VOL 2, NO.2 (2022) 11-26
https://jagst.utm.my

JAGST
Journal of Advanced Geospatial Science & Technology

Spatial-Temporal Analysis of Nitrogen Dioxide Using Sentinel-5P TROPOMI in Peninsular Malaysia during Coronavirus Pandemic Outbreak

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***Abstract* -** Nitrogen dioxide (NO_2) is a highly poisonous gas. Exposure to this gas produces inflammation of the lungs. In the troposphere, NO_2 gases were found, and the accumulation will cause serious air pollution. Due to the technological development of atmospheric satellites, remote sensing methods are becoming important for monitoring air pollution in the global atmospheric environment. Therefore, this study was implemented to see the trend of NO_2 gasses emission before and during the Movement Control Order (MCO) of the Covid 19 outbreak. The main objective of this study is to compare the analysis of the tropospheric NO_2 column spatial configuration over Peninsular Malaysia between similar periods in the year 2019 and 2020 (before and during MCO) based on the ESA Copernicus Sentinel-5P TROPOMI. The study used Air Pollutant Index (API) as the ground data measured by the Department of Environmental (DOE) before and during the MCO of the Covid 19 outbreak. The results show that the NO_2 concentration was recorded high before MCO and low during MCO. The comparison of this correlation analysis between Sentinel 5P image and ground-based data showed that the R^2 value range is 0.72, indicating a positive relationship with ground data. The study concludes that Sentinel-5P data can provide helpful information for monitoring and mapping air pollution.

Keywords *- Nitrogen dioxide, Sentinel-5P TROPOMI, Air pollution*

Article History: Received 14 January 2022, Accepted 25 March 2022, Published 31 August 2022

How to cite: Mohd Isa, M., Latif, M.T., Mohamed Jamil, H., Ahmad Hazmi, N.S. and Samad, R. (2022). Spatial-Temporal Analysis of Nitrogen Dioxide Using Sentinel-5P TROPOMI in Peninsular Malaysia during Coronavirus Pandemic Outbreak. Journal of Advanced Geospatial Science & Technology . 2(2), 11-26.

1. Introduction

Nitrogen oxides, particularly NOx (NO and NO_2), are important trace gases in the troposphere and the stratosphere [1]. Nitrogen dioxide (NO_2) is a good indicator of air quality in urban and industrial areas [2]. The sources of NO_2 in the atmosphere consist of two components firstly, natural emissions resulting created from the natural combustion of biomass, atmospheric lightning process, and nitrates of microbial action; and secondly, artificial emissions originate from agricultural burning, burning of fossil fuels, industrial production, and vehicle exhaust emissions [3]. NO_2 are short-lived (NOx lifetime of 1–12 hours), but their photochemical processing leads to longer-lasting effects via the formation of ozone3 and aerosols, as well as acid rain [4]. In line with the Movement Control Order (MCO) announced by the Malaysian Government, all offices throughout Malaysia were closed from 18 March until 14 April 2020 [5]. According to a press statement by the Ministry of Environment and Water of Malaysia, NO_2 has significantly decreased by 55%-68% during MCO in 2020 [6]. During MCO, all offices in Malaysia were locked down, which caused a decrease in the vehicle's traffic intensities and operationalised industries, so the emission of NO_2 gasses declined at that time [6]. Due to this condition, the government's move to implement MCO is not only possible to block the spread of Covid-19 disease, which is showing a decline in the present, but also air pollution to the environment shows a declining trend due to the reduction of activities such as vehicle smoke emissions, industrial chimney smoke emissions and open burning [7]. The objective of this study is to perform a comparative analysis of the NO_2 pollutant spatial configuration based on Sentinel-5P data during this MCO, dated 27 March 2019 and 27 March 2020. This study analysed the NO_2 levels during the sudden transition of MCO and at the normal peak of vehicle traffic conditions. The TROPOMI instrument on the ESA Sentinel-5P satellite provides high-quality daily measures of the NO_2 tropospheric column from space suitable to perform atmospheric measurements with a high spatial-temporal resolution, to be used for air quality, ozone, UV radiation, climate monitoring, and forecasting [8]. As the first imaging spectrometer to provide global data in medium spatial resolution, TROPOMI has a significant advantage over the previous sensor in spatial resolution (7 x 3.5km) and several clear-sky observations per day [3].

2. Materials and Methodology

2.1 Study Area

Peninsular Malaysia was chosen as the study area because it is suitable for Sentinel 5P, which has a resolution of 7.5km [8]. Peninsular Malaysia, also known as West Malaysia, is a part of Malaysia which occupies the southern half of the Malay Peninsula in Southeast Asia and nearby islands [9]. A total of 47 air pollution monitoring stations are distributed throughout Peninsular Malaysia. Temperatures average about 27 °C in most lowland areas. In coastal regions of East Peninsular Malaysia, minimum temperatures range from low to mid -23°C, and maximum temperatures around 32°C; temperatures are lower in the interior highland regions. The mean annual rainfall is approximately 100 inches (2,540 mm); the driest location, Kuala Kelawang (in the district of Jelebu), near Kuala Lumpur, receives about 65 inches (1,650 mm) of rain per year. In contrast, the wettest, Maxwell's Hill, northwest of Ipoh, receives some 200 inches (5,000 mm) annually [10].

Figure 1. Study area

2.2 Data

The study used Sentinel 5P images and API data that DOE has measured as ground data. The ESA (European Space Agency) Sentinel-5 Precursor (S5P) is a low earth orbit polar satellite to provide information and services on air quality, climate, and the ozone layer in the time frame of 2015–2022 [1]. The mission's payload is the TROPOspheric Monitoring Instrument (TROPOMI), measuring key atmospheric constituents, including ozone, NO_2, SO_2, CO, CH_4, CH_2O, and aerosol properties [1]. TROPOMI is a passive sun backscatter imaging spectrometer that allows for the acquisitions of 8-band imagery, covering multiple spectral domains from UV and visible to near-infrared (NIR) and shortwave infrared (SWIR) [11]. Featuring a higher spatial resolution than its predecessors, of 7 × 3.5 km2 (along and across-track), it offers new potential for air quality research, making it suitable for polluting emission sources monitoring [12]. This study uses the offline Level 2 NO_2 (S5P L2 NO_2) tropospheric column data for the date 27 March 2019 and 27 March 2020, downloaded from *https://s5phub.copernicus.eu/dhus/#/home*. The offline product was chosen over the reprocessed product for its timely availability and the near-real-time product for better quality [2]. The ambient air quality measurement in Malaysia is described in terms of the Air Pollutant Index (API). The API is developed in easily understood ranges of values to report air quality instead of using the actual concentration of air pollutants [13]. This index also reflects its effect on human health, ranging from good to hazardous. It can also be categorised according to the action criteria stipulated in the National Haze Action Plan. The Malaysian API system closely follows the Pollutant Standard Index (PSI) developed by the United States Environmental Protection Agency (US-EPA) [13].

Category	AQI	Parameter Breakpoint						
Parameter		O_3 (ppm)	O_3 (ppm)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)
Averaging Time		8-h	1-h	24-h	24-h	8-h	1-h	1-h
Good	0-50	0.000-0.059	-	0-54	0.0-12.0	0.0-4.4	0.000-0.035	0.000-0.053
Moderate	51-100	0.060-0.075	-	55-154	12.1-50.4	4.5-9.4	0.036-0.075	0.054-0.100
Unhealthy for Sensitive Groups	101-150	0.076-0.095	0.125-0.164	155-254	50.5-55.4	9.5-12.4	0.076-0.185	0.101-0.360
Unhealthy	151-200	0.096-0.115	0.165-0.204	255-354	$(55.5\text{-}150.4)^3$	12.5-15.4	$(0.186\text{-}0.304)^4$	0.361-0.649
Very unhealthy	201-300	0.116-0.374	0.205-0.404	355-424	$(150.5\text{-}250.4)^3$	15.5-30.4	$(0.305\text{-}0.604)^4$	0.650-1.249
Hazardous	301-400	$(^2)$	0.405-0.504	425-504	$(250.5\text{-}350.4)^3$	30.5-40.4	$(0.605\text{-}0.804)^4$	1.250-1.649
Hazardous	401-500	$(^2)$	0.505-0.604	505-604	$(350.5\text{-}500.4)^3$	40.5-50.4	$(0.805\text{-}1.004)^4$	1.650-2.049

Figure 2. Breakpoint value for the API calculation suggested based on US-EPA breakpoints and Malaysian Air Quality Standard (IT-22018)

2.3 Methodology

The study used The Sentinel Application Platform (SNAP) for earth observation processing and analysis. SNAP is an open-source ESA toolbox ideal for exploiting earth observation data. The multi-temporal images of Sentinel 5P used SNAP for the processing image. Several image processing techniques using SNAP, including re-project, terrain correction, and subset boundary, were performed for each image. The flowchart of the overall methodology is shown in Figure 3.

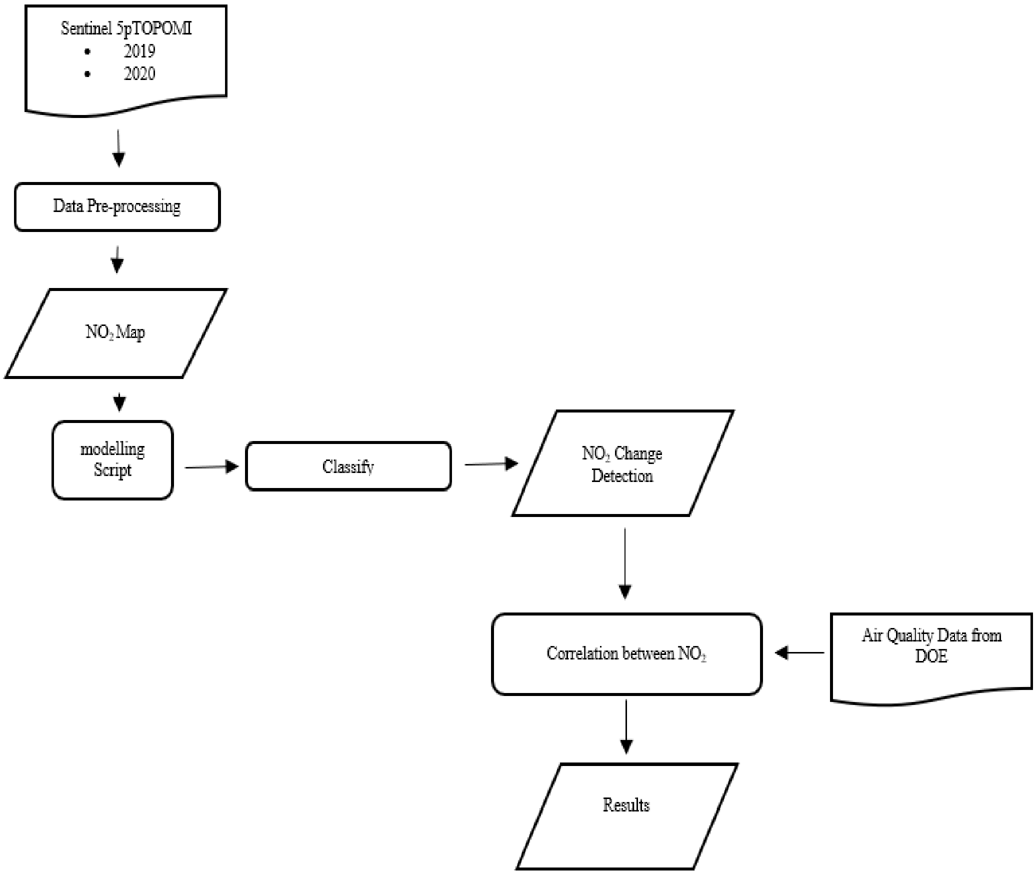


Figure 3. Data processing workflow

2.3.1 Re-Projection

Sentinel-5 Precursor (S5P) images were used in this study. All images were re-projected from the WGS84 projection to Rectified Skew Orthomorphic (RSO) projection to match the point location of the air pollution monitoring station for the overlay process.

2.3.2 Terrain Correction

Terrain Correction is a correction to gravity data required because the surroundings are not all at the same elevation as the meter. The study used corrections from a topographic map.

2.3.3 Regression Analysis

Linear regression is the most widely used statistical technique; it is a way to model a relationship between two sets of variables. The result is a linear regression equation that can be used to make predictions about data.

$$\mathbf{Y = a + bX}$$

Where X is the explanatory variable and Y is the dependent variable. The slope of the line is b, and a is the intercept (the value of y when x = 0).

3. Results and Discussion

3.1 Spatio-Temporal Distribution of the NO_2 Pollution in Peninsular Malaysia

The location map of the air pollution monitoring stations of Peninsular Malaysia is shown in Figure 4. Ground-based measurements data were collected every hour because NO_2 pollution disperses dynamically in just a few minutes depending on wind speed and could transport them away from the emission sources [13].

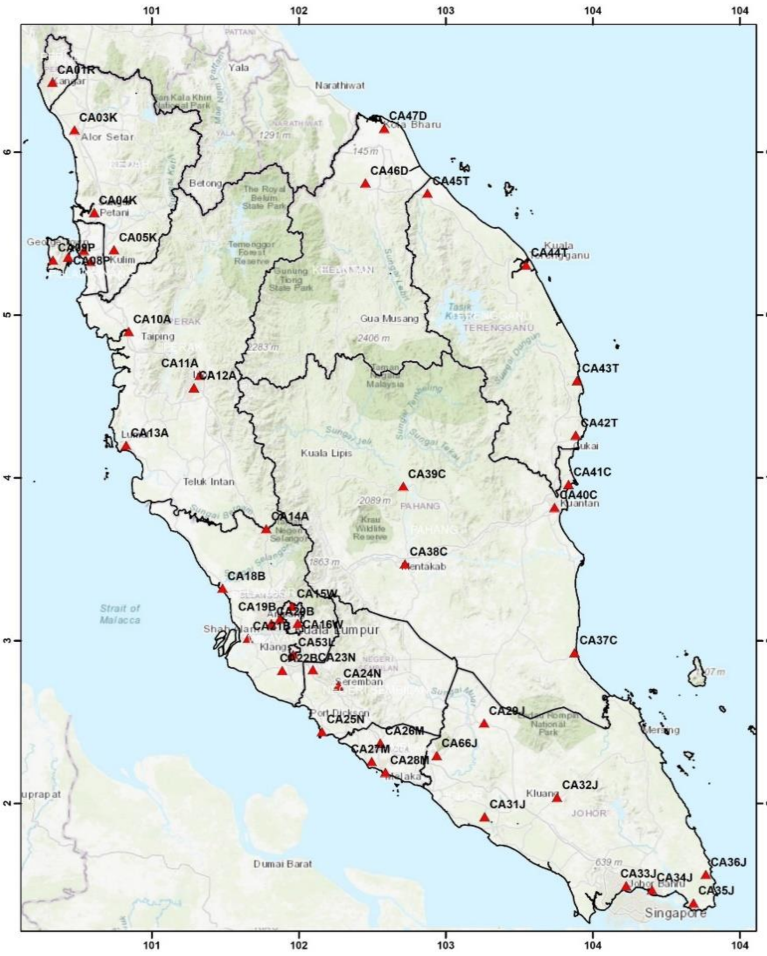


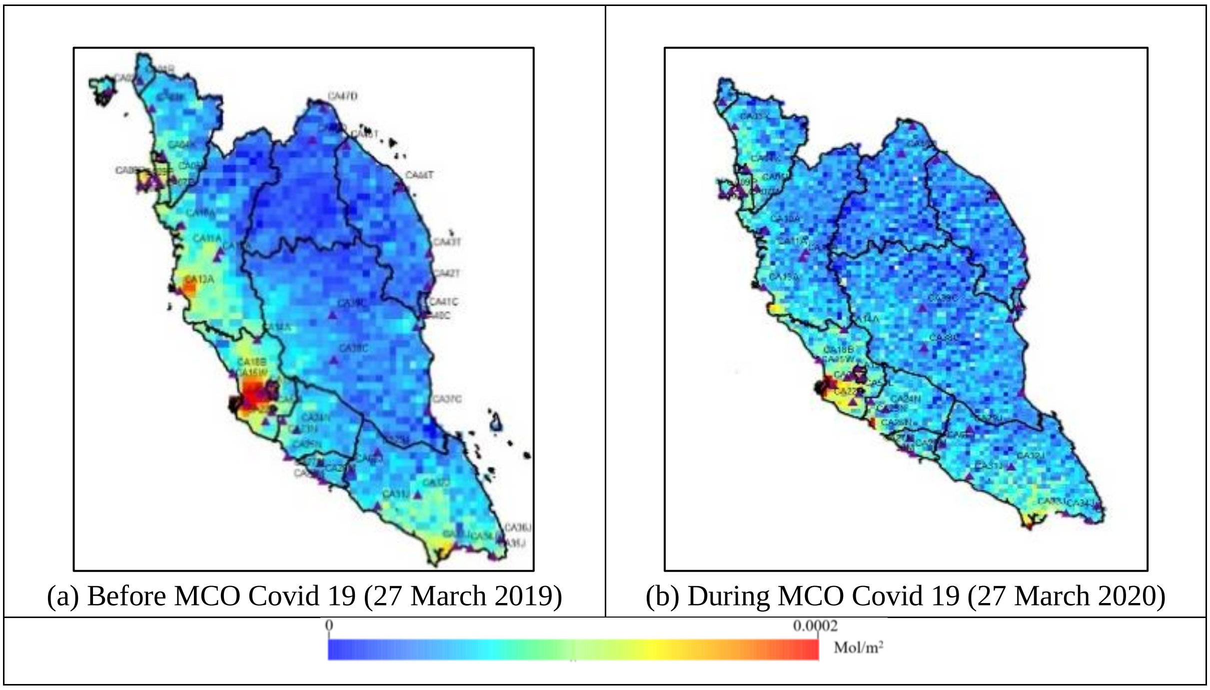
Figure 4. Location map of air pollution monitoring stations in Peninsular Malaysia

Table 1. List of air pollution monitoring stations in Peninsular Malaysia

STATION ID	LOCATION
CA45T	Besut, Terengganu
CA42T	Kemaman, Terengganu
CA44T	Kuala Terengganu, Terengganu
CA43T	Paka, Terengganu
CA31J	Batu Pahat, Johor
CA32J	Kluang, Johor
CA36J	Kota Tinggi, Johor
CA33J	Larkin, Johor
CA34J	Pasir Gudang, Johor
CA35J	Pengerang, Johor
CA29J	Segamat, Johor
CA66J	Tangkak, Johor
CA03K	Alor Setar, Kedah
CA05K	Kulim Hi-Tech, Kedah
CA02K	Langkawi, Kedah

CA04K	Sungai Petani, Kedah
CA47D	Kota Bharu, Kelantan
CA46D	Tanah Merah, Kelantan
CA26M	Alor Gajah, Melaka
CA28M	Bandaraya Melaka, Melaka
CA27M	Bukit Rambai, Melaka
CA23N	Nilai, Negeri Sembilan
CA25N	Port Dickson, Negeri Sembilan
CA24N	Seremban, Negeri Sembilan
CA41C	Balok Baru Kuantan, Pahang
CA40C	Indera Mahkota Kuantan, Pahang
CA39C	Jerantut, Pahang
CA37C	Rompin, Pahang
CA38C	Temerloh, Pahang
CA09P	Balik Pulau, Pulau Pinang
CA08P	Minden, Pulau Pinang
CA06P	Seberang Jaya, Pulau Pinang
CA07P	Seberang Perai, Pulau Pinang
CA12A	Pegoh Ipoh, Perak
CA13A	Seri Manjung, Perak
CA10A	Taiping, Perak
CA14A	Tanjung Malim, Perak
CA11A	Tasek Ipoh, Perak
CA01R	Kangar, Perlis
CA22B	Banting, Selangor
CA21B	Klang, Selangor
CA18B	Kuala Selangor, Selangor
CA19B	Petaling Jaya, Selangor
CA20B	Shah Alam, Selangor
CA15W	Batu Muda, W.P. Kuala Lumpur
CA16W	Cheras, W.P. Kuala Lumpur
CA17W	Putrajaya, W.P. Putrajaya

This study, analysis of NO_2 gasses emission was performed by comparing NO_2 reading from ground data with Sentinel 5P satellite images before and after the Covid 19 outbreak Movement Control Order (MCO) in Peninsular Malaysia. The NO_2 conditions before MCO were observed on 27 March 2019, while during MCO were observed on 27 March 2020. The amount of NO_2 in Peninsular Malaysia before and during MCO was shown in Sentinel 5P satellite images ranging from 0 - 0.0002 mol/m2 (Figure 5). It can be seen that NO_2 concentrations have higher occurred in urban areas. This is in line with high human activities such as industrial and transportation activities in this urban area, as NO_2 is one of the waste products from both activities.



(a) Before MCO Covid 19 (27 March 2019) (b) During MCO Covid 19 (27 March 2020)

Figure 5. Comparison map of tropospheric NO_2 column extracted from Sentinel 5P satellite images over Peninsular Malaysia dated 27 March 2019 and 27 March 2020

3.2 Trendlines Spatiotemporal Differences Years of NO_2 Pollution Monitoring Station

The trendlines reveal decreasing tropospheric NO_2 column for 2020 compared to 2019 for all selected locations (Figure 6). The ground measurements verify this trend for both years (Figure 7). Regarding the NO_2 concentration in Kuala Lumpur state (Figure 8), NO_2 pollution decreased during the lockdown by 73% within the Cheras area (CA16W), for Selangor state is 35% within the Petaling Jaya area (CA19B) and 52% for Putrajaya (CA17W). In the northern regions of Peninsular Malaysia, NO_2 pollution decreased by 49% at Alor Setar, Kedah (CA03K), and 43% at Seberang Perai, Pulau Pinang (CA06P), while in southern regions, NO_2 pollution decreased was 61% at Pasir Gudang, Johor (CA34J) and 83% at Kota Tinggi, Johor (CA36J). In addition, eastern regions decreased by 59% at Kota Bharu, Kelantan (CA47D), for Kuala Terengganu, Terengganu (CA44T), NO_2 pollution decreased is 51%.

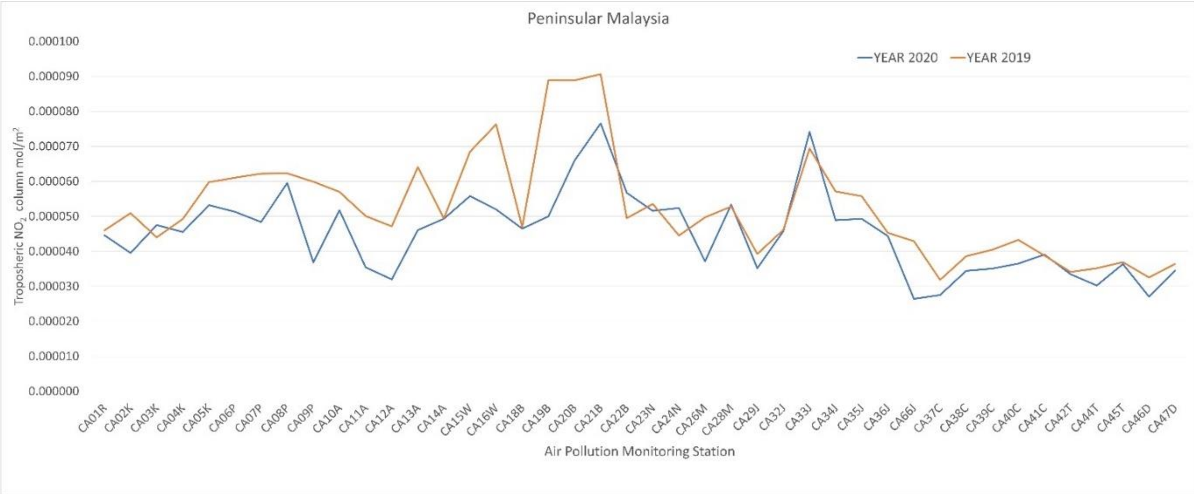


Figure 6. Comparison of tropospheric NO_2 column extracted from Sentinel 5P satellite images over Peninsular Malaysia dated 27 March 2019 and 27 March 2020

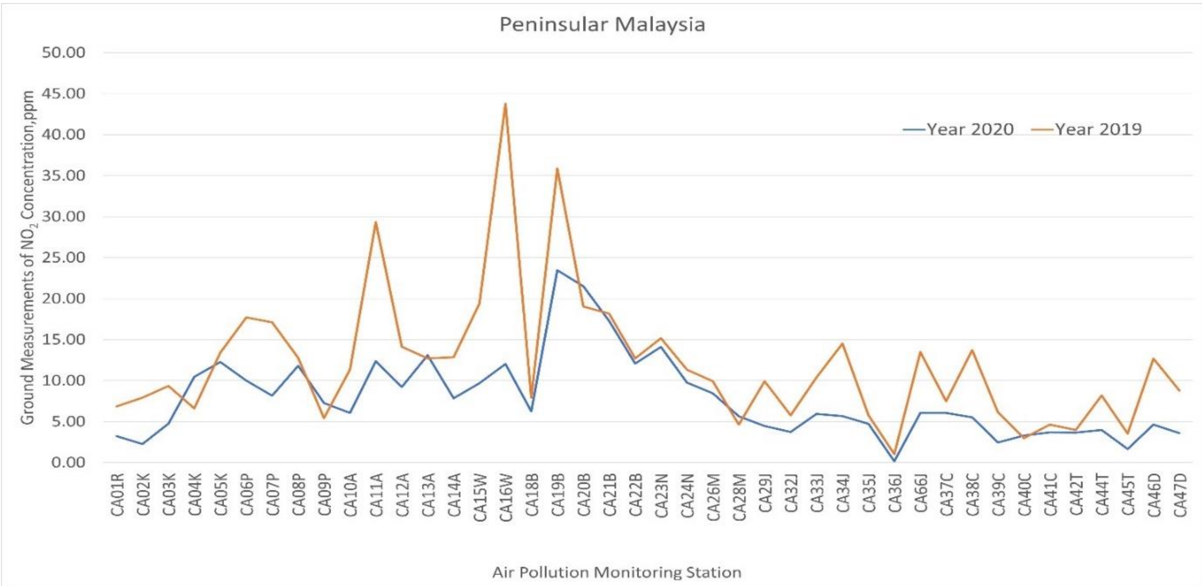


Figure 7. Comparison of ground-based measurement daily NO_2 value over Peninsular Malaysia dated 27 March 2019 and 27 March 2020

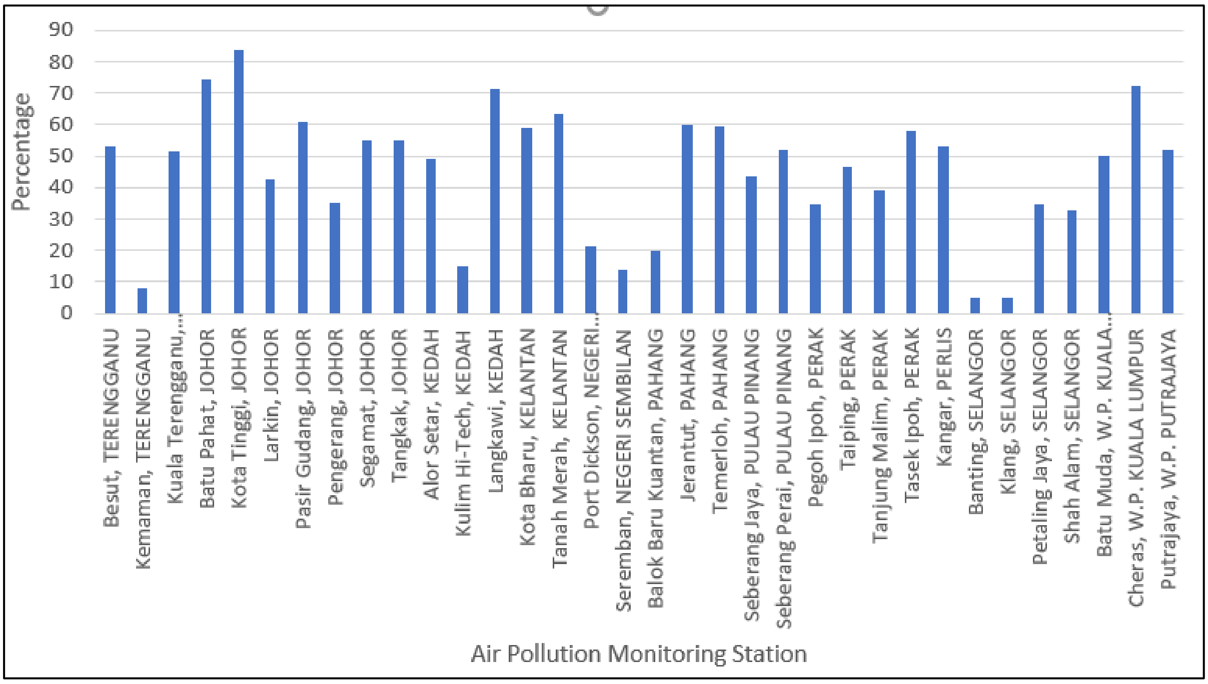


Figure 8. Percentage decrease vs ground-based measurement daily NO_2 value over Peninsular Malaysia dated on 27 March 2019 and 27 March 2020

3.3 Correlation between Tropospheric NO_2 TROPOMI and Ground-Based Air Quality Station Measurements Data

Figures 9 and 10 show a good correlation between tropospheric NO_2 TROPOMI extracted from Sentinel 5P satellite images with ground-based air quality measurement data. The validation results showed strong correlation coefficients between satellite and ground-based measurement data, with the R2 varying from 0.7085 (27 March 2019) to 0.7167 (27 March 2020). The linear regression coefficient is determined based on the strength of the correlation coefficient, where 0.31–0.5 represents a weak correlation, 0.51–0.7 means a normal correlation, 0.71– 0.90 represents a strong correlation, and 0.91–1.0 represents a strong correlation [14]. The study found a significant relationship between a decrease in NO_2 gasses emission and the total lockdown of human activities, particularly on decreased vehicle movement and industries operationalisation before and during the MCO of Covid 19. These are also supported by the same study in the European region [15], City of Brescia (Northern Italy) [16] and China [17].

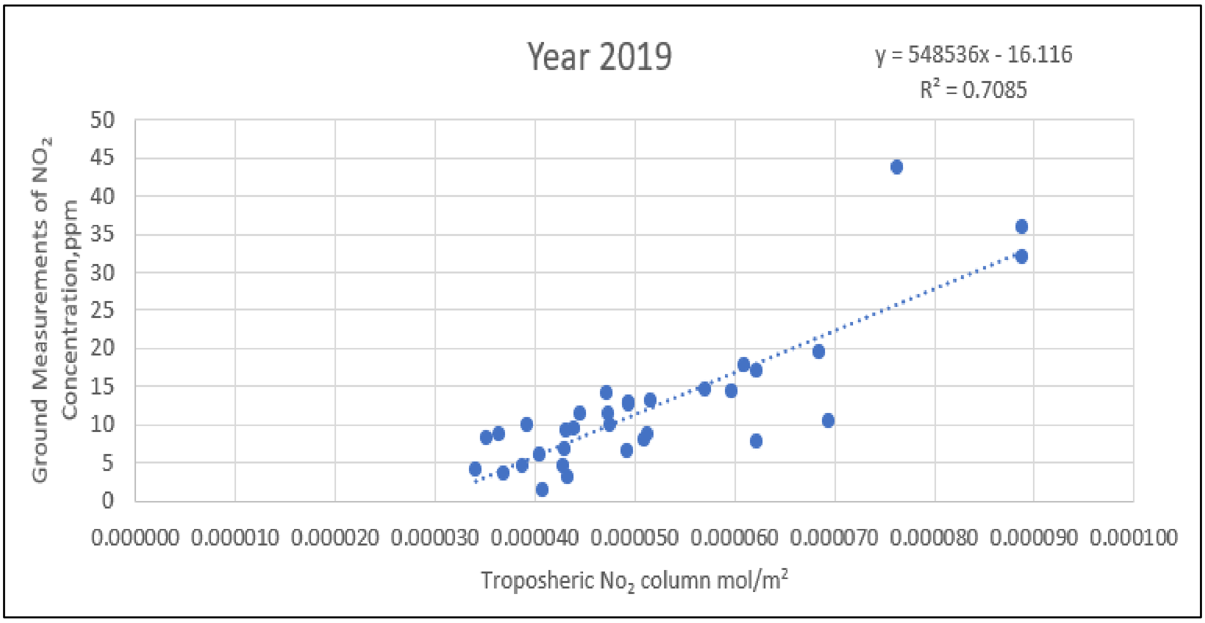


Figure 9. Correlation between Ground-based measurements of daily NO_2 and Tropospheric NO_2 for the year 2019

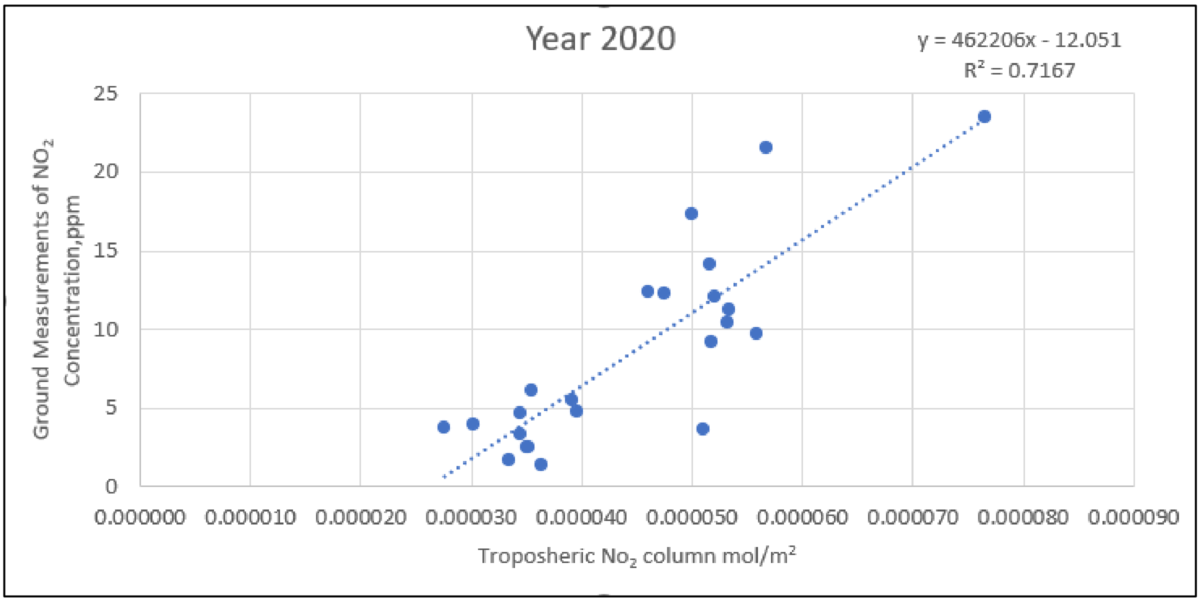


Figure 10. Correlation between Ground-based measurements of daily NO_2 and Tropospheric NO_2 for the year 2020

3.4 Comparison of Tropospheric NO_2 TROPOMI with Ground-Based Air Quality Measurements Data Before and During MCO Covid 19

The study found that ground measurement data of NO_2 concentration in 2020 decreased in many cities in western Peninsular Malaysia compared with a high reading of NO_2 in 2019 (Figure 10) which is parallel with the tropospheric NO_2 measurement extracted from Sentinel

5P satellite images in the same year (Figure 11). These can be observed in other cities such as Thailand [18], Spain [19] and India [20].

The small differences decreased NO_2 concentration in the underdeveloped areas such as Besut, Terengganu and Segamat, Johor. The study found that the population density also influenced the distribution of the NO_2 pollution in Peninsular Malaysia. Most big cities have a high density of population with highly in vehicle movement and operationalise industries.

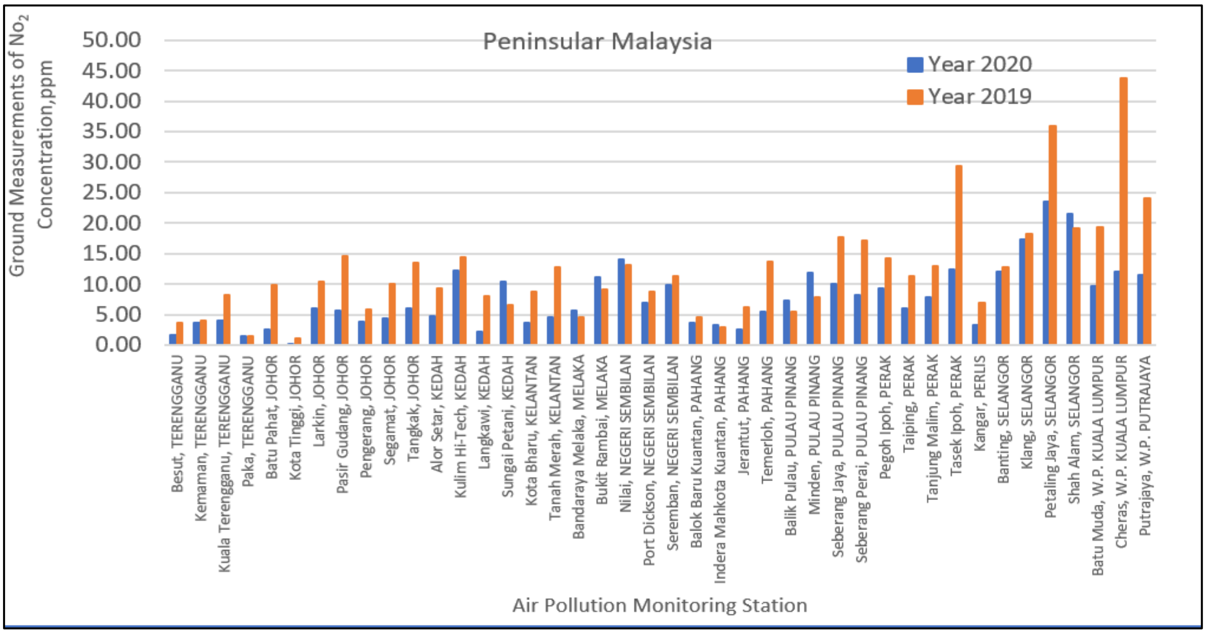


Figure 11. Ground-based measurement of daily NO_2 value over Peninsular Malaysia dated on 27 March 2019 and 27 March 2020

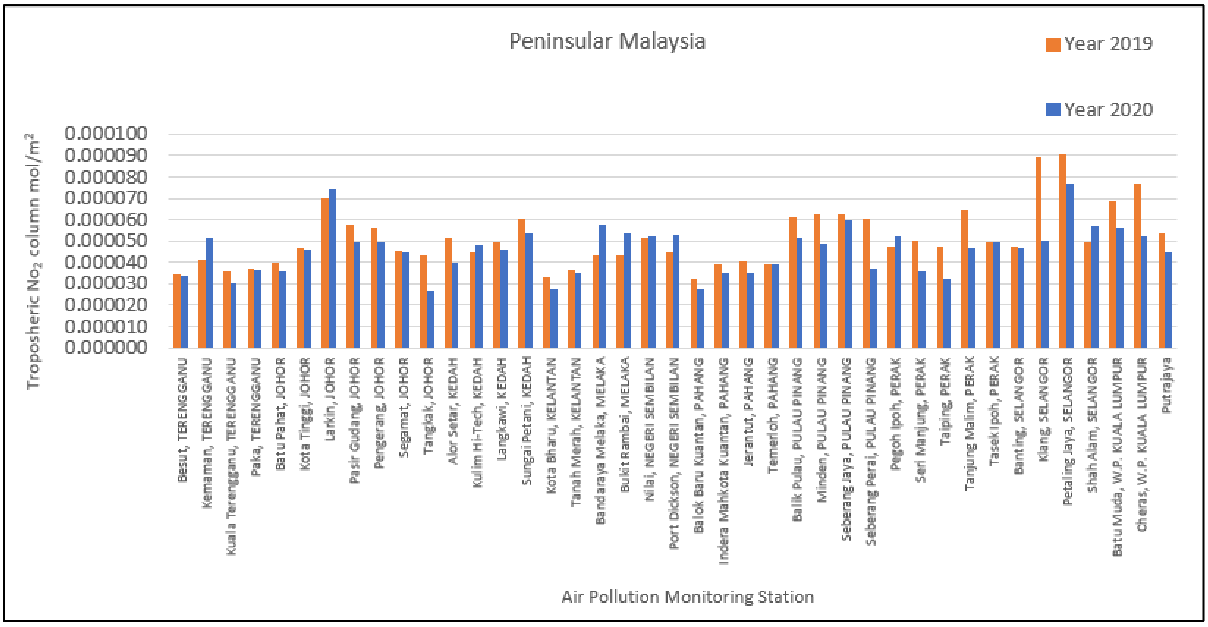


Figure 12. Tropospheric NO_2 measurement daily value over Peninsular Malaysia dated on 27 March 2019 and 27 March 2020

4. Conclusion

The study results showed that the changes in NO_2 gas concentrations were high before MCO and low during MCO. This study shows that the Sentinel-5P time-series satellite is very useful in managing, monitoring, and determining the level of NO_2 pollution for a large coverage area. In addition, it represents an example of a tool for monitoring various air pollution and assisting in decision-making at the local level within the country's boundary. The study concludes that Sentinel-5P data can provide helpful information for monitoring and mapping air pollution. The COVID-19 lockdown episode shows that levels of air pollution can be reduced and even controlled. More studies need to be done to monitor and determine the level of NO_2 pollution in Malaysia, especially involving satellite imagery, other parameters such as wind speed, wind direction, local climate (dry and wet season), and GIS techniques. Large area and repetitive coverage synonyms to remote sensing are for collecting data on dynamic themes such as pollution. Meanwhile, GIS allows integration with other relevant data towards accurate analysis and better decision making.

Acknowledgement

The authors would like to acknowledge ESA for the freely available Sentinel-5P satellite imageries used in this study. We also express our gratitude to the Malaysian Space Agency for the opportunity to be involved in this study and the Malaysian Department of Environment for providing us with ground-based NO_2 data.

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