed in larger areas with the use of low spatial satellite images like Sentinel-5P and the capability of spatial interpolation methods like IDW. This study has shown that there was some reduction in PM_{2.5}, PM₁₀, O₃, AAI, and NO₂ during MCO periods due to no industrial activity and other economic activities. However, the concentrations of these pollutants were increase back during post-MCO periods. Thus, it was proven that air pollution was mainly caused by human activities and it can be reduced if anthropogenic activities can be smartly controlled and monitored.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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