

IMPACT OF COVID-19 PANDEMIC ON PM_{2.5} CONCENTRATIONS IN MALAYSIA

ABSTRACT

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The 2019 coronavirus novel (2019-nCoV) outbreak that initially in Wuhan, China has spread around the world including Malaysia on January 25th, 2020 which was the starting point for pandemic in the country. The aim of this study is to determine the impact of COVID-19 pandemic on PM_{2.5} concentrations in Malaysia where data of Air Quality Index (AQI) is obtained from DOE and divided into three timelines, i.e., 20 days before MCO, during MCO and during phase 6 of MCO which was known as CMCO. The data then is compared between timeline to identify and evaluate the changes in variation of PM_{2.5} concentrations that determine the air quality status in every region of Malaysia. It was found that MCO implemented by Malaysian Government has indirectly reduced the concentration of air pollution level noticeably at the end of phase 3 of MCO where there was decline in vehicle uses and operation of industrial activities was prohibited. The reduction of PM_{2.5} concentrations can be observed in more than 50% of whole monitoring stations during MCO was implemented in the whole regions. The fine particulate matter (PM_{2.5}) concentrations started to rise back in some areas placed under CMCO significantly in the North and Central regions where more flexibilities were given to public to carry out activities during this period. This study could provide insight on the major contribution of air pollution from man-made activities primarily economic sectors and vehicular emissions.

Keywords: COVID-19, pandemic, MCO, CMCO, , PM_{2.5}, Malaysia,

1.0 INTRODUCTION

In Wuhan, the capital city of Hubei Province in Central China, the first cases of pneumonia caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in which also known as 2019 novel coronavirus (2019-nCoV) have been identified in December 2019. Most infected patients with SARS-CoV-2 have developed symptoms such as dry cough, pharyngitis, and fever to date and several fatal complications (Sohrabi et al., 2020). The number of cases detected and reported subsequently increased rapidly as the virus has the ability to transmit from person to person (Chan et al., 2020; Li et al., 2020). The disease then reported spreading at other countries such as Japan, Singapore, Malaysia, United States and others (Rothan & Byrareddy, 2020). Considering the alarming threat, the World Health Organization (WHO) declared that COVID-19 could be described as a pandemic on 11 March (World Health Organization, 2020).

The first case of COVID-19 was identified in Malaysia on 25th January 2020 involving Chinese tourist who travelled to Malaysia from Singapore. The number of cases reported since then has been developed slowly until 16th February 2020 that marked the first wave of COVID-19 pandemic in Malaysia (Elengoe, 2020) but there was no intensive control measures applied as the number of cases was in under control. Second wave started on Feb 27th where a sudden increase of COVID-19 cases reported attending mass gatherings and events located in Kuala Lumpur (Razak A. & Pfordten, D, 2020). According to the Health Director-general Tan Sri Dr Noor Hisham Abdullah, the spread of the disease became more aggressive as the virus has been mutated and looking at the significant number of cases of the infection, several measures have been taken by the government together with Ministry of Health (MOH) to control the spread

the virus and protect the health of Malaysian people. This includes compliance of health screening of tourists or locals returning from abroad and isolation of those that are detected to have fever in a designated area and implementation of Movement Control Order (MCO) with different courses of action in areas where the number of cases were high corresponding with the epidemic progression in order to limit movement of people into or out of a region (Shah et al., 2020).

Some activities like mass gatherings include religious, sports and cultural activities were prohibited. Both government and private premises were also given order not to operate with the exception of those essential services (Malaysian National Security Council, 2020). As most people were working from home and few industries have been closed, the use of vehicles and emissions from industrial activities were minimized. These control measures to some extent affecting air quality as main causes of air pollution in Malaysia are from vehicles and industrialization.

Several researches have been carried out to investigate the impact of COVID-19 pandemic on every aspects and many of the researches focus on the effects of pandemic on mental health, socio-economic and environment such as air quality but most of the studies look at the quality of air in foreign countries and have almost same outcomes. Majority of the studies stated that there was reduction in concentration of nitrogen dioxide (NO₂), ozone (O₃), carbon monoxide (CO), sulphur dioxide (SO₂) and particulate matters (PM_{2.5}, PM₁₀) during lockdown compared to reading of these pollutants before period of lockdown (Agami, 2020a; El-magd & Zanyat, 2020a; Gama et al., 2020a).

In contrary, although same study has been conducted in assessing impact of the pandemic on air quality in Malaysia yet it is still limited as only few parameters of air pollutants were analyzed. A study performed by (Nadzir et al., 2020) found that carbon monoxide (CO) concentration reduced about 50% while both fine particulate matter (PM_{2.5}) and coarse particulate matter (PM₁₀) concentrations increased by 60% and 9.7% during the lockdown days compared to the normal days. However, another study done by (Abdullah et al., 2020) illustrated a high reduction of PM_{2.5} up to 58.4% during the MCO. This shows that every study has diverse outcomes on air quality reading at different locations.

In this present study, the impact of COVID-19 pandemic on PM_{2.5} concentrations in this country was assessed from 20 days before MCO was implemented to early phases of Conditional Movement Control Order (CMCO) applied to all regions. The results obtained from this study conducted are significant to understand if there are any positive changes on air quality during lockdown and partial lockdown days compared to the days where no different levels of MCO were implemented. Other than that, this study intent to discover the status of air quality changes during CMCO days compared to MCO days as both control measures implemented have same objectives in which to limit the movement of human activities and to control the spread of the diseases but these control measures have different flexibilities. Apart from that, the study outcome might be able to provide information to help researchers to understand on how industrial activities contribute pollution to the air in depth and related agencies to propose interventions to reduce the pollution.

2.0 MATERIALS AND METHODS

2.1 *Study site and population*

This study was conducted in Malaysia where it is a Southeast Asia country and basically categorized into 6 main regions, namely the Northern Region (Perlis, Kedah, Penang, Perak), East Coast Region (which includes Kelantan, Terengganu, Pahang), Southern Region (Negeri Sembilan, Malacca, Johor), Central Region (that includes Selangor, Kuala Lumpur, Putrajaya) that are located in Peninsular Malaysia. While another two regions in the East of Malaysia, Sabah and Sarawak are separated from Peninsular Malaysia by the South China Sea. The total geographical area of the country is 30,345 km² with an estimated total population of 32.735 million (2019). The regions in Malaysia was illustrated in Figure I.

There are almost 80% of population in Malaysia living in the urban areas in which the major ethnic groups consisting of Malay, Chinese and India. Most of heavy industries such as mining of minerals, manufacturing of food products and textiles are situated in Peninsular Malaysia while industry activities like petroleum processing and logging are commonly carried out in Sabah and Sarawak. In general, the climate in the country is fairly humid, where characteristics of days are warm and sunny and nights are moderately cool. The temperatures experienced by Malaysia ranging from 20°C to 30°C throughout the year (Leinbach, T. R., 2021). The whole regions in Malaysia are chosen in this study because all the states experienced MCO for almost 2 months and CMCO for about a month started on early May, 2020.



Figure I: A map of Malaysia comprises of 6 regions, namely the Northern Region (Perlis, Kedah, Penang, Perak), East Coast Region (Kelantan, Terengganu, Pahang), Southern Region (Negeri Sembilan, Malacca, Johor), Central Region (Selangor, Kuala Lumpur, Putrajaya), Sabah and Sarawak

2.2 Study Design

The study design applied was descriptive type that intent to assess the impact of COVID-19 pandemic on air quality in Malaysia. A retrospective study was conducted using data of Air Pollution Index (API) from February, 2020 until end of October, 2020 of every 65 continuous air quality monitoring stations (CAQMS) in Malaysia. The data obtained from Department of Environment (DOE), Malaysia under the Ministry of Environment and Water. There are two types of variables involved in this study which are independent and dependent variables. The independent variable were 6 regions comprise of Northern region, Central region, Southern region, East Coast region and the East Malaysia Sabah and Sarawak as well as monitoring stations in every state in Malaysia. On the other hand, for the dependent variable included in this study were the trend of PM_{2.5} concentrations in every region and the variation changes of PM_{2.5} concentrations in every continuous air quality monitoring stations from days before implementation of MCO until end of phase 6 of MCO (CMCO).

The inclusion criteria included in this study was data of daily PM_{2.5} concentrations from early of February, 2020 until end of October, 2020. In addition, the focus of this study was the PM_{2.5} concentrations data of 65 CAQMS in Malaysia. As for the exclusion criteria, this study excluded the variables on the reading of other types of air pollutant recorded by DOE such as sulphur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO) and ozone (O₃). Other than that, the focus of this study was not related on the daily PM_{2.5} concentrations on mobile air quality monitoring stations (MAQMS) as well as other meteorological variables (temperature, rainfall and relative humidity) that could affect the variation changes of PM_{2.5} concentrations. Summary of study design illustrated in Table I.

Table I: Summary on the study profile consisting of study variables, inclusion criteria and exclusion criteria

Objectives	Independent variables	Dependent variables	Inclusion Criteria	Exclusion criteria
Identify the pattern of PM _{2.5} concentrations changes during COVID-19 pandemic.	Malaysia consists of 6 main regions; ▪ North ▪ Central ▪ South ▪ East Coast ▪ Sabah ▪ Sarawak	Trend of PM _{2.5} concentrations in every region from late February, 2020 to early of June, 2020.	Data collection of PM _{2.5} concentrations from late February, 2020 to early of June 2020 daily	Other data of air pollutants; ▪ sulphur dioxide (SO₂) ▪ nitrogen dioxide (NO₂) ▪ carbon monoxide (CO) ▪ ozone (O₃)
Determine the variation changes of PM _{2.5} concentrations in every monitoring station during the COVID-19 pandemic.	65 continuous air quality monitoring stations (CAQMS)	Variation of PM _{2.5} concentrations in every monitoring station	Data of the PM _{2.5} concentrations of 65 CAQMS in Malaysia	Data of the PM _{2.5} concentrations from mobile air quality monitoring stations (MAQMS) in Malaysia

2.3 *Data collection and management*

The Air Pollutant Index (API) is an air quality status indicator for specific area where in Malaysia, the dominant air pollutant is PM_{2.5} concentrations that was used to determine the API value since several years ago. Department of Environment (DOE) of Malaysia is in charge to monitor the amount of pollutants in the environment that may cause harm to human health and environment and to determine the air quality status in all regions. The six main pollutants measured by DOE are ozone (O₃), sulphur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), coarse particulate matter (PM₁₀) and fine particulate matter (PM_{2.5}) concentrations. In this study, the API data particularly PM_{2.5} concentrations of all regions in Malaysia was acquired from DOE on hourly basis through email from authorized employee working in DOE. The data was collected from early of February, 2020 to early of November 2020 which was the latest data of API taken at 65 continuous air quality monitoring stations as listed in the Appendix I but the data used in this study was until end of CMCO days in the phase 6 of MCO from 27th February 2020 until 9th June 2020 to create a timeline.

2.4 Data processing

Before analysis of data could be performed, data acquired from DOE must be processed in which in this study, it involved several parts. The daily of API data was converted into PM_{2.5} concentrations ($\mu\text{g}/\text{m}^3$) using specific calculation issued by DOE as shown in Table II. The data then was categorized into 3 different timelines, i.e., 20 days before MCO (from 27th February to 17th March 2020); during MCO (18th March to 3rd May 2020) and during phase 6 of MCO which was known as CMCO (from 4th May to 9th June 2020). In order to understand the pattern of PM_{2.5} concentrations in all regions in Malaysia, the converted data was calculated to get the average reading of the day. As an example, data of PM_{2.5} concentrations on 27th February 2020 in all monitoring stations located in Central region were summed up and divided by 8 monitoring stations. Same data processing was performed for other regions according to its timeline.

The daily of PM_{2.5} concentrations in each monitoring station was also calculated to get the average reading for every timeline. Same formula was applied to get the average reading. For instance, the daily of PM_{2.5} concentrations for 20 days before lockdown period in Tangkak, Johor monitoring station were summed up and divided by the 20 days. The reduction average in percentage of each region was calculated by the total average of PM_{2.5} concentrations ($\mu\text{g}/\text{m}^3$) of all monitoring stations in a region over a period of time minus the total average of PM_{2.5} concentrations ($\mu\text{g}/\text{m}^3$) of the initial timeline of the same region. Then, the value was divided with initial average and multiply by 100. For an example, the total average reading of concentrations in 14 monitoring stations in Northern region during the MCO was summed up and minus with total average reading of PM_{2.5} concentrations before

MCO (initial) and divided by total initial average, then multiply by 100. All the extraction data was performed in Microsoft Excel 2016 spread sheet. The significant changes of PM_{2.5} concentrations variation in 6 regions in Malaysia at different times was calculated by using statistic package for social science (SPSS) version 21. Overall statistical analysis used a p-value of below 0.05.

Table II: Calculation of API and PM_{2.5} concentration

API	Breakpoint of concentration	Equation for API
X= PM _{2.5} (24 h average, unit: µg/m ³)		
0-50	$0 \leq X \leq 12.0$	$API = 4.1667 * X$
51-100	$12.0 \leq X \leq 75.5$	$API = 0.7741 * (X - 12.1) + 51$
101-200	$75.5 \leq X \leq 150.4$	$API = 1.3218 * (X - 75.5) + 101$
201-300	$150.5 \leq X \leq 250.4$	$API = 0.9909 * (X - 150.5) + 201$
301-400	$250.5 \leq X \leq 350.4$	$API = 0.9909 * (X - 250.5) + 301$
401-500	$350.5 \leq X \leq 500.4$	$API = 0.6604 * (X - 350.5) + 401$

*Source: Department of Environment (DOE, 2019)

2.5 *Data analysis*

Data analysis could be defined as a process involving inspection and transformation of data that has been processed in order to find the meaning behind the data transformed and to develop conclusions. There were two parts involved in this study analysis in which the first part was analysis of data to identify the pattern of PM_{2.5} concentrations in every region before MCO until end of phase 6 of MCO (CMCO) and the second part was analysis of data to determine the variation changes of PM_{2.5} concentrations during the COVID-19 pandemic.

Understanding the direct and indirect factors influencing concentration of air pollution trends in the air is significant as a guidance for researches to study more deeply to strengthen the evidence of the connection with the concentration of air pollution levels. In this present study, the pattern of PM_{2.5} concentrations in every region has been carried out in a form of line graph which represented the level of PM_{2.5} concentrations on daily basis for 68 days at different timelines, i.e., 20 days before MCO (from 27th February to 17th March 2020); during MCO (18th March to 3rd May 2020) and during phase 6 of MCO which was known as CMCO (from 4th May to 9th June 2020).

The variation changes of PM_{2.5} concentrations of each monitoring station was calculated by subtracting the average reading of PM_{2.5} concentrations during implementation of MCO with the average reading of PM_{2.5} concentrations 20 days before the implementation and same method used to calculate the variation changes between PM_{2.5} concentrations during implementation of CMCO in the phase 5 and phase 6 and PM_{2.5} concentrations during implementation of MCO. In order to get the percentage of variation changes, the new value obtained after subtraction process was

divided by initial average value and multiple by 100. Same formula was used to determine the reduction average of PM_{2.5} concentrations in every region that was then illustrated in the form of clustered bar graph.

The mean differences between different period of COVID-19 pandemic in a region was also been calculated and was further analyzed by using parametric test which is known as Paired sample *t-test* to compare the mean value between each data sets of same dependent variable (PM_{2.5} concentrations) as the variable was normally distributed. Overall statistical analysis used p-value below 0.05. The purpose of the statistical analysis was to identify the significant changes of PM_{2.5} concentrations from one independent variable to another (days before MCO, MCO days and CMCO days).

3.0 RESULT

3.1 *Pattern of PM_{2.5} concentrations in every region of Malaysia during COVID-19 pandemic*

The present study was carried out in all 6 regions in Malaysia with 3 different timelines during COVID-19 pandemic. In order to understand the pattern of PM_{2.5} concentrations in each region, this study has generated a line graph of data covering a duration of 73 days illustrated in Figure II. For a clearer view of PM_{2.5} concentrations trend, the graph analysis displayed in different colour of lines to represent the regions, i.e., blue (Central), orange (Sabah), grey (Sarawak), yellow (North), dark blue (South), green (East) and black colour represent mean values of PM_{2.5} concentrations of whole Malaysia while different timelines were parted by dashed lines.

A few significant patterns can be seen from the graph of PM_{2.5} concentrations pattern in every region of Malaysia. Generally, this study shows that most of the regions illustrated fluctuating pattern of PM_{2.5} concentrations when Movement Control Order (MCO) was implemented in Malaysia. Before MCO, the level of PM_{2.5} concentrations in some of the regions such as Central, North and East regions were more than 30 $\mu\text{g}/\text{m}^3$ and highest level of PM_{2.5} concentrations recorded at Central region with average reading more than 50 $\mu\text{g}/\text{m}^3$ but the concentrations of PM_{2.5} started to decrease and drastically reduced at the end of April, 2020 during implementation of MCO. However, the average reading of PM_{2.5} concentrations level started to rise again during CMCO days. In contrary, the PM_{2.5} concentrations in Sabah and Sarawak showed some decrease average readings at the end of implementation of CMCO around early of June, 2020.

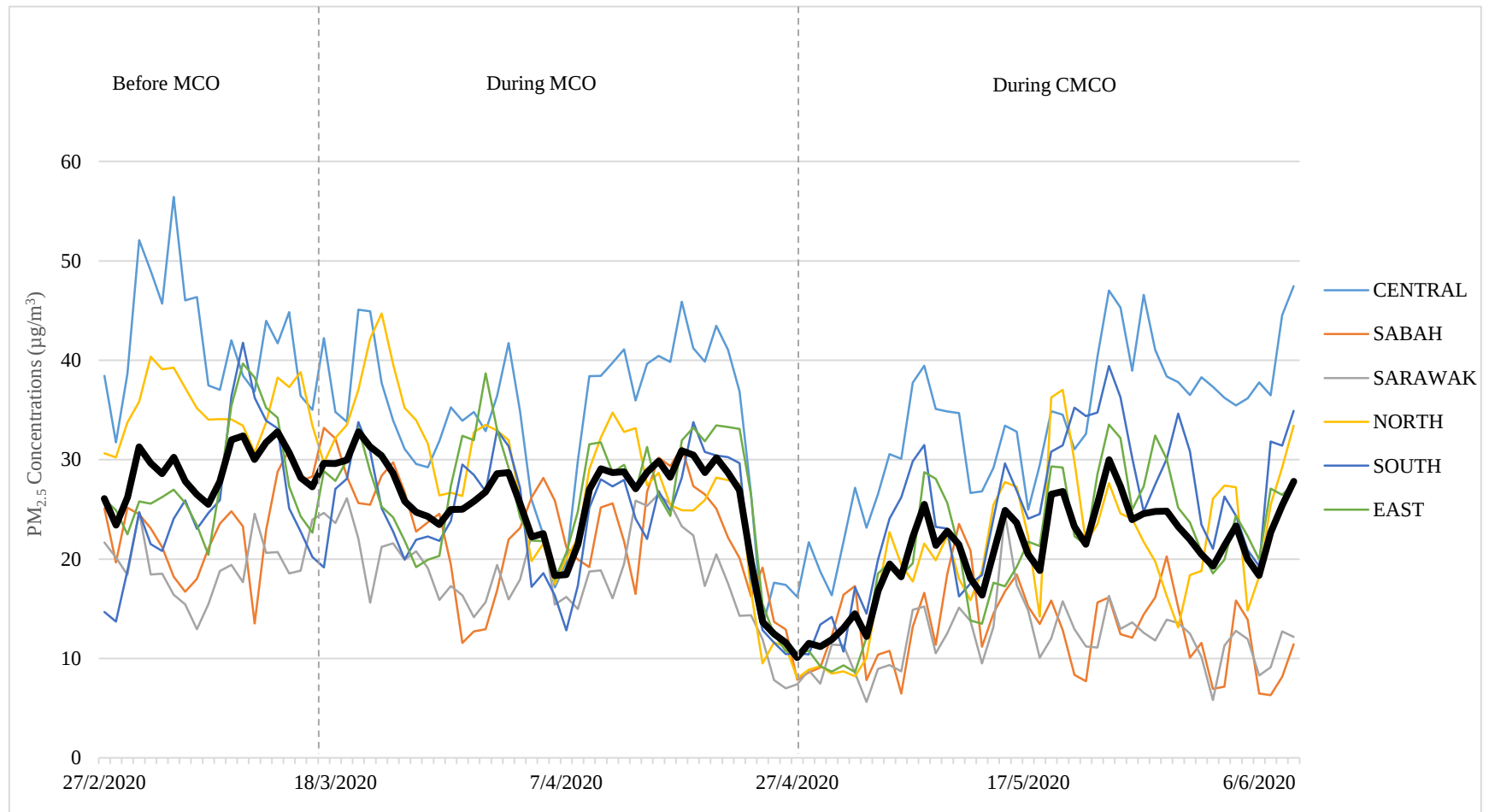


Figure II: Daily PM_{2.5} concentrations before MCO to end of CMCO of COVID-19 pandemic in Malaysia.
 *Note: Before MCO: Feb 27th, 2020 to Mac 17th, 2020; During MCO: Mac 18th, 2020 to May 3rd, 2020;
 During CMCO: Mac 4th, 2020 to June 9th, 2020

3.2 Variation changes of $PM_{2.5}$ concentrations during COVID-19 pandemic

Data of daily $PM_{2.5}$ concentrations of all continuous air quality monitoring stations in Malaysia obtained from DOE was compiled to determine the variation changes of $PM_{2.5}$ concentrations ($\mu\text{g}/\text{m}^3$) and in the form of percentage (%). Table III demonstrated the average reading of $PM_{2.5}$ concentrations and its variation changes between different period.

From the results presented, 57 of monitoring stations exhibited a decrease in $PM_{2.5}$ concentrations that contribute about 87.7% of overall monitoring stations when comparing the $PM_{2.5}$ concentrations between during MCO days and days before MCO. The result also indicated that Taiping (S10) experienced highest reduction level of $PM_{2.5}$ concentrations with $17.33\mu\text{g}/\text{m}^3$ (40.79%), followed by Minden (S8) with $14.77\mu\text{g}/\text{m}^3$ (38.10%), while the lowest reduction can be seen at Mukah (S59) with only decrease of $0.02\mu\text{g}/\text{m}^3$ (0.23%).

When observing the result of variation changes of $PM_{2.5}$ concentrations between MCO days and CMCO days, only 40 of monitoring stations experienced reduction of $PM_{2.5}$ concentrations, which attributed for 61.54% of total monitoring stations. The highest reduction of $PM_{2.5}$ concentrations occurred in Kimanis, Sabah (S51) with $14.45\mu\text{g}/\text{m}^3$ (60.71%) while Seberang Perai (S7) recorded to be the station that demonstrated lowest reduction with a decrease of $0.10\mu\text{g}/\text{m}^3$ (0.37%). In contrary, Kota Tinggi showed drastic increase of $PM_{2.5}$ concentrations with an increase of $10.59\mu\text{g}/\text{m}^3$ (103.42%) when comparing with the level of $PM_{2.5}$ concentrations during MCO.

Table III: Variation changes of daily PM2.5 concentrations before MCO until during CMCO of COVID-19 pandemic in Malaysia

Region	Location	Before MCO	During MCO	During CMCO	Variation Changes		Variation Changes	
		(a)	(b)	(c)	(b - a)		(c - b)	
		PM _{2.5} concentrations (µg/m ³)			µg/m ³	%	µg/m ³	%
North	Kangar	28.80 ± 7.30	22.22 ± 8.53	19.46 ± 7.77	-6.58	-22.85	-2.76	-12.42
	Langkawi	27.74 ± 3.25	20.69 ± 9.59	14.69 ± 9.04	-7.05	-25.41	-6.00	-29.00
	Alor Setar	35.96 ± 6.73	24.72 ± 12.69	19.05 ± 9.67	-11.24	-31.26	-5.67	-22.94
	Sungai Petani	36.31 ± 4.92	25.39 ± 13.08	24.51 ± 8.35	-10.92	-30.07	-0.88	-3.47
	Kulim Hi-Tech	35.20 ± 5.12	22.54 ± 11.54	21.65 ± 8.31	-12.66	-35.97	-0.89	-3.95
	Seberang Jaya	39.98 ± 6.47	30.06 ± 13.16	28.65 ± 7.96	-9.92	-24.81	-1.41	-4.69
	Seberang Perai	37.45 ± 5.18	26.76 ± 11.47	26.66 ± 7.62	-10.69	-28.54	-0.10	-0.37
	Minden	38.77 ± 5.59	24.00 ± 11.46	26.95 ± 15.77	-14.77	-38.10	2.95	12.29
	Balik Pulau	37.71 ± 6.27	30.95 ± 12.68	26.22 ± 10.52	-6.76	-17.93	-4.73	-15.28
	Taiping	42.49 ± 6.19	25.16 ± 12.20	23.49 ± 9.00	-17.33	-40.79	-1.67	-6.64
	Tasek Ipoh	36.84 ± 4.43	26.75 ± 13.21	24.46 ± 5.19	-10.09	-27.39	-2.29	-8.56
	Pegoh Ipoh	34.98 ± 3.12	27.70 ± 10.83	25.72 ± 5.51	-7.28	-20.81	-1.98	-7.15
	Seri Manjung	37.13 ± 6.03	29.98 ± 10.27	25.96 ± 7.52	-7.15	-19.26	-4.02	-13.41
Tanjung Malim	19.99 ± 8.42	14.89 ± 10.40	12.01 ± 8.24	-5.1	-25.51	-2.88	-9.61	
Central	Batu Muda	38.34 ± 7.13	31.70 ± 9.52	39.53 ± 6.01	-6.64	-17.32	7.83	24.70
	Cheras	44.43 ± 15.94	28.67 ± 9.51	36.62 ± 12.12	-15.76	-35.47	7.95	27.73
	Putrajaya	39.93 ± 12.48	33.47 ± 14.64	31.59 ± 11.47	-6.46	-16.18	-1.88	-5.62
	Kuala Selangor	38.36 ± 5.83	28.37 ± 13.05	31.91 ± 7.11	-9.99	-26.04	3.54	12.48
	Petaling Jaya	45.63 ± 8.85	30.66 ± 8.66	36.10 ± 7.31	-14.97	-32.81	5.44	17.74
	Shah Alam	44.68 ± 11.94	34.74 ± 12.23	36.44 ± 9.20	-9.9	-22.16	1.70	4.89
	Klang	44.50 ± 5.74	38.58 ± 6.15	42.40 ± 7.84	-5.92	-13.30	3.82	9.90
	Banting	40.33 ± 15.29	28.93 ± 11.64	32.37 ± 6.10	-11.40	-28.27	3.44	11.89
South	Nilai	36.45 ± 7.43	30.62 ± 9.34	38.70 ± 7.00	-5.83	-15.99	8.08	26.39
	Seremban	26.59 ± 8.70	22.53 ± 11.07	29.70 ± 6.77	-4.06	-15.27	7.17	31.82
	Port Dickson	30.65 ± 6.72	25.32 ± 11.47	29.38 ± 7.33	-5.33	-17.39	4.06	16.03
	Alor Gajah	20.7 ± 9.90	20.96 ± 10.70	33.32 ± 8.35	0.21	1.01	12.36	58.97
	Bukit Rambai	29.77 ± 7.45	23.98 ± 9.59	32.99 ± 7.46	-5.79	-19.45	9.01	37.57
	Bandaraya Melaka	27.71 ± 9.79	24.59 ± 9.75	31.04 ± 10.71	-3.12	-11.26	6.45	26.23
	Segamat	24.90 ± 10.40	30.38 ± 10.50	27.49 ± 7.02	5.48	22.01	-2.89	-9.51
	Batu Pahat	27.44 ± 11.57	20.33 ± 11.36	22.31 ± 9.56	-7.11	-25.91	1.98	9.74
	Kluang	15.08 ± 9.71	14.33 ± 8.80	17.89 ± 9.12	-0.75	-4.97	3.56	24.84
	Larkin	33.63 ± 14.19	24.45 ± 8.05	33.22 ± 10.12	-9.18	-27.30	8.77	35.87

Table III: Continue

Region	Location	Before MCO	During MCO	During CMCO	Variation Changes		Variation Changes	
		(a)	(b)	(c)	(b – a)		(c – b)	
		PM _{2.5} concentrations (µg/m ³)			µg/m ³	%	µg/m ³	%
EAST	Pasir Gudang	24.18 ± 10.46	23.76 ± 7.13	27.67 ± 11.07	-0.42	-1.74	3.91	16.46
	Pengerang	14.15 ± 8.93	23.13 ± 13.24	16.08 ± 9.04	8.98	63.46	-7.05	-30.48
	Kota Tinggi	13.70 ± 8.51	10.24 ± 4.61	20.83 ± 12.89	-3.46	-25.26	10.59	103.42
	Tangkak	29.55 ± 8.74	23.85 ± 10.25	22.69 ± 8.05	-5.70	-19.29	-1.16	-4.86
	Rompin	17.34 ± 7.71	35.33 ± 19.93	17.94 ± 7.96	17.99	103.75	-17.39	-49.22
	Temerloh	30.69 ± 5.11	24.98 ± 11.10	28.44 ± 8.97	-5.71	-18.61	3.46	13.85
	Jerantut	30.64 ± 6.54	22.16 ± 11.75	26.97 ± 8.89	-8.53	-27.84	4.81	21.71
	Indera Mahkota Kuantan	19.50 ± 9.59	13.97 ± 7.74	18.65 ± 9.79	-5.53	-28.36	4.68	33.50
	Balok Baru Kuantan	25.79 ± 5.96	16.77 ± 9.40	20.29 ± 9.53	-9.02	-34.97	3.52	21.00
	Kemaman	31.10 ± 4.99	22.90 ± 7.84	23.80 ± 8.55	-8.20	-26.37	0.9	3.93
	Paka	18.79 ± 7.90	14.95 ± 10.79	14.58 ± 8.50	-3.84	-20.44	-0.37	-2.47
	Kuala Terengganu	33.41 ± 8.02	27.20 ± 10.96	30.31 ± 6.53	-6.21	-18.59	3.11	11.43
Besut	28.86 ± 8.48	22.56 ± 9.99	21.86 ± 7.61	-6.30	-21.83	-0.70	-3.10	
Tanah Merah	39.72 ± 7.74	35.09 ± 8.95	27.03 ± 6.27	-4.63	-11.66	-8.06	-22.97	
Kota Bharu	32.63 ± 9.47	29.97 ± 12.61	29.12 ± 6.73	-2.66	-8.15	-0.85	-2.84	
SABAH	Tawau	9.54 ± 6.00	9.28 ± 4.09	7.38 ± 2.52	-0.26	-2.73	-1.90	-20.47
	Sandakan	21.72 ± 6.88	17.62 ± 7.74	13.63 ± 7.63	-4.1	-18.88	-3.99	-22.64
	Kota Kinabalu	27.75 ± 4.03	20.79 ± 10.18	10.26 ± 7.71	-6.96	-25.08	-10.53	-50.65
	Kimanis	30.79 ± 11.00	23.80 ± 12.04	9.35 ± 7.00	-6.99	-22.70	-14.45	-60.71
	Keningau	23.76 ± 7.98	24.64 ± 9.05	15.71 ± 9.28	0.88	3.70	-8.93	-36.24
	Labuan	27.46 ± 9.91	31.00 ± 10.30	22.49 ± 12.44	3.54	12.89	-8.51	-27.45
SARAWAK	Limbang	21.84 ± 10.92	17.77 ± 6.49	15.29 ± 15.14	-4.06	-18.59	-2.48	-13.96
	ILP Miri	31.15 ± 10.06	27.95 ± 12.81	11.25 ± 7.32	-3.20	-10.27	-16.70	-59.75
	Miri	32.22 ± 8.03	21.66 ± 9.12	18.49 ± 7.95	-10.56	-32.77	-3.17	-14.64
	Samalaju	26.90 ± 6.08	22.09 ± 8.83	14.10 ± 8.39	-4.81	-17.88	-7.99	-36.17
	Bintulu	31.15 ± 3.41	27.86 ± 9.16	25.53 ± 8.41	-3.29	-10.56	-2.33	-8.36
	Mukah	8.88 ± 3.51	8.86 ± 4.10	7.02 ± 1.95	-0.02	-0.23	-1.84	-20.77
	Kapit	10.90 ± 5.73	8.63 ± 4.17	7.13 ± 1.41	-2.27	-20.83	-1.50	-17.38
	Sibu	20.77 ± 7.66	19.00 ± 9.49	15.43 ± 8.87	-1.77	-8.52	-3.57	-18.79
	Sarikei	12.75 ± 6.13	10.16 ± 8.34	7.12 ± 1.84	-2.59	-20.31	-3.04	-29.92
	Sri Aman	11.72 ± 5.68	12.63 ± 7.60	8.54 ± 2.74	0.91	7.76	-4.09	-32.38
	Samarahan	8.82 ± 3.37	13.24 ± 8.57	7.94 ± 3.60	4.42	50.11	-5.30	-40.03
	Kuching	16.93 ± 8.30	16.40 ± 9.95	12.38 ± 7.44	-0.53	-3.13	-4.02	-24.51

*Note: Before MCO: Feb 27th, 2020 to Mac 17th, 2020; During MCO: Mac 18th, 2020 to May 3th, 2020; During CMCO: Mac 4th, 2020 to June 9th, 2020

For the purpose of providing a clearer view of the decrease percentage of $PM_{2.5}$ concentrations in main regions of Malaysia, a graph of reduction average in percentage of each region was illustrated in Figure III. In this study, higher reduction average of $PM_{2.5}$ concentrations between implementation of MCO and before MCO can be seen in North and Central regions with 28.1% and 24.13% respectively while South region showed lowest reduction average with only 10.15%.

However, Sabah and Sarawak, the East of Malaysia recorded higher reduction average of $PM_{2.5}$ concentrations when comparing between CMCO days and MCO days with 37.99% and 27.17% respectively. In contrary, East Coast region in Peninsular Malaysia demonstrated the lowest region experiencing reduction average with 2.61%. In general, the graph showed regions in Peninsular Malaysia experienced high reduction average during MCO days compared to East of Malaysia, Sabah and Sarawak but when comparing with implementation of CMCO, reversely, the East of Malaysia were the ones illustrated high reduction average in percentage.

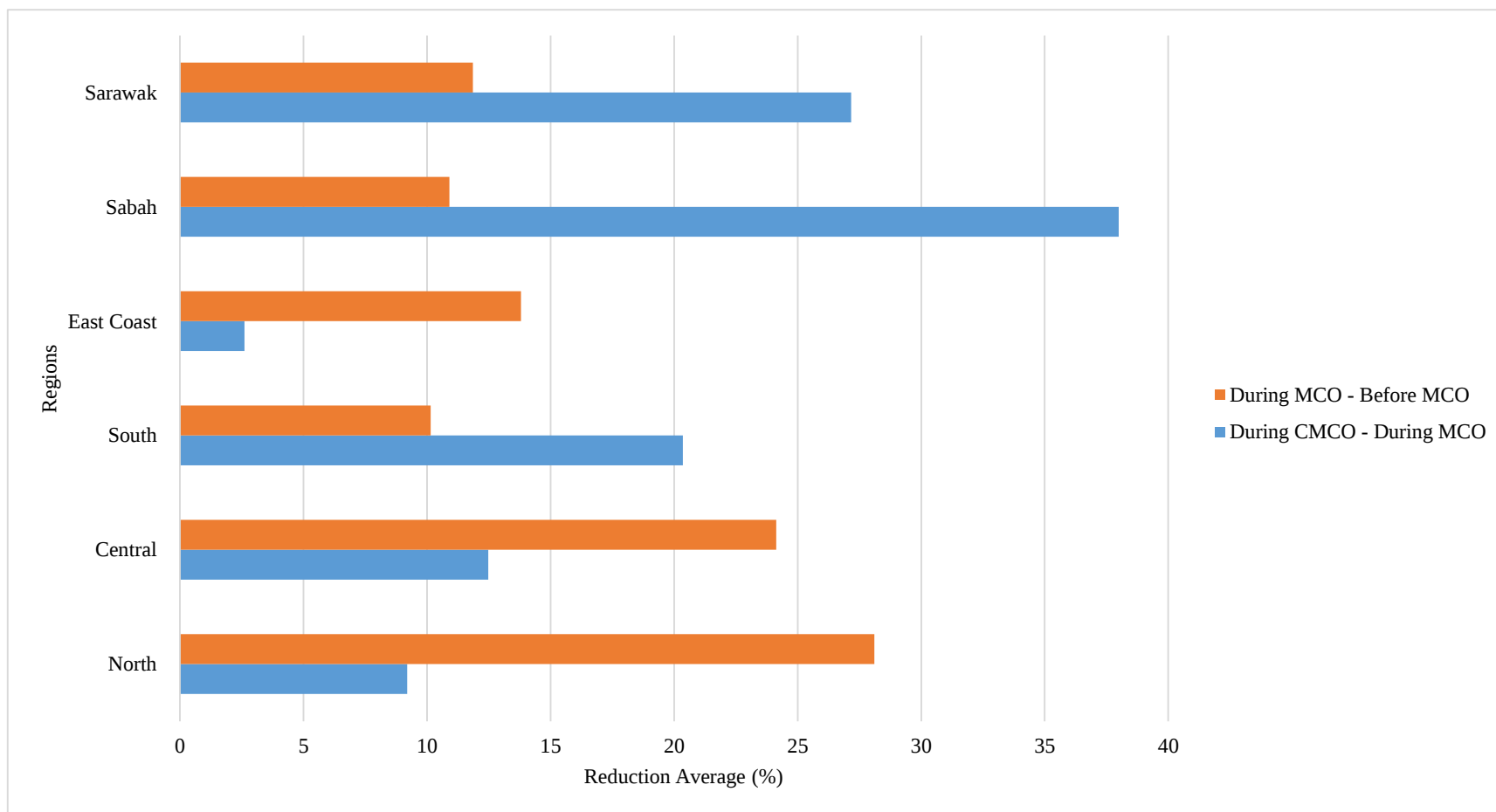


Figure III: Reduction average in percentage of PM2.5 concentrations before MCO to end of CMCO of COVID-19 pandemic in Malaysia. *Note: Before MCO: Feb 27th, 2020 to Mac 17th, 2020; During MCO: Mac 18th, 2020 to May 3rd, 2020; During CMCO: Mac 4th, 2020 to June 9th, 2020

A Paired sample *t*-test or also known as dependent *t*-test was used for further analysis in determining the mean difference of PM_{2.5} concentrations between each region of Malaysia in different periods during COVID-19 pandemic. Table IV revealed that there were statistical significant mean differences in some of the regions when comparing between means of PM_{2.5} concentrations during MCO implementation and before MCO. Based on the table, the means difference in North and Central regions were found to be the only regions that showed statistically significant (p-value: 0.23) and (p-value: 0.001) respectively. On the other hand, mean differences of other 4 regions (South, East Coast, Sabah and Sarawak) were not statistically significant with the p-value were more than 0.05.

Conversely, when dependent *t*-test was used to compare mean differences of PM_{2.5} concentrations between MCO days and CMCO days, most of the regions were discovered to be statistically significant (North; p-value <0.001; Central; p-value: <0.001; East Coast; p-value: 0.001; Sabah; p-value: <0.001; Sarawak; p-value: <0.001) while South was the only region that was not statistically significant with p-value of 0.214. When summarizing the result in the Table IV, majority of regions showed significant mean differences throughout the period of 73 days in the early of COVID-19 pandemic in Malaysia.

Table IV: Mean difference of PM_{2.5} concentrations in 6 regions before MCO until CMCO days in Malaysia

Region	Mean Average (µg/m ³)			Mean Difference (b - a)		Mean Difference (c - b)	
	Before MCO	During MCO	During CMCO	µg/m ³	T-test (P value)	µg/m ³	T-test (P value)
North	34.96 ± 3.23	25.13 ± 10.03	22.82 ± 5.87	-9.83	0.23	-2.31	<0.001
Central	42.03 ± 6.13	31.89 ± 9.41	35.87 ± 5.79	-10.14	<0.001	3.98	<0.001
South	25.32 ± 7.43	22.75 ± 7.14	27.38 ± 5.85	-2.57	0.985	4.63	0.214
East Coast	28.04 ± 5.50	24.17 ± 8.39	23.55 ± 5.13	-3.87	0.127	-0.62	0.001
Sabah	23.50 ± 4.91	21.19 ± 6.75	13.14 ± 4.33	-2.31	0.904	-8.05	<0.001
Sarawak	19.50 ± 3.25	17.19 ± 5.60	12.52 ± 3.22	-2.31	0.762	-4.67	<0.001

*Note: Before MCO: Feb 27th, 2020 to Mac 17th, 2020; During MCO: Mac 18th, 2020 to May 3th, 2020; During CMCO: Mac 4th, 2020 to June 9th, 2020

4.0 DISCUSSION

Air pollution in Malaysia is mainly comes from anthropogenic activities in which it can be from vehicle emissions and industrial activities. Fine particulate matter ($PM_{2.5}$) has been taken into consideration by Department of Environment (DOE) to determine the status of air quality in Malaysia as this type of pollutant can be produced by complex mixture of pollutants in the air directly from man-made sources and penetrate deep into parts of human body and to the extent, it can cause mortality (Afroz et al., 2003; Alias et al., 2020; Ee-Ling et al., 2015). The harm of $PM_{2.5}$ to human health has led for DOE to set stringent limit for the emission of the toxic pollutants in the New Malaysia Ambient Air Quality Standard (NMAAQS) in which the concentration of $PM_{2.5}$ is $35 \mu\text{g}/\text{m}^3$ for 24-hour average (Department of Environment, 2020). Since the COVID-19 pandemic hit Malaysia at the end of January 2020, government of Malaysia has taken control measures to break the chain of the disease by implementing Movement of Control Order (MCO) in 4 phases with different intensity in which such control measures may have influence the reduction of air pollution in Malaysia.

In general, it has been discovered that implementation of MCO has helped to reduce the air pollution, specifically $PM_{2.5}$ concentrations as most of regions in Malaysia experienced reduction in the fine particulate matter concentrations noticeably at the end of phase 3 until end of phase 4 of the MCO which is between 27th April 2020 and 3rd May 2020. The highest reduction of $PM_{2.5}$ concentrations occurred in North region with 28.1% while the lowest reduction can be seen in South region with only 10.15%. There were 3 different timelines involved in this study which are 20 days before MCO, during MCO days and CMCO days. The reduction of

PM_{2.5} concentrations mostly occurred during MCO days where another level of MCO, Enhanced Movement of Control Order (EMCO) was also enforced in several areas that were declared to be red zones with confirmed positive cases of COVID-19 more than 40 such as Cheras, Petaling Jaya, Klang, Kluang, Jerantut and Kota Bharu in which people in the involved areas were given strict order not to operate any businesses, access roads into the area were blocked and people in the areas were prohibited to exit their own homes except for the purpose of purchasing necessities.

Based on the result, when observing the variation changes of PM_{2.5} concentrations in continuous air quality monitoring stations in each region during days before MCO and MCO days of COVID-19 pandemic in Malaysia in depth, most of monitoring stations showed reduction level of PM_{2.5} concentrations where the highest variation changes of PM_{2.5} concentrations took place in Taiping, Perak with 40.79% reduction while the lowest variation changes of the particulate matter concentration occurred in Mukah, Sarawak with 0.23% with the level of air pollutant in some areas still surpass the recommended level set by DOE ($>35 \mu\text{g}/\text{m}^3$). The reason behind of the major reduction of the air pollutants in some areas such as Taiping may be linked with the main sectors in the state which are oil and gas and tourism sectors were banned from operating normally and low vehicle emissions due to the implementation of MCO for about 49 days which would be considered long period of time that is capable of influencing the decreasing of the fine particulate matter concentrations.

Despite the average of PM_{2.5} concentrations in some areas such as Central, South and East Coast were still high during MCO days, this can be explained that vital services such as pharmacies, petrol stations and food and beverage businesses were

still allowed to be functioned where urban and sub-urban areas have more such services. This type of measures might have influence the $PM_{2.5}$ concentrations in the areas as there were movement of human activities but with the standard operating procedures (SOPs) applied at the place.

After a decrease in COVID-19 cases, government of Malaysia has changed the control measures into implementation of CMCO. Conditional Movement Control Order (CMCO) was considered to be the relaxation of restriction under MCO where sectors of economic were permitted to operate but with SOPs such as social distancing must be applied and most of outdoor and activities involving gathering of people were still not allowed. Based on the result, although such control measures have been implemented, it indicated that the concentrations of $PM_{2.5}$ were again rising during CMCO in some areas where mostly occurred in Peninsular Malaysia in which 37% of overall monitoring stations demonstrated increase of $PM_{2.5}$ concentrations. Kota Tinggi, Johor showed the highest increase of the air pollutant concentration with an increase of 10.59% $\mu g/m^3$ (103.42%) when comparing with MCO days. This may be due to the fact that reopening of economic sectors in the states allow human activities to take place like use of vehicles on the roads and industrial activities emit air pollutants to atmosphere which might have influence the increasing level of the air pollutant particularly $PM_{2.5}$ concentrations.

In reference to Figure III, surprisingly, Sabah and Sarawak showed significant reduction average (%) of $PM_{2.5}$ concentrations compared to other regions in Malaysia with 37.99% and 27.17% respectively when comparing the reduction average between MCO days and CMCO days. This is likely due to economic sector in the regions being more focused on tourism where the sector was still not feasible for travelers until the

implementation of CMCO and impacting other services such as transportation and logistics, manufacturing of food and wholesale businesses. Other main activities in the East of Malaysia like mining and petroleum production were also greatly disrupted due to restrictions of cross-border (Tawie, S., 2020).

On the other side, some researchers elaborated that there are many direct and indirect factors could influence the level of air pollutant in the air, particularly PM_{2.5} concentrations. In a study performed by Nadzir et al., 2020, suggested that wind direction is one of the meteorological factors that may affect the level of air pollutants. He also found that other contributing factor in increasing the level of air pollution during MCO was human activities such as small combustion activities at the area of their houses. While other researchers proposed that other meteorological parameters and conditions such as rainfall, wind speed and temperature play significant roles in dispersion of air pollutants (El-magd & Zanaty, 2020b; Gama et al., 2020b; Rahman et al., 2020).

From the finding of this study, it was proven that implementation of MCO with different levels has indirectly contributed in reduction of PM_{2.5} concentrations. A decline in number of transportation on road, industrialization and other human activities that emit hazardous pollutants in the air will help in reducing the level of PM_{2.5} concentrations to a safe level that pose less harm on humans. Thus, relevant agencies should put concern on this matter seriously, stringent inspection and monitoring must be carried out periodically in the industries to comply with the emissions level limits.

5.0 CONCLUSION

In summary, the findings from this study further strengthen the studies conducted by other researches to prove that implementation of Movement Control Order (MCO) has indirectly influence in reducing the level of air pollutant, particularly level of PM_{2.5} concentrations that has been considered to be life-threatening pollutant in most of regions in Malaysia where the main contribution sources of the air pollutant are the use of vehicles and industrial sectors have been minimized and as the movement of human activities begin to grow, the level of pollutants released to the air also rise. Relevant authorities such as Department of Environment (DOE) shall monitor the emission of air pollutants from industrial activities to make sure the industries comply with the New Malaysia Ambient Air Quality Standard (NMAAQS) to curb the air pollution problems that have plagued Malaysia for many years. Despite of this study provides newer knowledge on the effects of COVID-19 pandemic on air quality, other meteorological factors and topography constraints must be taken into consider for further research to provide stronger justification on the influence of the global pandemic on air quality status.

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APPENDIX I

Continuous air quality monitoring stations in Malaysia

Station	Region	State	Location
S1	North	Perlis	Kangar
S2		Kedah	Langkawi
S3		Kedah	Alor Setar
S4		Kedah	Sungai Petani
S5		Kedah	Kulim Hi-Tech
S6		Penang	Seberang Jaya
S7		Penang	Seberang Perai
S8		Penang	Minden
S9		Penang	Balik Pulau
S10		Perak	Taiping
S11		Perak	Tasek Ipoh
S12		Perak	Pegoh Ipoh
S13		Perak	Seri Manjung
S14		Perak	Tanjung Malim
S15	Central	Kuala Lumpur	Batu Muda
S16		Kuala Lumpur	Cheras
S17		Putrajaya	Putrajaya
S18		Selangor	Kuala Selangor
S19		Selangor	Petaling Jaya
S20		Selangor	Shah Alam
S21		Selangor	Klang
S22		Selangor	Banting
S23	South	Negeri Sembilan	Nilai
S24		Negeri Sembilan	Seremban
S25		Negeri Sembilan	Port Dickson
S26		Melaka	Alor Gajah
S27		Melaka	Bukit Rambai
S28		Melaka	Bandaraya Melaka
S29		Johor	Segamat
S30		Johor	Batu Pahat
S31		Johor	Kluang
S32		Johor	Larkin

Appendix I: Continue

Station	Region	State	Location
S33	East	Johor	Pasir Gudang
S34		Johor	Pengerang
S35		Johor	Kota Tinggi
S36		Johor	Tangkak
S37		Pahang	Rompin
S38		Pahang	Temerloh
S39		Pahang	Jerantut
S40		Pahang	Indera Mahkota Kuantan
S41		Pahang	Balok Baru Kuantan
S42		Terengganu	Kemaman
S43	Sabah	Terengganu	Paka
S44		Terengganu	Kuala Terengganu
S45		Terengganu	Besut
S46		Kelantan	Tanah Merah
S47		Kelantan	Kota Bharu
S48		Sabah	Tawau
S49		Sabah	Sandakan
S50		Sabah	Kota Kinabalu
S51		Sabah	Kimanis
S52		Sabah	Keningau
S53	Sarawak	Labuan	Labuan
S54		Sarawak	Limbang
S55		Sarawak	ILP Miri
S56		Sarawak	Miri
S57		Sarawak	Samalaju
S58		Sarawak	Bintulu
S59		Sarawak	Mukah
S60		Sarawak	Kapit
S61		Sarawak	Sibu
S62		Sarawak	Sarikei
S63		Sarawak	Sri Aman
S64		Sarawak	Samarahan
S65		Sarawak	Kuching