*Journal of Sustainability Science and Management*
*Volume 18 Number 11, November 2023: 148-163*

*eISSN: 2672-7226*

# INCONSISTENCY OF AIR QUALITY LEVEL DURING SEVERAL PHASES OF COVID-19 MOVEMENT RESTRICTIONS IN MALAYSIA

SAMSURI ABDULLAH[1]*, NOR HANAN SYAFIQAH CHE ROZALI[1], AMALINA ABU MANSOR[2], AIMI NURSYAHIRAH AHMAD[1], ALI NAJAH AHMED[3], NAZRI CHE DOM[4], MOHAMMAD FAKHRATUL RIDWAN ZULKIFLI[1], SURIANI MAT JUSOH[1], WAN NURDIYANA WAN MANSOR[1] AND MARZUKI ISMAIL[2]

*[1]Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia. [2]Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia. [3]Institute of Energy Infrastructure (IEI), Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia. [4]Centre of Environmental Health & Safety Studies, Faculty of Health Sciences, Universiti Teknologi MARA, UITM Cawangan Selangor, 42300 Puncak Alam, Selangor, Malaysia.*

**Corresponding author: samsuri@umt.edu.my*

*Submitted final draft: 14 July 2023* *Accepted: 22 August 2023* http://doi.org/10.46754/jssm.2023.11.011

**Abstract:** Analysing the air quality during the COVID-19 pandemic is important to evaluate air quality management strategies and plans. This study aims to assess the air quality changes during Movement Control Order (MCO) in Malaysia by investigating air pollutants trends and evaluating the relative changes of air pollutant during different Movement Control Order (MCO) phases. Data from 18 March 2020 to 30 June 2020 was acquired which comprised Sulphur Dioxide ($SO_2$), Carbon Monoxide (CO), Nitrogen Dioxide ($NO_2$), Ozone ($O_3$), and Particulate Matter ($PM_{2.5}$, $PM_{10}$) this was checked on an hourly basis at 65 stations in Malaysia. The data were retrieved from the Department of Environment (DOE). The trend of air pollutants for all parameters decreased during the restricted lockdown phases and increased during the unrestricted lockdown phases. During strict lockdown, the average relative changes for the highest percentage reduction of $PM_{10}$, $PM_{2.5,}$ $SO_2$, $NO_2$, $O_3$, and CO were 61.5%, 63.2%, 51.9%, 35.0%, 66.9%, and 47.3% while highest percentage reduction during unrestricted lockdown with value 23.1%, 29.3%, 38.7%, 9.1%, 56.6%, and 29.4%. In conclusion, there are variations in the levels of criteria pollutants during the different MCOs in Malaysia due to the COVID-19 pandemic.

Keywords: Air quality, lockdown, Malaysia, relative changes.

## Introduction

The initial case of Coronavirus Disease 2019 (COVID-19) was observed in late 2019 and spread exponentially in Wuhan City, China (Zhang *et al.,* 2020). According to Mazinani and Rude (2020), the earliest case occurred at an open market for seafood that is consumed live. It has been described as a zoonotic disease in animals. Some studies suggested that snakes were mentioned as hosts, while bats and pangolins were considered animal hosts by others (Lam *et al.,* 2020; Zhang *et al.,* 2020). They were considered as the root of the infection because the genomic sequences of the coronavirus origin of those two species were identical to COVID-19 (Mazinani & Rude, 2020). This infection was dangerous because of the severe respiratory symptoms caused by the coronavirus of SARS-CoV-2. This catastrophic and novel coronavirus spread rapidly among people in close contact with infected people. COVID-19 caused a severe respiratory infection that could result in pneumonitis or other types of pneumonia with several signs such as fever and dyspnoea (Hashim *et al.,* 2021). The first case of COVID-19 in Malaysia was found on 25 January 2020 [Malaysian Ministry of Health (MOH), 2020]. The spread of these cases increased till now with total cases of 34,173, total active cases of 9168, and total mortality of 253 up to 2 November 2020 (MOH, 2020). A movement control order was the best method to prevent the spread of this pandemic in Malaysia. Several practices, including company operations, were not authorised during the MCO, excluding critical facilities and services [Malaysian National Security Council (NSC), 2020]. The social constraints force function limited the diffuse of COVID-19, especially traffic in several major cities, resulting in sudden and essential changes in air pollutant release trends and severely reduced. This was due to some sectors being closed or running at drastically reduced rates because only critical categories were allowed to operate (Patel *et al.,* 2020).

Air contaminants were produced from numerous sources, including both natural and man-made or anthropogenic activities (Biswas *et al.,* 2020). Air pollution typically comes from three primary roots: Stationary sources, open burning, and transportation sources. Malaysia dominated stationary sources, which contain dust pollution from urban construction work and factories, and mobile sources were pollution from traffic (Halim *et al.,* 2018). Due to this lockdown, decreasing activities reduced the pollution in the air. For the existence of all living things, air was a vital element. Therefore, keeping it clean and secure is important. Anthropogenic activities were a kind of activity that caused the emission of many hazardous substances. The leading cause of ambient air pollution is a high concentration of contaminants that are dangerous to our health (Hashim *et al.,* 2021). The status and level quality of the air was represented in accordance with the Air Pollutant Index (API) of each six criteria pollutant which were Carbon Monoxide (CO), Nitrogen Dioxides ($NO_2$), Sulphur Dioxide ($SO_2$), Particulate Matter ($PM_{2.5}$, $PM_{10}$), and Ozone ($O_3$). Exposure to air pollutants had to be resulted in health implications, such as cardiovascular, gastrointestinal, neurological, and psychological disorders and was a significant contributor to the burden of global illnesses (DeFlorio-Barker *et al.,* 2020; Jung *et al.,* 2021; Khojasteh *et al.,* 2021;). It can be said that 9 out of 10 individuals worldwide are dealing with contaminated air, as reported by the World Health Organisation (WHO) (Zhou *et al.,* 2019). This study was concerned with the changes in the air quality level based on the air pollutants parameters during COVID-19, on the Movement Control Order (MCO) in Malaysia. Air quality analysis has become integral to controlling and preventing air pollution (Ma *et al.,* 2019; Roy, 2021). This study aims to identify the changes in air quality during the COVID-19 pandemic in Malaysia within different periods and phases. Reducing atmospheric particulate pollution could be a useful way to control COVID-19 infection. Stakeholders should pay attention to reducing atmospheric particulate pollution concentrations. Policies to combat air pollution need to be clarified by the Department of Environment, Malaysia when this pandemic occurred. Furthermore, the intended research significantly identifies great improvement in the socio-economic and health aspects in Malaysia. The Health Ministry of Malaysia will receive the benefit of preparing the worst-case scenario when the COVID-19 cases rise as a result of pollutants increase and this study is perfectly in line with the 11th United Nations Sustainable Development Goals 2030 for sustainable cities and communities. This MCO can result in the reduction of pollutants because of the movement restriction by decreasing the emission of contaminants into the air. On 18 March 2020, the Movement Control Order was carried out, forcing the hold of all enterprises, excluding those offering essential services and products. Regulation of the directive has been increasingly tightened, resulting in substantial changes (Khor *et al.,* 2020). The restriction prohibits motion and assemblies at all places worldwide, including ritual religion, and other service demands were discontinued, all commerce premises excluding manufacturers, processing, suppliers, marketers, and food opening.

## Materials and Methods

The study areas cover the 14 states of Malaysia. Table 1 shows all study areas, consisting of 65 Air Quality Monitoring Stations (AQMs). In this study, the parameters involved were Sulphur Dioxide ($SO_2$), Nitrogen Dioxide ($NO_2$), Carbon Monoxide (CO), Ozone ($O_3$), and Particulate Matter ($PM_{2.5}$, $PM_{10}$). All these parameters were acquired from the Department of Environment (DOE) under The Water and Environment Ministry (Halim *et al.,* 2020) by using standard measurement methods to quantify the concentrations. $PM_{2.5}$ concentrations were measured using a Thermo Scientific TEOM 1405-DF, a continuous dichotomous ambient air monitoring system with two Filter Dynamics Measurements Systems. It provides three measurements: $PM_{10}$, $PM_{2.5}$, and PM-Coarse while accounting for volatile and non-volatile PM fractions with accuracy for mass measurement ± 0.75%. $NO_2$, $SO_2$, and CO concentrations were measured using Thermo Scientific Model 42i $NONO_2$-$NO_x$ Analyser, Thermo Scientific Model 43i $SO_2$ Analyser, and Thermo Scientific Model 48i CO Analyser respectively (Ash'aari *et al.,* 2020). As part of quality assurance and quality control (QA/QC), all data has gone through pre-processing treatment, including detecting errors and missing values. The data is collected on an hourly basis starting from 18 March 2020 until 30 June 2020. The data that supports the findings of this study are available at the Air Quality Division, Department of Environment, Malaysia but restrictions apply to the availability of this data, which is used under license for the current study, and so is not publicly available. Data is however available from the authors upon request and with permission of the Air Quality Division, Department of Environment, Malaysia. This data was classified into six phases, 18 March 2020-12 May 2020 (four phases of MCO), 13 May-9 June 2020 (one phase of CMCO), and 10- 30 June 2020 (one phase of RMCO). MCO Phase I (18–31 March 2020) (n = 106,058), during Phase II MCO (1 March–14 April 2020) (n = 106,179) and Phase III MCO (15–28 April 2020) (n = 105,800), Phase IV MCO (29 April–12 May 2020) (n = 105,751), Phase V CMCO (13 May–9 June 2020) (n = 211,907), and Phase VI RMCO (10–30 June 2020) (n = 158,007). There is a 13.48% missing data, and the total data used in this study is 687,644. The missing data is omitted in this study. The mean value has been calculated to compare the concentration of each parameter involved for 65 stations on an hourly basis concentration. The New Ambient Air Quality Standard (NAAQS) acted as a guideline of recommendation or guidance on protecting human beings or receptors in the environment from the adverse effects of air pollutants. The relative changes (%) were measured using variations in pollutant concentration between periods calculated to figure out the relative changes in air quality.

Table 1: Study areas (DOE, 2020)

| Region | Station | State | Location of Station | Classification |
|---|---|---|---|---|
| **North** | S1 | PERLIS | Kangar | Sub Urban |
| | S2 | KEDAH | Langkawi | Sub Urban |
| | S3 | KEDAH | Alor Setar | Sub Urban |
| | S4 | KEDAH | Sungai Petani | Sub Urban |
| | S5 | KEDAH | Kulim Hi-Tech | Industrial |
| | S6 | PULAU PINANG | Seberang Jaya | Urban |
| | S7 | PULAU PINANG | Seberang Perai | Sub Urban |
| | S8 | PULAU PINANG | Minden | Urban |
| | S9 | PULAU PINANG | Balik Pulau | Sub Urban |
| | S10 | PERAK | Taiping | Sub Urban |
| | S11 | PERAK | Tasek Ipoh | Urban |
| | S12 | PERAK | Pegoh Ipoh | Sub Urban |

| | | | | |
|---|---|---|---|---|
| | S13 | PERAK | Seri Manjung | Rural |
| | S14 | PERAK | Tanjung Malim | Sub Urban |
| **Central** | S15 | W.P. KUALA LUMPUR | Batu Muda | Sub Urban |
| | S16 | W.P. KUALA LUMPUR | Cheras | Urban |
| | S17 | W.P. PUTRAJAYA | Putrajaya | Sub Urban |
| | S18 | SELANGOR | Kuala Selangor | Rural |
| | S19 | SELANGOR | Petaling Jaya | Sub Urban |
| | S20 | SELANGOR | Shah Alam | Urban |
| | S21 | SELANGOR | Klang | Sub Urban |
| | S22 | SELANGOR | Banting | Sub Urban |
| **South** | S23 | NEGERI SEMBILAN | Nilai | Sub Urban |
| | S24 | NEGERI SEMBILAN | Seremban | Urban |
| | S25 | NEGERI SEMBILAN | Port Dickson | Sub Urban |
| | S26 | MELAKA | Alor Gajah | Rural |
| | S27 | MELAKA | Bukit Rambai | Sub Urban |
| | S28 | MELAKA | Bandaraya Melaka | Urban |
| | S29 | JOHOR | Segamat | Sub Urban |
| | S30 | JOHOR | Batu Pahat | Sub Urban |
| | S31 | JOHOR | Kluang | Rural |
| | S32 | JOHOR | Larkin | Urban |
| | S33 | JOHOR | Pasir Gudang | Sub Urban |
| | S34 | JOHOR | Pengerang | Industrial |
| | S35 | JOHOR | Kota Tinggi | Sub Urban |
| | S36 | JOHOR | Tangkak | Sub Urban |
| **East** | S37 | PAHANG | Rompin | Rural |
| | S38 | PAHANG | Temerloh | Sub Urban |
| | S39 | PAHANG | Jerantut | Sub Urban |
| | S40 | PAHANG | Indera Mahkota Kuantan | Sub Urban |
| | S41 | PAHANG | Balok Baru Kuantan | Industrial |
| | S42 | TERENGGANU | Kemaman | Industrial |
| | S43 | TERENGGANU | Paka | Industrial |
| | S44 | TERENGGANU | Kuala Terengganu | Urban |
| | S45 | TERENGGANU | Besut | Sub Urban |
| | S46 | KELANTAN | Tanah Merah | Sub Urban |
| | S47 | KELANTAN | Kota Bharu | Sub Urban |
| **Sabah** | S48 | SABAH | Tawau | Sub Urban |
| | S49 | SABAH | Sandakan | Sub Urban |

| | | | | |
|---|---|---|---|---|
| | S50 | SABAH | Kota Kinabalu | Sub Urban |
| | S51 | SABAH | Kimanis | Industrial |
| | S52 | SABAH | Keningau | Background |
| | S53 | W.P. LABUAN | Labuan | Sub Urban |
| **Sarawak** | S54 | SARAWAK | ILP Miri | Rural |
| | S55 | SARAWAK | Miri | Sub Urban |
| | S56 | SARAWAK | Samalaju | Industrial |
| | S57 | SARAWAK | Bintulu | Sub Urban |
| | S58 | SARAWAK | Mukah | Rural |
| | S59 | SARAWAK | Kapit | Rural |
| | S60 | SARAWAK | Sibu | Sub Urban |
| | S61 | SARAWAK | Sarikei | Rural |
| | S62 | SARAWAK | Sri Aman | Rural |
| | S63 | SARAWAK | Samarahan | Rural |
| | S64 | SARAWAK | Kuching | Urban |
| | S65 | SARAWAK | Limbang | Rural |

## Results and Discussion

The time series were plotted for daily concentrations of PM$_{10}$, PM$_{2.5}$, SO$_2$, NO$_2$, O$_3$, and CO at different movement control order (MCO) phases in Malaysia. The six phases are from 18 March 2020 to 12 May 2020 (MCO) Phase 1 (18–31 March 2020), Phase 2 (1 March–14 April 2020), Phase 3 (15–28 April 2020), and Phase 4 (29 April–12 May 2020), 13 May to 9 June 2020 (CMCO) Phase 5 (13 May–9 June 2020), and 10 to 30 June 2020 (RMCO) Phase 6 (10–30 June 2020). As shown in Figure 1(a), there is a substantial variation in PM$_{10}$ concentration during the different phases of the MCO. At the beginning of the movement control order (MCO), PM$_{10}$ demonstrates decreasing Phase 1 to Phase 4 of MCO. The highest concentration of pollutants was 108.6 µg/m$^3$ and followed by 103.5 µg/m$^3$ in Phase 2 and Phase 3, respectively. Phase 5 and Phase 6 showed a gradually increasing trend of pollutant behaviour in which most economic sectors and activities were allowed to operate with Standard Operating Procedures (SOP) such as social distancing (Ash'aari *et al.,* 2020).

Moreover, interstate travel was allowed from 10 June (Malaysia National Security Council (NSC), 2020). The high level of concentration in some periods during the lockdown was possible because several small, medium, and heavy industries were likely to be operating (Sahoo *et al.,* 2020). Table 2 illustrates the dramatic decline in PM$_{10}$ concentrations during P1 and P2 at 51 sites, accounting for 78.9% of total stations. The largest decrease was 33.9% in Minden (S8) (P1 = 25.7 g/m$^3$; P2 = 17 g/m$^3$), whereas the smallest drop was 0.1% at Bukit Rambai (S27) (reduced by 1.7 g/m$^3$). Throughout P2 and P3 (MCO), PM$_{10}$ concentrations were reduced at 50 sites, accounting for 76.9% of total stations. Kota Bharu (S47) had the largest reduction of 32.6% (P2 = 26.1 g/m$^3$; P3 = 17.6 g/m$^3$), whereas Balok Baru, Kuantan (S41), and Pasir Gudang (S33) had the lowest reductions at 0.6% (decrease at 0.1 g/m$^3$). PM$_{10}$ concentrations were reduced at 53 sites between P3 and P4 (MCO), accounting for 81.5% of stations. Rompin (S37) had the largest decrease of 53.7% (P3 = 36.1 g/m$^3$; P4 = 16.7 g/m$^3$), while Petaling Jaya (S19) had the lowest reduction of 0.5% (reduction at

0.1 g/m$^3$). During P4 and P5 (MCO & CMCO), $PM_{10}$ concentrations were reduced at six sites, accounting for 9.2% of total stations. Kimanis (S51) achieved the largest decrease of 34.1% (P4 = 17 g/m$^3$; P5 = 11.2 g/m$^3$), while ILP Miri (S55) achieved the lowest reduction of 3.0% (reduction at 0.4 g/m$^3$). During P5 and P6 (CMCO & RMCO), $PM_{10}$ concentrations were reduced at 24 sites, accounting for 36.9% of total stations. Alor Gajah (S26) had the largest decrease at 25.5% (P5 = 22 g/m$^3$; P6 = 16.4 g/m$^3$), while Besut (S45) had the lowest reduction at 1.2% (reduction at 0.3 g/m$^3$).

The concentration of $PM_{2.5}$ is seen in Figure 1(b). The trend was steadily declining from Phase 1 to Phase 4 (MCO). Phase 2 was 78.1 µg/m$^3$ and 43.6 µg/m$^3$, while Phase 3 denotes the highest value concentration with 98.7 µg/m$^3$. These results corroborated the finding that the 2020 Malaysia movement control order had a substantial effect on lowering $PM_{2.5}$ levels in Malaysia (Abdullah *et al.,* 2020). Phase 5 and Phase 6 shows an increasing trend. Table 3 shows that the $PM_{2.5}$ concentration signifies the reduction at 51 stations, which ascribed to 78.5% of stations during P1 and P2 (MCO). The largest decrease was at Minden (S8), with 35.7% (P1 = 7 µg/m$^3$; P2 = 19.6 µg/m$^3$), while the lowest reduction was at Samalaju (S27), with 0.8% (reduce at 0.2 µg/m$^3$). The relevant reductions for $PM_{2.5}$ were between 19 and 42% at industrial, and between 23 and 32% at the urban sites (Kinnah *et al.,* 2020) where S27 was industrial and S8 was an urban region. During P2 and P3 (MCO), the reduction of $PM_{2.5}$ concentrations occurred at 48 stations, which accounted for 73.8% of stations. Kota Bharu (S47) had the largest decrease at 37.9% (P2 = 19.8 g/m$^3$; P3 = 12.3 g/m$^3$), whereas Larkin (S32) had the lowest reduction at 0.7% (reduction at 0.1 g/m$^3$). $PM_{2.5}$ concentrations were reduced at 60 sites during P3 and P4 (MCO), accounting for 92.3% of stations. Rompin (S37) had the largest decrease at 71.1% (P3 = 29.4 g/m$^3$; P4 = 8.5 g/m$^3$), while Bukit Rambai (S27) had the lowest reduction at 1.6% (reduction at 0.2 g/m$^3$). According to Abdullah *et al.* (2020), the MCO phase results in the greatest reductions in pollutant emissions, notably $PM_{2.5}$ concentrations, due to the absence of motor vehicles and industrial activity. P4 and P5 (MCO & CMCO) saw a decrease in $PM_{2.5}$ concentrations at five stations, accounting for 7.7% of stations. Kimanis (S51) had the largest overall decrease at 35.4% (P4 = 8.2 g/m$^3$; P5 = 5.3 g/m$^3$), while Besut (S45) had the lowest reduction at 4.9% (reduction at 0.5 g/m$^3$). $PM_{2.5}$ concentrations were reduced at 33 stations during P5 and P6 (CMCO and RMCO), accounting for 50.8% of stations. Kimanis (S51) had the largest decrease at 28.3% (P5 = 5.3 g/m$^3$; P6 = 3.8 g/m$^3$), while Besut (S45) had the lowest reduction at 1.0% (reduction at 0.1 g/m$^3$).

Particulate matter concentration was primarily affected by transport, and it was influenced by local biomass burning, traffic, and industries (Karagulian *et al.,* 2015). A vehicle might contribute to the $PM_{10}$ concentration with 33% from the exhaust and 49% from the non-exhaust (Lawrence *et al.,* 2016). In Delhi, the vehicles that contribute to $PM_{10}$ the most are cars (34%), buses (23%), and heavy commercial vehicles (17%) (Singh *et al*., 2020). Further, Breuer *et al.* (2020) highlighted that vehicles that use diesel contribute to the high emission of particulate matter. During the lockdown period, the anthropogenic origin is lesser with the closure of several sources, reducing the $PM_{10}$ level in India (Gayen *et al.,* 2021). The findings are parallel with Orak and Ozdemir (2021), which clarified that $PM_{10}$ concentration has the lowest concentration in April 2020 in Turkey as a result of the lockdown due to less human mobility, and 67% of the cities had a lower average of $PM_{10}$ concentrations as compared to the previous 5-years. Furthermore, Morocco also recorded a low $PM_{10}$ level during the lockdown period, which reduces motor vehicles and industrial emissions (Otmani *et al.,* 2020). It is further supported by Agarwal *et al.* (2021) that the effects of minimum flow of vehicular movement in Bareilly, India, both $PM_{10}$ and $PM_{2.5}$ concentrations recorded the lowest values in April 2020, while in China, the $PM_{10}$ and $PM_{2.5}$ levels both reduced during the lockdown and increased again in September 2020 (Wang & Yang, 2021). The lessening industrial and construction activities, with the reduction movement of most of the transport key to reducing the exhaust and non-exhaust emissions, typically suspended dust, may cause a reduction of the PM level (Singh *et al.,* 2020) during MCO. Furthermore, it is noted that the $PM_{10}$ concentrations were reduced by 28-39% at the industrial sites and by between 26 and 31% in urban areas during the lockdown (Kanniah *et al.,* 2020).

Additionally, Figure 1(c) depicts the trend in Sulphur Dioxide ($SO_2$) air pollution concentrations throughout the course of six MCO phases. Several restrictions on mass movement and gathering are implemented for Malaysians travelling, tourists and visitors entering, educational institutions, government, and private agencies (except for essential services) (Abdullah *et al.,* 2020), resulting in a decreasing $SO_2$ pattern with only increases in Phase 1 and Phase 4 concentrations (Abdullah *et al.,* 2020). In Phase 5, $SO_2$ concentrations increased to a maximum of 0.0318 ppm. Table 4 summarises the various stages of $SO_2$ concentration. Data is unavailable at 12 of the 65 sites, including S13, S18, S26, S31, S37, S54, S55, S59, S60, S62, S63, and S64. During P1 and P2 (MCO), $SO_2$ concentrations reduced by 49.1% at 26 sites. Kota Kinabalu (S50) had the largest reduction at 72.9% (P1 = 0.001155 ppm; P2 = 0.000708 ppm), while Tawau (S48) had the lowest reduction at 0.2% (reduction at 0.000001 ppm). In this context, Wuhan's column density of $SO_2$ has decreased significantly (almost 71%) as a result of industrial shutdowns and the suspension of full-scale operations of several businesses (Ghahremanloo *et al.,* 2021). During P2 and P3 (MCO), $SO_2$ concentrations were reduced at 38 stations, accounting for 71.7% of stations. Batu Muda (S15) had the largest reduction of 67.6% (P2 = 0.000789 ppm; P3 = 0.000256 ppm), while Pengerang (S34) had the lowest reduction of 0.3% (reduction at 0.000005 ppm). During P3 and P4 (MCO), $SO_2$ concentrations were reduced at 27 stations, accounting for 50.9% of stations. The largest drop was 60.3% in Pegoh Ipoh (S12) (P3 = 0.000948 ppm; P4 = 0.000376 ppm), while the lowest reductions were 0.1% at Paka (S43) and Tanah Merah (S46) (reduce at 0.000001 ppm). During P4 and P5 (MCO & CMCO), $SO_2$ concentrations were reduced at 19 stations, accounting for 35.8% of stations. Labuan (S53) had the largest reduction of 66.9% (P4 = 0.001253 ppm; P5 = 0.000415 ppm), whereas Minden (S8) had the lowest reduction of 0.8% (reduction at 0.000008 ppm). During P5 and P6 (CMCO and RMCO), $SO_2$ concentrations reduced at 22 stations, accounting for 41.5% of stations. Kuching (S65) had the largest reduction at 67.5% (P5 = 0.000515 ppm; P6 = 0.000763 ppm), while Banting (S22) had the lowest reduction at 0.9% (reduction at 0.000011 ppm). Several studies noticed that the $SO_2$ concentration during lockdown declined in five cities (Beijing, Bengaluru, Delhi, Las Vegas, and London) (Kumari & Toshniwal., 2020). Sulfur dioxide ($SO_2$) was released as a result of human-caused emissions linked with fossil-fuel combustion and sulfur-containing air pollution (Bari *et al.,* 2020; Kharol *et al.,* 2020). As a significant pollutant emitted by stationary sources (industries and power plants), $SO_2$ is projected to decrease by between 9 and 20% in urban areas and between 17 and 19% in suburban areas by 2020 (Kanniah *et al.,* 2020).

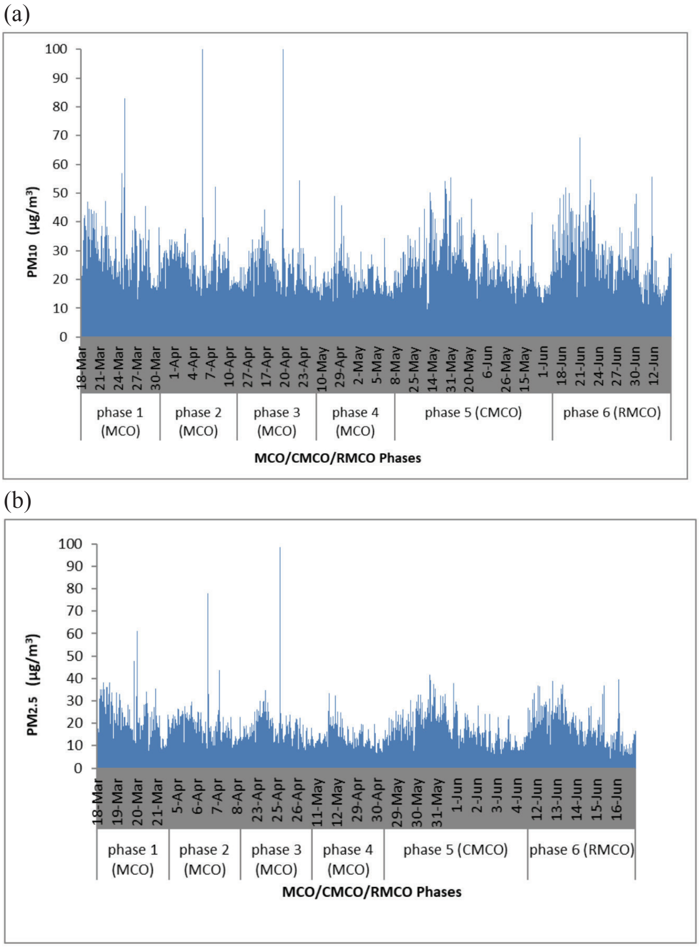
Figure 1(d) shows the Nitrogen Dioxide ($NO_2$) trend from Phase 1 to Phase 4 where the lower level of $NO_2$ has been documented. Overall, $NO_2$ during Phase 1 to Phase 4 (MCO) manifests the trend of a slight decrease in which the concentrations decreased significantly during the lockdown due to the stoppage of transport and low mobility (Muhammad *et al.,* 2020), and $NO_2$ level dropped due to the decrease in road densities, a week before the strict lockdown (Sbai *et al.,* 2021). Phase 5 (CMCO) of $NO_2$ has increased, with the highest concentration level of 0.0864 ppm. Phase 6 (RMCO) shows the trend increased with the second-highest concentration of pollution 0.0793 ppm. These finding of $NO_2$ concentration is shown in Table 5 which 12 stations have unavailable data out of 65 overall stations and were omitted namely S13, S18, S26, S31, S37, S54, S55, S62, S63, and S64. Notably, during P1 and P2 (MCO),

$NO_2$ concentrations were reduced at 38 sites, or for 71.7% of stations. Paka (S43) had the largest reduction at 92.3% (P1 = 0.001236 ppm; P2 = 0.000954 ppm), while Balik Pulau (S9) had the lowest reduction at 1.9% (a reduction of 0.000060 ppm). $NO_2$ concentrations were reduced by 49.1% at 26 sites during P2 and P3 (MCO). The largest drop was 39.2% in Kangar (S1) (P2 = 0.001795 ppm; P3 = 0.001091 ppm), while the lowest reduction was 0.7% at Pengerang (S34) (reduced at 0.000021 ppm). During P3 and P4 (MCO), $NO_2$ concentrations were reduced at 27 sites, accounting for 50.9% of stations. Tangkak (S36) had the largest reduction of 40.3% (P3 = 0.002955 ppm; P4 = 0.001763 ppm), while Labuan (S53) had the lowest reduction of 1.4% (reduction at 0.000018 ppm). During P4 and P5 (MCO & CMCO), 19 stations had a drop in $NO_2$ concentrations, accounting for 35.8% of stations. The largest drop was 1.7% at Tanah Merah (S46) (P4 = 0.003325 ppm; P5 = 0.003269 ppm), with no station reporting the lowest reduction. During P5 and P6 (CMCO and RMCO), $NO_2$ concentrations were reduced at 22 stations, accounting for 4.5% of stations. Port Dickson (S25) had the largest reduction of 21.6% (P5 = 0.004313 ppm; P6 = 0.003383 ppm), while Keningau (S52) had the lowest reduction of 0.4% (reduction at 0.000009 ppm). Pacheco *et al.* (2020) reported that the air quality in Ecuador was greatly improved during the lockdown, with a 23% decrement in the $NO_2$ concentration due to highly stringent lockdowns representing a significant determinant of major reductions in $NO_2$ concentrations (Ghahremanloo *et al.,* 2021). (Ghahremanloo, Lops, Choi, & Mousavinezhad, 2021) $NO_2$ concentrations decreased significantly in the spring of 2020 compared with prior years. This drop neared 34%, 27%, and 30% in Manila, Kuala Lumpur, and Singapore, respectively (Kanniah *et al.,* 2020), due to company and factory closures and transportation restrictions caused by partial or general lockdown (Muhammad *et al.,* 2020). Existing studies examine differences in $NO_2$ (-62.39% and -38.16%) variation between strict lockdown and before lockdown in urban and rural stations (Gautam, 2020a; Martorell-Marugan *et al.,* 2020; Filonchyk *et al.,* 2021).

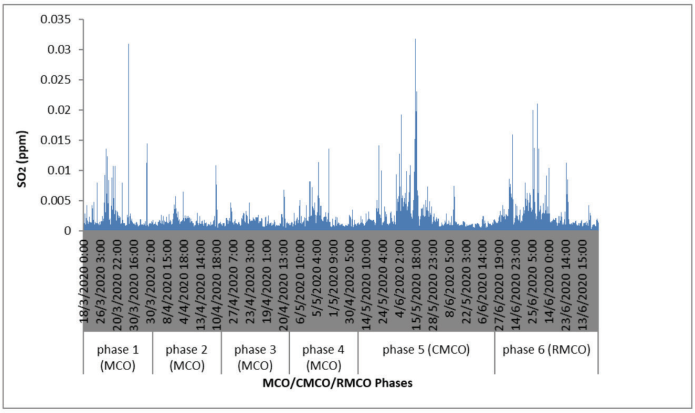
The trend of air pollution for Ozone ($O_3$) is shown in Figure 1(f). During Phase 1 to Phase 4 (MCO), the levels of $O_3$ were increased but still lower than in the other phases. At the beginning of Phase 5, the level of $O_3$ was gradually decreasing before it increased to the second highest with 0.0953 ppm. During Phase 6 (RMCO), the concentration behaviour rises with the highest value of $O_3$ (0.0996 ppm). Table 6 shows all phases of $O_3$ concentration, which there are 12 stations have unavailable data out of 65 stations and were omitted, namely S5, S13, S18, S26, S31, S34, S37, S41, S42, S43, S51, S54, S55, S57, S59, S60, S62, S63, and S64. O3 concentrations were reduced at 38 stations, accounting for 71.7% of stations during P1 and P2 (MCO). Bandaraya Melaka (S28) had the largest reduction of 44.9% (P1 = 0.026598 ppm; P2 = 0.014664 ppm), while Labuan (S53) had the lowest reduction of 0.5% (reduction at 0.000087 ppm). During Phases 2 and 3 (MCO), O3 concentrations were reduced by 49.1%at 26 sites. The maximum decrease was 33.5% at Batu Muda (S15) (P2 = 0.020072 ppm; P3 = 0.013346 ppm), while the lowest reduction was 1.6% at Segamat (S29) (reduce at 0.000235 ppm), and its levels are mostly stable throughout the year in Malaysia. However, a minor rise (3-7%) was seen at urban locations in 2020 (Kanniah *et al.,* 2020) due to a drop in NO levels, comparable with that observed in other urban environments (Dantas *et al.,* 2020). During Phases 3 and 4 (MCO), $O_3$ concentrations were reduced at 27 stations, accounting for 50.9% of stations. Klang (S21) had the largest reduction of 32.5% (P3 = 0.023937 ppm; P4 = 0.016155 ppm), while Alor Setar (S3) had the lowest reduction of 0.4% (reduction at 0.000084 ppm). According to Murugan *et al.* (2021), $O_3$ levels in urban and rural stations vary between +50.09 and +15.58% under severe lockdown and before lockdown. During P4 and P5 (MCO & CMCO), 19 stations had a drop in $O_3$ concentrations, accounting for 35.8% of stations. Tawau (S48) had the largest reduction of 36.0% (P4 = 0.013077 ppm; P5 = 0.008375 ppm), while Bintulu (S57) had the lowest reduction of 1.7% (reduction at 0.000197 ppm). During P5 and P6 (CMCO & RMCO), 22 stations experienced a decrease in $O_3$ concentrations, accounting for 4.5% of stations. Pasir Gudang (S33) had the largest reduction of 44.3% (P5 = 0.012914 ppm; P6 = 0.007187 ppm), while Kota Kinabalu (S50) had the lowest reduction of 2.5% (reduction at 0.000278 ppm). $O_3$ has increased as a result of human activities due to the unrestricted movement and photochemical processes influenced by anthropogenic emissions of ozone precursors ($NO_2$ and VOCs) (Zoran *et al.,* 2020). Thus, VOC emissions reduction must be planned as a part of air pollution control strategies. CO activities might also be affected because, under low $NO_x$ levels, ozone depletion can occur; however, under high $NO_x$ levels, CO can contribute to ozone formation (Tobias *et al.,* 2020; Sbai *et al.,* 2021). In another study, $O_3$ increases during the lockdown because of the lower titration of $O_3$ by NO and $NO_x$ emissions (Bracher, 2021). In addition, most of the parameters show relative changes of $PM_{2.5}$, $O_3$, $NO_2$, $SO_2$, and CO in four different cities in China on lockdown with a significant reduction towards $PM_{2.5}$ (-53% to -31%), $NO_2$ (-76% to -45%), and CO (-46% to -14%) (Liu *et al.,* 2020).

Figure 1(g) shows the Carbon Monoxide (CO) trend distribution during all phases of MCO. CO trends during Phase 1 to Phase 4 (MCO) are at a low level with less than 3.264 ppm. CO was observed at the end of lockdown concentrations and slowly increased (Vultaggio *et al.*, 2020). In Phase 5 (CMCO), the trend shows a significant increment with the highest value of 6.735 ppm compared to other phases. During Phase 6 (RMCO), the trend increased and afterwards had a decreasing trend. Table 7 summarises all stages of CO concentration; data for 12 of the 65 sites are unavailable. CO concentrations were reduced at 38 sites between P1 and P2 (MCO), accounting for 71.7% of stations. Sandakan (S49) had the largest reduction of 32.6% (P1 = 0.531186 ppm; P2 = 0.358214 ppm), while Bintulu (S) had the lowest reduction of 0.7% (reduction at 0.003000 ppm). During P2 and P3 (MCO), CO concentrations were reduced at 26 sites, accounting for 49.1% of stations. Taiping (S10) had the largest reduction of 40.2% (P2 = 0.268141 ppm; P3 = 0.160360 ppm), while Bukit Rambai (S27) had the lowest reduction of 0.1% (reduction at 1.7 ppm). CO levels have decreased in each of the four areas during the lockdown, with the greatest decrease occurring in the IGP region (Singh *et al.*, 2020). During P3 and P4 (MCO), CO concentrations were reduced at 27 sites, accounting for 50.9% of stations. The largest drop was 39.9% in Pegoh Ipoh (S12) (P3 = 0.413660 ppm; P4 = 0.248651 ppm), while the lowest reduction was 1.8% at Klang (S21) (reduce at 0.010713 ppm). Kanniah *et al.* (2020) observed a between 25 and 31% reduction in CO concentrations in Malaysian metropolitan areas during lockdown circumstances in comparison to the same times in 2018 and 2019. Additionally, they discovered considerable decreases in CO concentrations in Malaysia's industrial, suburban, and rural areas. CO concentrations were reduced at 19 stations between P4 and P5 (MCO & CMCO), accounting for 35.8% of stations. Kota Bharu (S8) had the largest reduction of 34.60% (P4 = 0.474974 ppm; P5 = 0.310843 ppm), while Keningau (S27) had the lowest reduction of 0.8% (reduction at 0.005139 ppm). During P5 and P6 (CMCO & RMCO), CO concentrations were reduced at 22 stations, accounting for 4.5% of stations. Kota Kinabalu (S8) had the largest reduction of 54.60% (P5 = 0.546997 ppm; P6 = 0.248330 ppm), whereas Cheras (S27) had the lowest reduction of 0.2% (reduction at 0.001485 ppm).

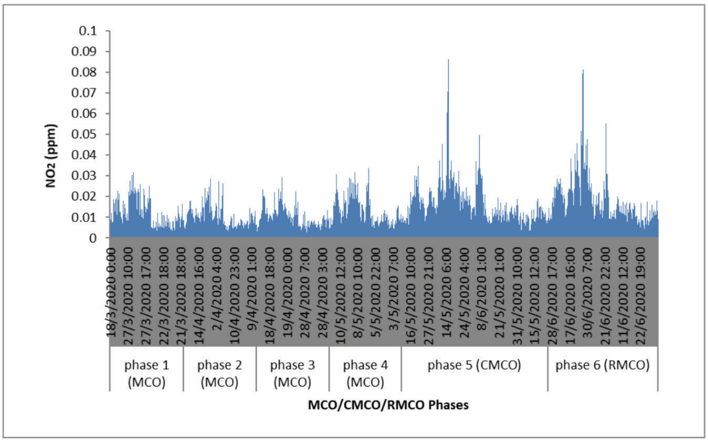
In general, limiting combustion activities resulted in a decrease in CO levels, a pollutant produced directly by incomplete combustion sources (vehicular traffic and biomass burning). CO reductions are greater (at between 25 and 32%) in urban and suburban areas of between 25 and 27% (Kanniah *et al.,* 2020). The air pollutants of $NO_2$, $SO_2$, $PM_{2.5}$, and CO levels decreased by 24.16%, 19.51%, 20.25%, and 6.88%, respectively, during the lockdown $O_3$ increased by a maximum of 4.52% (Roy *et al.,* 2021). In addition, Sahraei *et al.* (2021) found that the $PM_{2.5}$, $PM_{10}$, $SO_2$, and $NO_2$ decreased by 16%, 21%, 41%, and 35%, which was associated with the reduction in public transport usage, and the same findings by Shen *et al.* (2021) established that the $PM_{2.5}$, $PM_{10}$, $SO_2$, $NO_2$, and CO reductions in different urban types ranged from 6.6% to 62.4%, except for $O_3$. The movement control order which the Malaysian government implemented, could become a pioneer in reducing air pollution. It is clarified that the main culprit of emissions is motor vehicles. Thus, a stringent policy should be implemented, which in turn can reduce the air pollution problem. Although the changes in air quality during this COVID-19 pandemic are short-term, exploring the strict emission control plan with the related stakeholders can improve the air quality of the Malaysian government despite intermittent and sudden interventions. Reduced economic activity, the closure of high-energy-consuming plants, the suspension of air and railway traffic, the reduction of automobile traffic, and a reduction in power production all contributed to a reduction in emissions into the atmosphere, resulting in a noticeable improvement in air quality (Gautam, 2020b). The findings provide a unique chance to develop future environmental protection measures following the COVID-19 pandemic to ensure the region's greatest air quality. The findings indicate that even brief changes in anthropogenic activity can have a major effect on air quality (Filonchyk *et al.,* 2020). It can serve as a guide for various countries as they examine COVID-19's influence on the global environment.



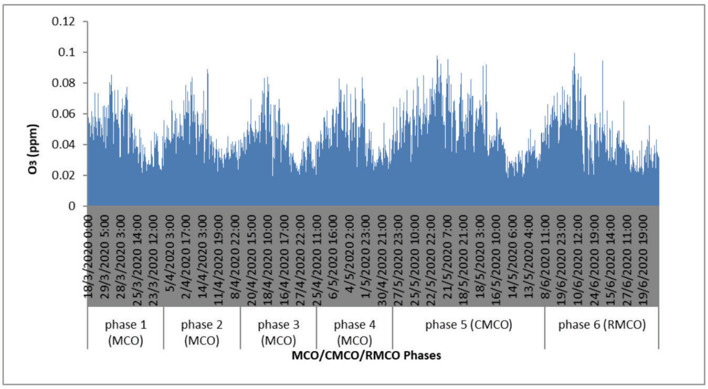
(c)


0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
SO2 (ppm)
18/3/2020 0:00
26/3/2020 3:00
20/3/2020 22:00
30/3/2020 16:00
30/3/2020 2:00
8/4/2020 15:00
4/4/2020 18:00
13/4/2020 14:00
10/4/2020 18:00
27/4/2020 7:00
23/4/2020 3:00
19/4/2020 1:00
20/4/2020 13:00
6/5/2020 10:00
5/5/2020 4:00
1/5/2020 9:00
30/4/2020 5:00
14/5/2020 10:00
24/5/2020 4:00
4/6/2020 2:00
15/5/2020 18:00
28/5/2020 23:00
8/6/2020 5:00
22/5/2020 3:00
6/6/2020 14:00
27/6/2020 19:00
14/6/2020 23:00
25/6/2020 5:00
14/6/2020 0:00
23/6/2020 14:00
13/6/2020 15:00
phase 1 (MCO)
phase 2 (MCO)
phase 3 (MCO)
phase 4 (MCO)
phase 5 (CMCO)
phase 6 (RMCO)
MCO/CMCO/RMCO Phases

(d)


0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
NO2 (ppm)
18/3/2020 0:00
27/3/2020 10:00
27/3/2020 17:00
22/3/2020 18:00
21/3/2020 18:00
14/4/2020 16:00
2/4/2020 4:00
10/4/2020 23:00
9/4/2020 1:00
18/4/2020 18:00
19/4/2020 0:00
28/4/2020 7:00
28/4/2020 3:00
10/5/2020 12:00
8/5/2020 10:00
5/5/2020 22:00
3/5/2020 7:00
16/5/2020 10:00
27/5/2020 21:00
14/5/2020 6:00
24/5/2020 4:00
8/6/2020 1:00
21/5/2020 1:00
31/5/2020 10:00
15/5/2020 12:00
28/6/2020 17:00
17/6/2020 16:00
30/6/2020 7:00
21/6/2020 22:00
11/6/2020 12:00
22/6/2020 19:00
phase 1 (MCO)
phase 2 (MCO)
phase 3 (MCO)
phase 4 (MCO)
phase 5 (CMCO)
phase 6 (RMCO)
MCO/CMCO/RMCO Phases

(e)


0.12
0.1
0.08
0.06
0.04
0.02
0
O3 (ppm)
18/3/2020 0:00
29/3/2020 5:00
28/3/2020 3:00
25/3/2020 14:00
23/3/2020 12:00
5/4/2020 3:00
2/4/2020 17:00
14/4/2020 3:00
11/4/2020 19:00
8/4/2020 22:00
20/4/2020 15:00
18/4/2020 10:00
16/4/2020 17:00
27/4/2020 22:00
25/4/2020 11:00
6/5/2020 16:00
4/5/2020 2:00
1/5/2020 23:00
30/4/2020 21:00
27/5/2020 23:00
25/5/2020 10:00
22/5/2020 22:00
21/5/2020 7:00
18/5/2020 21:00
18/5/2020 3:00
16/5/2020 10:00
14/5/2020 6:00
13/5/2020 4:00
8/6/2020 11:00
19/6/2020 23:00
10/6/2020 12:00
24/6/2020 19:00
15/6/2020 14:00
27/6/2020 11:00
19/6/2020 19:00
phase 1 (MCO)
phase 2 (MCO)
phase 3 (MCO)
phase 4 (MCO)
phase 5 (CMCO)
phase 6 (RMCO)
MCO/CMCO/RMCO Phases

(f)

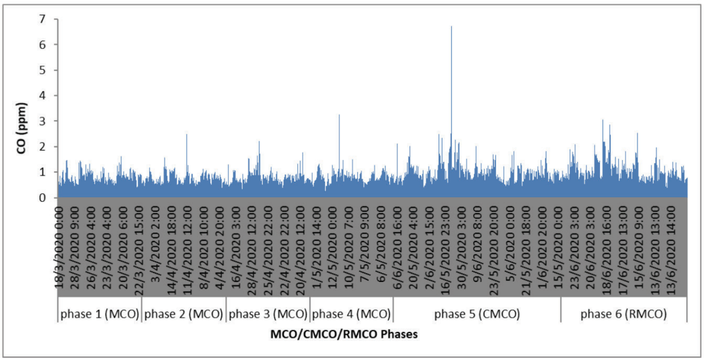


Figure 1: Concentration of criteria pollutants during different Phases of MCO; (a) $PM_{10}$, (b) $PM_{2.5}$, (c) $SO_2$, (d) $NO_2$, (e) $O_3$, and (f) CO

## Conclusion

In conclusion, the findings showed that $PM_{2.5}$, $PM_{10}$, $SO_2$, $NO_2$, $O_3$, and CO show a sharp declining trend with up and down and a significant reduction during the lockdown periods in MCO phases. The criteria air pollutants increased significantly during CMCO and RMCO, which was affected by COVID-19 unrestricted lockdown and reopening policies. Most of the reduction occurred during lockdown phases during Phases 1, 2, 3, and 4 which most stations have the highest decline. Moreover, during Phases 5 and 6, which are unrestricted lockdowns, most stations have a lower reduction in all parameters.

## Acknowledgements

We acknowledge Universiti Malaysia Terengganu by providing a Matching Grant 1+3 (Ref: UMT/PPP/2- 2/2/15 Jld.2 (68)) (VOT: 53482) for funding this study. Additionally, we would like to express our gratitude to the Air Quality Division of the Malaysian Department of Environment for the air quality data.

## References

Abdullah, S., Mansor, A. A., Napi, N. N. L. M., Mansor, W. N. W., Ahmed, A. N., Ismail, M., & Ramly, Z. T. A. (2020). Air quality status during the 2020 Malaysia Movement Control Order (MCO) due to the 2019 novel coronavirus (2019-nCoV) pandemic. *Science of The Total Environment*, *729*, 139022. https://doi.org/10.1016/j.scitotenv.2020.139022

Agarwal, S., Saxena, D. K., & Boyina, R. (2021). Analysis of air pollutants in COVID 19 pandemic lockdown- A case study of Bareilly, UP, India. *Current Research in Green and Sustainable Chemistry*, *4*, 100087. https://doi.org/10.1016/j.crgsc.2021. 100087

Ash'aari, Z. H., Aris, A. Z., Ezani, E., Ahmad Kamal, N. I., Jaafar, N., Jahaya, J. N., Manan, S. A., & Umar Saifuddin, M. F. (2020). Spatiotemporal variations and contributing factors of air pollutant concentrations in Malaysia during Movement Control Order (MCO) due to pandemic COVID-19. *Aerosol and Air Quality Research*, *20*(10), 2047-2061. https://doi.org/10.4209/aaqr.2020.06.0334

Bari, M. A., Kindzierski, W. B., & Roy, P. (2020). Identification of ambient $SO_2$ sources in industrial areas in the lower Athabasca oil sands region of Alberta, Canada. *Atmospheric Environment*, *231*, 117505. https://doi.org/10.1016/j.atmosenv.2020.117505

Biswas, K., Chatterjee, A., & Chakraborty, J. (2020). Comparison of air pollutants between Kolkata and Siliguri, India, and its relationship to temperature change. *Journal* *of Geovisualization and Spatial Analysis*, *4*, 25. https://doi.org/10.1007/s41651-020-00065-4

Brancher, M. (2021). Increased ozone pollution alongside reduced nitrogen dioxide concentrations during Vienna's first COVID-19 lockdown: Significance for air quality management. *Environmental Pollution*, *284*, 117153. https://doi.org/10.1016/j.envpol.2021.117153

Breuer, J. L., Samsun, R. C., Peters, R., & Stolten, D. (2020). The impact of diesel vehicles on NOx and PM10 emissions from road transport in urban morphological zones: A case study in North Rhine-Westphalia, Germany. *Science of The Total Environment*, *727*, 138583. https://doi.org/10.1016/j.scitotenv.2020.138583

Dantas, G., Siciliano, B., França, B. B., da Silva, C. M., & Arbilla, G. (2020). The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. *Science of The Total Environment*, *729*, 139085. https://doi.org/10.1016/j.scitotenv.2020.139085

DeFlorio-Barker, S., Lobdell, D. T., Stone, S. L., Boehmer, T., & Rapazzo, K. M. (2020). Acute effects of short-term exposure to air pollution while being physically active, the potential for modification: A review of the literature. *Preventive Medicine*, *139*, 106195. https://doi.org/10.1016/j.ypmed.2020.106195

Department of Environment Malaysia, (2021). *Air quality*. https://www.doe.gov.my/portalv1/en/info-umum/kuality-udara/114 (accessed 4 January 2021).

Filonchyk, M., Hurynovich, V., & Yan, H. (2021). Impact of COVID-19 lockdown on air quality in Poland, Eastern Europe. *Environmental Research*, *198*, 110454. https://doi.org/10.1016/j.envres.2020.110454

Filonchyk, M., Hurynovich, V., Yan, H., Gusev, A. & Shpilevskaya, N. (2020). Impact Assessment of COVID-19 on variations of SO2, NO2, CO and AOD over East China. *Aerosol and Air Quality Research*, *20*, 1530–1540. https://doi.org/10.4209/aaqr.2020.05.0226

Gautam, S. (2020a). COVID-19: Air pollution remains low as people stay at home. *Air Quality, Atmosphere and Health, 13*, 853–857. https://doi.org/10.1007/s11869-020-00842-6.

Gautam, S. (2020b). The influence of COVID-19 on air quality in India: A boon or inutile. *Bulletin of Environmental Contamination and Toxicology*, *104*, 724–726. https://doi.org/10.1007/s00128-020-02877-y

Gayen, A., Haque, S. K., & Mishra, S. V. (2021). COVID-19 induced lockdown and decreasing particulate matter ($PM_{10}$): An empirical investigation of an Asian megacity. *Urban Climate*, 36, 100786. https://doi.org/10.1016/j.uclim.2021.100786

Ghahremanloo, M., Lops, Y., Choi, Y., & Mousavinezhad, S. (2021). Impact of the COVID-19 outbreak on air pollution levels in East Asia. *Science of The Total Environment*, *754*, 142226. https://doi.org/10.1016/j.scitotenv.2020.142226

Halim, A. N. D., Latif, M. T., Ahamad, F., Dominick, D., Chung, J. X., Juneng, L., & Khan, M. F. (2018). The long-term assessment of air quality on an island in Malaysia. *Heliyon, 4*(12), e01054. https://doi.org/10.1016/j.heliyon.2018.e01054

Halim, N. D. A., Latif, M. T., Mohamed, A. F., Maulud, K. N. A., Idrus, S., Azhari, A., Othman, M., & Sofwan, N. M. (2020). Spatial assessment of land use impact on air quality in mega urban regions, Malaysia. *Sustainable Cities and Society*, *63*, 102436. https://doi.org/10.1016/j.scs.2020.102436

Hashim, B. M., Al-Naseri, S. K., Al-Maliki, A., & Al-Ansari, N. (2021). Impact of COVID-19 lockdown on $NO_2$, $O_3$, $PM_{2.5}$ and $PM_{10}$ concentrations and assessing air quality changes in Baghdad, Iraq. *Science of the Total Environment*, *754*, 141978. https://doi.org/10.1016/j.scitotenv.2020.141978

Jung, J., Park, J. Y., Kim, Y. C., Lee, H., Kim, E., Kim, Y. S., Lee, J. P., & Kim, H. (2021). Effects of air pollution on mortality of patients with chronic kidney disease: A large observational cohort study. *Science of the Total Environment*, *786*, 147471. https://doi.org/10.1016/j.scitotenv.2021.147471

Kanniah, K. D., Kamarul Zaman, N. A. F., Kaskaoutis, D. G., & Latif, M. T. (2020). COVID-19's impact on the atmospheric environment in the Southeast Asia region. *Science of The Total Environment*, *736*, 139658. https://doi.org/10.1016/j.scitotenv.2020.139658

Karagulian, F., Belis, C. A., Dora, C. F. C., Pruss-Ustun, A. M., Bonjour, S., Adair-Rohani, H., & Amann, M. (2015). Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at the global level. *Atmospheric Environment, 120*, 475-483. https://doi.org/10.1016/j.atmosenv.2015.08.087

Kharol, S. K., Fioletov, V., McLinden, C. A., Shephard, M. W., Sioris, C. E., Li, C., & Krotkov, N. A. (2020). The ceramic industry at Morbi is a large source of SO2 emissions in India. *Atmospheric Environment, 223*, 117243. https://doi.org/10.1016/j.atmosenv.2019.117243

Khojasteh, D. N., Goudarzi, G., Taghizadeh-Mehrjardi, R., Asumadu-Sakyi, A. B., & Fehresti-Sani, M. (2021). Long-term effects of outdoor air pollution on mortality and morbidity–prediction using nonlinear autoregressive and artificial neural networks models. *Atmospheric Pollution Research, 12*(2), 46-56. https://doi.org/10.1016/j.apr.2020.10.007

Khor, V., Arunasalam, A., Azli, S., Khairul-Asri, M. G., & Fahmy, O. (2020). Experience from Malaysia during the COVID-19 movement control order. *Urology, 141*, 179-180. https://doi.org/10.1016/j.urology.2020.04.070

Kumari, P., & Toshniwal, D. (2020). Impact of lockdown on air quality over major cities across the globe during the COVID-19 pandemic. *Urban Climate*, *34*, 100719. https://doi.org/10.1016/j.uclim.2020.100719

Lam, T. T. Y., Shum, M. H. H., Zhu, H. C., Tong, Y. G., Ni, X. B., Liao, Y. S., Wei, W., Cheung, W. Y. M., Li, W. J., Li, L. F., Leung, G. M., Holmes, E. C., Hu, Y. L. & Guan, Y. (2020). Identifying SARS-CoV-2 related coronaviruses in Malayan pangolins. *Nature*, *582*, 282-285. https://doi.org/10.1038/s41586-020-2169-0

Lawrence, S., Sokhi, R., & Ravindra, K. (2016). Quantification of vehicle fleet $PM_{10}$ particulate matter emission factors from the exhaust and non-exhaust sources using tunnel measurement techniques. *Environmental Pollution, 210*, 419-428. https://doi.org/10.1016/j.envpol.2016.01.011

Li, W.-W. (2020). Chapter 2 - Air pollution, air quality, vehicle emissions and environmental regulations. In H. Khreis, M. Nieuwenhuijsen, J. Zietsman, & T. Ramani (Eds.), *Traffic-related air pollution* (pp. 23-49). Elsevier.

Ma, J., Cheng, J. C. P., Lin, C., Tan, Y., & Zhang, J. (2019). Improving air quality prediction accuracy at larger temporal resolutions using deep learning and transfer learning techniques. *Atmospheric Environment*, *214*, 116885. https://doi.org/10.1016/j.atmosenv.2019.116885

Malaysian National Security Council (NSC), (2020). *Malaysian National Security Council (NSC) Movement Control Order (MCO)*. https://www.mkn.gov.my/web/ms/COVID-19/

Martorell-Marugán, J., Villatoro-García, J. A., García-Moreno, A., Lopez-Dominguez, R., Requena, F., Merelo, J. J., Lacasana, M., de Dios Luna, J., Diaz-Mochon, J. J., Lorente, J. A., & Carmona-Saez, P. (2020). DatAC:

A visual analytics platform to explore climate and air quality indicators associated with the COVID-19 pandemic in Spain. *The Science of the Total Environment, 750*, 141424. https://doi.org/10.1016/j.scitotenv.2020.141424

Mazinani, M., & Rude, B. J. (2020). The novel Zoonotic Coronavirus disease 2019 (COVID-19) pandemic: Health perspective on the outbreak. *Journal of Healthcare Quality Research*. https://doi.org/10.1016/j.jhqr.2020.09.004

Ministry of Health Malaysia (MOH), (2020). *COVID-19*. http://COVID-19.moh.gov.my/faqsop/faq-COVID-19-kkm,(Accessed 10 November 2020)

Muhammad, S., Long, X., & Salman, M. (2020). COVID-19 pandemic and environmental pollution: A blessing in disguise? *Science of the Total Environment*, *728*, 138820. https://doi.org/10.1016/j.scitotenv.2020.138820

Orak, N. H., & Ozdemir, O. (2021). The impacts of COVID-19 lockdown on $PM_{10}$ and $SO_2$ concentrations and association with human mobility across Turkey. *Environmental Research, 197*, 111018. https://doi.org/10.1016/j.envres.2021.111018

Otmani, A., Benchrif, A., Tahri, M., Bounakhla, M., Chakir, E. M., Bouch, M. E. & Krombi, M. (2020). Impact of COVID-19 lockdown on $PM_{10}$, $SO_2$ and $NO_2$ concentrations in Salé City (Morocco). *Science of the Total Environment*, *735*, 139541. https://doi.org/10.1016/j.scitotenv.2020.139541

Pacheco, H., Díaz-López, S., Jarre, E., Pacheco, H., Méndez, W., & Zamora-Ledezma, E. (2020). $NO_2$ levels after the COVID-19 lockdown in Ecuador: A trade-off between environment and human health. *Urban Climate*, *34*, 100674. https://doi.org/10.1016/j.uclim.2020.100674

Patel, H., Talbot, N., Salmond, J., Dirks, K., Xie, S., & Davy, P. (2020). Implications for air quality management of changes in air quality during lockdown in Auckland (New Zealand) in response to the 2020 SARS-CoV-2 epidemic. *Science of the Total Environment, 746*, 141129. https://doi.org/10.1016/j.scitotenv.2020.141129

Roy, A. (2021). Atmospheric pollution retrieval using path radiance derived from remote sensing data. *Journal of Geovisualization and Spatial Analysis*, *5*, 26. https://doi.org/10.1007/s41651-021-00093-8

Roy, S., Saha, M., Dhar, B., Pandit, S., & Nasrin, R. (2021). Geospatial analysis of COVID-19 lockdown effects on air quality in the South and Southeast Asian region. *Science of the Total Environment*, *756*, 144009. https://doi.org/10.1016/j.scitotenv.2020.144009

Sahoo, P., Mangla, S., Pathak, A., Salãmao, G., & Sarkar, D. (2020). Pre-to-post lockdown impact on air quality and the role of environmental factors in spreading the COVID-19 cases - A study from a worst-hit state of India*. International Journal of Biometeorology*, *65*(2), 205-222. https://doi.org/10.1007/s00484-020-02019-3

Sahraei, M.A., Kuskapan, E., & Codur, M.Y. (2021). Public transit usage and air quality index during the COVID-19 lockdown. *Journal of Environmental Management*, *286*, 112166. https://doi.org/10.1016/j.jenvman.2021.112166

Sbai, S., Mejjad, N., Norelyaqine, A., & Bentayeb, F. (2021). Air quality change during the COVID-19 pandemic lockdown over the Auvergne-Rhône-Alpes region, France. *Air Quality, Atmosphere & Health, 14,* 617-628. https://doi.org/10.1007/s11869-020-00965-w

Shen, L., Wang, H., Zhu, B., Zhao, T., Liu, A., Lu, W., Kang, H., & Wang, Y. (2021). Impact of urbanization on air quality in the Yangtze River Delta during the COVID-19 lockdown in China. *Journal of Cleaner Production*, *296*, 126561. https://doi.org/10.1016/j.jclepro.2021.126561

Singh, V., Biswal, A., Kesarkar, A.P., Mor, S., & Ravindra, K. (2020). High-resolution vehicular $PM_{10}$ emissions over megacity Delhi: Relative contributions of exhaust and non-exhaust sources. *Science of the Total Environment*, *699*, 134273. https://doi.org/10.1016/j.scitotenv.2019.134273

Singh, V., Singh, S., Biswal, A., Kesarkar, A. P., Mor, S., & Ravindra, K. (2020). Diurnal and temporal changes in air pollution during COVID-19 strict lockdown over different regions of India. *Environmental Pollution*, *266*, 115368. https://doi.org/10.1016/j.envpol.2020.115368

Tobías, A., Carnerero, C., Reche, C., Massagué, J., Via, M., Minguillón, M. C., Alastuey, A., & Querol, X. (2020). Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. *Science of the Total Environment*, *726*, 138540. https://doi.org/10.1016/j.scitotenv.2020.138540

Wang, Q., & Yang, X. (2021). How do pollutants change post-pandemic? Evidence from changes in five key pollutants in nine Chinese cities most affected by COVID-19. *Environmental Research*, *197*, 111108. https://doi.org/10.1016/j.envres.2021.111108

Zhang, S., Wang, X., Zhang, H., Xu, A., Fei, G., Jiang, X., Tu, J., Qu, G., Xu, X., & Li, Y. (2020). The absence of coronavirus in expressed prostatic secretion in COVID-19 patients in Wuhan city. *Reproductive Toxicology*, *96*, 90-94. https://doi.org/10.1016/j.reprotox.2020.06.006

Zhou, C., Wei, G., Zheng, H., Russo, A., Li, C., Du, H., & Xiang, J. (2019). Effects of potential recirculation on air quality in coastal cities in the Yangtze River Delta. *Science of the Total Environment*, *651*, 12-23. https://doi.org/10.1016/j.scitotenv.2018.08.423

Zoran, M. A., Savastru, R. S., Savastru, D. M., & Tautan, M. N. (2020). Assessing the relationship between surface levels of $PM_{2.5}$ and $PM_{10}$ particulate matter impact on COVID-19 in Milan, Italy. *Science of the Total Environment*, *738*, 139825. https://doi.org/10.1016/j.scitotenv.2020.139825