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A Long Term Observation of Meteorological Influence on COVID-19 Pandemic Spread in Malaysia – A Case Study

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Abstract: This study aims to investigate the relationship between meteorological parameters and the Coronavirus (COVID-19) pandemic spread in every state in Malaysia. This study uses the secondary data of COVID-19, meteorology parameters, including AQI from the Ministry of Health Malaysia, NASA POWER Data Access Viewer, and Air Quality Historical Data Platform webpage, respectively. The parameters included in this study are daily cases, daily deaths, total daily cases, total daily deaths, temperature (T) (°C), relative humidity (RH) (%), wind speed (WS) (m/s), precipitation (P) (mm), dew point (DP) (°C), and air quality index (AQI) (API) during Movement Control Order (MCO), Conditional Movement Control Order (CMCO), and Recovery Movement Control Order (RMCO) phases. Statistical analyses such as Pearson's correlation, factor analysis, and factor score were used for data analysis and interpretation. Overall, T, WS, P, and DP are significant parameters to the COVID-19 outbreak in Malaysia. Every lockdown phase is influenced by different meteorological parameters. The correlation analysis revealed that meteorological parameters had a significant impact on the COVID-19 outbreak in Johor, Kelantan, Negeri Sembilan, Sabah, Sarawak, Selangor, and W.P. Kuala Lumpur. The study also reveals that the optimal ranges of T (26.5 °C - 28.5 °C), RH (78% - 87%), WS (1.4 m/s – 2.7 m/s), P (6 mm - 11 mm), and DP (23.8 °C - 24.75 °C) influenced the COVID-19 outbreak irrespective of states and MCOs. However, API (<50 API) favours lesser COVID-19 outbreaks in the country. The HYSPLIT trajectory model was also used to study the backward air mass movement to identify the sources of air pollutants reaching the selected states (W.P. Kuala Lumpur and Sabah). The results revealed that the source of air pollutants was from multiple directions, with mixed contributions from the land and ocean. The attempt to observe the influence of local climatic patterns on the pandemic has revealed that short term climate change in the country is significant which may support the COVID-19 spread. The research outcome would be helpful to understand the role of meteorology in the long-term effect of COVID-19 spread in Malaysia. This study also helps the health policymakers, Malaysian Government, and NGOs to curb the spread in the next episode of COVID-19 and other related pandemics.

Keywords: COVID-19; Movement control order; Temperature; AQI; Infected cases.

Introduction

The COVID-19 disease has been affecting a large number of people globally for over a year now. The COVID-19 outbreak originating from Wuhan, Hubei Province, China happened in late December 2019. COVID-19 disease is caused by a novel coronavirus known as the severe acute respiratory coronavirus-2 (SARS-CoV2), which is categorised in the same virus family such as the severe acute respiratory syndrome coronavirus (SARS-CoV1) and the middle eastern respiratory syndrome coronavirus (MERS-CoV) (Guan et al., 2020; Hu et

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al., 2020; Wu et al., 2020). Nevertheless, this pandemic occurred at a larger regional scale as compared to the severe acute respiratory syndrome (SARS) outbreak in 2002 and middle eastern respiratory syndrome (MERS) in 2012 (Wang et al., 2020; Wu et al., 2020). The number of COVID-19 cases has been steadily increasing globally since the outbreak began in December 2019 (Chidambaram et al., 2021). On 11th March 2020, the World Health Organization (WHO) declared a world pandemic due to the uncontrolled number of COVID-19 cases (WHO, 2020). As of 8th November 2021, a total of 249,743,428 confirmed cases of COVID-19 with 5,047,652 deaths have been reported globally (WHO, 2021). Several studies described the transmission of the SARS-CoV2 virus is linked to respiratory droplets produced during oral speeches and can easily be passed from human to human through close contact (Marr et al., 2019; Chaudhuri et al., 2020). Meselson (2020), Van Doramalen et al. (2020), and Hu et al. (2021) mentioned that the SARS-CoV2 virus is transmissible via liquid droplets or in smaller particles such as aerosols. Individuals infected by COVID-19 are either asymptomatic or symptomatic. Common symptoms are fever, cough, and fatigue (Huang et al., 2020). The COVID-19 transmission routes are still being debated by scientists and researchers. However, several studies have agreed that the possibility of transmitting the COVID-19 disease airborne is high and was recognized as the main route of global transmission similar to the previous SARS-CoV1 outbreak (Booth et al., 2005; Chan et al., 2011; Feng et al., 2020; Morawska et al., 2020; Setti et al., 2020; Greenhalgh et al., 2021). Worldwide studies have revealed that meteorological parameters such as T, RH, WS, P, DP, and AQI are linked with the COVID-19 spread (Figure 1). The studies were conducted with different sets of methodologies and different climate patterns (Table 1). Through the studies, every country highlighted the main factors that influenced the spread of COVID-19 (Table 2).

Hence, this study aims to determine the relationship between meteorological factors and AQI with COVID-19 spread of every state in Malaysia. Also, this study attempts to identify the main factor(s) contributing to the COVID-19 spread in Malaysia during different movement control order phases. In addition, the source of air pollutants to the main cities is attempted. Based on the detailed literature review, the studies in Malaysia mainly highlight medical-related issues, with only a few studies performed from an environmental perspective with a restricted period of data collection. However, there is still a limited comprehensive study to observe the long-term influence of meteorological parameters with the spread of COVID-19 in the states of Malaysia, thus indicating the research gaps for the current study.

Study Area

Malaysia is part of the Southeast Asian country located near the equator in a tropical region. The country lies between latitude 4.2105 °N and longitude

Figure 1: Distribution of worldwide studies on environmental factors and the Covid-19 spread in 2020. Adapted and modified from "Learn ArcGIS" by Esri, 2021 (https://learn-arcgis-learngis.hub.arcgis.com/). Copyright 2021 by Esri.

Table 1: Studies conducted with different sets of methodologies and different climate patterns by authors in different parts of the world

Country Sample	*Meteorology factor(s)*	*Methodology*	*References*
Climate type : 4 seasons (Spring, Summer, Autumn, Winter)			
United States of America	Temperature and Humidity	Kendall and Spearman correlation rank test	Bashir et al. (2020)
China	Temperature and Humidity	General Additive Model (GAM)	Ma et al. (2020)
India	Air Quality Index	Ground and satellite observations	Singh and Chauhan (2020)
Iran	Wind Speed	Partial Correlation Coefficient (PCC) and Sobol'- Jansen method	Ahmadi et al. (2020)
Japan	Humidity	Descriptive analysis, Multivariate linear regression, Trend analysis	Kodera et al. (2020)
Russia	Temperature and Dew Point	Pearson's correlation analysis, Principal Component Analysis, Varimax Rotation and Kaiser Normalisation	Shankar et al. (2021)
Spain	Air quality	Remote sensing	Tobias et al. (2020)
Climate type : Tropical and Warm			
Brazil	Temperature and Humidity	GAM, Descriptive analysis	Prata et al. (2020), Auler et al. (2020)
Southeast Asia	Temperature, Humidity, and Air Quality Index	Spearman's correlation test, comparative study	Abdullah et al. (2020), Tosepu et al. (2020)
Climate type : Mediterranean			
Turkey	Wind Speed	Spearman's correlation test	Sahin (2020)

101.9758 °E, covering approximately 329847 km^2 land areas with an estimated population density of 32.7 million in 2020 (Department of Statistics Malaysia [DOSM], 2020). Geographically, it is divided into two large landmasses, Peninsular Malaysia (West Malaysia) and East Malaysia (North Borneo territories), separated by the South China Sea (Azman et al., 2017; Prasanna & Chidambaram, 2021). The Peninsular Malaysia comprises of 13 states (Johor, Kedah, Kelantan, Melaka, Negeri Sembilan, Pahang, Perak, Perlis, Pulau Pinang, Selangor, Terengganu, and two federal territories which are Wilayah Persekutuan (W.P.) Kuala Lumpur and W.P. Putrajaya) (Figure 2). Similarly, East Malaysia comprises 3 states (Sabah, Sarawak, and the only federal territory which is W.P. Labuan) (Figure 3). However, Peninsular Malaysia is experiencing rapid urbanisation and industrialisation such as manufacturing, processing, tourism, shipping, and factories compared to East Malaysia (Othman & Latif, 2021). Also, increase usage of vehicles and road traffic activities in the cities influenced air pollution. Throughout the year, Malaysia experiences consistently high T (24 °C to 38 °C) and RH (70% to 90%), light WS, long hours of daylight with an annual average high Prate in East Malaysia (5080 mm) compared with Peninsular Malaysia (2500 mm) (Makaremi et al., 2012; Prasanna & Chidambaram, 2021). The country's annual climate is associated with the Southwest (SW) Monsoon (April to September), which favours drier weather with less P, and the Northeast (NE) Monsoon (October to March), which favours more P (Kwan et al., 2013).

Methodology COVID-19 Data

The COVID-19 data were obtained from the open source of The Ministry of Health Malaysia Covid-19 Portal (https://covid-19.moh.gov.my/) and the Desk of the Director-General of Health Malaysia Portal (https://kpkesihatan.com/). The data comprised daily cases (DC), average daily cases (ADC), total daily cases (TDC), daily deaths (DD), average daily deaths (ADD), total daily deaths (TDD), and total recoveries (TR) from 1st January to 31st December 2020 which represents the pre–lockdown, lockdown, and post–lockdown. The data were obtained state-wise. However, due to insufficient data, the TR data were only obtained for Malaysia as a whole. Table 3 shows the dates of implementation of four different lockdown periods in Malaysia.

Table 2: Summarised literature review on recent studies on Covid-19 conducted in different parts of the world

Author(s)	*Aim*	*Methodology*	*Factor(s)*	*Key finding(s)*
Sample 1: America				
Auler et al. (2020)	To analyse how humidity can affect the spread of COVID-19 in five Brazilian (São Paulo, Rio de Janeiro, Brasília, Manaus and Fortaleza) cities.	Descriptive analysis	Humidity	Higher relative humidity at 79% throughout 30 days increases the Covid-19 spread in Brazil.
Bashir et al. (2020)	To examine the correlation between climate factors and the Covid-19 pandemic in New York City.	Kendall and Spearman rank correlation test	Temperature, Humidity	At minimum temperature (lowest 3 °C, highest 13 °C) and average temperature (lowest 1 °C, highest 15 °C) are correlated significantly with the spread of Covid-19 in New York City. Significant negative correlation between relative humidity was with the number of Covid-19 cases due to increase in annual population.
Prata, Rodrigues, and Bermejo (2020)	To determine the relationship of temperature to Covid-19 infection for the state capital cities of Brazil.	General Additive Model	Temperature	The annual average temperature in Brazil (16.8 °C to 27.4 °C), showing a negative correlation to the confirmed cases. With an average temperature of less than 25.8 °C an increase in 1 °C resulting in a 4.9% decrease of confirmed Covid-19 cases in Brazil.
Sample 2 : China				
Fareed et al. (2020)	To examine the association between air quality index (AQI) and Covid-19 mortality rate counts in Wuhan, China.	Wavelet analysis	AQI	Poor air quality at lower relative humidity increases the mortality rate. Authors recommended the Covid-19 patients are provided with cleaner environment to speed up the recovery processes.
He et al. (2020)	To investigate the impacts of lockdown on air quality in China.	Descriptive analysis	AQI	A significant improvement in the air quality by 19% during the implementation of lockdowns in the cities. Lockdowns showed positive air quality effects in a colder and urbanised cities in China.
Liu et al. (2020)	To investigate the impact of meteorological factors on the Covid-19 virus transmission in 30 provincial capital cities in China.	Generalised Linear Model (GLM)	Temperature	Every 1 °C increase in ambient temperature (AT) and diurnal temperature (DTR) is associated with the decline in the Covid-19 confirmed cases. The novel coronavirus can survived longer in an environment with smaller DTR or constant temperature.
Ma et al. (2020)	To study the association between Covid-19 deaths, and meteorological factors in the origin country, Wuhan, China.	General Additive Model	Temperature, Humidity	A negative correlation between temperature at 2 °C to 18 °C and mortality rate counts due to Covid-19. DTR between 7 °C to 9 °C showed a positive correlation as every increment in 1 °C DTR unit will increase the Covid-19 death counts by 2.92%.

				An absolute humidity from 59% to 97% was found correlated negatively with mortality rates. Humidity plays a significant role in the mortality rate due to Covid-19.
Qi et al. (2020)	To examine the associations of daily relative humidity (ARH) with the daily counts of COVID-19 cases in 30 Chinese provinces in Hubei, China.	General Additive Model	Humidity	Negative correlation between relative humidity ranging from 67% to 86%, where in every increment of 1% in relative humidity will decrease the number of daily Covid-19 cases.
Wang and Su (2020)	To assess the air quality during lockdown in China.	Descriptive analysis	AQI	During lockdown period, the Covid-19 pandemic did influence the air quality in China but in short term. Reducing economic activities and restricting mobile activities significantly affect China's air pollution rates.
Xu et al. (2020)	To analyse the correlation between AQI and Covid-19 confirmed cases in 33 locations in China.	Poisson regression model	AQI	The AQI influenced the number of confirmed Covid-19 cases. Temperature ranging from 10 °C to 20 °C and relative humidity ranging from 10% to 20% are strongly associated with AQI in transmitting the SARS-CoV2 virus.
Sample 3: Europe				
Briz-Redón and Serrano-Aroca (2020)	To analyse the effect of daily temperature with the accumulated Covid-19 cases across the provinces in Spain	Spatial-temporal analysis	Temperature	Found an insignificant correlation between temperature and Covid-19 transmission.
Tobias et al. (2020)	To observe the changes in air quality during a one month lockdown period	Google Earth Engine, data plotting	AQI	Nitrogen dioxide and black carbon (BC) reduced by 50% during lockdown
Sample 4: Global				
Bukhari and Jameel (2020)	To analyse the local weather patterns of the regions effected by SARS-CoV2 virus	Descriptive and trend analysis	Humidity	The transmission of Covid-19 is not restricted only to cooler but also warmer and humid climates Observed a spike in the number of cases in the last week of March 2020 in warmer countries such as Asia, South America, and Africa
Sarkodie and Owusu (2020)	To investigate the influence of meteorological factors on the Covid-19 pandemic within the top 20 countries	Descriptive analysis	Wind speed, Dew point	Positive correlation between average wind speed from sampled countries (2.44 m/s at 2m) and Covid-19 cases Dew points are good predictor to Covid-19 deaths and recovery cases Every 1% increase in dew point, the confirmed cases and deaths will increase by approximately 11%

(*Contd.*)

Table 2: (*Contd.*)

Author(s)	*Aim*	*Methodology*	*Factor(s)*	*Key finding(s)*
Sobral et al. (2020)	To analyse the associations between transmission of and deaths caused by SARS-CoV-2 and precipitation	Panel data regression model	Precipitation	Positive corelation between precipitation and Covid-19 Countries with higher rainfall measurements increase the Covid-19 transmission No significant correlation between precipitation and Covid-19 mortality
Sample 5: India				
Kumar (2020)	To study the effect of meteorological factors on the spread of Covid-19 during the lockdown	Descriptive analysis	Temperature	Average daily temperature at 22 °C to 33 °C are positively correlated to the new confirmed Covid-19 cases in India. Both temperatures are steadily rising in March and April with the confirmed Covid-19 cases despite lockdowns have been implemented.
Kumar and Kumar (2020)	To investigated the correlation between meteorological factors and Covid-19 spread in Mumbai, India.	Spearman's correlation test	Humidity	A Significant positive correlation with relative humidity from 67% to 86% and the Covid-19 cases
Mahato et al. (2020)	To study the effect of air quality during Covid-19 pandemic lockdowns	Descriptive analysis	AQI	Air quality index decreased drastically by 40% to 50% in just a few days after lockdown was implemented.
Sample 6: Iran				
Ahmadi et al. (2020)	To investigate the effect of climate factors on Covid-19 spread in Iran	Partial correlation coefficient (PCC) and Sobol'-Jansen method	Wind speed	Average wind speed at 3.53 m/s is the most influential factor in the SARS-CoV2 virus spread. The COVID-19 cases were more common in provinces with low wind speeds than in provinces with high wind speeds.
Sample 7: Japan				
Kodera, Rashed, and Hirata (2020)	To investigate the correlation between humidity and the morbidity and mortality rates due to the Covid-19 pandemic in Japan	Descriptive analysis, Multivariate linear and regression trend analysis	Humidity	Negative correlation between humidity to morbidity and mortality rates
Sample 8: Southeast Asia				
Abdullah et al. (2020)	To study the air quality status before and during the first two lockdown phases (MCO I and MCO II) in Malaysia	Comparative study	AQI	The concentration of reduced significantly during the two phases movement control orders

Pani et al. (2020)	To investigate the influence of hot tropical weather in Singapore and the Covid-19 transmission	Spearman and Kendall rank correlation tests	Temperature, Dew point	Temperature ranging from 24 °C to 34 °C showed a positive correlation with daily and cumulative Covid-19 cases. Average dew point (20 °C to 27 °C) showed a significant positive correlation with daily cumulative Covid-19 cases
Suhaimi et al. (2020)	To examine the correlation between meteorology factors and Covid-19 cases in Kuala Lumpur, Malaysia	Statistical Package for Social Sciences (SPSS)	Temperature, Humidity	Weak negative correlation between ambient temperature (27.92 °C to 30.08 °C) with new daily confirmed cases. The SARS-CoV2 virus may spread at a higher temperature. Weak positive correlation between relative humidity (65% to 82%) and new Covid-19 cases
Tosepu et al. (2020)	To analyse the association between hot weather and Covid-19 cases in Jakarta, Indonesia	Spearman's correlation test	Temperature, Humidity, Precipitation	Average temperature (lowest 26.1 °C, highest 28.6 °C) showed a significant correlation with confirmed Covid-19 cases. No significant correlation between humidity and Covid-19 cases in Indonesia No significant correlation between precipitation and Covid-19 cases in Indonesia
Sample 9: Turkey				
Sahin (2020)	To investigate the impact of temperature on the Covid-19 pandemic over nine cities in Turkey	Spearman's rank correlation test	Temperature, Humidity, Wind speed	Negative correlation between the temperature and the Covid-19 cases on the day Negative correlation between relative humidity (55% to 94%) with confirmed Covid-19 cases Positive correlation between wind speed (2 m/s to 14m/s) with confirmed Covid-19 cases.

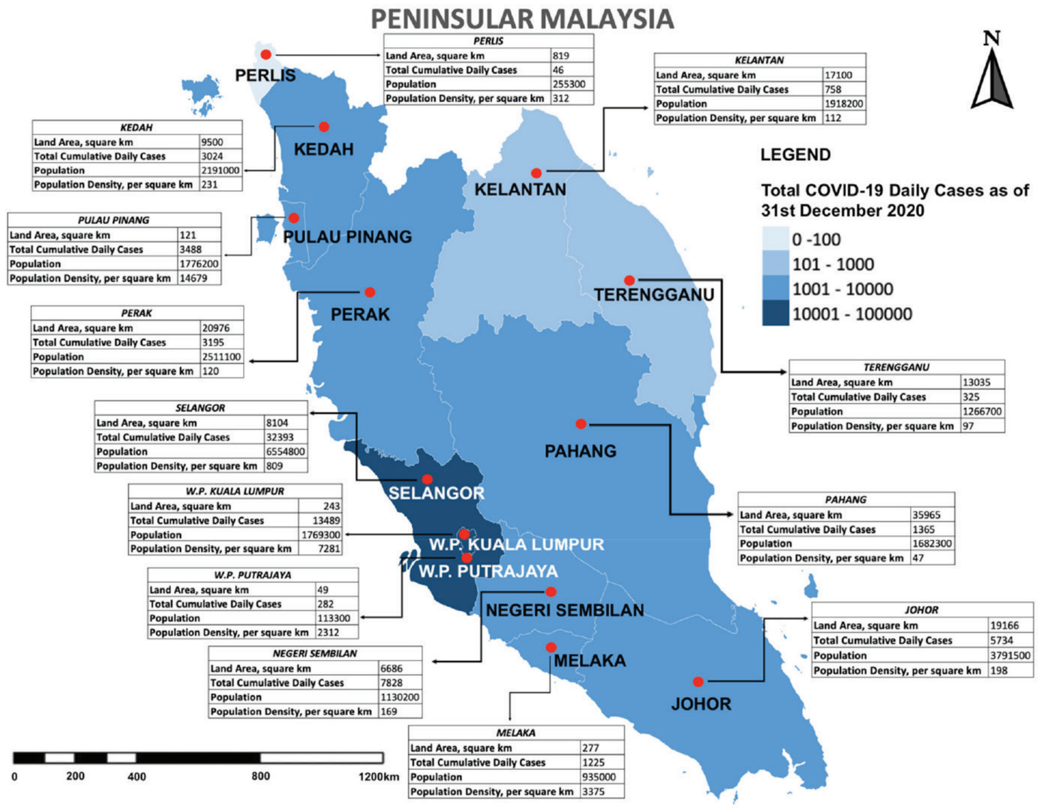


Figure 2: Map of Peninsular Malaysia. Created and constructed with Microsoft Excel.

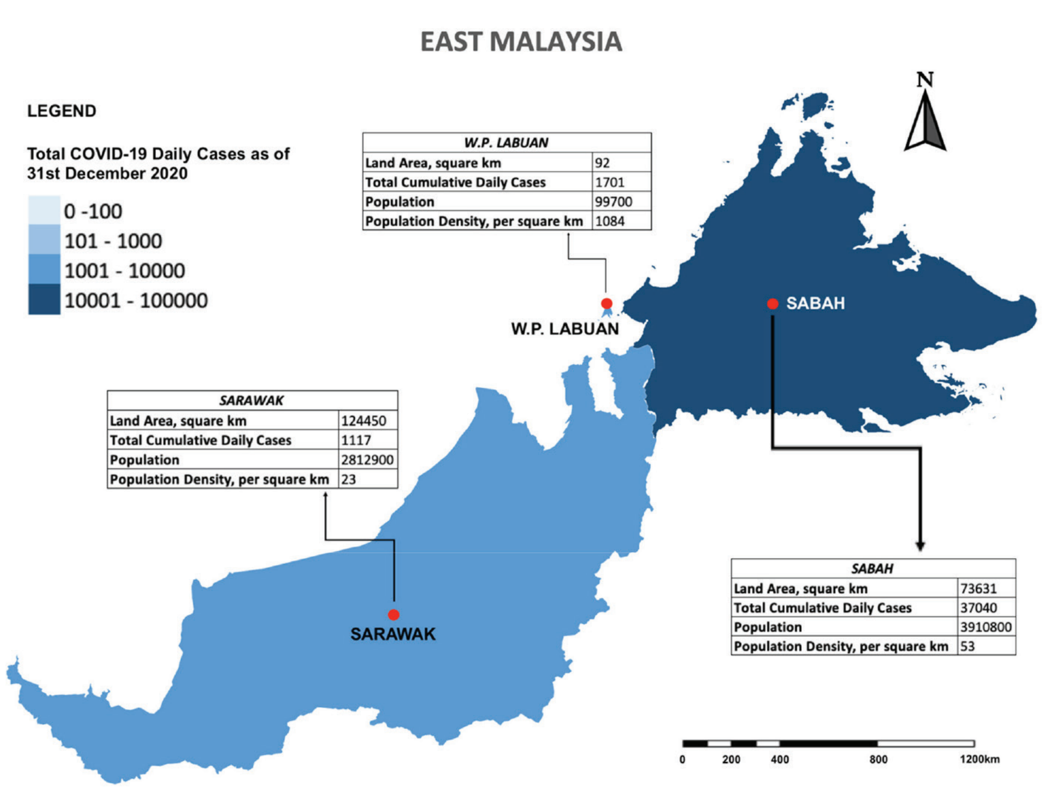


Figure 3: Map of East Malaysia. Created and constructed with Microsoft Excel.

Table 3: The lockdown periods in Malaysia

Period	*Date Commenced*
Pre – lockdown	1st January 2020 to 17th March 2020
Movement Control Order (MCO)	18th March 2020 to 3rd May 2020
Conditional Movement Control Order (CMCO)	4th May 2020 to 9th June 2020
Recovery Movement Control Order (RMCO)	10th June 2020 to 31st December 2020

Meteorological Data

Open source of NASA Power Data Access Viewer (https://power.larc.nasa.gov/data-access-viewer/) was used to collect daily T(°C), daily RH (%), daily DP rate (°C), daily Prate (mm day-1), daily WS rate (m/s), and daily AQI (API) data. Then, for each lockdown, the average value for each parameter was calculated and included for further interpretation of data.

Correlation and Factor Analysis

As the data were not normally distributed, correlation and factor analysis were performed for three lockdown periods by utilising a statistical software, Statistical Package for Social Studies (SPSS) version 17. Pearson's correlation rank test was carried out to examine the relationship between the COVID-19 data, meteorological, and AQI data. Then, principal component analysis (PCA) was used to identify factors influencing the COVID-19 morbidity in each state. The factors scores were used to identify influencing factors in each state. Varimax rotation and Kaiser Normalisation were utilised to extract eigenvalue greater than one (Prasanna et al., 2010; Prasanna & Chidambaram, 2021). Microsoft Excel was used to construct graphs and other statistical illustrations for this study.

HYSPLIT Model

The application of the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model was an attempt to determine the source of air pollutants reaching the study area. The model was provided by the United States National Atmospheric and Oceanic Administration (NOAA) (https://www.ready.noaa.gov/HYSPLIT_traj.php). Three different levels of attitudes were selected as 100 meters (m) (red), 500 m (blue), and 1000 m (green) above ground level. This trajectory model was configured based on MCO (transitional NE to SW monsoon), CMCO (SW monsoon), and RMCO (SW monsoon) periods, which represent the different monsoon seasons in Malaysia. For this study, W.P. Kuala Lumpur was selected to represent Peninsular and Sabah to represent East Malaysia. The selected study areas were considered based on their weekly high AQI readings, number of DC, and population.

Results

COVID-19 Scenario in Malaysia

Malaysia reported its first confirmed case of COVID-19 on 25th January 2020. The number of reported COVID-19 cases increased significantly in early March 2020 due to a religious event that occurred in Sri Petaling, Kuala Lumpur (Elengoe, 2020). Later, the country recorded the highest number of confirmed COVID-19 cases in Southeast Asia. The rapid rising in the number of DC has led the Malaysian government to implement regional movement restrictions called the MCO, introducing the standard operating procedures (SOPs), and a mandatory fourteen days quarantine to reduce the COVID-19 spread in Malaysia (Elengoe, 2020). As of 31st December 2020, a total of 113,010 confirmed daily Covid-19 cases, 471 deaths, and 88,941 recoveries have been reported (Ministry of Health Malaysia [MOH], 2020).

This study considered a total of 16 states involving Peninsular and East Malaysia. ADC, ADD, TDC, and TDD from MCO, CMCO, and RMCO were considered for the following discussion. Figure 4 illustrates the total daily confirmed COVID-19 cases during the implementation of three lockdown periods in Malaysia; MCO, CMCO, and RMCO with the population in each state. Overall, cases are increasing rapidly during RMCO in most of the states. However, during the CMCO period, a significant declining trend was observed in some states such as Johor, Perak, Kedah, Pulau Pinang, Perlis, W.P. Labuan, and on the east coasts of Peninsular Malaysia, Terengganu and Kelantan.

Table 4 shows the overall TDC, TDD, and populations of every state in Malaysia. Sabah, in East Malaysia, has recorded the highest cumulative number of confirmed cases (37,040), followed by Selangor (32,392) and W.P. Kuala Lumpur (13,489). Selangor, a highly urbanized state in Peninsular Malaysia with the highest population among all the states in Malaysia (6,554,800), has recorded a high number of confirmed COVID-19 cases. Meanwhile in W.P. Labuan, an island with the smallest population density in Malaysia (99,700), still recorded a higher number of confirmed DC overtaking Sarawak which has a bigger land mass and population. The

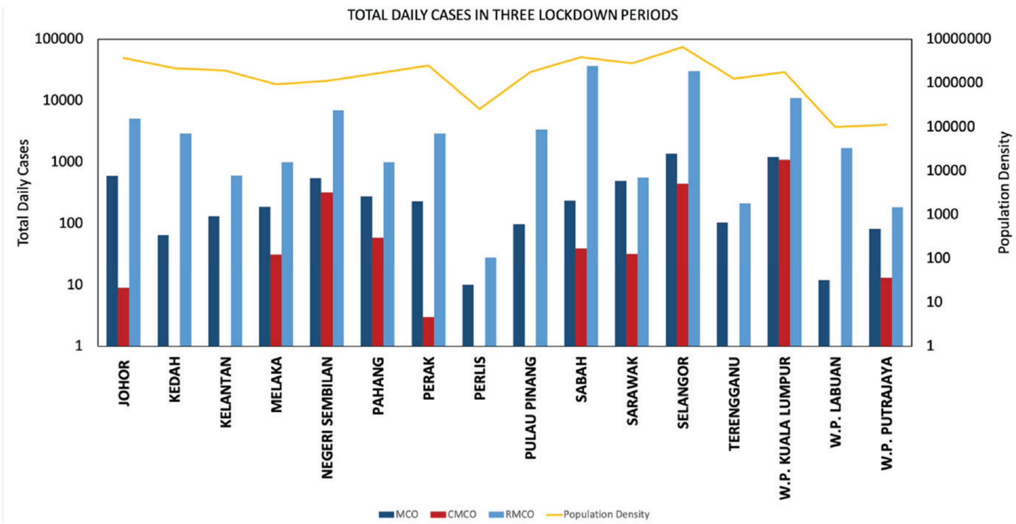


Figure 4: Total daily cases during MCO, CMCO, and RMCO with population density in each state.

Table 4: Total daily COVID-19 cases, total daily COVID-19 deaths, and populations in the year 2020 by states

States	*TDC*	*TDD*	*Populations*
Sabah	37040	264	3910800
Selangor	32393	46	6554800
W.P. Kuala Lumpur	13489	23	1769300
Negeri Sembilan	7828	13	1130200
Johor	5734	36	3791500
Pulau Pinang	3488	9	1776200
Perak	3195	15	2511100
Kedah	3024	12	2191000
W.P. Labuan	1701	9	99700
Pahang	1365	7	1682300
Melaka	1225	6	935000
Sarawak	1117	19	2812900
Kelantan	758	8	1918200
Terengganu	325	1	1266700
W.P. Putrajaya	282	2	113300
Perlis	46	1	255300

highest cumulative DD was reported in states such as Sabah, Selangor, and Johor.

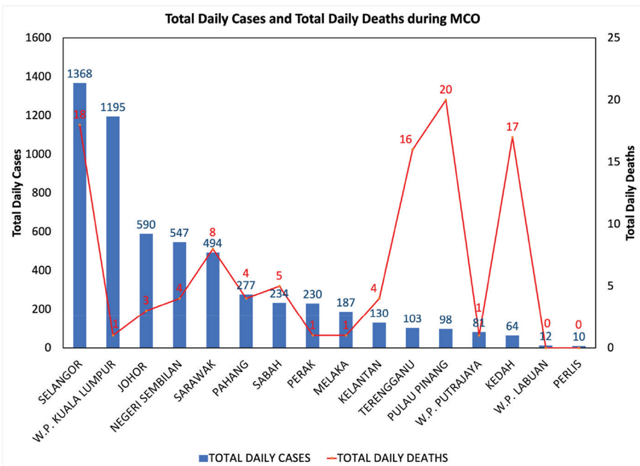
However, Perlis has recorded the lowest number of confirmed cases out of all the states in Malaysia with a total of 46 confirmed cases. Interestingly, in W.P. Putrajaya, the cumulated confirmed COVID-19 cases were 282 cases. Although it is located in the Central Peninsular, the number of cases is much lower compared to W.P. Kuala Lumpur and Selangor. Similarly, in the east coast of Peninsular Malaysia; Kelantan and Terengganu, the cumulative number of confirmed cases were recorded below 1000 cases, i.e, 758 and 328 cases respectively. The lowest cumulative DD were reported in W.P. Putrajaya, Terengganu, and Perlis.

COVID-19 Scenario in Malaysia, State Wise

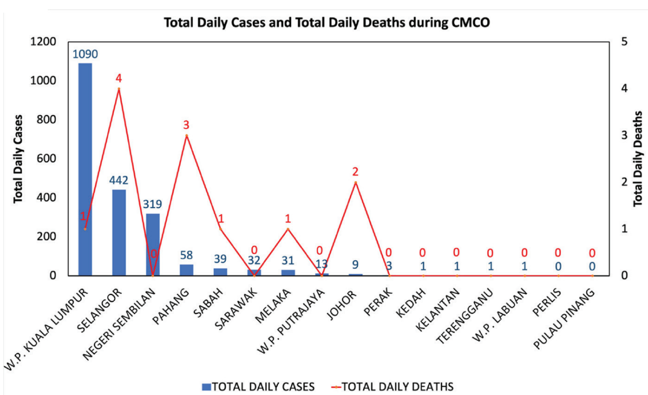
Figure 5 illustrates trend variations in the number of TDC and TDD in three lockdown periods for each state. During the MCO period, Selangor and W.P. Kuala Lumpur recorded the highest total cumulative cases, i.e. 1368 and 1195 cases, respectively, followed by Johor (590 cases) and Negeri Sembilan (547 cases) (Figure 5a). However, states such as W.P. Labuan and Perlis recorded total cumulative cases of less than 15 during the MCO period. Pulau Pinang had the highest cumulative number of deaths (20 deaths), despite having a significantly lower TDC (98 cases) than the majority of the states. Similarly, the reported TDD in Kedah and Terengganu was 17 and 16 deaths, respectively. Selangor was found to have a high number of TDC and TDD (18 deaths).

During the CMCO period, a total of more than 300 cases were recorded in W.P. Kuala Lumpur (1090 cases), Selangor (442 cases), and Negeri Sembilan (319 cases) (Figure 5b). States such as Kedah, W.P. Labuan, and the east coast of Peninsular Malaysia (Kelantan and Terengganu) have only recorded one case. Nevertheless, no COVID-19 cases have been reported in northern Peninsular Malaysia (Perlis and Pulau Pinang). Selangor had the highest number of TDD (4 deaths). No deaths were reported in Negeri Sembilan, Sarawak, W.P. Putrajaya, Perak, Kedah, Kelantan, Terengganu, W.P. Labuan, Perlis, and Pulau Pinang.

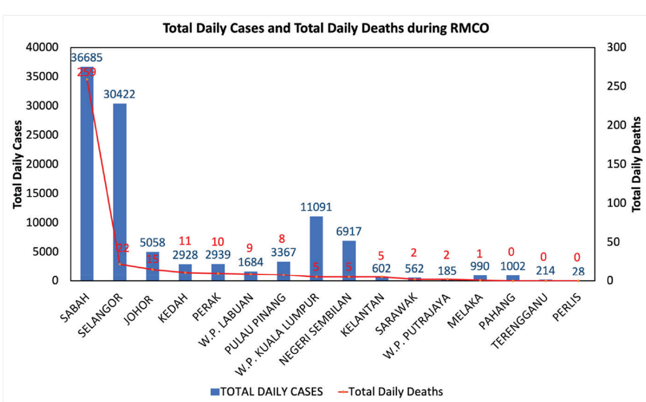
The number of TDC increased rapidly in the majority of the states during the RMCO period. Sabah (36, 685 cases), Selangor (30,422 cases), and W.P. Kuala Lumpur (11,091 cases) were reported with the highest number of TDC (Figure 5c). States such as Kelantan, Sarawak, W.P. Putrajaya, Melaka, Pahang, Terengganu, and Perlis have reported a TDC of less than 1000 cases. Sabah has recorded the highest number of deaths out of all the states in Malaysia with a total of 259 deaths.



(a)



(b)



(c)

Figure 5: Total daily cases and total daily deaths during (a) MCO, (b) CMCO, and (c) RMCO.

A consistently high number of confirmed cases were recorded in the central region of Peninsular Malaysia (Selangor and W.P. Kuala Lumpur) and Negeri Sembilan throughout the implementation of three lockdown periods. However, Perlis has recorded the lowest number of confirmed cases out of all the states in Malaysia during MCO, CMCO, and RMCO periods.

Multivariate Analysis

An attempt was made to determine the relationship between COVID-19 cases and meteorological parameters by applying multiple approaches. Pearson's correlation analysis and PCA were utilised. The values produced from these analyses determined the positive or negative relationship between the variables. Also, the strength of the relationship between the parameters for both analyses was determined based on the classification given by Akoglu (2018) (Table 5). Meanwhile, for factor scores, the positive loading indicates a location is influenced by a factor from PCA.

Table 5: The interpretation of correlation coefficient strength

Correlation Coefficient	*Correlation Strength*
±1	Perfect
±0.9 – ±0.7	Strong
±0.6 – ±0.6	Moderate
±0.3 – ±0.1	Weak
0	None

Source: H. Akoglu, 2018

Pearson's Correlation Analysis

Table 6 shows Pearson's correlation analysis between COVID-19 cases and meteorological parameters during MCO. Average precipitation (AP), average dew point (ADP), and average air quality index (AAQI) showed a weak positive correlation to ADC and TDC. Average relative humidity (ARH), ADP, and AP showed a weak positive correlation to ADD and TDD. However, average wind speed (AWS) showed no correlation with COVID-19 during the MCO period.

Table 7 shows Pearson's correlation analysis between COVID-19 cases and meteorological parameters during CMCO. AAQI showed a moderate positive correlation to ADC and TDC. However, ADP (-0.39), average temperature(AT) (-0.28), and AWS (-0.11)

Table 6: Pearson's correlation analysis of the Covid-19 cases and meteorological factors during movement control order (MCO)

	ADC	*ADD*	*TDC*	*TDD*	*AP*	*ARH*	*ADP*	*AT*	*AWS*	*AAQI*
ADC										
ADD	0.900057137									
TDC	1	0.900057137								
TDD	0.900057137	1	0.900057137							
AP	0.252193623	0.180272177	0.252193623	0.180272177						
ARH	0.054590865	0.146688363	0.054590866	0.146688363	0.083638248					
ADP	0.130758586	0.273779661	0.130758585	0.273779661	0.146539303	-0.14939389				
AT	0.035622359	0.062845699	0.035622359	0.062845699	0.034428084	-0.797066098	0.71544164			
AWS	-0.064138114	0.002014281	-0.064138114	0.002014281	-0.477815233	-0.05819354	0.358569783	0.254106671		
AAQI	0.299071491	0.066070141	0.299071491	0.066070141	0.188060618	-0.382126533	0.340510563	0.463798877	0.085323377	

ADC – Average Daily Cases; ADD – Average Daily Deaths; TDC – Total Daily Cases; TDD – Total Daily Deaths; AP – Average Precipitation; ARH – Averge Relative Humidity; ADP – Average Dew Point; AT – Average Temperature; AWS – Average Wind Speed; AAQI – Average Air Quality Index. The representation of colour codes are; blue (positve correlation, r = +1); white (no correlation, r = 0), red (negative correlation, r = -1).

Table 7: Pearson's correlation analysis of the Covid-19 cases and meteorological factors during conditional movement control order (CMCO)

	ADC	*ADD*	*TDC*	*TDD*	*AP*	*ARH*	*ADP*	*AT*	*AWS*	*AAQI*
ADC										
ADD	0.247751417									
TDC	0.999999727	0.247628525								
TDD	0.218381969	0.925012718	0.218337034							
AP	-0.081894099	-0.255835945	-0.081595727	-0.271688926						
ARH	0.041371048	-0.302648912	0.041254413	-0.266121867	-0.108587455					
ADP	-0.399759576	0.273590459	-0.399707264	0.306035065	-0.239015343	-0.59529059				
AT	-0.288200101	0.3192609	-0.288114192	0.324203286	-0.112917689	-0.842362803	0.934416538			
AWS	-0.116203467	0.491153653	-0.116178396	0.515107094	-0.16387179	-0.745364774	0.691197965	0.794519228		
AAQI	0.498415799	0.122678138	0.498409584	0.1207748	-0.382191765	-0.334631234	0.279165842	0.334557462	0.417888985	

ADC – Average Daily Cases; ADD – Average Daily Deaths; TDC – Total Daily Cases; TDD – Total Daily Deaths; AP – Average Precipitation; ARH – Averge Relative Humidity; ADP – Average Dew Point; AT – Average Temperature; AWS – Average Wind Speed; AAQI – Average Air Quality Index. The representation of colour codes are; blue (positve correlation, r = +1); white (no correlation, r = 0), red (negative correlation, r = -1).

showed a weak negative correlation to ADC and TDC. Nevertheless, all meteorological parameters showed a correlation to mortality rates during CMCO. AWS showed a moderate positive correlation (0.49 and 0.52) to ADD and TDD, respectively. ADP, AT, and AAQI showed a weak positive correlation to ADD and TDD. AP and ARH showed a weak positive correlation to ADD and TDD.

Table 8 shows Pearson's correlation analysis between COVID-19 cases and meteorological parameters during RMCO. AWS showed a weak positive correlation to ADC and TDC with a coefficient reading of 0.29. ARH and ADP, with respective coefficient readings -0.25 and -0.21, showed a weak negative correlation to ADC and TDC. However, there was no correlation to morbidity rates was observed for AP, AT, and AAQI in RMCO. All meteorological parameters except ARH showed a correlation to mortality rates in RMCO. AAQI showed the highest coefficient reading (-0.51) which indicates a moderate negative correlation to ADD and TDD. Similarly, ADP and AT showed a weak negative correlation to ADD and TDD. AP and AWS showed a weak positive correlation to ADD and TDD with coefficients of 0.16 and 0.18, respectively.

Principal Component Analysis

In this study, PCA was applied on 10 parameters, similar to Pearson's correlation analysis which are ADC, TDC, ADD, TDD, AP, ARH, ADP, AT, AWS, and AAQI.

MCO

Table 9 shows the PCA of COVID-19 cases and meteorological parameters during the implementation of MCO. Factor 1 (F1) in MCO showed the highest eigenvalue (4.019) with a total variance of 40.189% and it shows a strong positive loading for ADC, ADD, TDC, and TDD. A weak positive loading was observed for AP, ARH, ADP, and AAQI. States such as Johor, Negeri Sembilan, Sarawak, Selangor, and W.P. Kuala Lumpur are influenced by F1 (Table 10). Also, these states are positioned in the top five states with a higher number of confirmed COVID-19 cases during the MCO period.

Factor 2 (F2) had eigenvalue of 2.517 with a total variance of 25.165% and it shows a strong positive loading for AT, moderate positive loading for ADP and AAQI, and strong negative loading for ARH. States such as Johor, Kelantan, Melaka, Negeri Sembilan, Perlis, Pulau Pinang, Selangor, Terengganu, W.P. Labuan, and W.P. Putrajaya are influenced by F2.

Factor 3 (F3) had the lowest eigenvalue (1.446) with a total variance of 14.457%. AP showed a strong negative loading. AWS showed a strong positive loading. Factor scores revealed that Johor, Kelantan, Melaka, Pahang, Sabah, Sarawak, Terengganu, and W.P. Labuan are influenced by F3.

CMCO

Table 11 shows the PCA of COVID-19 cases and meteorological parameters during the implementation of CMCO. F1 showed an eigenvalue of 4.033 with a total variance of 40.334% and it shows a strong positive loading for ADP, AT, AWS, AAQI, and a strong negative loading for ARH. Factor scores revealed that states such as Johor, Kelantan, Melaka, Negeri Sembilan, Perlis, Pulau Pinang, Selangor, Terengganu, W.P. Labuan, and W.P. Putrajaya are influenced by F1 (Table 12).

F2 showed an eigenvalue of 2.871 with a total variance of 28.708% and it shows a strong positive loading for ADC, TDC, and a weak negative loading for ARH, ADP, and AT. Factor scores revealed that states such as Negeri Sembilan, Selangor, Terengganu, W.P. Kuala Lumpur, and W.P. Putrajaya are influenced by F2.

F3 are loaded with positive loading between ADD, TDD, and AWS with an eigenvalue of 1.336 and a total variance of 13.359%. Factor scores revealed that Johor, Pahang, Perak, Sabah, Selangor, and W.P. Kuala Lumpur are influenced by F3.

Factor 4 (F4) are loaded with positive loading of ARH, ADP, AAQI, and a strong negative loading of AP. F4 showed an eigenvalue of 1.117 with a total variance of 1.117%. Factor scores revealed that Johor, Pahang, Perak, Sabah, Selangor, and W.P. Kuala Lumpur are influenced by F3. Factor scores revealed that Kelantan, Melaka, Negeri Sembilan, Pahang, Perak, Sarawak, Selangor, Terengganu, and W.P. Putrajaya are influenced by F4.

RMCO

Table 13 shows the PCA of COVID-19 cases and meteorological parameters during the implementation of RMCO. F1 showed an eigenvalue of 3.916 with a total variance of 39.158% and it shows a strong positive loading for ADC, ADD, TDC, TDD, and a weak positive loading for ARH, ADP, and AAQI. Factor scores revealed that Sabah, Selangor, and W.P. Kuala Lumpur are influenced by F1 due to a higher number of TDC in the RMCO period (Table 14).

F2 had an eigenvalue of 3.45 with a total variance of 34.503% and it shows a strong positive loading for ADP, AT, AWS but showed no correlation between COVID-19 morbidity and mortality rates. Factor scores revealed that Johor, Kelantan, Melaka, Perlis, Pulau

Table 8: Pearson's correlation analysis of the Covid-19 cases and meteorological factors during recovery movement control order (RMCO)

	ADC	*ADD*	*TDC*	*TDD*	*AP*	*ARH*	*ADP*	*AT*	*AWS*	*AAQI*
ADC										
ADD	0.775984356									
TDC	1	0.775984355								
TDD	0.775984356	1	0.775984355							
AP	-0.086393475	0.164835303	-0.086393476	0.164835303						
ARH	-0.258278799	-0.076769038	-0.258278798	-0.076769038	-0.29902158					
ADP	-0.211115842	-0.337478692	-0.211115842	-0.337478692	0.1033965	-0.660524133				
AT	-0.009732338	-0.17546031	-0.009732338	-0.17546031	0.206927138	-0.884313325	0.934599872			
AWS	0.293208646	0.189149692	0.293208646	0.189149692	0.16840268	-0.597375722	0.658025338	0.691241672		
AAQI	-0.06004333	-0.515554796	-0.060043329	-0.515554796	-0.412462078	-0.418449609	0.352274556	0.415590399	0.167772723	

ADC – Average Daily Cases; ADD – Average Daily Deaths; TDC – Total Daily Cases; TDD – Total Daily Deaths; AP – Average Precipitation; ARH – Averge Relative Humidity; ADP – Average Dew Point; AT – Average Temperature; AWS – Average Wind Speed; AAQI – Average Air Quality Index. The representation of colour codes are; blue (positve correlation, $r = +1$), white (no correlation, $r = 0$), red (negative correlation, $r = -1$).

Table 9: Principal Component Analysis (PCA) of the Covid-19 cases and meteorological factors during MCO

Parameters	*Factor 1*	*Factor 2*	*Factor 3*
ADC	0.956	0.077	-0.147
ADD	0.978	0.015	0.018
TDC	0.956	0.077	-0.147
TDD	0.978	0.015	0.018
AP	0.202	0.145	-0.792
ARH	0.199	-0.778	0.035
ADP	0.246	0.674	0.261
AT	0.006	0.957	0.131
AWS	0.033	0.216	0.868
AAQI	0.157	0.687	-0.191
Eigenvalues	4.019	2.517	1.446
% of Variance	40.189	25.165	14.457
Cumulative %	40.189	65.355	79.812

The representation of colour codes are; dark green (positve correlation, $r = +1$), white (no correlation, $r = 0$), dark grey (negative correlation, $r = -1$).

Pinang, Selangor, Terengganu, and W.P. Labuan are influenced by F2.

F3 showed an eigenvalue (1.502) with a total variance of 15.018% and it shows a strong positive loading for AP and strong negative loading for AAQI. Factor scores revealed that Kelantan, Melaka, Perak, Perlis, Sabah, Sarawak, Terengganu, and W.P. Labuan are influenced by F3.

Linear Regression Analysis

Figure 6 shows linear regression between AT and TDC during MCO, CMCO, and RMCO for every state in Malaysia. The overall trend indicates a weak negative correlation (r = -0.2156) between AT and TDC in Malaysia. An increase in AT reduced the number of confirmed COVID-19 cases. Similarly, in CMCO, the trend showed a weak negative correlation of -0.2883. However, no correlation between AT and TDC was observed during MCO and RMCO.

Figure 7 shows linear regression between ARH and TDC during MCO, CMCO, and RMCO for every state in Malaysia. Overall, there was no correlation between ARH and TDC. The infected COVID-19 cases during MCO and CMCO did not show any correlation with ARH. However, only in RMCO, the correlation

Table 10: Factor analysis scores of the Covid-19 cases and meteorological factors during MCO of every state

States	*Factors*		
	1	2	3
JOHOR	1.184089087	0.520948362	1.277542074
KEDAH	-0.873045982	-0.548594218	-1.564962709
KELANTAN	-0.428095455	0.705061629	1.30611657
MELAKA	-0.453780155	0.471858665	0.048540086
NEGERI SEMBILAN	0.286456877	0.239455918	-0.457228652
PAHANG	-0.244390641	-0.599436954	0.988199593
PERAK	-0.221023369	-2.236019782	-1.035530347
PERLIS	-1.089588916	0.951855725	-0.043240965
PULAU PINANG	-0.792583796	1.260006117	-1.27756296
SABAH	-0.221075452	-1.341491825	1.824832266
SARAWAK	1.059133583	-0.821405913	0.116593129
SELANGOR	2.151203912	1.548902986	-0.479869227
TERENGGANU	-0.575529741	0.261741817	0.506874298
W.P. KUALA LUMPUR	1.762534442	-0.852264942	-1.031468238
W.P. LABUAN	-0.694705058	0.091237966	0.362137845
W.P. PUTRAJAYA	-0.849599335	0.348144449	-0.540972764

The representation of colour codes are as follows; green (positve loadings) and red (negative loadings).

Table 11: PCA of the Covid-19 cases and meteorological factors during CMCO

Parameters	*Factor 1*	*Factor 2*	*Factor 3*	*Factor 4*
ADC	-0.19	0.948	0.208	-0.013
ADD	0.213	0.158	0.955	0.101
TDC	-0.19	0.948	0.208	-0.013
TDD	0.213	0.158	0.955	0.101
AP	-0.027	-0.057	-0.175	-0.955
ARH	-0.89	-0.101	-0.151	0.247
ADP	0.844	-0.301	0.074	0.272
AT	0.96	-0.159	0.119	0.074
AWS	0.849	0	0.314	0.094
AAQI	0.478	0.698	-0.131	0.42
Eigenvalues	4.033	2.871	1.336	1.117
% of Variance	40.334	28.708	13.359	1.117
Cumulative %	40.334	69.042	82.401	93.567

The representation of colour codes are; dark green (positve correlation, $r = +1$), white (no correlation, $r = 0$), dark grey (negative correlation, $r = -1$).

Table 12: Factor analysis scores of the Covid-19 cases and meteorological factors CMCO of every state

States	*Factors*			
	1	*2*	*3*	*4*
JOHOR	1.262335305	-0.260474781	0.849920703	-0.431949652
KEDAH	-1.185237345	-0.352625426	-0.450837248	-0.334788251
KELANTAN	1.169656519	-0.159787937	-0.865580131	0.639666837
MELAKA	0.414565697	-0.16059695	-0.046062592	0.663318233
NEGERI SEMBILAN	0.16123406	1.014010178	-0.928775417	0.865098138
PAHANG	-0.708637794	-0.82995076	1.994477294	1.108723237
PERAK	-2.20965986	-0.867519269	0.037378051	0.480183656
PERLIS	0.162570901	-0.547490884	-0.442025221	-0.701113583
PULAU PINANG	0.853033457	-0.005605009	-0.787487624	-1.111136873
SABAH	-0.511352526	-0.58730059	0.738719106	-1.665490991
SARAWAK	-0.589267425	-0.751032222	-0.350543516	0.260562054
SELANGOR	1.224866836	0.879359837	2.332997131	0.208300862
TERENGGANU	0.707315346	-0.220358935	-0.788551496	1.476820157
W.P. KUALA LUMPUR	-1.238730428	3.180930867	0.029527036	-0.424377329
W.P. LABUAN	0.374814562	-0.369485498	-0.494204759	-1.955157808
W.P. PUTRAJAYA	0.112492696	0.037927378	-0.828951317	0.921341312

The representation of colour codes are as follows; green (positve loadings) and red (negative loadings).

Table 13: PCA of the Covid-19 cases and meteorological factors during RMCO

Parameters	*Factor 1*	*Factor 2*	*Factor 3*
ADC	0.962	0.096	-0.145
ADD	0.912	-0.084	0.336
TDC	0.962	0.096	-0.145
TDD	0.912	-0.084	0.336
AP	-0.048	0.269	0.853
ARH	-0.171	-0.902	0.019
ADP	-0.3	0.888	-0.035
AT	-0.107	0.979	-0.03
AWS	0.264	0.798	0.055
AAQI	-0.231	0.408	-0.794
Eigenvalues	3.916	3.45	1.502
% of Variance	39.158	34.503	15.018
Cumulative %	39.158	73.661	88.68

The representation of colour codes are; dark green (positve correlation, r = +1), white (no correlation, r = 0), dark grey (negative correlation, r = -1).

between ARH and TDC is a weak negative correlation (r = -0.258).

The linear regression between AWS and TDC showed a weak positive correlation (r = 0.2363) (Figure 8). In MCO, no correlation was found between TDC and AWS. The R-value in CMCO shows the lowest (r = -0.1161), indicating a weak negative correlation between TDC and AWS. The AWS showed a positive correlation with TDC during RMCO, but it has a weak correlation of 0.2932.

Overall, AP showed a positive correlation to TDC but with a weak correlation (r = 0.1676) (Figure 9). A positive correlation between AP and TDC was observed during the MCO period but with a weak correlation (r = 0.2521). The linear regression between AP and TDC revealed that there was no correlation between the parameters during CMCO and RMCO periods.

ADP showed a correlation with TDC for all three lockdown periods (Figure 10). Overall, the linear regression indicated a weak negative correlation between ADP and TDC. The number of people infected by COVID-19 increased when there was a decrease in DP. During the MCO period, the correlation between

Table 14: Factor analysis scores of the Covid-19 cases and meteorological factors during RMCO of every state

States	*Factors*		
	1	*2*	*3*
JOHOR	-0.015770347	0.936128836	-0.510907249
KEDAH	-0.286692935	-1.109782288	0.072238455
KELANTAN	-0.488244116	0.995678816	0.6045626
MELAKA	-0.424148658	0.035327889	-0.68059175
NEGERI SEMBILAN	-0.030360345	-0.198442254	-1.254986506
PAHANG	-0.422986192	-0.310632069	-0.072996356
PERAK	-0.202526343	-2.256159266	0.246850543
PERLIS	-0.556663033	0.38184651	0.636085115
PULAU PINANG	-0.287143828	0.910498961	-0.002383705
SABAH	3.300674096	-0.395833293	1.377471305
SARAWAK	-0.635465031	-0.250874509	0.756714257
SELANGOR	1.344191797	1.578401732	-1.793213432
TERENGGANU	-0.550405259	0.723131813	0.713831019
W.P. KUALA LUMPUR	0.186320791	-1.409154501	-1.161812804
W.P. LABUAN	-0.536588013	0.637960913	1.902531097
W.P. PUTRAJAYA	-0.394192584	-0.26809729	-0.833392592

The representation of colour codes are as follows: green (positve loadings) and red (negative loadings).

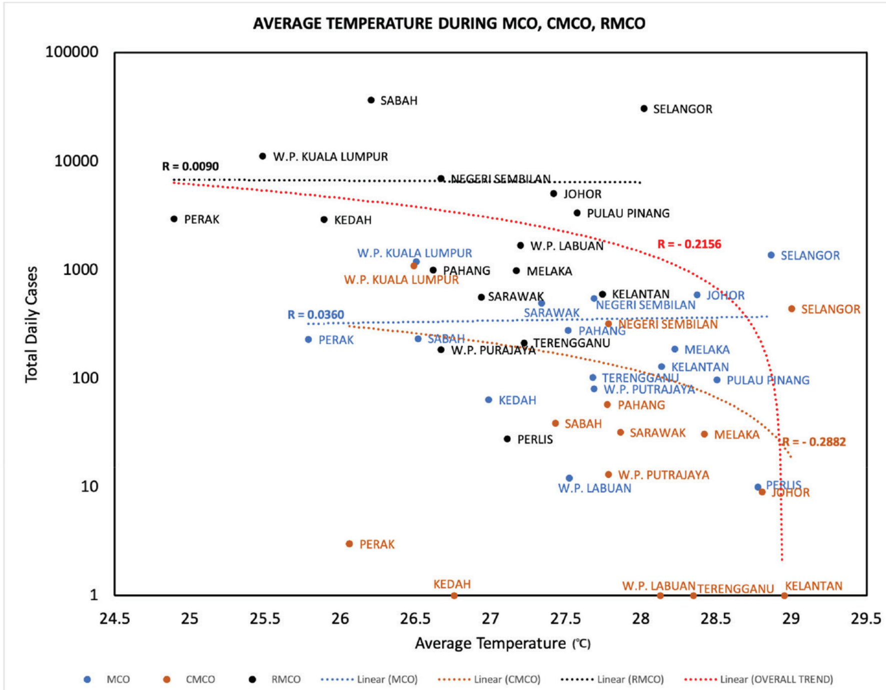


Figure 6: Linear regression between average temperature and total daily cases during MCO, CMCO, and RMCO.

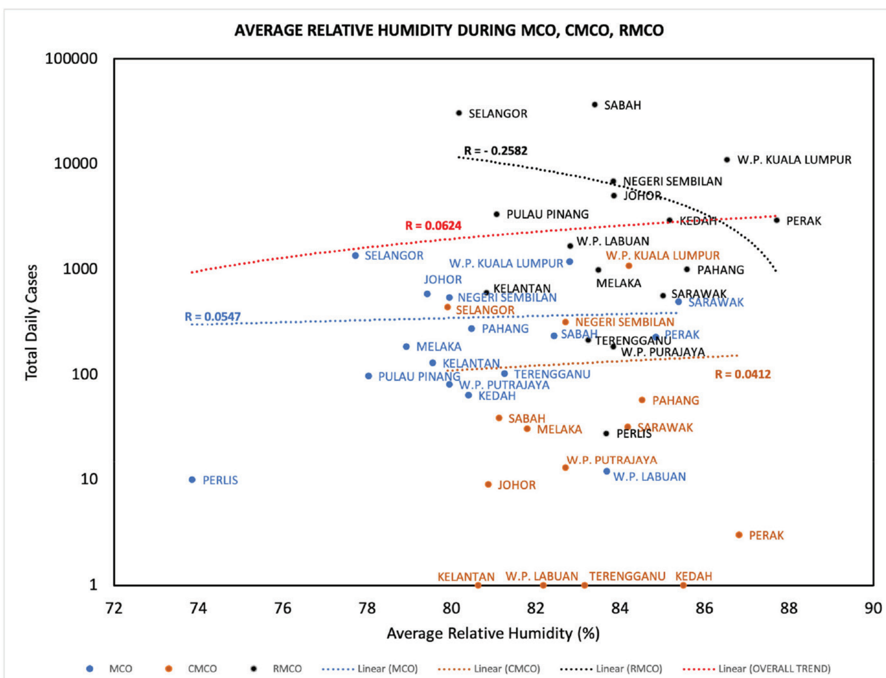


Figure 7: Linear regression between average relative humidity and total daily cases during MCO, CMCO, and RMCO.

ADP and TDC indicated a weak positive correlation (*r* = 0.1307). However, the correlation between ADP and TDC during the CMCO period showed the highest (*r* = -0.399) and is correlated negatively. A decrease in the number of DC as the DP increased was observed in states such as W.P. Labuan, Kedah, Terengganu, Kelantan, Johor, and W.P. Putrajaya. A negative correlation between ADP and TDC was observed during the RMCO period but with a weak correlation (*r* = -0.211). A higher number of TDC as the DP decreased

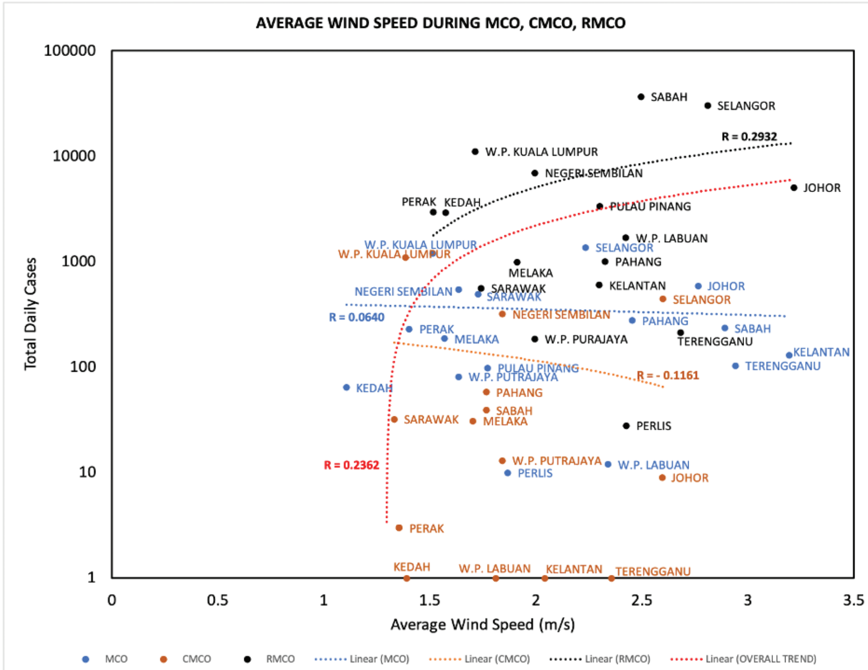


Figure 8: Linear regression between average wind speed and total daily cases during MCO, CMCO, and RMCO.

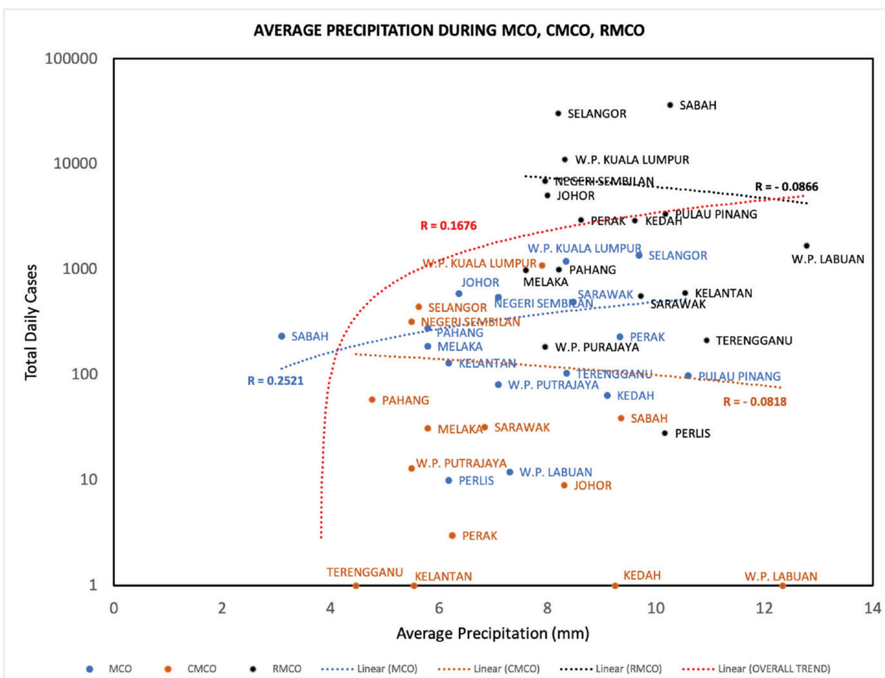


Figure 9: Linear regression between average precipitation and total daily cases during MCO, CMCO, and RMCO.

was observed in states such as Sabah, W.P. Kuala Lumpur, Negeri Sembilan, Kedah, and Perak.

Figure 11 shows linear regression between AAQI and TDC during the three phases of lockdown: MCO, CMCO, and RMCO. No correlation between AAQI and TDC was observed in the overall trend and during RMCO. However, a weak positive correlation (r = 0.2989) was observed during MCO. The correlation between AAQI and TDC during CMCO showed to be the highest (r = 0.4983) and it is a moderate positive

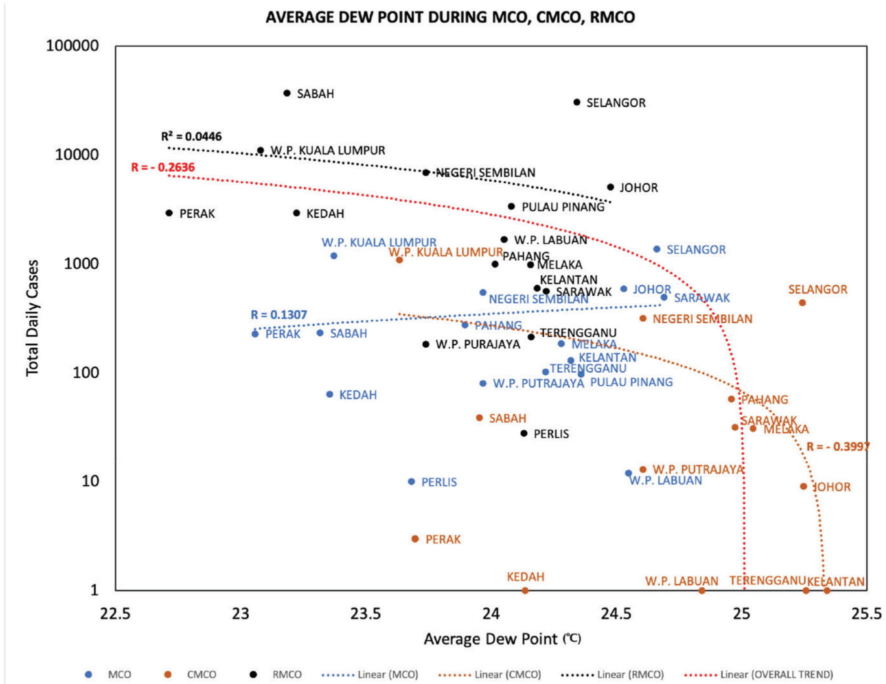


Figure 10: Linear regression between average dew point and total daily cases during MCO, CMCO, and RMCO.

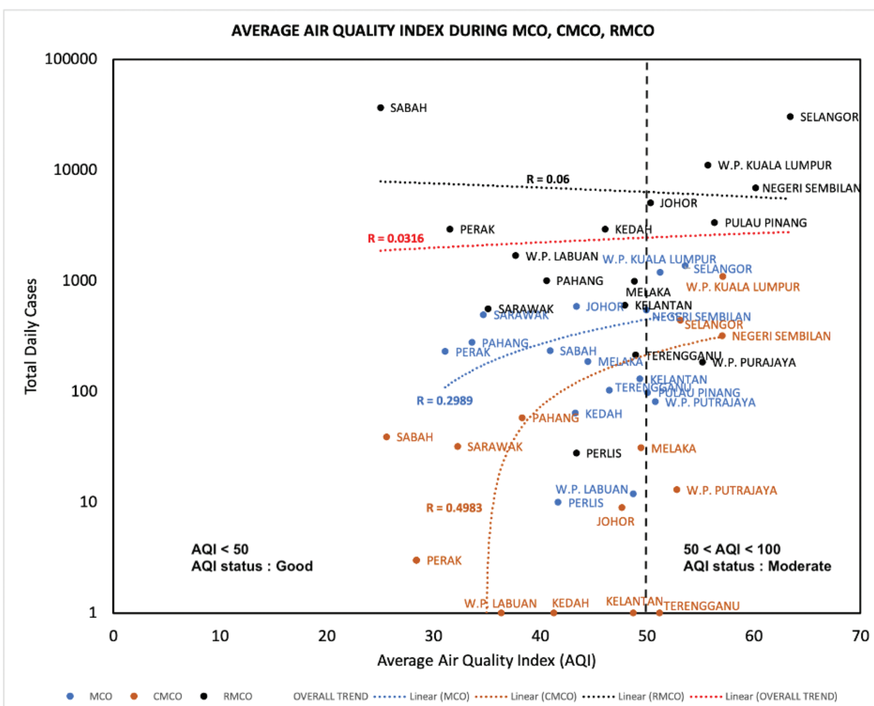


Figure 11: Linear regression between average air quality index and total daily cases during MCO, CMCO, and RMCO.

correlation. Although the linear regression for overall and RMCO showed no correlation between AAQI and TDC, this clearly states with poor air quality such as Selangor, W.P. Kuala Lumpur, and Negeri Sembilan due to rapid urbanisation and industrialisation, which has led to rising in the COVID-19 infection rates. As proposed by Department of Environment Malaysia (DOEM), an AQI of less than 50 AQI indicates good air quality. AQI reading of more than 50 but less than 100 is considered moderate air quality (DOEM, 2021).

Discussion

Relationship Between COVID-19, Meteorological Parameters, and Air Quality Index

Overall, among six meteorological parameters, only AT (r = -0.2156), AWS (r = 0.2362), AP (r = 0.1676), and ADP (r = -0.2636) were significantly correlated with COVID-19 in whole Malaysia, but with weak contribution (Table 15). However, this study focusses on the COVID-19 spread during the implementation of MCO, CMCO, and RMCO. So, it was found out that the COVID-19 cases for different lockdown phases in every state are influenced by different meteorological parameters.

Temperature

Temperature (T) is a crucial aspect of people's daily lives, and it is significant in public health especially in epidemic development, control, and prevention (McMichael et al., 2008; Pani et al., 2020; Tobias and Molina, 2020). A weak negative correlation was observed during CMCO (r = -0.2883), which agreed to the findings from several studies describing that higher T reduced the COVID-19 morbidity rates (Prata et al., 2020; Sahin, 2020; Suhaimi et al., 2020). States such as Johor, Kelantan, Perlis, Pulau Pinang, Terengganu, and W.P. Labuan proved that at a higher T (28.45 °C average), the number of infected cases is below 10 cases throughout the CMCO period. Analysing the confirmed COVID-19 cases in three lockdown phases, it was found out that at an optimal T ranging from 26.5 °C to 28.5 °C the majority of the cases are likely to occur. Also, these optimal values agreed to a study conducted by Tosepu et al. (2020) in Jakarta, Indonesia where the average T (lowest 26.1 °C, highest 28.6 °C) showed a significant correlation with confirmed COVID-19 cases.

Relative Humidity

Virus transmission is affected by several factors, including weather conditions such as T and RH, and population density (Dalziel et al., 2018; Tosepu et al., 2020). The SARS-CoV2 virus is predicted to prolong in a lower humidity environment (Suhaimi et al., 2020). A weak negative correlation (r = -0.2582) is observed between ARH and TDC during the RMCO period. The findings revealed that the number of COVID-19 cases increases at lower humidity, agreeing to a study by Suhaimi et al. (2020), in Malaysia. Another study done by Wu et al. (2020) revealed that an increase of 1% in RH reduced the daily new cases by 0.85%. Selangor showed the lowest ARH (80.17%) during the RMCO period but ranked second in the number of TDC (30,422 cases) after Sabah (36,685). The majority of the cases during the three lockdown phases occurred between 78% and 87%. Similar findings were found in China by Qi et al. (2020), where a negative correlation between RH (67% to 86%) and COVID-19 was observed. They also added that every increment of 1% in RH would decrease the number of daily COVID-19 cases.

Wind Speed

Several studies suggested that the transmission route of the SARS-CoV2 virus through airborne is possible (Setti et al., 2020; Wilson et al., 2020; Zhang et al., 2020). Van Doramalen et al. (2020) mentioned that the SARS-CoV2 virus can withstand smaller particles such as aerosols for approximately three hours. Therefore, the SARS-CoV2 virus may spread over greater distances when associated with the aerosols and eventually become airborne. A

Table 15: Summary of *r*-values between the COVID-19 total daily cases and meteorological parameters for overall and during the implementation of lockdown periods in Malaysia

Meteorological parameters	*Overall*	*MCO*	*CMCO*	*RMCO*
AT	- 0.2156 (Weak)	-	- 0.2882 (Weak)	-
ARH	-	-	-	- 0.2582 (Weak)
AWS	0.2362 (Weak)	-	- 0.1161 (Weak)	0.2932 (Weak)
AP	0.1676 (Weak)	0.2521 (Weak)	-	-
ADP	- 0.2636 (Weak)	0.1307 (Weak)	- 0.3997 (Weak)	- 0.2111 (Weak)
AAQI	-	0.2989 (Weak)	0.4983 (Moderate)	-

weak negative correlation (*r* = -0.1161) between WS and TDC during the CMCO period is highly influenced in the east coast of Peninsular Malaysia (Kelantan and Terengganu), with AWS 2.1987 m/s and a total of one confirmed case throughout the CMCO period. Thus, this indicates that the COVID-19 outbreak on the east coast of the Peninsular area is lower at a higher WS. However, the finding on the correlation between WS and TDC in the CMCO period contradicts a study by Ahmadi et al. (2020) in Iran. They mentioned that COVID-19 cases were more common in the provinces with low WS than in provinces with high WS. A weak positive correlation (*r* = 0.2932) between AWS and TDC observed during the RMCO period is affected by states such as Sabah and Selangor. The COVID-19 cases in these states are at their peak during the RMCO period at an AWS of 2.6523 m/s. This finding agreed with a study done in Turkey by Sahin (2020). He found that the spreading of COVID-19 occurred at a WS ranging 2 m/s to 14 m/s. The optimal range of AWS for COVID-19 cases is likely to occur at 1.4 m/s to 2.7 m/s in most of the states in Malaysia.

Precipitation

Rainfall is a vital component of the hydrological cycle that provides information on climatic patterns (Oguntunde et al., 2011). Furthermore, rainfall is one of the most important processes for removing the atmospheric pollutants that may carry the viruses in the air (Duhanyan & Roustan, 2011; Guo et al., 2016; Ouyang et al., 2015, Prasanna & Chidambaram, 2021). The period of the implementation of MCO, CMCO, and RMCO includes the SW monsoon that extends from April to September and NE monsoon that extends from October to March. A weak positive correlation (*r* = 0.2521) between AP and TDC in the MCO period is highly influenced by states such as Selangor, Sarawak, and W.P. Kuala Lumpur. The number of confirmed COVID-19 cases and AP in these states are higher than in most of the states in Malaysia. The transition between NE to SW monsoon in the MCO period could be the triggering factor to the rise in COVID-19 cases in some parts of Malaysia. Corrigan et al. (2006) mentioned that NE monsoon favours more P, which means air pollutants reduction in the atmosphere and cleaner air. Conversely, they added that the SW monsoon which favours drier weather brings more pollutants to the atmosphere and thus deteriorating the air quality. The majority of the COVID-19 cases in Malaysia occurred at an optimal P ranging between 6 mm and 11 mm.

Dew Point

The T at which the air must be cooled to become saturated with water vapour without changing the pressure is defined as the DP. A weak positive correlation between ADP and TDC was observed in Sarawak (24.69 °C), Selangor (24.66 °C), and Johor (24.52 °C) with cases above three digits values during the MCO period. The weak negative correlation (*r* = -0.3997) between ADP and TDC in the CMCO period revealed that W.P. Kuala Lumpur experienced the lowest ADP (23.63 °C) out of all the states, with the highest number of TDC (1090 cases). Similarly, in the RMCO period, W.P. Kuala Lumpur showed lower ADP (23.07 °C) with a high number of cases (11, 091 cases) followed by Sabah (ADP = 23.18 °C, TDC = 36,685 cases). Analysing the occurrence of infected cases with ADP during three lockdowns revealed that a higher number of spreading can be observed between 23.8 °C to 24.75 °C. According to a study done in Singapore by Pani et al. (2020), DP ranging between 20 °C to 27 °C showed a significant correlation with daily cumulative Covid-19 cases in Singapore. Hence, these selected optimal values are reliable with a similar climatic pattern.

Air Quality Index

The rapid growth of industrial sectors, urbanization, population, and mobile traffics in Malaysia has deteriorated the air quality for the past decade (Latif et al., 2011). The source of air pollution in Malaysia are motor vehicles, open burning, and industrial areas (Abdullah et al., 2019). Barcelo (2020) mentioned that air quality appears to be a significant environmental factor in SARS-CoV2 virus transmission. Also, the SARS-CoV2 virus is likely to transmit faster in cities with poor air quality, thus increasing Covid-19 transmission rates.

AQI in both MCO and CMCO periods are positively correlated to TDC, but with a weak and moderate correlation respectively. TDC in central Peninsular Malaysia (Selangor and W.P. Kuala Lumpur) and southern Peninsular (Negeri Sembilan) are affected by AQI during the MCO period. The number of TDC in Selangor and W.P. Kuala Lumpur cumulated above 1000 cases when their air quality is moderate (50 <AQI<100). In Negeri Sembilan, the number of TDC accumulated to 547 cases when the air quality is about to exceed the good category (AQI = 49.89 API). A similar finding was observed in the CMCO period, but with a moderate positive correlation (*r* = 0.4983). These states have common characteristics, i.e., rapid growth in industrial activities, dense traffic, and rapid urbanization which deteriorates the air quality. Another factor linked to poor AQI is less P due to the SW monsoon that occurred during MCO and CMCO.

Backward Air Mass Trajectory

The attempts were made in W.P. Kuala Lumpur on the fifth week of April (MCO and SW monsoon), the third week of May (CMCO and SW monsoon), and the third week of June SW monsoon). Similarly, in Sabah; the fourth week of March (MCO and NE monsoon), the fourth week of May (CMCO and SW monsoon), and the first week of September (RMCO and SW monsoon).

Figure 12 shows air pollutants travelled to Peninsular Malaysia from the NE direction with contribution from the South China Sea during the MCO period (SW

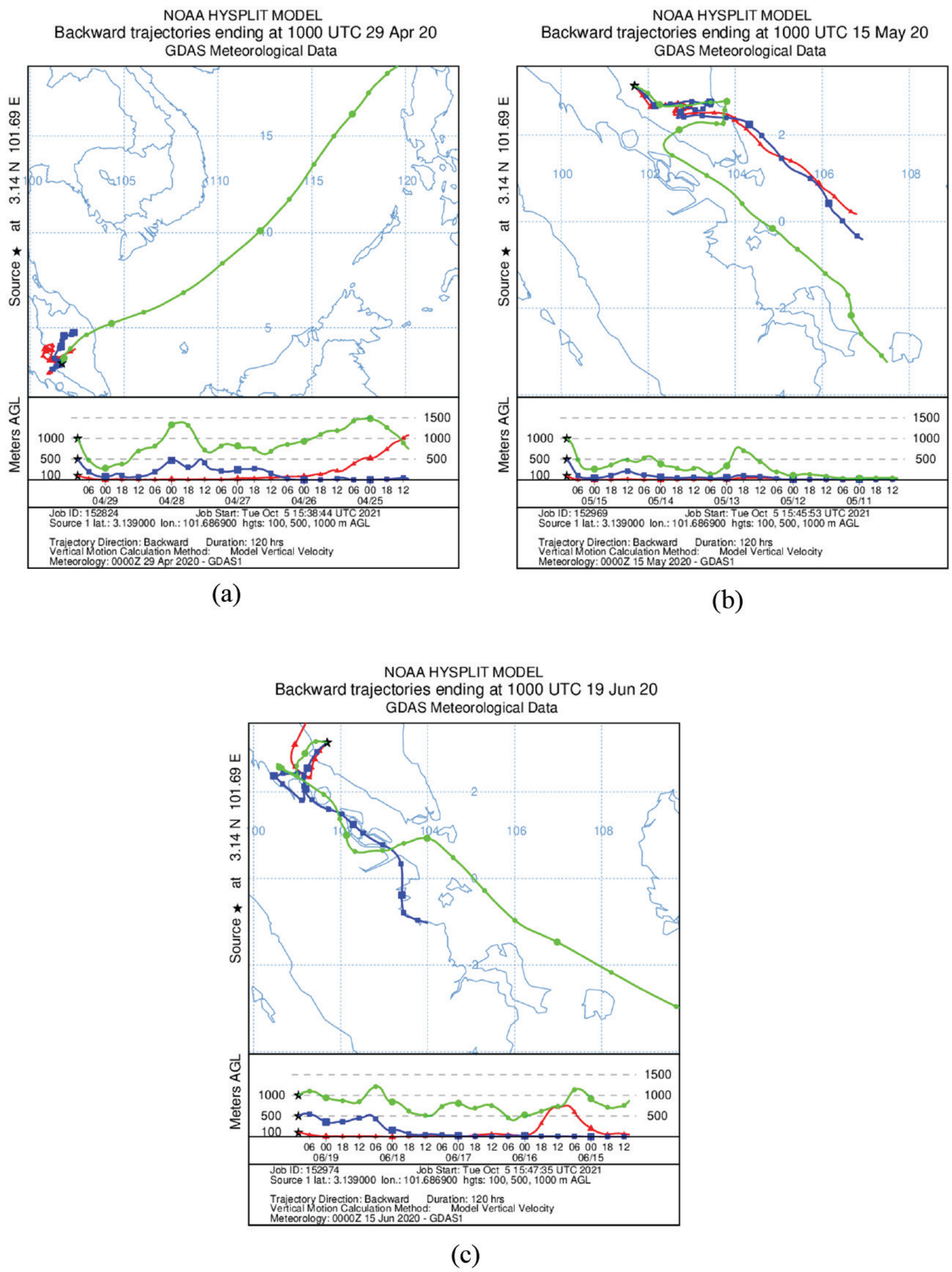


Figure 12: Backward 120 hours trajectories at 500 m, 1000 m, 1500 m above ground level simulated by HYSPLIT model reaching W.P Kuala Lumpur during (a) MCO (b) CMCO and (c) RMCO.

monsoon). At 100 m and 500 m above ground levels, the air circulated within the terrestrial part of central Peninsular Malaysia. The circulation of air pollutants in the lower atmosphere due to local emissions from industrial activities and exhaust from vehicles (Latif et al., 2018), led to the increase in the number of COVID-19 cases during MCO. While at 1000 m above ground level showing a further trajectory towards the ocean. However, during CMCO (SW monsoon), the air pollutants travelled from the southeast (SE) direction, mainly from Indonesia. A similar trend and source were observed during RMCO (SW monsoon) period.

During MCO (NE monsoon), air pollutants entered Sabah (East Malaysia), with contributions from the NE direction, i.e., the Pacific Ocean and the landmass of the Philippines (Figure 13). During the CMCO period (SW monsoon), air pollutants came primarily from the Pacific Ocean (SE direction), with minor influence from land area. During the RMCO period, a similar trend and source were observed (SW monsoon). At 100 m and 500 m trajectories, the air circulated primarily within the land area, with a significant contribution from the ocean. The circulation of air pollutants within the lower atmosphere was due to mobile traffics, industrial

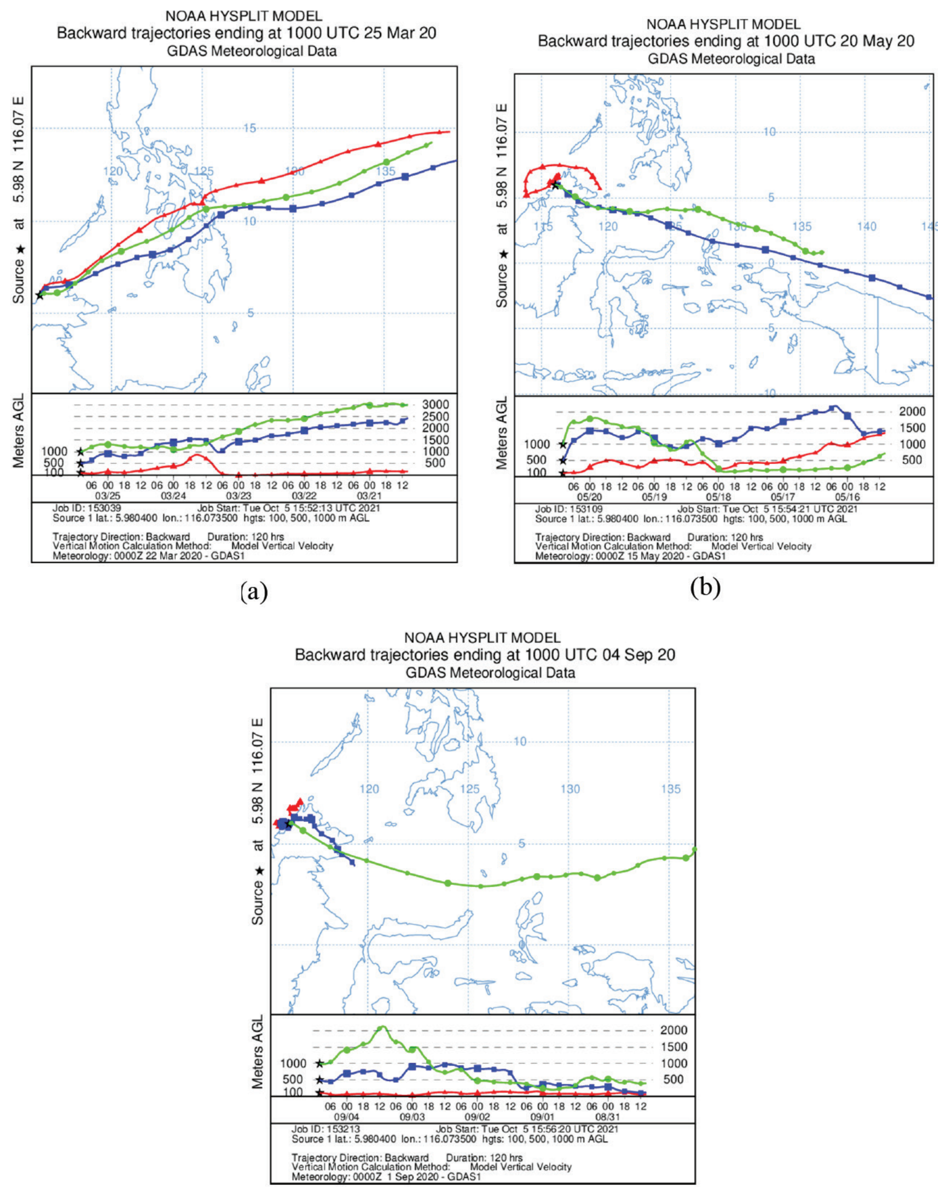


Figure 13: Backward 120 hours trajectories at 500 m, 1000 m, 1500 m above ground level simulated by HYSPLIT model reaching Sabah during (a) MCO (b) CMCO and (c) RMCO.

activities, and meteorological conditions (Latif et al., 2018).

Overall, the direction of air mass trajectories changed during CMCO and RMCO. The shift in direction may have resulted in changes in atmospheric air quality, resulting in variation in the number of confirmed daily Covid-19 cases.

Impact of Climate Change in Malaysia

Climate change is a global phenomenon often associated with human activities. Lofgren et al. (2007) and Wu et al. (2016) revealed that climate change does affect the spread of infectious diseases. According to Ahmad and Hossain (2015), Malaysia is vulnerable to the effects of global warming. They also added that the country experienced a significant rise in annual T and rainfall irregularities for the past two decades. This also means the Earth is getting warmer and humid each day. Hence an attempt was made to observe the influence of local climatic patterns on the pandemic. In this study, W.P. Kuala Lumpur (Peninsular Malaysia) and Sabah (East Malaysia) were considered based on COVID-19 cases, where the number of industrial activities and populations as both states showed distinct features. The climate change data includes T, P, and AQI. Due to insufficient data from the year 2019, the selected year for this study was from the years 2018 and 2020 for comparison. Pre-lockdown, MCO, CMCO, and RMCO were considered for analysis. Figure 14 shows the climate change graph in W.P. Kuala Lumpur and Sabah.

Table 16 shows the annual average of P, T, and AQI and their fluctuation rates for the years 2018 and 2020. In W.P. Kuala Lumpur, the annual AP rate in 2020 decreased by 0.60 mm per day. However, in Sabah, the annual AP rate increased by 1.42 mm per day in 2020. The annual AT in W.P. Kuala Lumpur and Sabah increased by 0.18 °C and 0.11 °C respectively, in the year 2020. The air quality in W.P. Kuala Lumpur is deteriorating in 2020 by 11.64 API. Meanwhile, in Sabah, the air quality fluctuation rate showed a little variation for the year 2020, which increases by 0.92 API.

The climatic patterns in both states vary. In 2018, W.P. Kuala Lumpur experienced a higher annual AP (7.77 mm) and AQI (43.39 API) compared to Sabah. But, the annual T in Sabah (26.07 °C) is higher than in W.P. Kuala Lumpur (25.60 °C). In 2020, Sabah experienced more P (7.46 mm) than W.P. Kuala

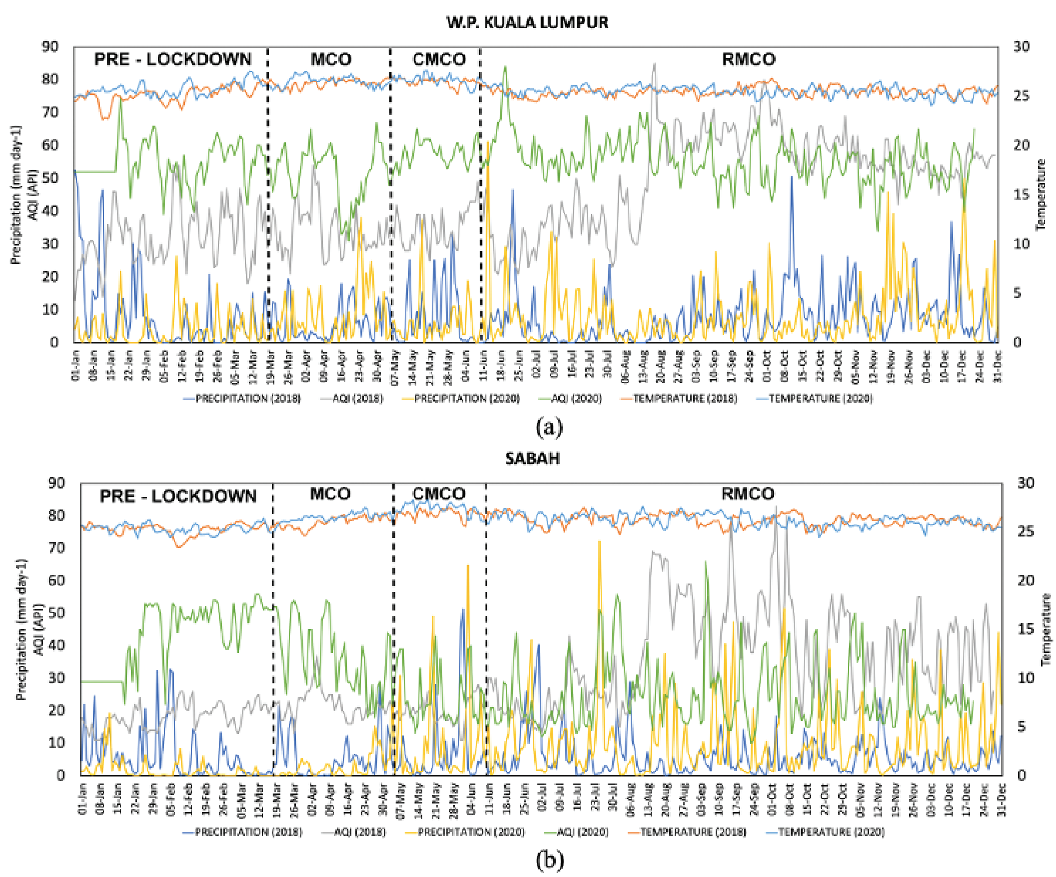


Figure 14: Climate change graph in (a) W.P. Kuala Lumpur and (b) Sabah.

Table 16: Annual average of P, T, and AQI and their fluctuation rates for the years 2018 and 2020 in W.P. Kuala Lumpur and Sabah

States	*Climate Change Parameters*	*Year*		*Fluctuation Rate*
		2018	*2020*	
W.P. Kuala Lumpur	Precipitation, (mm)	7.77	7.17	- 0.60
	Temperature, (°C)	25.60	25.78	0.18
	Air Quality Index, (API)	43.39	55.03	11.64
Sabah	Precipitation, (mm)	6.03	7.46	1.43
	Temperature, (°C)	26.07	26.19	0.12
	Air Quality Index, (API)	29.42	30.34	0.92

Lumpur. Also, the annual AT in Sabah remained warmer (26.19 °C) compared to W.P. Kuala Lumpur (25.78 °C). The air quality status in W.P. Kuala Lumpur has changed to moderate (55.03 API) and Sabah has maintained good air quality status.

Table 17 summarises the findings from the year 2018 and 2020 according to their average climate change parameters values from pre-lockdown, MCO, CMCO, and RMCO in W.P. Kuala Lumpur where T and AQI are increasing significantly. This indicates that W.P. Kuala Lumpur has experienced a warmer climate and poorer air quality due to rapid urbanization and industrialization growth. Hence, the increasing number of confirmed COVID-19 cases was contributed by increasing T and AQI.

Interestingly, in Sabah, the findings showed contradicting results to the rapid rising of confirmed COVID-19 cases (Table 18). The air quality is much cleaner than in W.P. Kuala Lumpur. However, in the RMCO period, the AAQI in 2020 showed declination (-12.17 API) but the number of TDC is still high. So, this indicates that the AQI does not affect the COVID-19 cases in Sabah. Similarly, T and P did not contribute to the COVID-19 spread. Other factors like breaching SOPs and no social distancing may have contributed to the COVID-19 spread.

The attempt to observe the influence of local climatic patterns on the pandemic has revealed that short term climate change in the country is significant which may support the COVID-19 spread.

Air Quality Management Strategy Plans

Air pollution is one of the current environmental challenges faced by society globally. Malaysia's rapid growth in urbanisation, industrialisation, and vehicle usage has significantly affected the air quality (Latif et al., 2011). The Malaysian government bodies such as MOH and DOE have played a vital role in monitoring air quality and raising awareness on air pollution. Brohi et al. (2018) mentioned that motor vehicles are the primary source of air pollution in Malaysia. The reason is the lack of interest in public transportation and the high demand for the use of private cars among citizens. Agreeing to a study done by Othman and Latif (2021), reducing outdoor activities, private car use, and emissions from coal-fired power plants significantly improved the air quality, especially during MCO. They added that it is important in each state to develop systematic policies based on sources of pollution and their characteristics. They also mentioned that using green alternatives and adopting sustainable vehicle technology could significantly improve Malaysia's future air quality. Currently, Malaysia has 68 air quality monitoring systems (Air Pollutants Index of Malaysia [APIMS], 2021). However, these monitoring stations are mostly located in less congested areas and therefore unable to monitor areas at high risk of air pollution. As a result, the government must invest in monitoring stations in strategic locations to improve Malaysia's air quality monitoring systems in the future.

Conclusion

This study has investigated the relationship between meteorological factors, AQI with COVID-19 spread during the implementation of three different lockdown phases, i.e., MCO, CMCO, RMCO in every state in Malaysia. Overall, T and DP showed a weak negative correlation, and WS and P showed a weak positive correlation with COVID-19 cases in whole Malaysia. In the MCO period, P, DP, and AQI showed a weak positive correlation with TDC, which revealed that these parameters influenced the COVID-19 outbreak in Selangor, Sarawak, W.P. Kuala Lumpur, Johor, and Negeri Sembilan, showing a higher number of confirmed cases. In the CMCO period, T, WS, DP showed a weak positive correlation and AQI showed a moderate positive correlation with COVID-19 cases. These meteorological parameters affected the east coasts of Peninsular Malaysia (Kelantan and

Table 17: Summary of average climate change parameters, fluctuation rate, and total daily cases according to each lockdown period in W.P. Kuala Lumpur for the year 2018 and 2020

State : W.P. Kuala Lumpur					
Lockdown Period	*Climate Change Parameters*	*Year*		*Fluctuation Rate*	*Total Daily Cases*
		2018	*2020*		
Pre-Lockdown	Precipitation (mm)	8.77	4.10	- 4.67	82
	Temperature (°C)	25.14	25.73	0.59	
	Air Quality Index (API)	32.13	54.68	25.55	
MCO	Precipitation (mm)	6.02	8.34	2.32	1195
	Temperature (°C)	26.28	26.50	0.22	
	Air Quality Index (API)	34.00	51.49	17.49	
CMCO	Precipitation (mm)	7.53	5.72	- 1.81	1090
	Temperature (°C)	26.47	26.64	0.17	
	Air Quality Index (API)	34.84	57.32	22.49	
RMCO	Precipitation (mm)	7.84	8.32	0.48	11091
	Temperature (°C)	25.46	25.48	0.02	
	Air Quality Index (API)	51.40	55.58	4.19	

Table 18: Summary of average climate change parameters, fluctuation rate, and total daily cases according to each lockdown period in Sabah for the year 2018 and 2020

State : Sabah					
Lockdown Period	*Climate Change Parameters*	*Year*		*Fluctuation Rate*	*Total Daily Cases*
		2018	*2020*		
Pre-Lockdown	Precipitation (mm)	6.21	1.74	- 4.47	82
	Temperature (°C)	25.29	25.34	0.06	
	Air Quality Index (API)	18.30	42.94	24.64	
MCO	Precipitation (mm)	5.49	3.10	- 2.39	234
	Temperature (°C)	26.04	26.52	0.48	
	Air Quality Index (API)	21.83	36.15	14.32	
CMCO	Precipitation (mm)	7.41	9.36	1.95	39
	Temperature (°C)	26.83	27.43	0.60	
	Air Quality Index (API)	20.00	24.57	4.57	
RMCO	Precipitation (mm)	5.84	10.26	4.42	36685
	Temperature (°C)	26.24	26.20	- 0.03	
	Air Quality Index (API)	37.19	25.02	- 12.17	

Terengganu), and Central Peninsular Malaysia (W.P. Kuala Lumpur and Selangor). In the RMCO period, RH and DP showed a weak negative correlation while WS showed a weak positive correlation with COVID-19 cases. The COVID-19 outbreak in Sabah and Selangor was influenced by these meteorological parameters. The correlation findings revealed that meteorological parameters had a significant impact on the COVID-19 outbreak in Johor (T and DP), Kelantan (T), Negeri Sembilan (AQI), Sabah (RH and WS), Sarawak (P and DP), Selangor (RH, WS, P, DP, and AQI), and W.P. Kuala Lumpur (T, P, DP, and AQI). The COVID-19 outbreak in most of the states in Malaysia is likely to occur at an optimal T ranging from 26.5 °C to 28.5 °C. The RH between 78% and 87% encouraged a high number of Covid-19 cases. Wind speed between 1.4 m/s and 2.7 m/s led to a higher number of DC. The P ranging between 6 mm and 11 mm increased the number of DC. High infection COVID-19 rates are observed at an optimal DP between 23.8 °C and 24.75 °C in the majority of the states. Air quality less than 50 API shows a lower number of confirmed DC. Moderate air quality was observed in Peninsular Malaysia (W.P. Kuala Lumpur) and good air quality in East Malaysia (Sabah). The air mass trajectory model revealed a mix of contributions from land and ocean for both Peninsular and East Malaysia in all the lockdown phases. The source of air pollutants in the RMCO period is mostly from land, particularly at 100 m and 500 m elevation above the ground. The rapid emission from motor vehicles and industrial activities contributes to the poor air quality and rise in the number of COVID-19 cases for both Peninsular and East Malaysia towards the RMCO period. A study on the influence of climatic patterns on pandemics revealed that the short-term climate change in the country is significant which may support the COVID-19 spread. Apart from meteorological parameters, other factors such as population density, SOPs, social distancing, and individual immune systems also contribute to the COVID-19 outbreak in Malaysia.

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