UNIVERSITI TEKNOLOGI MARA

THE IMPACT OF MALAYSIA'S MOVEMENT CONTROL ORDER (MCO) ON THE NITROGEN DIOXIDE CONCENTRATION OF PENINSULAR MALAYSIA

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NURAISHAH BINTI AHMAD JEFRY

Dissertation submitted in partial fulfillment
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CONFIRMATION BY PANEL OF EXAMINERS

I certify that a Panel of Examiners has met on 15th July 2020 to conduct the final examination of Nuraishah binti Ahmad Jefry in her **Master of Science** thesis entitled "The Impact of Malaysia's Movement Control Order (MCO) on the Nitrogen Dioxide Concentration of Peninsular Malaysia" in accordance with Universiti Teknologi MARA Act 1976 (Akta 173). The Panel of Examiner recommends that the student be awarded the relevant degree. The Panel of Examiners was as follows:

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ABSTRACT

COVID-19 is the most recently discovered coronavirus since the outbreak began in Wuhan, China at the end of the year 2019. To reduce the possible effects due to the coronavirus in Malaysia, the Government decided to implement a nationwide Restriction of Movement Order which is known as the Malaysia's Movement Control Order (MCO) as a response of a sharp rise in the number of COVID-19 cases. Therefore, this study intended to analyse the impact of Malaysia's Movement Control Order (MCO) towards air quality Nitrogen Dioxide (NO_2) concentration in peninsular Malaysia based on the extraction of Sentinel-5 Precursor product. Compared with the conventional air pollution monitoring technology, the rapid development of the remote sensing monitoring method of atmospheric satellite has increasingly become the crucial technology means for global atmospheric environmental monitoring. So, the Sentinel-5P data product is extracted after the pre-processing of satellite image before being integrated with geographical information system to store, manipulate, query and analysis the extracted Nitrogen Dioxide (NO_2) column concertation. The high correlation between ground data from the Department of Environment and the extracted satellite images illustrates the reliability of Sentinel-5P data in monitoring the NO_2 emission, thus produce the NO_2 column concertation map. The extracted data of NO_2 column concentration from Sentinel-5P data is used to compare the emission between the phases in peninsular Malaysia. The NO_2 concentration during MCO is low and experience sudden increase in concentrations during the conditional MCO. Hotspots are observed in the Selangor and Johor state as a result of rapid urban development and probably influenced by the meteorological factor, wind speed. The mean NO_2 column concentration shows different land use types determined the influence of land use types towards the emission of NO_2. In conclusion, the remote sensing data and geographical information system techniques are utterly beneficial in monitoring air quality especially in mapping the air quality during this pandemic season.

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In the name of Allah, the most Gracious, the most Merciful

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Thank you.

To my beloved family, friends and loved ones;

Thank you for always standing by my side and supporting me. But even more than that, thank you for trusting and believing in me, even when I couldn't. Your support and faith always encouraging me through hard times. I'm blessed to have you as part of this journey and many more to come. I love you.

To my dear self,

In completion of this dissertation, I know how much you had struggled but in case I didn't tell you enough, you did this! Thank you for being so strong. Thank you for not giving up. And, thank you for being brave until the very end. I'm so proud of you.

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Abbreviations

API	Air Pollution Index
CAQM	Continuous Air Quality Monitoring
CO	Carbon Monoxide
DN	Digital Number
DoE	Department of Environment
ESA	European Space Agency
GIS	Geographical Information System
MCO	Movement Control Order
MERRA-2	Modern-Era Retrospective analysis for Research and Applications
NO_2	Nitrogen Dioxide
OMI	Ozone Monitoring Instrument
SO_2	Sulphur Dioxide
SPM	Suspended Particulate Matter
SPOT	Satellite Pour l'Observation de la Terre
SQMK	Sequential Mann-Kendall test
TROPOMI	Tropospheric Monitoring Instrument
UV	Ultraviolet

CHAPTER ONE

INTRODUCTION

1.1 Research Background

According to the World Health Organization (2020), coronavirus is a general name for a large type of virus which may cause illness in animals or humans. COVID-19 is the most recently discovered coronavirus since the outbreak began in Wuhan, China at the end of the year 2019. Ever since then, the pandemic had spread across the globe. In Malaysia, the Government decided to implement a nationwide Restriction of Movement Order which is known as the Malaysia's Movement Control Order (MCO) as a response of a sharp rise in the number of COVID-19 cases (Prime Minister's Office of Malaysia, 2020). The order is enforced under the Control and Prevention of Infectious Disease Act 1988 and the Police Act 1967 (Table 1.1). Therefore, the people of Malaysia are restricted to make activities outside of their home, unless there are important things they need to attend.

Air pollution is a combination of particulate matter and gases that can reach harmful concentrations in both circumstances, outside and indoors (Nunez, 2019). The effects of air pollution can range from higher disease risk to the rising temperature of the climate. A study of air pollution and health impacts conducted in Malaysia indicate that Suspended Particulate Matter (SPM) and Nitrogen Dioxide (NO_2) are the predominant pollutants (Afroz et al., 2003). Attention has been focused on the Klang Valley, an urban commercial industrial area, as the Nitrogen Dioxide (NO_2) is highly concentrated in the region aside from other places in Malaysia (Awang et al., 2005). The air pollution comes mainly from land transportation, industrial emission and open burning sources. Among them, land transportation contributes the most in air pollution. The main source of NO_2 in the ambient atmosphere are emission from motor vehicles and fossil fuel burning. Therefore, air quality monitoring is needed to control air pollution in Malaysia.

Air quality monitoring is part of the initial strategy in the pollution prevention program in Malaysia. The Department of Environment (DoE) is responsible in monitoring the country's ambient air quality since 1975 through a network of 51 Continuous Air Quality Monitoring (CAQM) stations. These monitoring stations are located strategically within residential, traffic and industrial area to detect any significant changes in the air quality which may be harmful to human health and the environment. Among the CAQM stations, they are divided into five (5) categories; industrial, residential, traffic, background and PM_{10} stations. Figure 1.1 shows the location of CAQM stations across Malaysia. There are 36 CAQM stations in peninsular Malaysia, and another 15 stations are in east Malaysia. The mapping of air quality in Malaysia particularly used the ground CAQM reading of provided parameter, in which they cannot provide description of total concentration of all the pollutants accurately at area without the existence of CAQM stations.

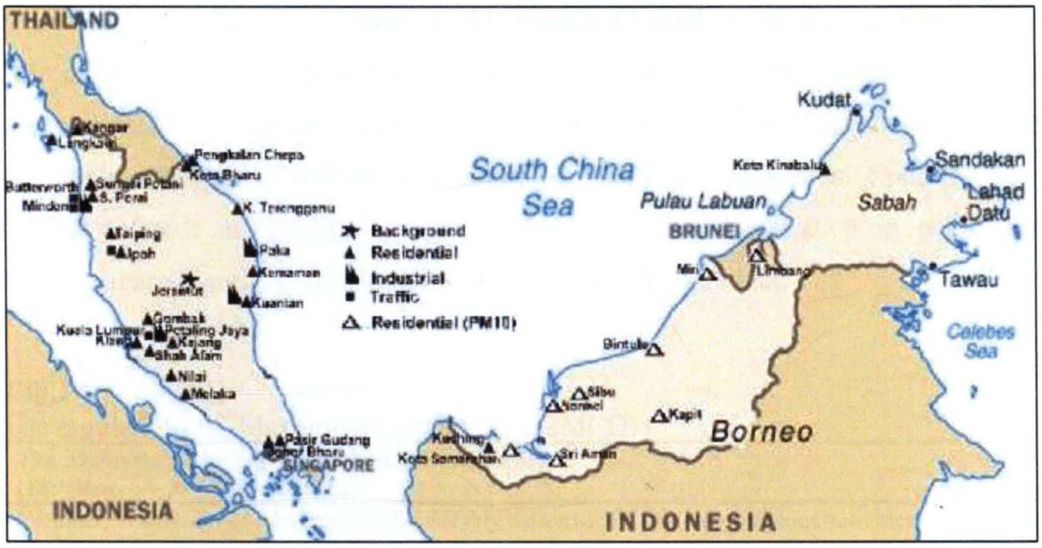


Figure 1.1 Location of CAQM stations (Source: Alam Sekitar Malaysia Sdn Bhd)

The advancement of technologies in remote sensing and Geographical Information System (GIS) lead to various studies and methods in mapping the air quality due to the availability of data from small to large scale area. The early air quality mapping with remote sensing and GIS techniques starts with extracting the digital number (DN) of several bands from Landsat 7 ETM+ to combine with CAQM station data (Narashid & Wan Mohd, 2010). The purpose of the extraction is to obtain the initial virtual air quality stations which are then being mapped Kriging interpolation method. Then, Ozone Monitoring Instrument (OMI) was utilized to observe the concentration of NO_2 within a large urban area. Scaling factors (scale-to-column ratios) method is utilized to relate the satellite column measurements to ground-level concentrations of NO_2 (Bechle et al., 2013). Since the launching of Sentinel-5 Precursor, the monitoring of air quality started to adapt the use of the remote sensing data, especially in the concentration of Nitrogen Dioxide (NO_2). Correlation analysis is used to find the coherence between the generated satellite image and surface observation obtained from the monthly report of air quality in projecting the concentration of NO_2 (Zheng et al., 2019). Apart from that, the sequential Mann-Kendall (SQMK) test proposed by Sneyers (1990) was used to identify the abrupt changes in significant trends of NO_2 concentrations (Shikwambana et al., 2020).

Based on the previous studies in air quality mapping, extraction of data from satellite images is the most practical method in producing the air quality map, especially from Sentinel-5 Precursor. Most of the studies focused on producing the map of Nitrogen Dioxide (NO_2) concentration. However, there is no particular study related to the production of air quality mapping with Sentinel-5 Precursor in Malaysia. Therefore, this study intended to analyse the impact of Malaysia's Movement Control Order (MCO) towards air quality Nitrogen Dioxide (NO_2) concentration in peninsular Malaysia based on the extraction of Sentinel-5 Precursor product.

Table 1.1
The regulations of Movement Control Order (MCO)

The Malaysia's Movement Control Order (MCO) (18th March – 31st March 2020)
Complete restriction of movement and assembly nationwide, including religious activities, sports, social and cultural events. To enforce this restriction, all houses of worship and business premises are to be closed, except supermarkets, public markets, sundry shops and convenience stores selling essential goods. Specifically, for Muslims, the suspension of all religious activities in mosques and Suraus, including the Friday prayers, is in line with decision of the Special Muzakarrah Committee that convened on the 15th of March 2020.
A complete travel restriction for all Malaysians going overseas. For Malaysians returning home, they are required to undergo health checks and voluntary self- quarantine for a period of 14 days
A complete restriction of foreign visitors and tourists into Malaysia.
Closure of all kindergartens, public and private schools, including day schools and residential schools, international schools, Tahfiz centers and all other institutions of learning in primary, secondary and pre-university levels.
Closure of all public and private institutions of higher learning nationwide, including skills training institutes.

Closure of all government and private premises except those involved in essential services (Water, electricity, energy, telecommunications, post, transportation, irrigation, oil, gas fuel, lubricants, broadcasting, finance, banking, health, pharmacy, fire prevention, prisons, ports, airports, security, defence, cleaning, food supply & retail)

(Prime Minister's Office of Malaysia, 2020)

1.2 Problem Statement

At present, most studies related to air quality in Malaysia is about observing the trend of air pollution and is based on ground measurements of CAQM stations. The ground CAQM stations' instruments are designed to monitor specific air pollutants (i.e. Sulphur Dioxide, Nitrogen Dioxide, Carbon Monoxide, Ozone, Hydrocarbon, PM_{10} and UV) but cannot provide description of total concentration of all pollutants accurately at area without the existence of CAQM stations. Many studies had proved the relationship between the ground-level measurement of air pollution with satellite column measurement (Bechle et al., 2013; Narashid & Wan Mohd, 2010; Shikwambana et al., 2020; Zheng et al., 2019). As a result, there is a highly spatial correlation between the column concentration from Sentinel-5P and individual ground-level measurement of NO_2 concentrations.

The most advanced method on mapping the air quality with remote sensing data use extracted DN of several bands from Landsat 7 ETM+ according to the pixel location of CAQM stations to produce a map of virtual air quality stations. Other than that, there is no related research on the use of satellite image such as Landsat, SPOT or Sentinel-5P to monitor the air quality in Malaysia. Therefore, this study is focused on monitoring the air quality Nitrogen Dioxide concentration in peninsular Malaysia based on the extraction of Sentinel-5 Precursor product during the implementation of the Malaysia's Movement Control Order.

1.3 Aim and Objectives

The aim of this study is to analyse the impact of Malaysia's Movement Control Order (MCO) towards air quality Nitrogen Dioxide concentration in peninsular Malaysia based on the extraction of Sentinel-5 Precursor product.

The research objectives are:

a) To generate the TROPOMI Nitrogen Dioxide (NO_2) column concentration maps of 2018, before, during and after MCO phase.

b) To determine the reliability of TROPOMI Nitrogen Dioxide (NO_2) column concentration maps generated from Sentinel-5P data.

c) To evaluate the effects of Malaysia's movement control order (MCO) on the retrieved Nitrogen Dioxide (NO_2) concentration

d) To evaluate the retrieved Nitrogen Dioxide (NO_2) concentration based on different land use types

1.4 Scope of Study

This research will cover approximately 132,090 km^2 study area. The study area comprises of the whole peninsular Malaysia. The factor that influence the selection of study area is due to the availability of air quality data of Nitrogen Dioxide (NO_2) parameter for CAQM stations and satellite images of study area. Other than the mentioned factors, the areas are also selected due to being indicated as the area with heavy air pollution with factors like urbanization, industry and motor vehicles for its contributor (Abdullah et al., 2012).

This study is focused on extracting air quality Nitrogen Dioxide (NO_2) from TROPOMI Sentinel-5 Precursor acquired from the European Space Agency (ESA) website. The satellite image will undergo four (4) important stages starting from preliminary study, data acquisition, data pre-processing and processing, and data analysis before generating the NO_2 column concentration map as shown in Figure 1.2. The pre-processing stages involves attaching pixel geo-coding, exporting to different file format and re-projecting datum into WGS84 in SNAP software. Then, satellite images undergo processing stage in ArcGIS software where the images are extracted according to the shapefile of study area and converted the pixel unit using GIS tools provided in the software.

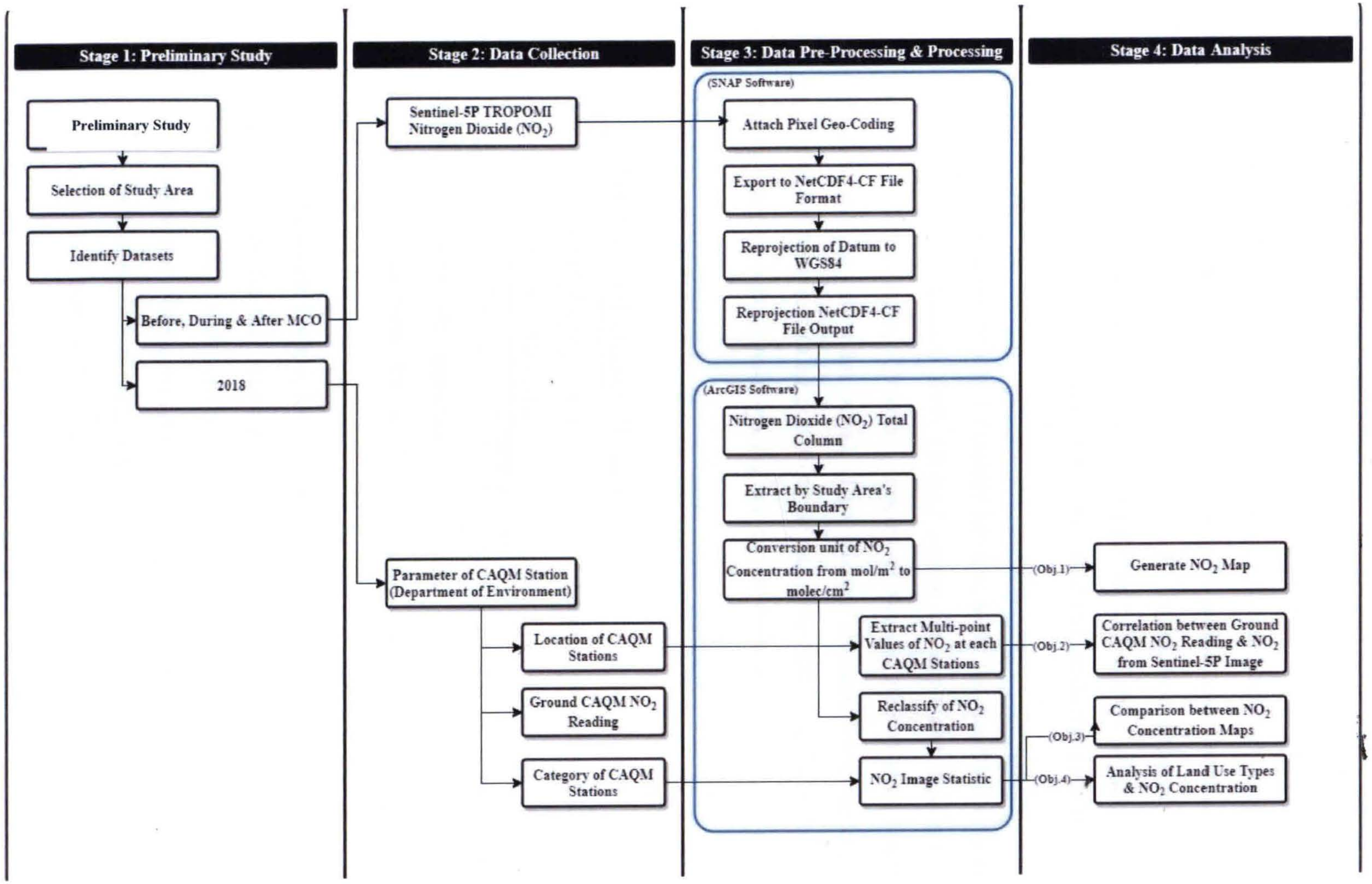


Figure 1.2 General Methodology

1.5 Chapter Organization

This report consists of five (5) chapters starting with introduction, literature review, methodology, results and analysis, and end with recommendation and conclusion. For the first chapter, Introduction, a background study about the purpose to conduct this project is explained followed by its problem statement and objectives. A study area is described to give an overview of the location this study conducted. An overall methodology is explained generally in this chapter to give the reader an overview on how to achieve the objectives stated and conduct the project.

In the second chapter, Literature Review, all of the summaries regarding to air quality mapping obtained from allowed source are explained in this chapter. The allowed sources consist of journals, articles, books and other reading materials either electronically or just plain books. This chapter concentrates more on air quality mapping; the overview of air pollution, air quality in Malaysia, the development of air quality mapping with remote sensing, air quality extraction techniques and air quality analysis.

For the third chapter, Research Methodology, a series of methodology is discussed in detail the procedure, stages and methodology involved in completing the impact of Malaysia's Movement Control Order (MCO) towards the air quality of Nitrogen Dioxide (NO_2) in Peninsular Malaysia. The methodology of this research divided into four (4) important stages which are selection of study area and identification of datasets, data acquisition, digital image processing, and data analysis.

In the fourth chapter, Results and Analysis, this chapter explains in detail of the results obtained for this research study. There are four (4) important tasks that are carried out to meet the objectives of this research study, which are generate NO_2 column concentration map for six (6) datasets, correlation analysis between ground-based data and remote sensing data, comparison of NO_2 concentration, and analyse the relationship between land use types and NO_2 concentrations.

Last chapter, Recommendation and Conclusion, highlighted the overall concept, process and analysis which had been conducted in this study. Recommendations for further work and references also being disclosed in this chapter for better understanding and improvements.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter comprises of the compilation of literature that significant with the application of remote sensing and GIS in producing air quality maps using remote sensing data. The literature review will be divided into five (5) main categories that related to the overview of air pollution, overview of air quality in Malaysia, the development of air quality mapping with remote sensing data, variation of techniques used in extraction of air quality and appropriate analysis conduction in relation with Geographical Information System.

2.2 Air Pollution

Air pollution is a combination of particulate matter and gases that can reach harmful concentrations in both circumstances, outside and indoors (Nunez, 2019). The effects of air pollution can range from higher disease risk to the rising temperature of the climate. According to the World Health Organization (2005), the ambient air quality had caused an estimation of 4.2 million death per years occurs around the world due to stroke, heart disease, lung cancer and chronic respiratory diseases. While most of studies mainly focused on respiratory and cardiovascular events attributes to short- and long-term exposures (Afroz et al., 2003; Day, 2004; Powell, 2012), a new generation of studies suggested that the effects are not specific to the outcome as shown in Table 2.1.

Table 2.1
Health effects of air pollution

Effects attributed to short-term exposure
• Daily mortality
• Respiratory and cardiovascular hospital admissions
• Respiratory and cardiovascular emergency department visits
• Respiratory and cardiovascular primary care visits
• Use of respiratory and cardiovascular medications
• Days of restricted activity
• Work absenteeism

• School absenteeism	
• Acute symptoms (wheezing, coughing, phlegm production, respiratory infections)	
• Physiological changes (e.g. lung function)	
Effects attributed to long-term exposure	
• Mortality due to cardiovascular and respiratory disease	
• Chronic respiratory disease incidence and prevalence (asthma, COPD, chronic pathological changes)	
• Chronic changes in physiologic functions	
• Lung cancer	
• Chronic cardiovascular disease	
• Intrauterine growth restriction (low birth weight at term, intrauterine growth retardation, small for gestational age)	

(Source: World Health Organization, 2005)

As the phenomena poses a major threat to health and climate, air pollutants may be either primary air pollutants or secondary air pollutants. Primary air pollutants are those of the physical state of air pollutants (such as gaseous and particulate matter) that are emitted into the atmosphere from a source such as factory chimney or exhaust pipe, or through suspension of contaminated dusts by the wind. Meanwhile, as for secondary air pollutants, these are naturally formed within the atmosphere itself. The process may involve some chemical reaction resulted from primary air pollutants, and then react with the natural components of the atmosphere, especially oxygen and water (World Health Organization, 2005).

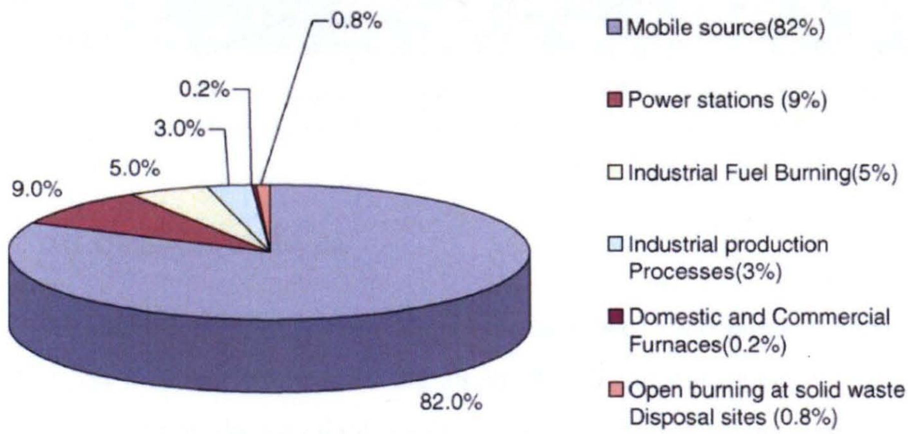


Figure 2.1 Sources of air pollution in Malaysia, year 1996 (Afroz et al., 2003)

In Malaysia, the three (3) main sources of air pollution in Malaysia are mobile sources, stationary sources, and open burning sources (Afroz et al., 2003). Figure 2.1 displayed the sources of air pollutions obtained from the Department of Environment. From figure, mobile sources (i.e. vehicles, motor, etc.) had been the ultimate source of air pollution, contributing 82% of the total air pollution, followed by power stations, 9%; industrial production process, 3%; open burning at solid waste disposal sites, 0.8%; and domestic and commercial furnaces 0.2%. Figure 2.2. shows a picture of the skyline of Kuala Lumpur city centre which clearly can be seen during the implementation of MCO.

Figure 2.2 The skyline of Kuala Lumpur city centre all clear on April 20 during the movement control order (Source: TheStar News, 2020)

2.3 Air Quality in Malaysia

Air quality defined by the National Oceanic and Atmospheric Administration (2020) as an indicator to measure the air in the atmosphere whether it is clean or polluted. Monitoring the air quality is crucial as the polluted air may cause, not only harm for the human, but also for the environment Ambient air quality standards identify individual pollutants and the concentrations at the point they are harmful to the public health and the environment. Typically, the standards are set without regards for economic feasibility of achieving them. Instead, they focus on public health, as well as the well-being of "sensitive" populations such as asthmatics, children and the elderly, and public welfare, including protection from limited visibility and damage to animals, crops, vegetation, fish stocks, and development area.

The Malaysian air pollution index (API) is obtained from the measurement of fine particles (below 10 mm) and several gases such as Carbon Monoxide, Sulphur Dioxide, and Nitrogen Dioxide. These gases are actually present in the atmosphere, although it is only small amount of them. Table 2.2 shows the air pollution index of Malaysia produced by the Department of Environment. The API value is divided into five (5) categories which are then labelled according to the health concern; good, moderate, unhealthy, very unhealthy and hazard.

Table 2.2
The Malaysia's air pollution index

API Numerical Value	Air Quality Index Levels of Health Concern	Meaning
0 – 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.
51 – 100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
101 – 200	Unhealthy	Everyone may begin to experience health effects; Members of sensitive groups may experience health effects.
201 – 300	Very unhealthy	Health alert: Everyone may experience more serious health effects.
201 – 500	Hazardous	Health warnings of emergency conditions. The entire population is more likely to be affected.

(Source: The Department of Environment, 2020)

A study conducted at Kuala Lumpur regarding the trend of air quality level and urban growth shows that there is a significant and strong relationship between the number of hazardous days and urban land use (Ling et al., 2010). The statement is supported when Abdullah et al., (2012) claimed that the reason of why Klang Valley suffered from quite severe acidified rain which indicates the level of air pollution contained within the area is because of the rapid growth of urban in the area. The relationship between the emission of pollution from motor vehicles and the growth of urban had been proved when the concentration of Nitrogen Dioxide is highly concentrated in Klang Valley aside from other places in Malaysia (Awang et al., 2005). The positive relationship between the population and the Nitrogen Dioxide was expected by Kaplan et al., (2019) as the study they had conducted in Turkey shows that about 80% of Nitrogen Dioxide in the citied comes from motor vehicle exhaust and burning of fossil fuel. Figure 2.3 shows the condition of air quality in Malaysia which has worsened due to urbanisation and seasonal haze in the country.

Figure 2.3 Grey skies: Air quality in Malaysia (Source: TheStar News, 2020)

2.4 Development of Air Quality Mapping with Remote Sensing

Compared with the conventional air pollution monitoring technology, the rapid development of the remote sensing monitoring method of atmospheric satellite has increasingly become the crucial technology means for global atmospheric environmental monitoring. In early 2010's, the air quality in the Klang Valley region was mapped by using Landsat 7 ETM+ and air pollution data at selected CAQM station obtained from the Department of Environment, Malaysia (Narashid & Wan Mohd, 2010). The study extracted the digital number (DN) of several bands from Landsat 7 ETM+ to combine with CAQM station data. The extraction is based on the pixel location of seven (7) CAQM stations within the study area. The images are then overlaid onto GIS layer. The purpose of the extraction is to obtain the initial virtual air quality stations. The combination of Landsat 7 ETM+ produced 148 virtual stations derived from regression analysis made between the DN and Carbon Dioxide concentration resulted in map of pollutant concentration obtained using Kriging interpolation method.

Then, a study by Bechle et al. (2013) demonstrate the use of Ozone Monitoring Instrument (OMI) and data concentration from US EPA ambient monitoring station in evaluating the capabilities of satellite data in resolving urban-scale gradients in ground-level Nitrogen Dioxide (NO_2) within a large urban area. The study used scaling factors (scale-to-column ratios) method to relate the satellite column measurements to ground-level concentrations of NO_2. The highly spatial correlation between OMI columns and corrected in-situ measurements indicate the reliability of observation of NO_2 using OMI sensor within a large urban area.

Since the launching of Sentinel-5 Precursor, the monitoring of air quality started to adapt the use of the remote sensing data. A study based on an application of Sentinel-5P product was demonstrated to observe the spatial variation of NO_2. Sentinel-5P tropospheric NO_2 column concentration from the Royal Netherland Meteorological Research Institute was rasterized to generate a time-series raster dataset. However, due to the loss of pixel in some area, interpolation by Kriging algorithm was used to restore the pixel loss region (Zheng et al., 2019). The high coherence between the generated satellite image and surface observation obtained from the Chinese Urban Air Quality monthly report shows the reliability of Sentinel-5P in projecting the concentration of NO_2.

Shikwambana et al., (2020) demonstrate the use of Sentinel-5P in observing the concentration of Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) in South Africa.

Earth Engine Code Editor used to extract the information from Sentinel-5P where Python code is utilized. Apart from that, the Modern-Era Retrospective analysis for Research and Applications (MERRA-2) and Ozone Monitoring Instrument (OMI) were utilized to obtain the surface mass concentration for SO_2 and NO_2, respectively based on previous study succession. The sequential Mann-Kendall (SQMK) test proposed by Sneyers (1990) was used to identify the abrupt changes in significant trends of SO_2 and NO_2 over South Africa.

2.5 Air Quality Extraction Techniques

Kriging interpolation method is used to produce a map of pollutant concentration obtained from virtual stations (Narashid & Wan Mohd, 2010). The virtual stations were obtained from map query analysis which derived from regression between the extracted DN from Landsat 7 ETM+ according to the pixel location of selected CAQM stations and reading of air quality concentration (i.e. CO and PM_{10}) on the CAQM stations. Kriging algorithm also being implied on restoring the loss of pixel in rasterized image of Sentinel-5P obtained from the Royal Netherland Meteorological Research Institute before production of tropospheric NO_2 column concentration mapping can be done (Zheng et al., 2019).

Earth Engine Code Editor used to extract Sentinel-5P data in order to obtain the concentration reading of SO_2 and NO_2 (Shikwambana et al., 2020). The Earth Engine Code Editor used a series of Python code in order to generate an air quality production. Most of the Python code are already available in the website as part of tutorial sessions in introducing the use of Sentinel-5P product.

2.6 Air Quality Analysis

In order to find the correlation between the extracted DN from Landsat 7 ETM+ according to pixel location of selected CAQM stations and reading of air quality concentration (i.e. CO and PM_{10}) on the CAQM stations, regression analysis had been implied. The strong correlation between DN and CO compared to DN and PM_{10} is used to determine the reliability of data to produce a map of virtual stations obtained from map query analysis (Narashid & Wan Mohd, 2010).

Bechle et al. (2013) demonstrate the use of scaling factors (surface-to-column ratios) to relate the satellite column measurements to ground-level concentrations. The highly correlation between OMI columns and corrected in-situ measurement indicate the reliability of observation of NO_2 using OMI sensor for large urban area. Similar method is implied by Zheng et al. (2019) where the study compare the rasterized tropospheric NO_2 column concentration with the Chinese Urban Air Quality monthly report. Meanwhile, in order to identify the abrupt changes in significant trends of SO_2 and NO_2 over South Africa, the sequential Mann-Kendall (SQMK) test proposed by Sneyer (1990) was used (Shikwambana et al., 2020).

2.7 Chapter Summary

Previous studies that are relevant with the air quality mapping indicate that there exist rapid development of the air quality mapping with remote sensing monitoring method of atmospheric satellite and various air quality extraction techniques can be adapted in order to produce better results in extracting air quality from remote sensing data as well as emphasizing the important of GIS in analysing the output. Thus, the provided methodology and techniques from the reviewed literature will be integrated to accomplish this study in extracting and analysing the air quality from remote sensing data.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter discuss in detail the procedure, stages and methodology involved in completing the impact of Malaysia's Movement Control Order (MCO) towards the air quality of Nitrogen Dioxide (NO_2) in Peninsular Malaysia. The methodology of this research can be divided into four (4) important stages which are selection of study area and identification of datasets, data acquisition, digital image processing, and data analysis. The detailed methodology of this study is shown in Figure 3.1.

3.2 Selection of Study Area

The study area of this research comprises of three (3) areas which are the whole of peninsular Malaysia, the whole of Selangor state including Wilayah Persekutuan Kuala Lumpur and Putrajaya, and the whole of Johor state. The factor that influence the selection of study area is due to the availability of air quality data of Nitrogen Dioxide (NO_2) parameter for CAQM stations and satellite images of study area. Other than the mentioned factors, the areas are also selected due to being indicated as the area with heavy air pollution with factors like urbanization, industry and motor vehicles for its contributor (Abdullah et al., 2012). Figure 3.2 shows the selected study area including the location of CAQM stations across Peninsular Malaysia.

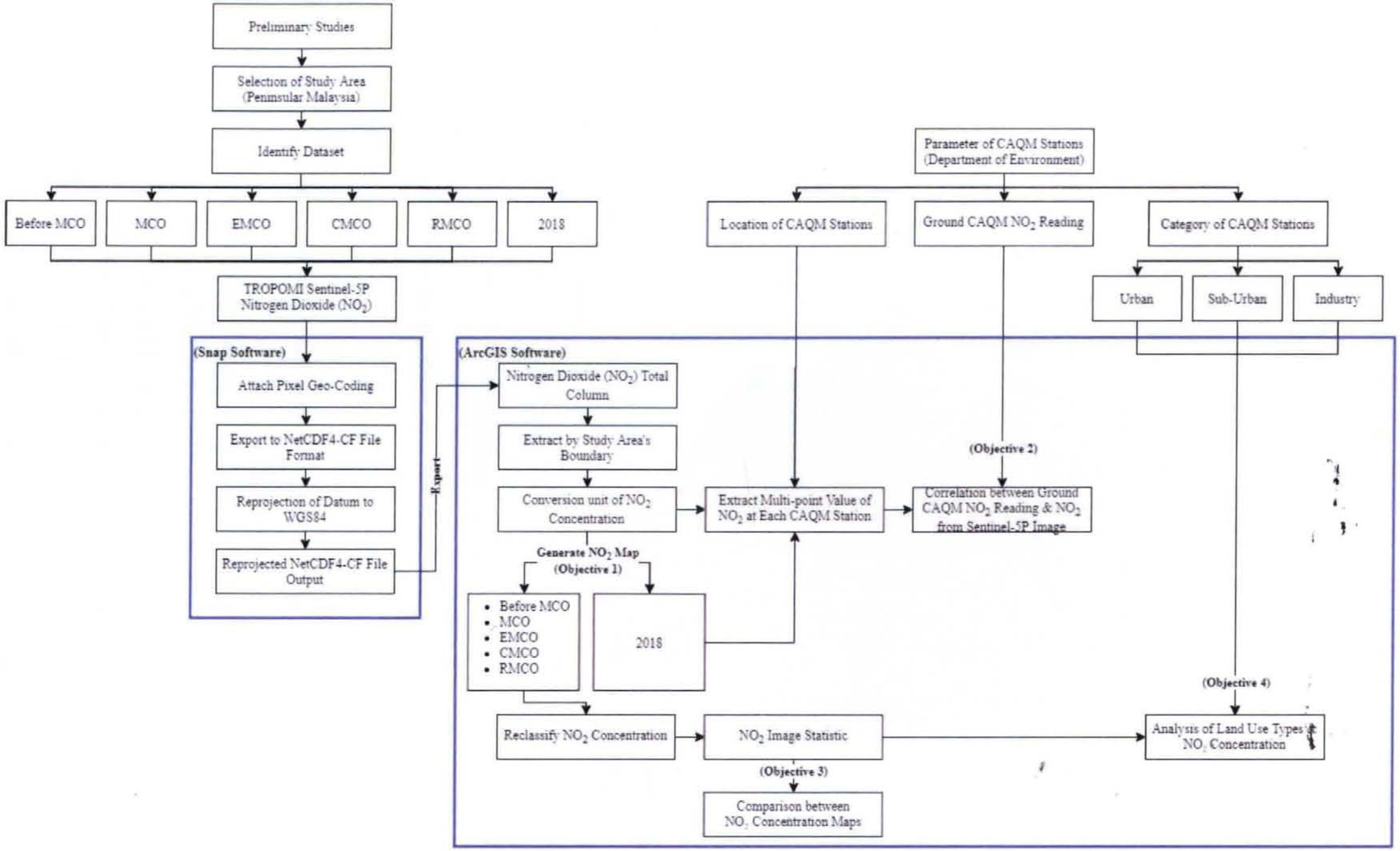


Figure 3.1 Research methodology flowchart

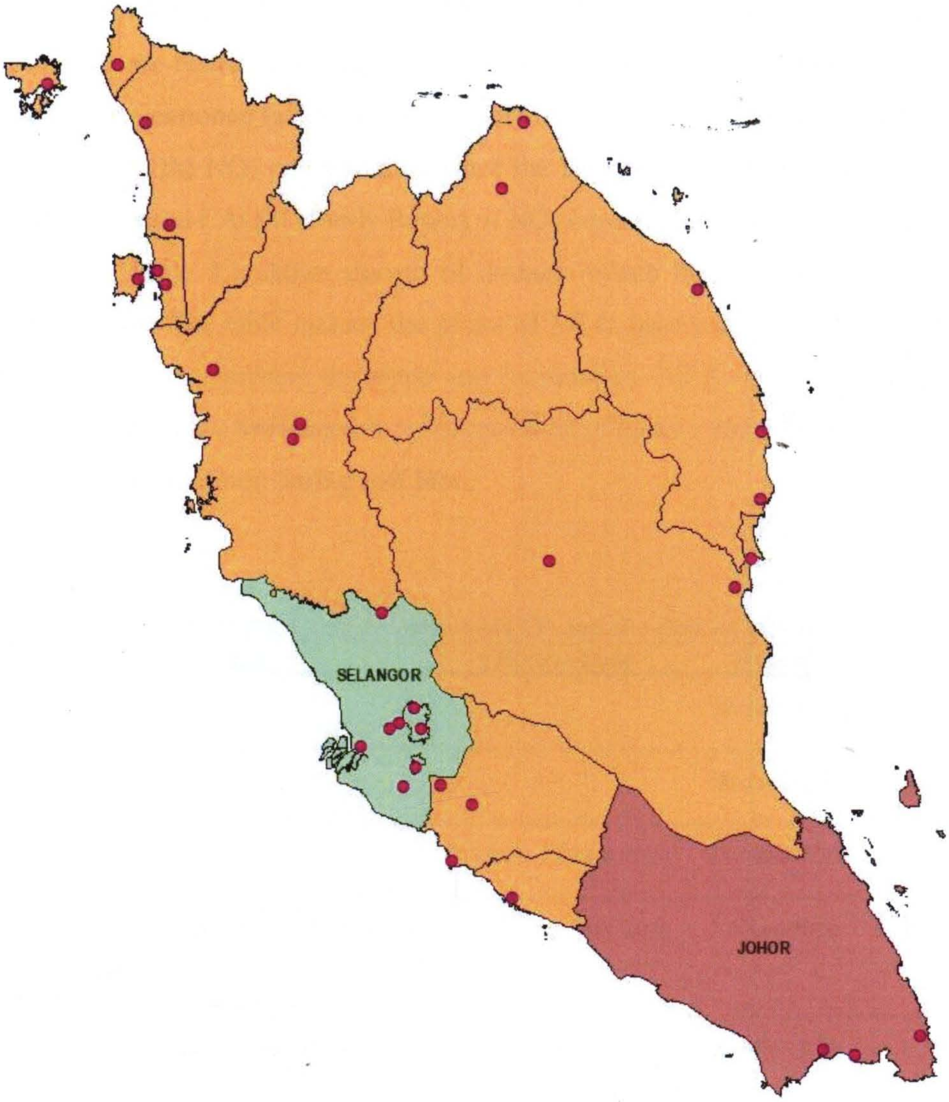


Figure 3.2 The selected study area and location of CAQM stations in Peninsular Malaysia

3.3 Identification of Datasets

Since the main factor that influenced the identification of dataset is the implementation of Movement Control Order (MCO) in Malaysia, this research highlighted three (3) conditions for the dataset which are before, during and after the enforcement of MCO. The Government of Malaysia decided to implement a nationwide Restriction of Movement Order which is known as the Malaysia's Movement Control Order (MCO) as a response of a sharp rise in the number of COVID-19 cases (Prime Minister's Office of Malaysia, 2020). The order is enforced under the Control and

Prevention of Infectious Disease Act 1988 and the Police Act 1967, in which the people of Malaysia are restricted to conduct any activities outside of their home. Aside from the previous mentioned factor, another reason of dataset identification is the availability of ground CAQM NO_2 concentration since the Department of Environment can only provide processed CAQM Hourly Report of NO_2 concentration starting from year 2018 and below. Table 3.1 shows the set of datasets which had been identified for this research study. The table include the phase of MCO involved, its effective dates, the date of dataset to represent the phase and its remarks. All the identified datasets are ensured to fall on the weekdays since the operation of factory and movement of vehicles and motors are common during that time.

Table 3.1
The phases of Movement Control Order (MCO) and the date of identified datasets

No.	Phase	Effective Date	Dataset	Remarks
1	-	-	20-Jun-2018	Correlation
2	-	-	08-Jan-2020	Before MCO
3	Movement Control Order	18-Mar – 31-Mar 2020	25-Mar-2020	MCO
4	Extended Movement Control Order	01-Apr – 03-May 2020	22-Apr-2020	EMCO
5	Conditional Movement Control Order	04-May – 09-Jun 2020	20-May-2020	CMCO
6	Recovery Movement Control Order	10-Jun – 31-Aug 2020	17-Jun-2020	RMCO

3.4 Data Acquisition

Data acquisition for this study involved collection of remote sensing data and CAQM data requested from the Department of Environment (DoE) Malaysia.

3.4.1 Remote Sensing Data

The total column NO_2 concentration data used in this research are produced by a Tropospheric Monitoring Instrument (TROPOMI) that is carried by a Sentinel-5

Precursor, also known as Sentinel-5P. Sentinel-5P is the first Copernicus mission dedicated to monitor the atmosphere with the main objective to perform atmospheric measurement with high spatio-temporal resolution, to be used for air quality, ozone and UV radiation, and climate monitoring and forecasting. The mission reduces gaps in the availability of global atmospheric data products between SCIAMACHY/Envisat, the OMI/AURA mission and the Copernicus Sentinel-4 and Sentinel-5 missions (European Space Agency - Sentinel Online, 2020). The TROPOMI is claimed to be the most advanced instrument for measuring ultraviolet-visible (270 – 500nm), near infrared (675 – 775nm) and short-wave infrared (2305 – 2385nm) spectral bands, which results to the various production of air pollution image such as NO_2, O_3, CH_2O, SO_2, CH_4 and CO more accurately than before (Galli et al., 2012). The specification summary of TROPOMI Sentinel-5P is shown in Table 3.2.

Table 3.2
Specification summary of TROPOMI Sentinel-5P

Property	Info
Spatial Resolution	Up to 5.5 km × 3.5 km
Sensor	Tropospheric Monitoring Instrument (TROPOMI), a spectrometer measuring ultraviolet and visible (270–495 nm), near infrared (675–775 nm) and shortwave infrared (2305–2385 nm) light
Revisit Time	Less than one day
Spatial Coverage	Global coverage
Data Availability	Since April 2018

(Source: European Space Agency, 2020)

The remotely sensed data can be freely accessed and downloaded from the Sentinel-5P Pre-Operations Data Hub website as shown in Figure 3.3. Before the data can be downloaded, user need to select the desired study area (orange-highlighted area) to narrow down the list of products which will be provided by the website. Then, select the options available at the box displayed at the left side of the figure. The options consist of the sensing and processing date of Sentinel-5P and the product type. Finally, the result will be shown in in purple-highlighted area which is overlaid on the study that is selected earlier.

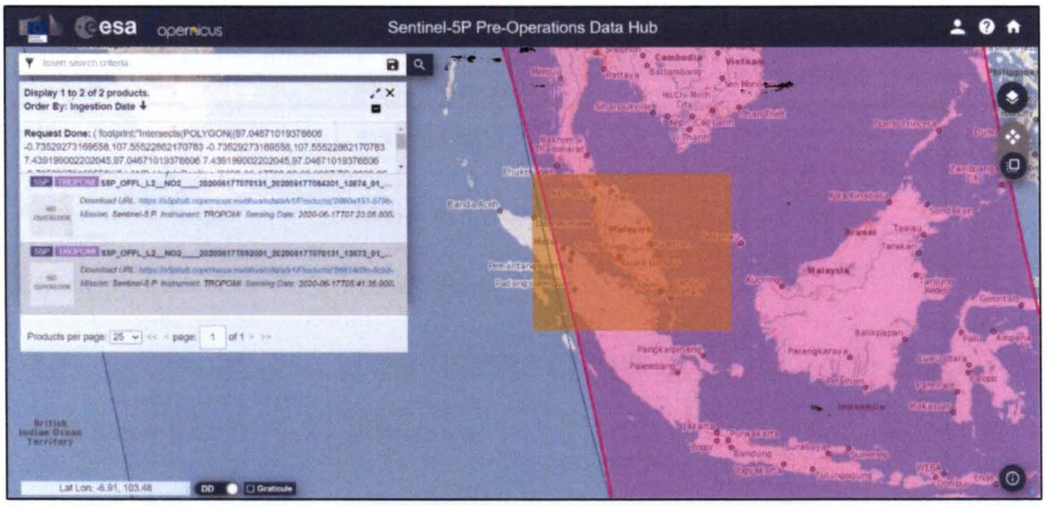


Figure 3.3 The overview of Sentinel-5P Pre-Operation Data Hub browser and data scene selection to be downloaded (https://s5phub.copernicus.eu/dhus/#/home)

Table 3.3 shows the summary information of the dataset downloaded from the Sentinel-5P Pre-Operations Data Hub website. The acquisition date of Sentinel-5P datasets are as identified earlier. The format of the datasets is netCDF file format and the product type for all the downloaded datasets are Level L2. The NO_2 L2 files are extended and can be used for many different purposes, including data assimilation, model validation, comparison with surface remote sensing observations or in-situ profile observations with aircraft, both for the troposphere or stratosphere. Furthermore, the data may be used directly to visualize the day-to-day variations in NO_2. The fields that users will read from the L2 file will depend on their specific application. Table 3.4 shows the list of TROPOMI Sentinel-5P data product provided for Level 2 processing.

Table 3.3
Summary information of downloaded datasets from the Sentinel-5P Pre-Operations Data Hub website

No.	Remarks	Acquisition Date	File Name	Format	Orbit Number (Start)	Product Type
1	Correlation	20-Jun-2018	S5P_RPRO_L2__NO2__20180620T060922		3545	
2	Before MCO	08-Jan-2020	S5P_OFFL_L2__NO2__20200108T052547		11589	
3	MCO	25-Mar-2020	S5P_OFFL_L2__NO2__20200325T063013	NetCDF	12682	L2_NO2
4	EMCO	22-Apr-2020	S5P_OFFL_L2__NO2__20200420T050417		13050	
5	CMCO	20-May-2020	S5P_OFFL_L2__NO2__20200520T054442		13476	
6	RMCO	17-Jun-2020	S5P_OFFL_L2__NO2__20200617T052001		13873	

Table 3.4
List of TROPOMI Sentinel-5P Level 2 data product

Product	Main Parameter
UV Aerosol Index	Aerosol Index
Aerosol Layer Height	Mid-level Pressure
Carbon Monoxide (CO)	Total Column
Cloud	Fraction, albedo, top pressure
Formaldehyde (HCHO)	Total column
Methane (CH_4)	Total column
Nitrogen Dioxide (NO_2)	Total, tropospheric, stratospheric column
Ozone profiles	Total and tropospheric profiles
Sulphur Dioxide (SO_2)	Total column
Ozone (O_3)	Total column
Tropospheric Ozone (O_3)	Tropospheric column
Ultraviolet (UV)	Surface irradiance erythemal dose

3.4.2 Continuous Air Quality Monitoring (CAQM) Data

The Department of Environment (DoE) is responsible in monitoring the country's ambient air quality since 1975 through a network of 51 Continuous Air Quality Monitoring (CAQM) stations. These monitoring stations are located strategically within residential, traffic and industrial area to detect any significant changes in the air quality which may be harmful to human health and the environment. Among the CAQM stations, they are divided into five (5) categories; industrial, residential, traffic, background and PM_{10} stations. There is a total of 36 CAQM stations in peninsular Malaysia, and another 15 stations are in east Malaysia. However, only 33 CAQM stations is utilized within the selected study area; seven (7) CAQM stations at Selangor, and three (3) CAQM stations at Johor (refer Figure 3.2). Table 3.5 shows the details of parameter of each CAQM stations requested in Peninsular Malaysia. The parameter consists of station ID, the category of the stations, the location and the station's coordinate.

Table 3.5
Parameter of each CAQM stations available in Peninsular Malaysia

No.	Station ID	Location	Station Category	Longitude	Latitude
1	CA01R	Kangar, Perlis	Sub Urban	100.211	6.430
2	CA02K	Langkawi, Kedah	Sub Urban	99.858	6.332
3	CA03K	Alor Setar, Kedah	Sub Urban	100.347	6.137
4	CA04K	Sungai Petani, Kedah	Sub Urban	100.468	5.630
5	CA06P	Seberang Jaya, Pulau Pinang	Urban	100.404	5.398
6	CA07P	Seberang Perai, Pulau Pinang	Sub Urban	100.443	5.329
7	CA08P	Minden, Pulau Pinang	Urban	100.308	5.356
8	CA10A	Taiping, Perak	Sub Urban	100.679	4.899
9	CA11A	Tasek Ipoh, Perak	Urban	101.117	4.629
10	CA12A	Pegoh Ipoh, Perak	Sub Urban	101.080	4.553
11	CA14A	Tanjung Malim, Perak	Sub Urban	101.524	3.688
12	CA15W	Batu Muda, WP Kuala Lumpur	Sub Urban	101.682	3.212
13	CA16W	Cheras, WP Kuala Lumpur	Urban	101.718	3.106
14	CA17W	Putrajaya, WP Putrajaya	Sub Urban	101.690	2.915
15	CA19B	Petaling Jaya, Selangor	Sub Urban	101.608	3.133
16	CA20B	Shah Alam, Selangor	Urban	101.556	3.105
17	CA21B	Klang, Selangor	Sub Urban	101.413	3.015
18	CA22B	Banting, Selangor	Sub Urban	101.623	2.817
19	CA23N	Nilai, Negeri Sembilan	Sub Urban	101.811	2.822
20	CA24N	Seremban, Negeri Sembilan	Urban	101.968	2.723

21	CA25N	Port Dickson, Negeri Sembilan	Sub Urban	101.867	2.441
22	CA27M	Bukit Rambai, Melaka	Sub Urban	102.173	2.259
23	CA33J	Larkin, Johor	Urban	103.736	1.495
24	CA34J	Pasir Gudang, Johor	Urban	103.893	1.470
25	CA36J	Kota Tinggi, Johor	Sub Urban	104.225	1.564
26	CA39C	Jerantut, Pahang	Sub Urban	102.367	3.948
27	CA40C	Indera Mahkota Kuantan, Pahang	Sub Urban	103.297	3.819
28	CA41C	Balok Baru Kuantan, Pahang	Industry	103.382	3.961
29	CA42T	Kemaman, Terengganu	Industry	103.426	4.262
30	CA43T	Paka, Terengganu	Industry	103.435	4.598
31	CA44T	Kuala Terengganu, Terengganu	Urban	103.120	5.308
32	CA46D	Tanah Merah, Kelantan	Sub Urban	102.135	5.811
33	CA47D	Kota Bharu, Kelantan	Sub Urban	102.249	6.147

(Source: Department of Environment, 2018)

The Department of Environment also provide the Nitrogen Dioxide (NO_2) hourly reading. Table 3.6 shows the example of cross tab by station ID for parameter NO_2. The NO_2 concentration provided is recorded hourly for 24-hours. Furthermore, the unit of the concentration is in parts per million (ppm). The NA remarks the non-availability of data, either for the data of the CAQM station was not requested or because of an error in obtaining the concentration reading. The rest of the cross tab reading of NO_2 is provided in Appendix 1.

Table 3.6

Cross tab by station ID for parameter Nitrogen Dioxide (NO_2) (ppm) (Hourly)

DATE/TIME	CA01R	CA02K	CA03K	CA04K	CA06P	CA07P	CA08P	CA10A	CA11A	CA12A	CA13A	CA14A	CA15W	CA16W	CA17W
20/6/2018 0:00	0.0093	0.0017	0.0133	0.0214	0.0234	0.0279	0.0229	0.0113	NA	0.0137	NA	0.0117	0.0312	0.0334	0.0133
20/6/2018 1:00	0.0038	0.0012	0.0092	0.0172	0.0245	0.0235	0.0141	0.0098	NA	0.0146	NA	0.0084	0.0298	0.031	0.0137
20/6/2018 2:00	0.0013	0.0031	0.0005	0.0144	0.0268	0.018	0.0098	0.0077	NA	0.0112	NA	0.0089	0.0249	0.0303	0.014
20/6/2018 3:00	0.0011	0.0017	0.0017	0.0119	0.0162	0.0028	0.0021	0.0076	0.0107	0.0098	NA	0.0075	0.0193	0.0245	0.0135
20/6/2018 4:00	0.0017	0.0012	0.0006	0.0008	0.0104	0.004	0.0023	0.0046	0.0133	0.0111	NA	0.0053	0.0184	0.0212	0.0122
20/6/2018 5:00	0.0009	0.0007	0.0026	0.0021	0.007	0.0032	0.002	0.0034	0.0027	0.0099	NA	0.0057	0.017	0.0182	0.0118
20/6/2018 6:00	0.0014	0.0009	0.0026	0.0034	0.0136	0.0038	0.0017	0.005	0.0025	0.0097	NA	0.0062	0.0164	0.0205	0.0061
20/6/2018 7:00	0.0024	0.002	0.0022	0.0047	0.0174	0.006	0.0058	0.006	0.0043	0.0105	NA	0.0045	0.018	0.0135	0.0039
20/6/2018 8:00	NA	NA	NA	NA	NA	NA	0.0097	0.0088	0.0057	0.0107	NA	NA	NA	NA	NA
20/6/2018 9:00	0.0025	0.0039	0.0045	0.0086	0.0116	0.0134	0.0106	0.0076	NA	0.0134	NA	0.0068	0.0176	0.0129	0.0091
20/6/2018 10:00	0.0018	0.0032	0.0046	0.0069	0.0129	0.0128	NA	0.0045	0.0045	NA	NA	0.0051	0.0182	0.0106	0.0075
20/6/2018 11:00	0.0018	0.0007	0.0035	0.0055	0.0133	0.0058	0.0153	NA	0.0033	0.0181	NA	0.0096	0.0154	0.0078	0.0058
20/6/2018 12:00	0.0017	0.0006	0.0036	0.0062	0.0152	0.004	0.0058	0.0048	0.0033	0.0097	NA	0.0066	0.0088	0.0064	0.004
20/6/2018 13:00	0.0018	0.0014	0.0045	NA	0.0165	0.0021	0.0045	0.0043	0.006	0.0039	NA	0.0039	0.0086	0.0079	0.004
20/6/2018 14:00	0.0016	0.0041	0.003	0.0032	0.0177	NA	0.0038	0.0076	0.007	0.0032	NA	0.0023	0.006	0.0061	0.003
20/6/2018 15:00	0.001	0.0043	0.0026	0.0038	0.0156	0.0053	0.0059	0.0056	0.0068	0.0026	NA	0.0023	0.0095	0.0063	0.0035
20/6/2018 16:00	0.001	0.0028	0.0026	0.0024	0.0066	0.0044	0.0041	0.0077	0.0065	0.0022	NA	0.0023	0.0151	0.0058	0.0041

(Source: Department of Environment, 2018)

3.5 Data Pre-Processing

The pre-processing stage required to be done to make all the data used in a standardized format with attaching geographic coordinates and eliminate the distortion of image. These pre-processing were done as soon as the dataset is imported into SNAP software. Explanation of the pre-processing techniques as described follows.

3.5.1 Attach Pixel Geo-Coding

Georeferencing or geocoding refers to a process of assigning a spatial reference such as digital geographic coordinates (i.e. latitude and longitude pairs) to a data in order to tie that data to assigned locations (Montana, 2008). Pixel geocoding can be used if the data has two bands filled with accurate latitude and longitude values for each pixel. Attaching pixel geo-coding must be done in pre-processing stage before anything else. The latitude and longitude band had been included along with the downloaded datasets of TROPOMI Sentinel-5P. Latitude and longitude bands are what keeps the latitude and longitude values for each pixel, respectively. Attach Pixel Geo-Coding tools provided in SNAP software is used. The output for this process is saved in NetCDF4-CF file.

3.5.2 Reprojection of Datum to WGS84

Projection is the most crucial element that should be taken into consideration during pre-processing stage. All the dataset needs to be projected to WGS84 projections in order to preserve the same area in this study. Reprojection of datum is the mathematical process of flattening out the Earth onto a flat piece of paper or computer screen. The purpose of reprojection is to flatten the image and apply WGS84 datum onto it. Reprojection tools provided in the SNAP software does not involve any mathematical algorithm. The output data is ready to be exported into ArcGIS software for further processing.

3.6 Data Processing

The processing stage is done in order to manipulate the pre-processing remote sensing image before data analysis can be done. This stage involved extraction of raster image and conversion unit of datasets. All processing occurs in ArcGIS software using the Spatial Analyst tools provided. Explanation of the processing techniques as described as follows.

3.6.1 Extract by Study Area's Boundary

The pre-processed Sentinel-5P data is then imported into the ArcGIS software. There is a total of 71 data contained in the NetCDF file of the processed satellite image as shown in the folder as in Figure 3.4. Among all the data provided, Nitrogen Dioxide total column data product is utilized for this research.

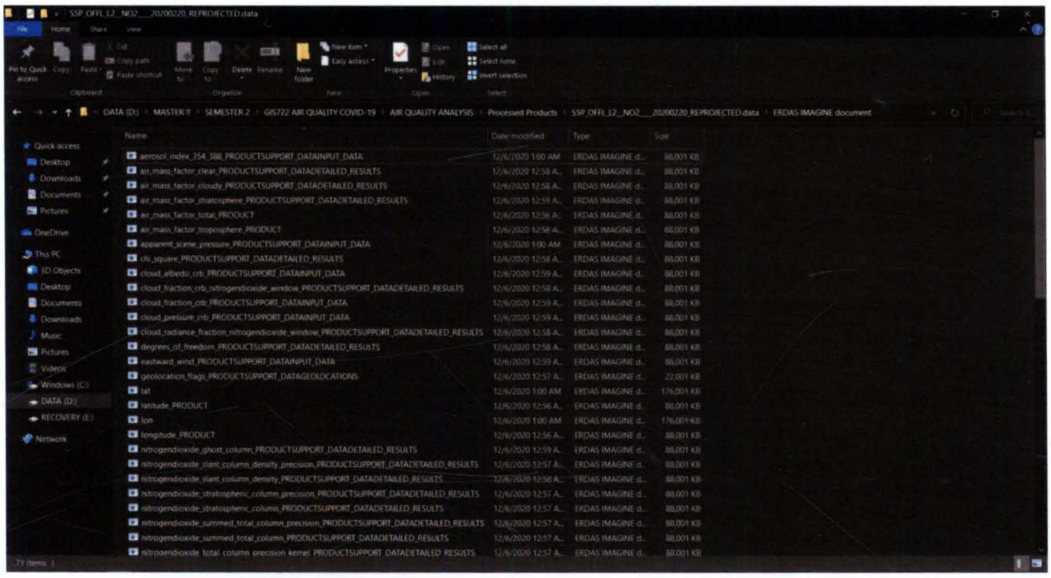


Figure 3.4 The list of data contained in a NetCDF file after pre-processing stage

Before the re-projected Sentinel-5P data is further processed, the image is extracted according to the study area's boundary. For this research, the shapefile of the study area is obtained through ArcGIS Online database. Extract by Mask toolset is used to extract the satellite image according to the boundary of study area. There will be a total of six (6) main extracted satellite image according to the shapefile of peninsular Malaysia of different dataset. Then, the images will be further extracted according to Selangor and Johor region.

3.6.2 Conversion Unit from mol/m^2 to molec/cm^2

The TROPOMI Sentinel-5 Precursor provide the Nitrogen Dioxide total column data product's trace gas concentrations in mol/m^2. In order to comply with the SI unit definitions, Product User Information of TROPOMI Level 2 geophysical product and user documentation provide multiplication factor to enable Sentinel-5P user to make conversion when necessary. Equation 1 shows the conversion unit from mol/m^2 to molec/cm^2. Most previous studies use molec/cm^2 to portray the column concentrations of NO_2 within study area (Kaplan et al., 2019; Shikwambana et al., 2020; Zheng et al., 2019). The document also provides the conversion of mol/m^2 into DU unit as shown in Equation 2.

$$mol/m^2 \rightarrow molec/cm^2 = 6.02214 \times 10^{19} \quad (1)$$

$$mol/m^2 \rightarrow DU = 2241.15 \quad (2)$$

So, Raster Calculator tools is used in conversion unit of pixel in ArcGIS software. Each of the pixel is multiplied according to the Equation 1 to convert the pixel into molec/cm^2 unit. Then, each of the converted pixel is converted to quadrillion (billiard) unit using the same tool, Raster Calculator. The end result shows that the NO_2 column concentration unit in 10^{15} molec/cm^2.

3.7 Data Analysis

Data analysis for this research consist of generate all six (6) datasets into Nitrogen Dioxide (NO_2) column concentration maps, validate the Nitrogen Dioxide (NO_2) column concentration extracted from Sentinel-5P, compare the produced concentration according to the identified phases, and identify the mean of Nitrogen Dioxide (NO_2) column concentration on land use types.

3.7.1 Generate Nitrogen Dioxide (NO_2) Column Concentration Maps

Reclassification techniques is utilized in order to generate the NO_2 column concentration maps. Since the concentration level of NO_2 in Malaysia is identified in low level, the reclassification technique does not follow any air pollution index, either in Malaysia or internationally. Reclassify tool in ArcGIS is used to perform this method. The NO_2 column concentration is divided into eight (8) classes according to the overall minimum and maximum of all processed images. Table 3.7 shows the range of NO_2 column concentration for each class.

Table 3.7
TROPOMI NO_2 column concentration classification

Class ID	NO_2 Range (10^{15} molec/cm^2)
1	0.01 - 2.00
2	2.01 - 3.00
3	3.01 - 4.00
4	4.01 - 5.00
5	5.01 - 6.00
6	6.01 - 7.00
7	7.01 - 8.00
8	> 8.00

3.7.2 Validate the Nitrogen Dioxide (NO_2) Column Concentration

In statistics, correlation coefficient is normally used as a measure to determine whether the two or more variables are related to each other. The medium also used to determine the strength of relationship among the tested variables. The linear correlation denoted by r is computed from the sample data and measure the strength and direction of linear relationship between two quantitative variables.

The range of the correlation coefficient is from -1 to $+1$. Determination of strong linear relationship between the variables is when the value of r approach +1, and vice versa. Equation 3 shows the formula used to calculate the correlation coefficient manually. In this research, the X-value represented by the ground CAQM NO_2 concentration. Meanwhile, Y-value represented by the TROPOMI NO_2 column concentration.

$$R^2 = (\frac{S_{XY}}{\sqrt{SS_{XX} \times SS_{YY}}}) \tag{3}$$

Where;

$S_{XY} = \sum XY - \frac{(\sum X)(\sum Y)}{n}$

$SS_{XX} = \sum X^2 - \frac{(\sum X)^2}{n}$

$SS_{YY} = \sum Y^2 - \frac{(Y)^2}{n}$

To obtain the value of TROPOMI NO_2 column concentration, the Extract by Multi-Point toolset is used in ArcGIS software to extract the concentration value according to the location of CAQM stations provided using the generated NO_2 column concentration maps on 20-June-2018. The attributes are then transferred into Microsoft Excel to generate the correlation of the data.

3.7.3 Compare the Nitrogen Dioxide (NO_2) Column Concentration between Identified Phases

In order to identify the changes of NO_2 column concentration between the satellite images of different phases, the generated map of NO_2 column concentration for five (5) phases of MCO is arranged in a single map interface. To make it more accurately compared, the area of each class of NO_2 column concentration is obtained in ArcGIS software. The spatial resolution of Sentinel-5P is up to 5.5 km × 3.5 km. Therefore, the pixel count for each NO_2 column concentration class is multiplied according to the resolution of the pixel in Microsoft Excel software. With the obtained area, the percentage for each class is generated.

3.7.4 Identify the mean Nitrogen Dioxide (NO_2) Column Concentration on Land Use Types

Previous studies had shown that the land use type also influence the emission rate of NO_2 (Abdullah et al., 2012; Azmi et al., 2010; Kaplan et al., 2019; Mohd Talib

Latif et al., 2014; Ling et al., 2010). Therefore, using the category of CAQM stations provided by the Department of Environment (DoE), a descriptive statistic method is implied for the value of NO_2 column concentration which is extracted according to the category of CAQM stations to obtain the mean, standard deviation, minimum and maximum value of NO_2 column concentration. The category of CAQM stations determined the location of the station established; whether it is established in rural, industrial, urban or sub-urban area.

3.8 Chapter Summary

This chapter explains the procedure, stages and methodology involved including the selection of study area, identification of datasets, data collection, and data pre-processing and processing. The study area is located in peninsular Malaysia where it is then narrowed down to Selangor and Johor state when the two area being indicated as the area with heavy air pollution. The identification of dataset highlights the phase of Malaysia's MCO resulting in six (6) different dates. Remote sensing data of Sentinel-5P were acquired from the ESA website. Sentinel-5P undergone pre-processing in SNAP software and continue processing in ArcGIS software. The output of the extracted NO_2 column concentration is analysed and evaluated accordingly.

CHAPTER FOUR
RESULTS AND DISCUSSION

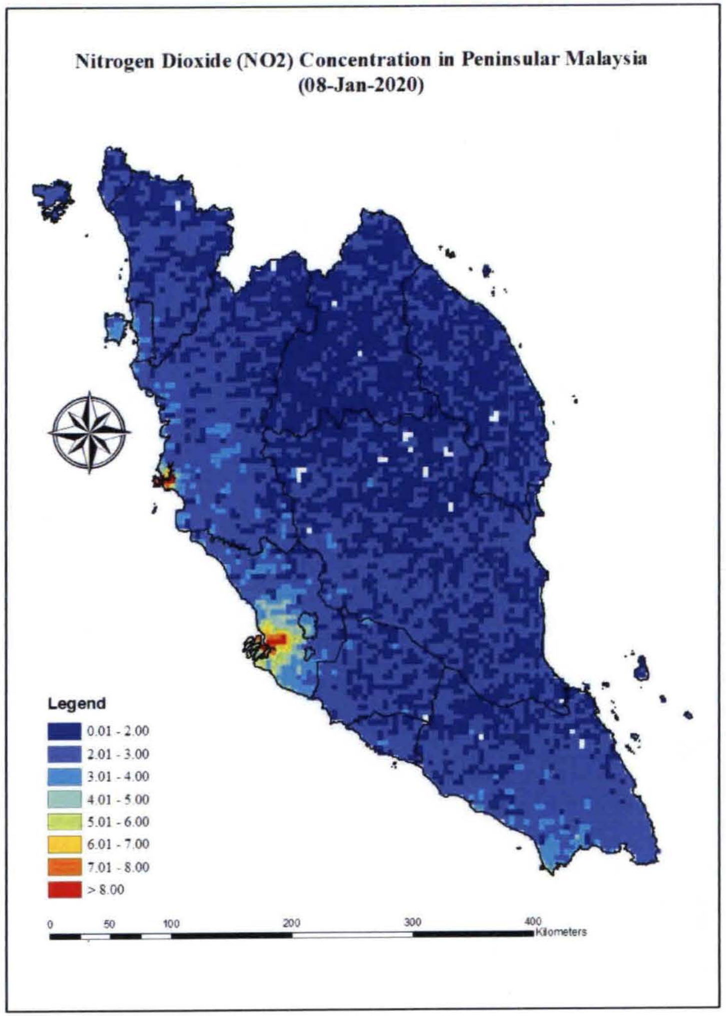
4.1 Introduction

This chapter explains in detail of the results obtained for this research study. In this chapter, there are four (4) important tasks that are carried out to meet the objectives of this research study, which are generate NO_2 column concentration map for six (6) datasets, correlation analysis between ground-based data and remote sensing data, comparison of NO_2 concentration, and analyse the relationship between land use types and NO_2 concentrations.

4.2 NO_2 Column Concentration Maps

Figure 4.1, 4.2 and 4.3 presents the NO_2 column concentration in Peninsular Malaysia extracted from TROPOMI Sentinel-5P for five (5) different dates. The extracted NO_2 column concentration is classified into eight (8) classes. The idea is to see the difference between concentrations and analyse which region is highly concentrated with NO_2. The location of CAQM stations are also included in the map to locate the number of CAQM stations available in each states of peninsular Malaysia. The purpose of this map production is to compare the concentration of NO_2 before, during and after Malaysia's Movement Control Order. The comparison of NO_2 concentration will be further discussed in the next section.

Meanwhile, Figure 4.4 presents the NO_2 column concentration in Peninsular Malaysia extracted from TROPOMI Sentinel-5P which is retrieved on 20th of June 2018. The same method is implied onto this map production as the previous ones. The only difference between these map productions are their purpose, where Figure 4.2 map is used to verify the correlation of NO_2 column concentration and surface monitoring concentration. The correlation between the data will be further discussed in the next section.



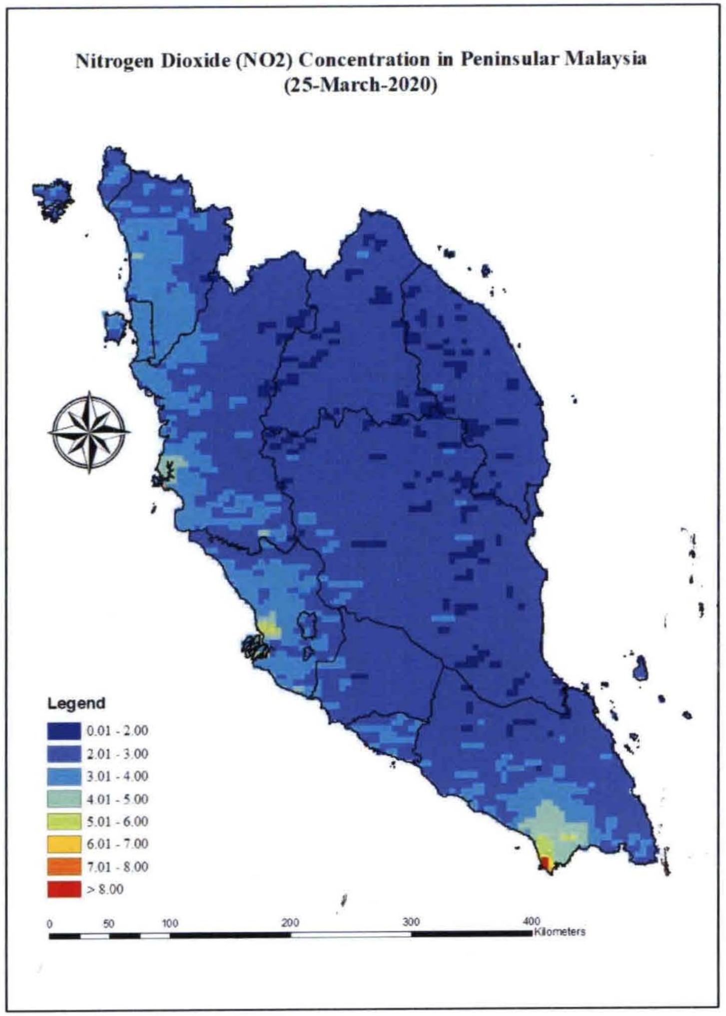
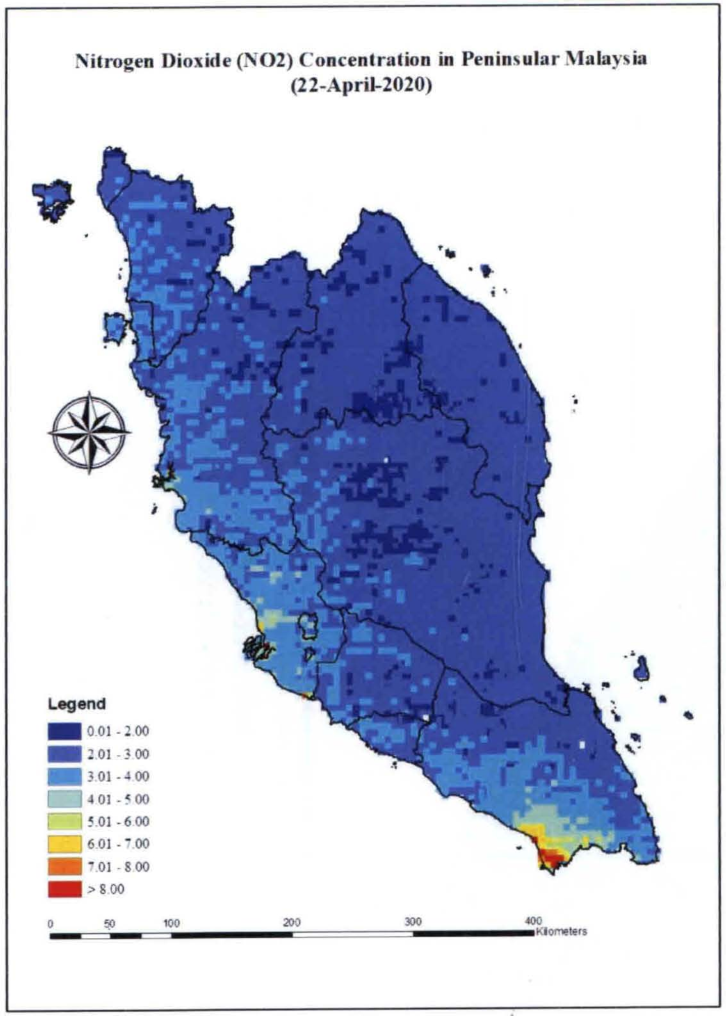


Figure 4.1 The NO_2 column concentration in Peninsular Malaysia extracted from TROPOMI Sentinel-5P on 08-June-2020 (left) and on 25-March-2020 (right)



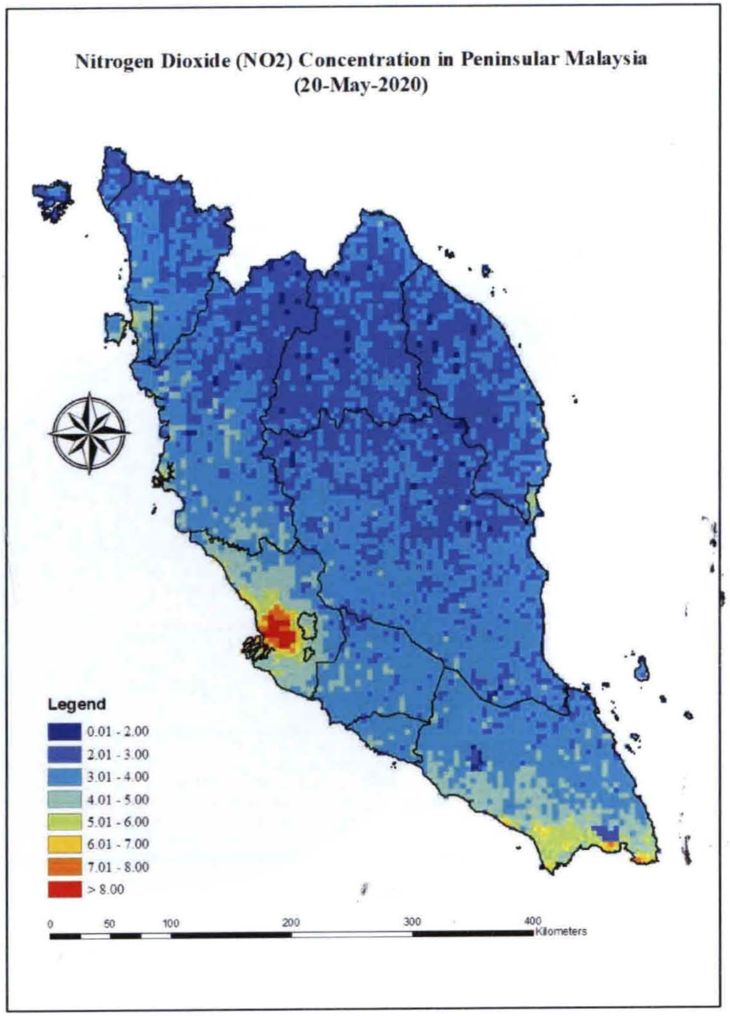


Figure 4.2 The NO_2 column concentration in Peninsular Malaysia extracted from TROPOMI Sentinel-5P on 22-April-2020 (left) and on 20-May-2020 (right)

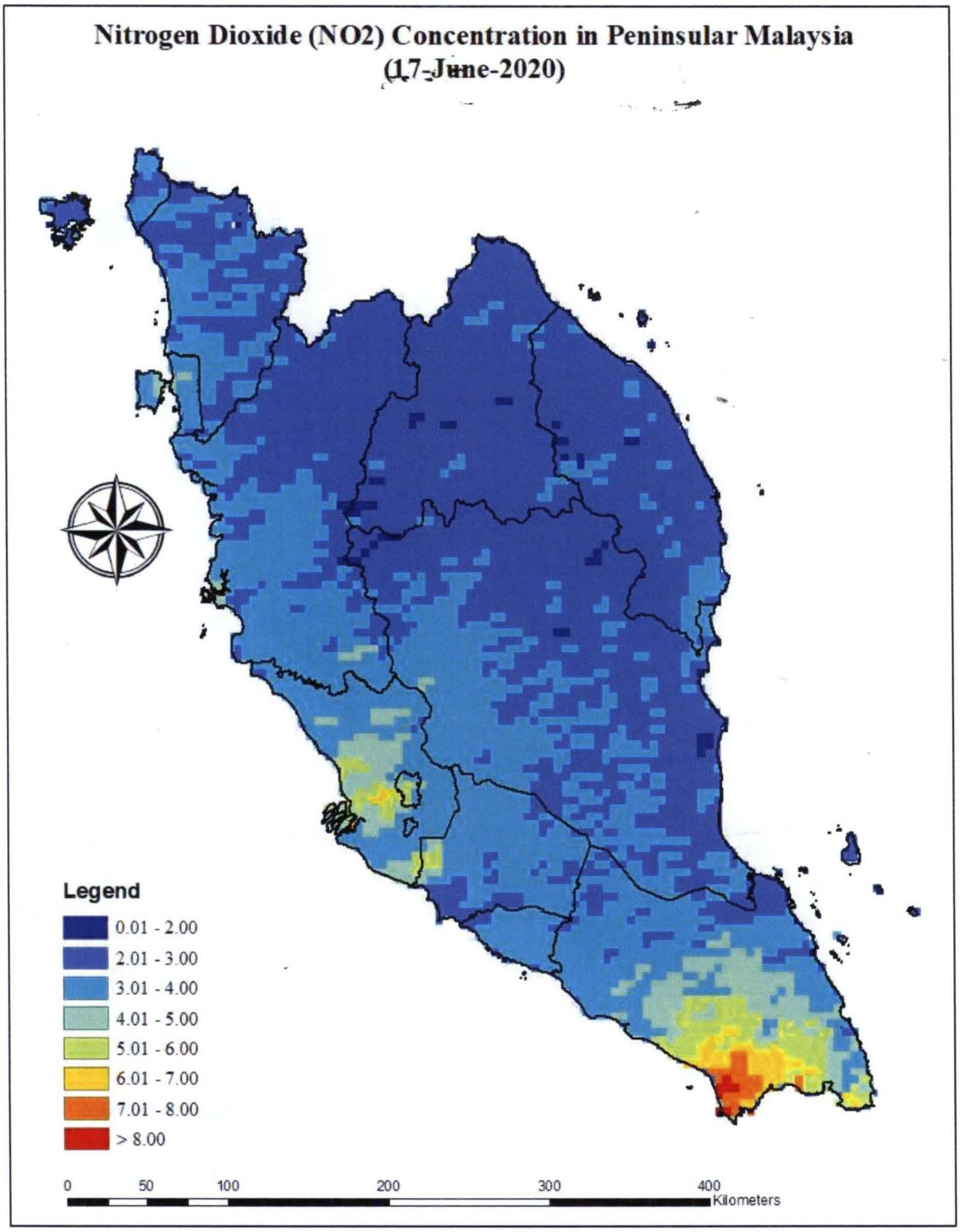


Figure 4.3 The NO_2 column concentration in Peninsular Malaysia extracted from TROPOMI Sentinel-5P on 17-June-2020

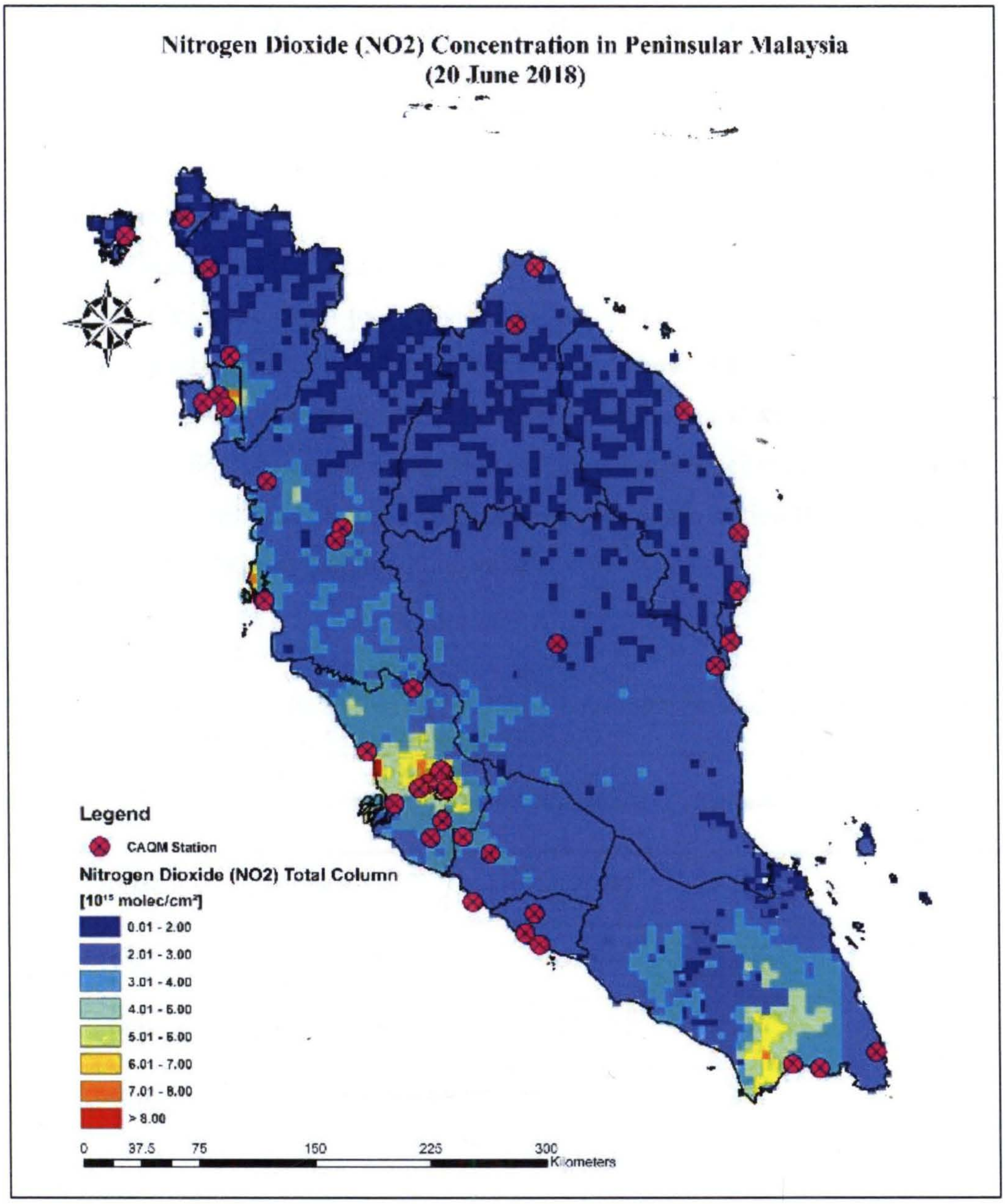


Figure 4.4 The NO_2 column concentration in Peninsular Malaysia extracted from TROPOMI Sentinel-5P on 20-June-2018

4.3 The Correlation between Ground CAQM NO_2 Concentration and the TROPOMI NO_2 Column Concentration

The correlation analysis is made between the retrieved value of NO_2 Column Concentration of Sentinel-5P product and the readings of CAQM Hourly Report obtained from the Department of Environment.

4.3.1 The TROPOMI NO_2 Column Concentration at CAQM Stations

As per mentioned, Figure 4.2 presents the map of NO_2 column concentration in Peninsular Malaysia which is retrieved on 20th of June 2018. In order to perform correlation analysis, the value of NO_2 column concentration of the generated map are extracted according to the location of CAQM station available within the study area using Extract by Multi-Point tool provided in ArcGIS software. The extracted values are then being tabulated for further analysis. Table 4.1 shows the list of values extracted from the NO_2 column concentration at each CAQM stations produced from TROPOMI Sentinel-5P. Aside from the extracted value of NO_2 column concentration, the table also provide detailed attributes of each CAQM station such as the station ID, the location of the station and its latitude and longitude value.

Table 4.1
The value of extracted TROPOMI NO_2 column concentration at each CAQM stations available within peninsular Malaysia on 20-June-2018

ID	Station ID	Location	Longitude	Latitude	NO_2 Column Concentration (10^{15} molec/cm^2)
1	CA01R	Kangar, Perlis	100.211	6.430	3.2047
2	CA02K	Langkawi, Kedah	99.858	6.332	2.9157
3	CA03K	Alor-Setar, Kedah	100.347	6.137	2.7906
4	CA04K	Sungai Petani, Kedah	100.468	5.630	3.3328
5	CA06P	Seberang Jaya, Pulau Pinang	100.404	5.398	5.0335
6	CA07P	Seberang Perai, Pulau Pinang	100.443	5.329	4.3907
7	CA08P	Minden, Pulau Pinang	100.308	5.356	3.9112
8	CA10A	Taiping, PERAK	100.679	4.899	4.0309
9	CA11A	Tasek Ipoh, Perak	101.117	4.629	4.6373
10	CA12A	Pegoh Ipoh, Perak	101.080	4.553	3.6651
11	CA14A	Tanjung Malim, Perak	101.524	3.688	4.3552

12	CA15W	Batu Muda, WP Kuala Lumpur	101.682	3.212	7.3928
13	CA16W	Cheras, WP Kuala Lumpur	101.718	3.106	7.1436
14	CA17W	Putrajaya, WP Putrajaya	101.690	2.915	5.2784
15	CA19B	Petaling Jaya, Selangor	101.608	3.133	7.2652
16	CA20B	Shah Alam, Selangor	101.556	3.105	6.7799
17	CA21B	Klang, Selangor	101.413	3.015	4.6037
18	CA22B	Banting, Selangor	101.623	2.817	4.3818
19	CA23N	Nilai, Negeri Sembilan	101.811	2.822	4.0087
20	CA24N	Seremban, Negeri Sembilan	101.968	2.723	4.0126
21	CA25N	Port Dickson, Negeri Sembilan	101.867	2.441	3.7058
22	CA27M	Bukit Rambai, Melaka	102.173	2.259	3.3490
23	CA33J	Larkin, Johor	103.736	1.495	5.2104
24	CA34J	Pasir Gudang, Johor	103.893	1.470	4.7202
25	CA36J	Kota Tinggi, Johor	104.225	1.564	3.1537
26	CA39C	Jerantut, Pahang	102.367	3.948	3.0907
27	CA40C	Indera Mahkota Kuantan, Pahang	103.297	3.819	3.0497
28	CA41C	Balok Baru Kuantan, Pahang	103.382	3.961	2.9767
29	CA42T	Kemaman, Terengganu	103.426	4.262	3.1833
30	CA43T	Paka, Terengganu	103.435	4.598	3.1923
31	CA44T	Kuala Terengganu, Terengganu	103.120	5.308	3.3321
32	CA46D	Tanah Merah, Kelantan	102.135	5.811	3.2935
33	CA47D	Kota Bharu, Kelantan	102.249	6.147	2.9077

4.3.2 Correlation Analysis

A series of study conducted have shown that the NO_2 column concentration extracted from remote sensing interpretation has a strong correlation with ground-based data, and the correlation coefficients are mostly above 0.7, which can be deduced as well reflects the characteristic of atmospheric NO_2 concentration (Bechle et al., 2013; Kramer et al., 2008; Zheng et al., 2019). The CAQM Hourly Report acquired from the Department of Environment Malaysia was used as the data source of NO_2 surface monitoring concentration. The hourly report provides hourly averages of NO_2 concentration at CAQM stations located within Peninsular Malaysia. In addition, prior to the dataset of CAQM Hourly Report acquired, data on year 2018 is selected because of the availability of data at the Department of Environment for public request. The results of correlation coefficient analysis between ground CAQM NO_2 concentration and TROPOMI NO_2 column concentration are shown in Figure 4.3. The results show that the NO_2 Column Concentration retrieved by TROPOMI is highly correlated with the ground CAQM NO_2 concentration ($R^2 = 0.692$).

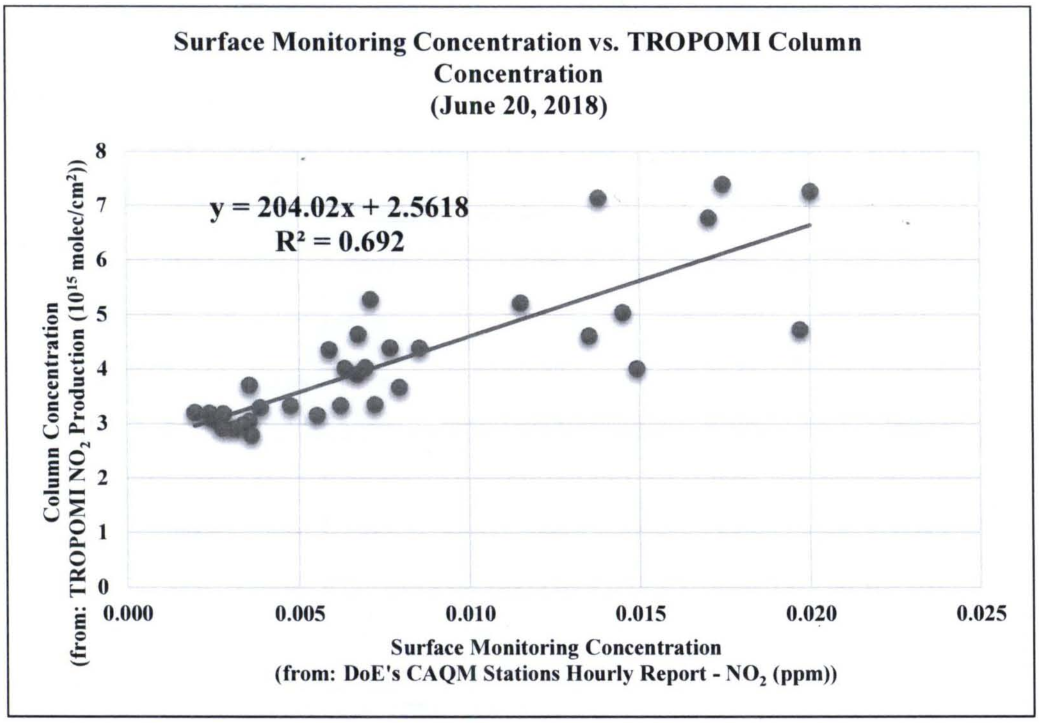


Figure 4.5 Linear regression between surface NO_2 monitoring concentration and TROPOMI NO_2 column concentration

4.4 Comparison of NO_2 Concentration Maps Extracted from TROPOMI Sentinel-5P

The map of extracted Nitrogen Dioxide (NO_2) column concentration retrieved from TROPOMI Sentinel-5P in peninsular Malaysia is compared according to the five (5) different dates which represent the phase of Malaysia's MCO, accordingly. The analysis is then narrowed down to the area with high concentration of NO_2 which falls onto Selangor and Johor state.

4.4.1 Nitrogen Dioxide (NO_2) Column Concentration in Peninsular Malaysia

Figure 4.6 displays the NO_2 column concentration in peninsular Malaysia extracted from TROPOMI Sentinel-5P before, during and after Malaysia's MCO. The most significant feature of the NO_2 column concentration in peninsular Malaysia is that it is higher in concentration in the south west region and lower in the east. Most of the NO_2 column concentration that are less than 3×10^{15} molec/cm^2 are concentrated at the at the east region of peninsular Malaysia, while the area with column concentration more than 4×10^{15} molec/cm^2 are mainly concentrated in Selangor and Johor state

Table 4.2
Summary of NO2 column concentration in Peninsular Malaysia before, during and after Malaysia's MCO

NO_2 Range (10^{15} molec/cm^2)	Before MCO		MCO		EMCO		CMCO		RMCO	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
0.01 - 2.00	60098.5	41.46	6006.0	5.41	2656.5	3.24	1232.0	0.99	866.3	0.84
2.01 - 3.00	76807.5	52.99	84796.3	76.45	59540.3	72.69	45083.5	36.35	53226.3	51.53
3.01 - 4.00	5698.0	3.93	17806.3	16.05	17305.8	21.13	61715.5	49.76	39424.0	38.17
4.01 - 5.00	1039.5	0.72	1809.5	1.63	1655.5	2.02	11492.3	9.27	5178.3	5.01
5.01 - 6.00	635.3	0.44	385.0	0.35	250.3	0.31	3022.3	2.44	2926.0	2.83
6.01 - 7.00	288.8	0.20	77.0	0.07	308.0	0.38	750.8	0.61	1020.3	0.99
7.01 - 8.00	173.3	0.12	0.0	0.00	77.0	0.09	385.0	0.31	519.8	0.50
> 8.00	211.8	0.15	38.5	0.03	115.5	0.14	346.5	0.28	134.8	0.13

Table 4.2 shows the summary statistic of NO_2 column concentration in peninsular Malaysia before, during and after Malaysia's MCO. From the table, the NO_2 column concentration that is less than 2×10^{15} molec/cm^2 shows that the concentration decreases during the implementation of MCO until after the MCO.

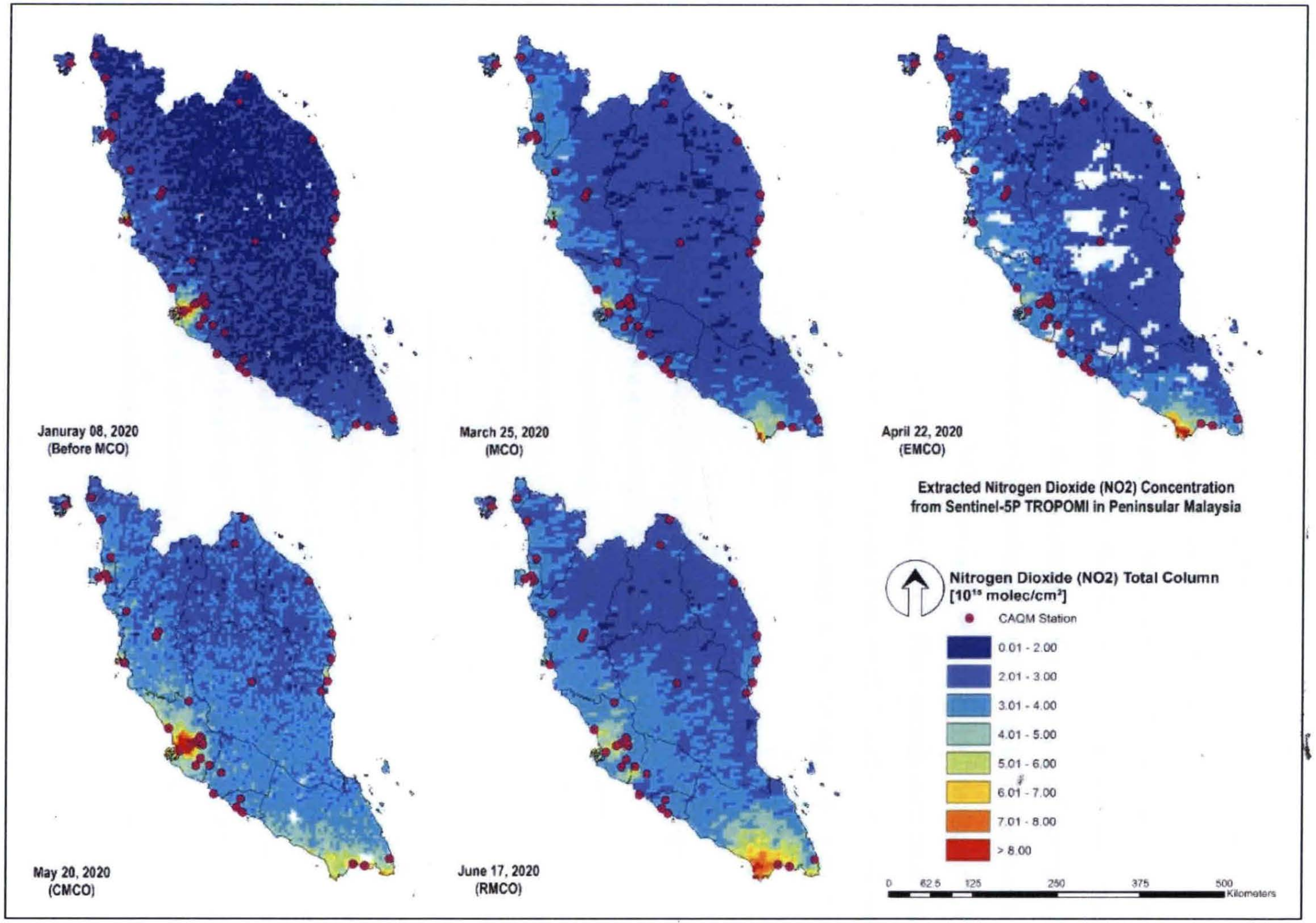


Figure 4.6 The NO_2 column concentration in Peninsular Malaysia extracted from TROPOMI Sentinel-5P before, during and after Malaysia's Movement Control Order

However, the NO_2 column concentration ranged between $2 - 4\times10^{15}$ molec/cm^2 increase during the MCO phase. But the concentration decreases after the MCO phase ended until CMCO. The concentration rises back during the recovery MCO phase. For the NO_2 column concentration that is more than 4×10^{15} molec/cm^2, the pattern of NO_2 distribution are as predicted. During MCO phase, the NO_2 column concentration sharply decrease. Then, the concentration gradually increases after the MCO phase starting from EMCO, CMCO and ended with RMCO. The NO_2 column concentration that is more than 8×10^{15} molec/cm^2 indicate the hotspot area for emission of Nitrogen Dioxide. Before MCO, the concentration only consists of 0.15% from total area which indicate as the normal concentration for NO_2 that is more than 8×10^{15} molec/cm^2. Then, the concentration decreases until 0.3% during MCO. The concentration rises back to the 'normal' percentage of NO_2 that is more than 8×10^{15} molec/cm^2. However, the concentrations exceed the 'normal' percentage level during CMCO to 0.28% and decrease back to 0.13% during RMCO.

The major contribution to the emission of NO_2 into the atmosphere is through the combustion of fossil fuels in stationary sources (heating, power generation) and in motor vehicles (internal combustion) (World Health Organization, 2000). The NO_2 column concentration before MCO being implemented is probably can be considered as a normal distribution of NO_2 concentration. This may be because of the factors to influence the changing rate of NO_2 concentration is absent, which is the combustion of fossil fuels from factory and vehicles. Meanwhile, during MCO, most of the NO_2 concentration less than 3×10^{15} molec/cm^2 dominate the study area. This is due to the restriction of movement that are enforced onto Malaysians as part of the order, which decrease the number of vehicles on streets of peninsular Malaysia. However, the NO_2 concentration that are more than 4×10^{15} molec/cm^2 sharply increases after MCO (during CMCO) as the restriction of movement had been stripped down, which allows the movement of vehicles and motors to roam on the streets, and the continuation of factory operations.

Based from the analysis in peninsular Malaysia, Selangor and Johor is identified as 'hotspot' area in the emission of Nitrogen Dioxide. Therefore, the NO_2 column concentration in the mentioned areas are discussed in the next section.

4.4.2 Nitrogen Dioxide (NO2) Concentration of Selangor, Malaysia

Figure 4.7 presents the NO_2 column concentration in Selangor, Malaysia extracted from TROPOMI Sentinel-5P before, during and after Malaysia's MCO. As mentioned in previous chapter, the study area of Selangor includes Federal Territories of Kuala Lumpur and Putrajaya as the two (2) states located within the boundary of Selangor state. The most significant feature of the NO_2 column concentration in the study area is that it is higher in concentration at the west side of Selangor, specifically at Klang and Petaling Jaya district, and lower at the east side of Selangor.

Table 4.3
Summary of NO_2 column concentration in Selangor before, during and after Malaysia's MCO

NO_2 Range (10^{15} molec/cm²)	Before MCO		MCO		EMCO		CMCO		RMCO	
	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%
0.01 - 2.00	866.3	9.59	0.0	0.00	19.3	0.38	0.0	0.00	0.0	0.00
2.01 - 3.00	4004.0	44.35	2983.8	43.06	1212.8	23.77	288.8	3.72	57.8	0.90
3.01 - 4.00	2156.0	23.88	3619.0	52.22	3291.8	64.53	2098.3	27.05	4081.0	63.47
4.01 - 5.00	943.3	10.45	192.5	2.78	539.0	10.57	3330.3	42.93	1617.0	25.15
5.01 - 6.00	577.5	6.40	134.8	1.94	38.5	0.75	1058.8	13.65	596.8	9.28
6.01 - 7.00	250.3	2.77	0.0	0.00	0.0	0.00	365.8	4.71	77.0	1.20
7.01 - 8.00	115.5	1.28	0.0	0.00	0.0	0.00	288.8	3.72	0.0	0.00
> 8.00	115.5	1.28	0.0	0.00	0.0	0.00	327.3	4.22	0.0	0.00

Table 4.3 shows the summary statistic of NO_2 column concentration in peninsular Malaysia before, during and after Malaysia's MCO. From the table, the NO_2 column concentration that is less than 2×10^{15} molec/cm^2 shows that the concentration decreases during the implementation of MCO. Then, after the MCO, the concentration bounces back to increase by 0.38% during EMCO. The concentration remains 0% after that until RMCO. The NO_2 column concentration ranged between $3 - 4\times10^{15}$ molec/cm^2 increase during the MCO phase until EMCO. But the concentration sharply decreases after the EMCO phase, during CMCO. The concentration rises back during the recovery MCO phase to 63.47%.

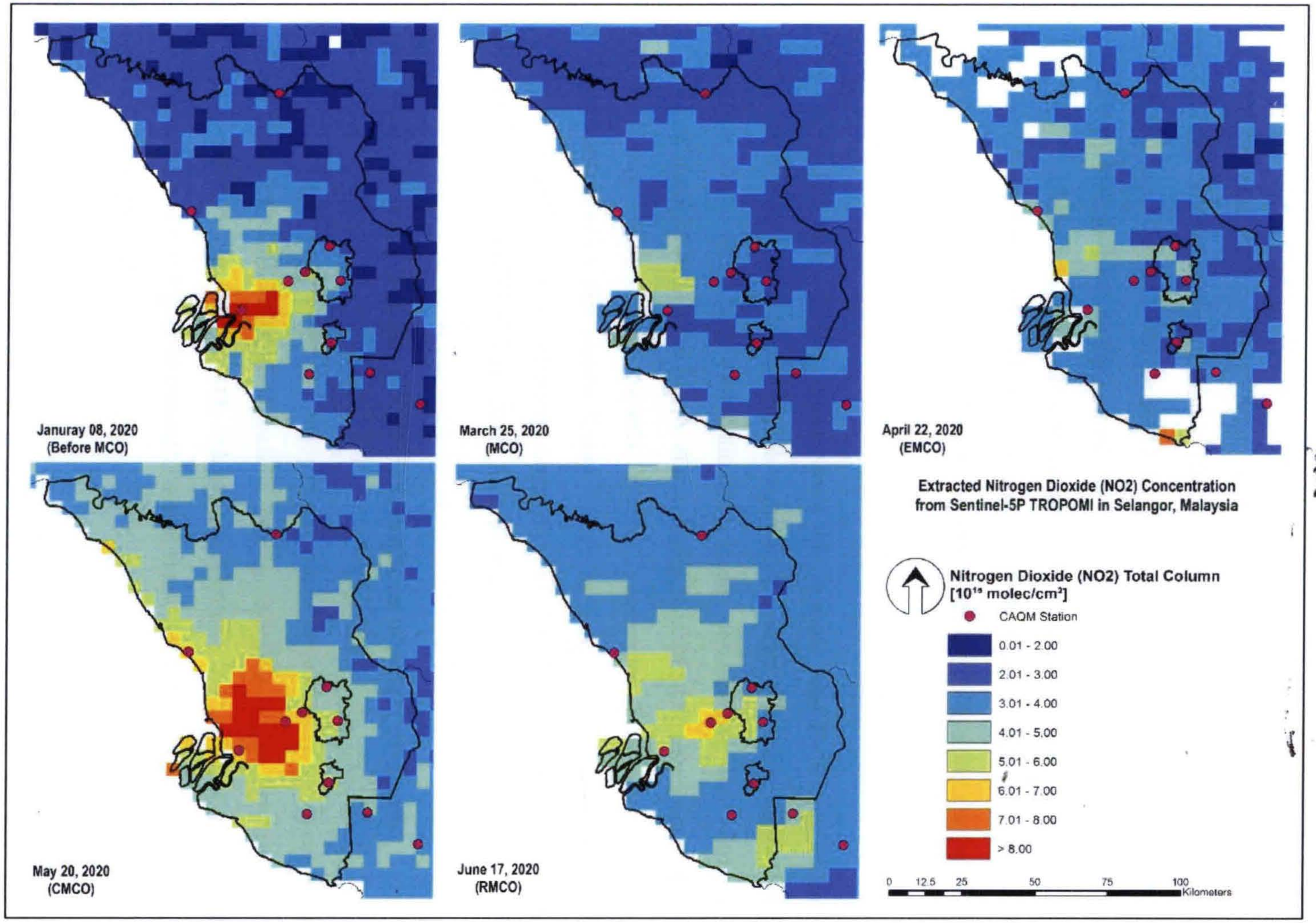


Figure 4.7 The NO2 column concentration in Selangor, Malaysia extracted from TROPOMI Sentinel-5P before, during and after Malaysia's Moevement Control Order

For the NO_2 column concentration that is more than 5×10^{15} molec/cm^2, the pattern of NO_2 distribution are as predicted. During MCO phase, the NO_2 column concentration sharply decrease. Then, the concentration gradually increases after the MCO phase starting from EMCO, CMCO and ended with RMCO. The NO_2 column concentration that is more than 8×10^{15} molec/cm^2 indicate the hotspot area for emission of Nitrogen Dioxide. Before MCO, the concentration only consists of 1.28% from total area which indicate as the normal concentration for NO_2 for concentration more than 8×10^{15} molec/cm^2. Then, the concentration decreases until 0% during MCO even after the MCO, during the EMCO. The concentration sharply rises from 0% to 4.22% of concentration from total study area. However, the concentrations decrease back to 0% during RMCO.

The NO_2 column concentration that is more than 8×10^{15} molec/cm^2 majorly occur within Klang Valley and Petaling Jaya district. The observation before MCO phase shows that Klang Valley district is highly concentrated with Nitrogen Dioxide. Then, during CMCO, the highly concentrated Nitrogen Dioxide spread from the inner of Klang Valley district towards Petaling Jaya region. This observations meets the previous studies that claims Klang Valley as rapid development area emits highly Nitrogen Dioxide concentration (Abdullah et al., 2012; Azmi et al., 2010; Mohd T Latif et al., 2015; Masseran et al., 2016; Mohtar et al., 2018).

4.4.3 Nitrogen Dioxide (NO2) Concentration of Johor, Malaysia

Figure 4.8 shows the NO_2 column concentration in Johor, Malaysia extracted from TROPOMI Sentinel-5P before, during and after Malaysia's MCO. The most significant feature of the NO_2 column concentration can be seen from the displayed figure is that it is higher in concentration at the lower part of Johor state during RMCO, which is after MCO.

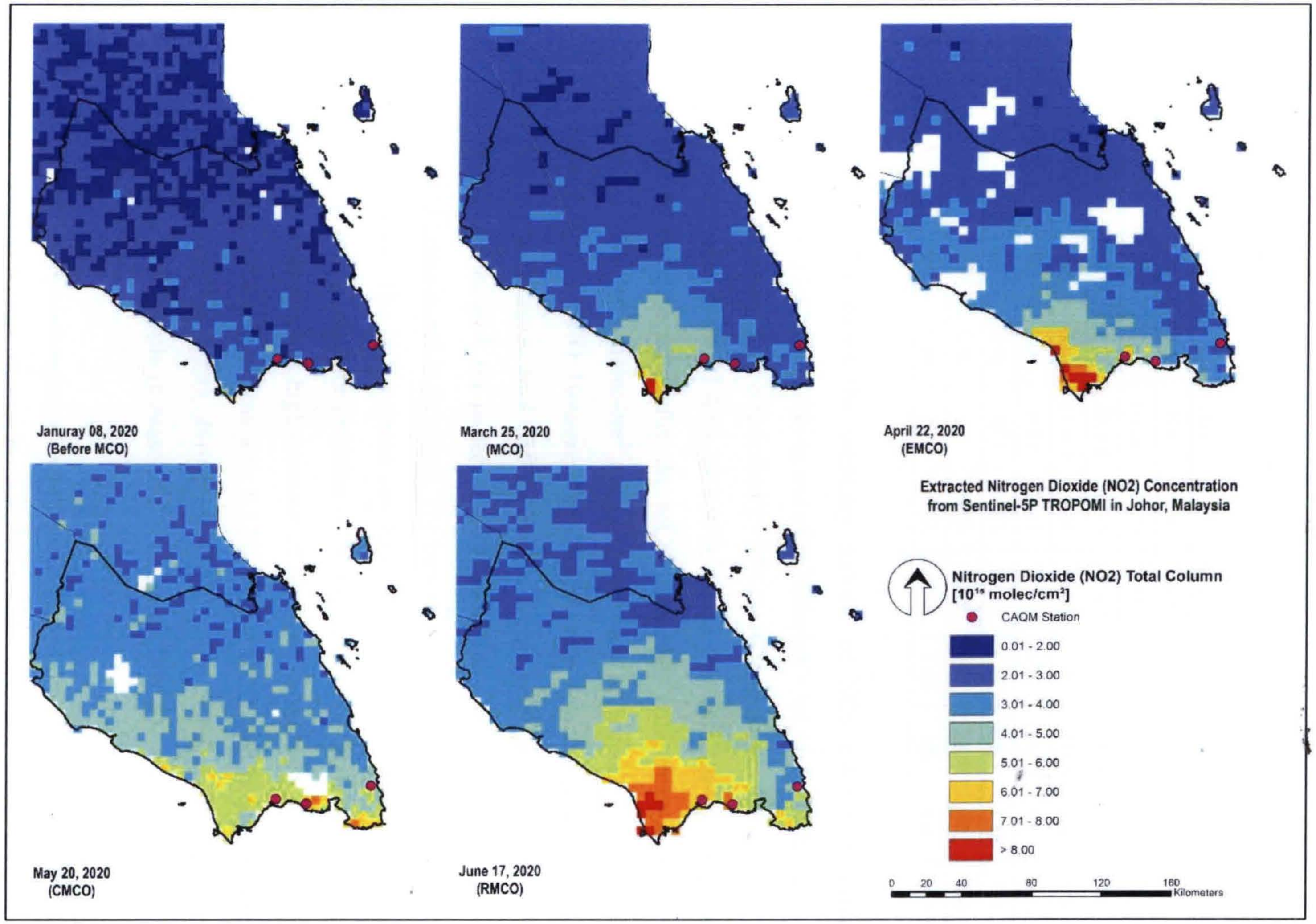


Figure 4.8 The NO_2 column concentration in Johor, Malaysia extracted from TROPOMI Sentinel-5P before, during and after Malaysia's Moevement Control Order

Table 4.4
Summary of NO_2 column concentration in Johor during, before and after Malaysia's MCO

NO_2 Range (10^{15} molec/cm^2)	Before MCO		MCO		EMCO		CMCO		RMCO	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
0.01 - 2.00	4928.0	23.49	308.0	1.96	38.5	0.33	0.0	0.00	0.0	0.00
2.01 - 3.00	14764.8	70.37	11126.5	70.75	5852.0	50.41	1001.0	5.78	1732.5	11.69
3.01 - 4.00	1232.0	5.87	2829.8	17.99	4196.5	36.15	9913.8	57.29	6487.3	43.77
4.01 - 5.00	38.5	0.18	1174.3	7.47	924.0	7.96	4466.0	25.81	2926.0	19.74
5.01 - 6.00	19.3	0.09	231.0	1.47	211.8	1.82	1636.3	9.45	2117.5	14.29
6.01 - 7.00	0.0	0.00	38.5	0.24	269.5	2.32	250.3	1.45	943.3	6.36
7.01 - 8.00	0.0	0.00	0.0	0.00	38.5	0.33	38.5	0.22	500.5	3.38
> 8.00	0.0	0.00	19.3	0.12	77.0	0.66	0.0	0.00	115.5	0.78

Table 4.4 shows the summary statistic of NO_2 column concentration in peninsular Malaysia before, during and after Malaysia's MCO. From the table, the NO_2 column concentration that is less than 2×10^{15} molec/cm^2 shows that the concentration sharply decreases from 23.49% to 1.96% during the implementation of MCO and continue to decrease until after the MCO. The NO_2 column concentration ranged between 2 – 4×10^{15} molec/cm^2 remains the same in percentage even during the implementation of MCO. However, the concentration decreases after the MCO phase and continue to decrease until CMCO. For the NO_2 column concentration that is more than 5×10^{15} molec/cm^2, the pattern of NO_2 distribution are as not as predicted as in peninsular Malaysia and in Selangor. The concentration keeps on increasing even after the MCO phase. The NO_2 column concentration that is more than 8×10^{15} molec/cm^2 indicate the hotspot area for emission of Nitrogen Dioxide. Before MCO, there is no area in Johor that contains high emission of Nitrogen Dioxide concentration. Then, the concentration suddenly increases by 0.12% during MCO, and keeps on increasing by 0.66% even after the MCO, during the EMCO. The concentration vanished during CMCO phase and sharply increase to 0.78% during RMCO.

The highly concentrated Nitrogen Dioxide (more than 8×10^{15} molec/cm^2) is mainly covered Pontian district during MCO is implemented. Then, the concentration spread from Pontian to Johor Bahru during RMCO. A study by Shikwambana et al.,(2020) mentioned wind speed plays an important factors affecting transport and dispersion of aerosol and gases.

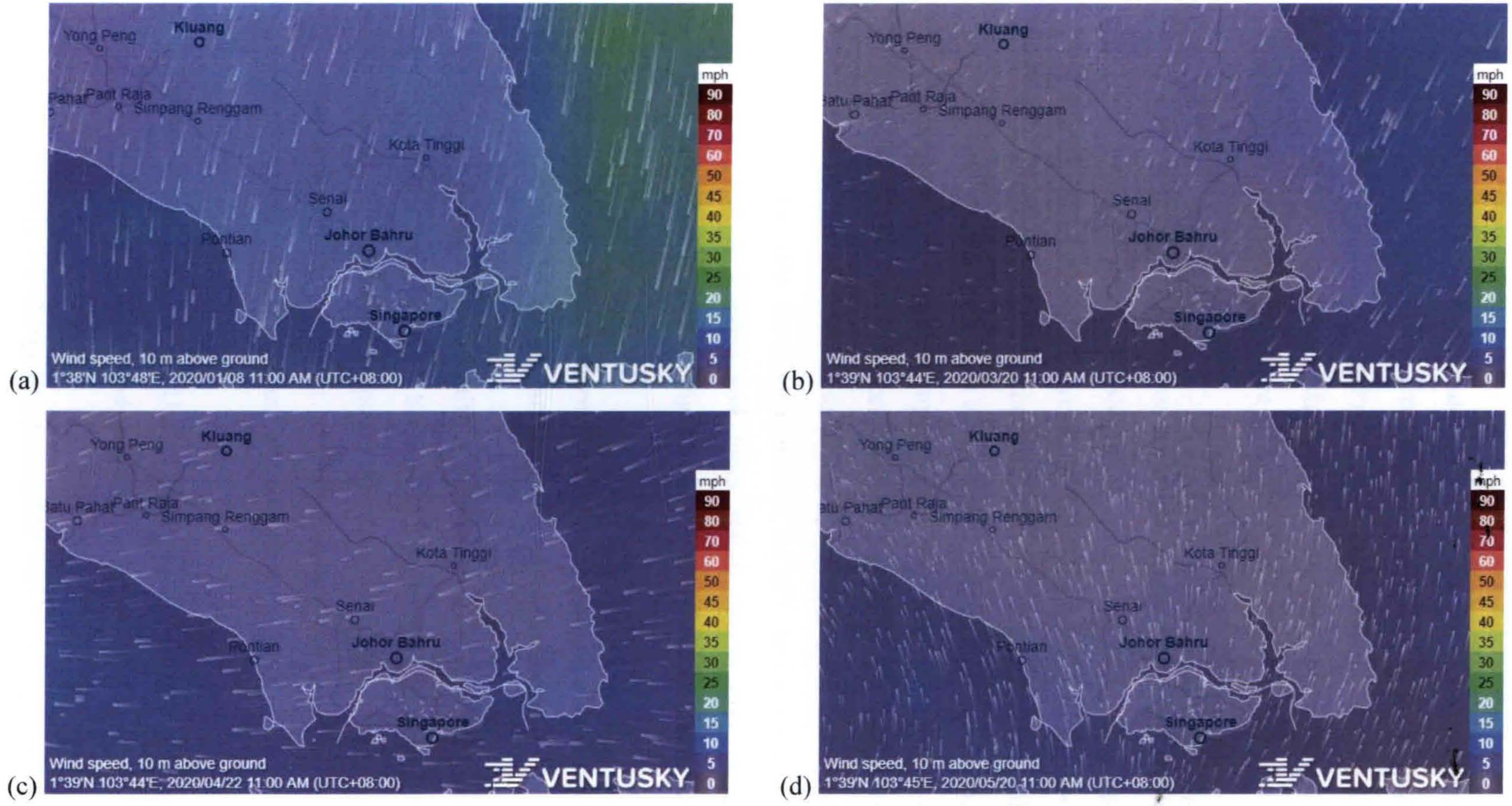


Figure 4.9 The wind direction at Johor, Malaysia (a) before MCO, (b) during MCO, (c) during EMCO and (d) during CMCO (from: https://www.ventusky.com/)

Figure 4.9 shows the wind direction at Johor, Malaysia before, during and after MCO acquired from Ventusky website. The white line represents the wind direction in which the direction flows from the narrow-end of the line to bold-end. The distribution of NO_2 column concentration before, during and after the MCO is not as it had been predicted as in peninsular Malaysia and Selangor district. Therefore, the wind direction is observed from 10m above ground.

Figure 4.9(a) shows the wind speed before the implementation of MCO. Meanwhile, Figure 4.9(b) shows the wind speed during the implementation of MCO. During MCO, the wind moves from north-east towards south, then bounce back towards west. Figure 4.9(c) shows the wind speeds from east to west, and Figure 4.9 (d) shows the wind moves from south to north. According to a series of study, the meteorological factors such as ambient temperature, wind speed and humidity can also influence the concentration of air pollution in the atmosphere (Azmi et al., 2010; Mohd Talib Latif et al., 2014). Based on the observation of the wind speed and the highly concentration of Nitrogen Dioxide, the concentration of the NO_2 during and after the implementation of MCO both in Pontian and Johor Bahru district may probably effected by the concentration of NO_2 in Singapore which is transferred by the wind speed.

4.5 Relationship between Land Use Types and Nitrogen Dioxide (NO_2) Column Concentration Produced by Sentinel-5P

The descriptive statistics of Nitrogen Dioxide (NO_2) column concentration is retrieved from TROPOMI Sentinel-5P on three (3) different land use types; industry, sub-urban and urban, respectively. The mean, standard deviation, minimum and maximum of NO_2 column concentration are calculated to analyse the relationship between the land use type and NO_2 column centration.

4.5.1 Industry Land Use Types and Nitrogen Dioxide (NO_2) Column Concentration Produced by Sentinel-5P

Table 4.5 shows the descriptive statistic of Nitrogen Dioxide (NO_2) column concentration retrieved from TROPOMI Sentinel-5P on industry land use type where mean, standard deviation, minimum and maximum concentration of NO_2 is generated in Microsoft Excel software. The unit for NO_2 column concentration retrieved is displayed in 10^{15} molec/cm^2. According to the table, the minimum concentration of NO_2 at industrial land use type before MCO is 1.923 and its maximum value is 2.232. During MCO, the minimum and maximum concentration increases to 2.301and 2.718, respectively. Then, the minimum and maximum concentration of NO_2 decrease back to 2.084 and 2.529, respectively after the MCO phase. The highest concentration of NO_2 recorded at the industrial land use type is 5.042 where it occurs during CMCO.

Table 4.5
Descriptive statistic of Nitrogen Dioxide (NO_2) column concentration retrieved from TROPOMI Sentinel-5P on industry land use type

NO_2 Column Concentration (10^{15} molec/cm^2)	Land Use: Industry				
	Before MCO	MCO	EMCO	CMCO	RMCO
Mean	2.047	2.564	2.264	4.274	2.753
Standard Deviation	0.163	0.228	0.234	0.952	0.410
Minimum	1.923	2.301	2.084	3.209	2.331
Maximum	2.232	2.718	2.529	5.042	3.150

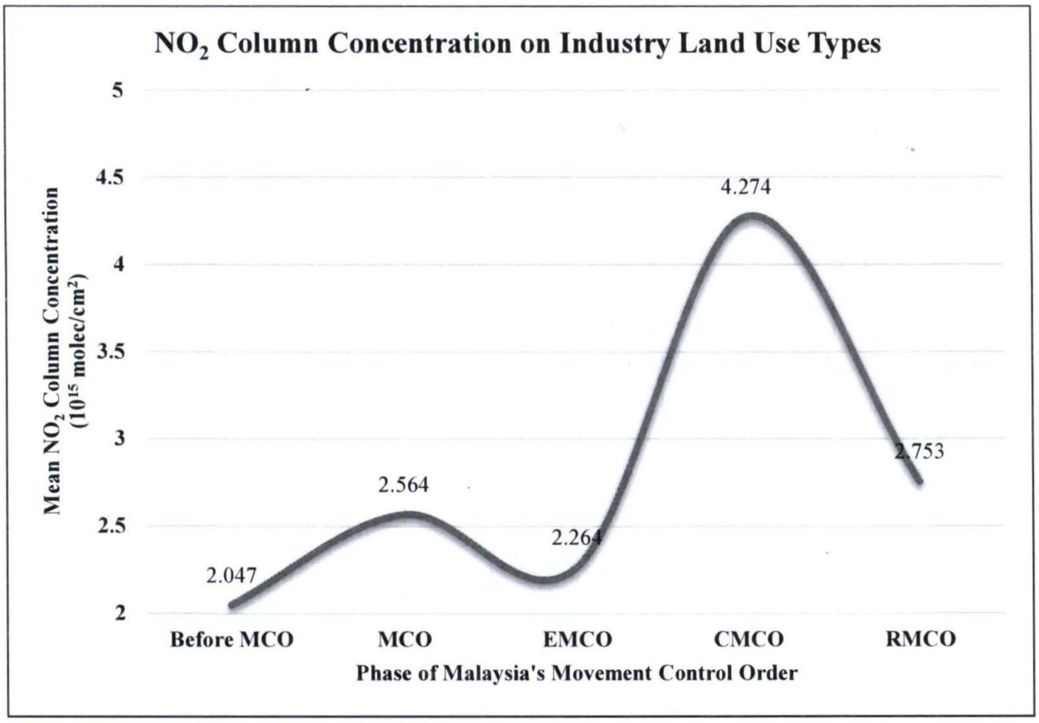


Figure 4.10 The mean of NO_2 column concentration on industry land use type for each Malaysia's MCO phase

Figure 4.10 shows the mean of NO_2 column concentration on industry land use type for each Malaysia's MCO phase that have been plotted into a scatter chart with smooth lines. The purpose of the chart is to observe the increment of the mean of NO_2 column concentration. From the figure, there is a slight increment of NO_2 column concentration from 2.047 to 2.564, before to during MCO. Then, the concentration drops down to 2.264 after the MCO during EMCO phase. However, the value still belongs in the same class according to the classification which had been made during the generation of NO_2 column concentration map. Then, starting from EMCO, the NO_2 column concentration sharply increases to 4.274 during CMCO and then decrease to 2.754 during RMCO. During CMCO, the value of NO_2 column concentration is considered high as the value belongs to the fourth class from NO_2 column concentration classification in this research.

4.5.2 Sub-Urban Land Use Types and Nitrogen Dioxide (NO_2) Column Concentration Produced by Sentinel-5P

Table 4.6 shows the descriptive statistic of Nitrogen Dioxide (NO_2) column concentration retrieved from TROPOMI Sentinel-5P on sub-urban land use type where mean, standard deviation, minimum and maximum concentration of NO_2 is generated in Microsoft Excel software. The unit for NO_2 column concentration retrieved is displayed in 10^{15} molec/cm^2.

Table 4.6
Descriptive statistic of Nitrogen Dioxide (NO_2) column concentration retrieved from Sentinel-5P on sub-urban land use type

NO_2 Column Concentration (10^{15} molec/cm^2)	Land Use: Sub-Urban				
	Before MCO	**MCO**	**EMCO**	**CMCO**	**RMCO**
Mean	2.892	2.828	3.014	3.801	3.537
Standard Deviation	1.623	0.353	0.697	1.244	0.842
Minimum	1.690	2.255	2.113	1.874	2.561
Maximum	8.898	3.430	4.447	6.674	6.083

According to the table, the minimum concentration of NO_2 at sub-urban land use type before MCO is 1.690 and its maximum value is 8.898. During MCO, the minimum concentration increases to 2.255 and decrease back to 2.113 after the MCO phase. Meanwhile, the maximum concentration sharply decreases to 3.430. Then, the concentration increases back to 4.447 after the MCO phase ended. The highest concentration of NO_2 recorded at the sub-urban land use type is 8.898 where it occurs before MCO.

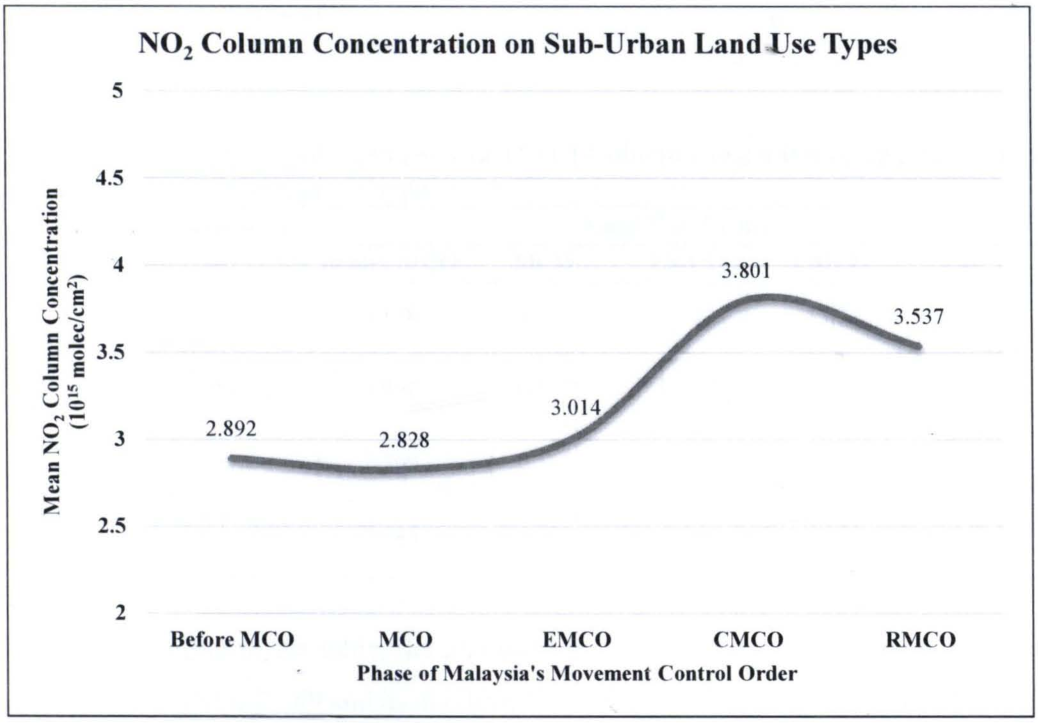


Figure 4.11 The mean of NO_2 column concentration on sub-urban land use types for each Malaysia's MCO phase

Figure 4.11 shows the mean of NO_2 column concentration on sub-urban land use type for each Malaysia's MCO phase that have been plotted into a scatter chart with smooth lines. The purpose of the chart is to observe the increment of the mean of NO_2 column concentration. From the figure, there is a slight decrease of NO_2 column concentration from 2.892 to 2.828, before to during MCO. Then, the concentration increases to 3.014 after the MCO during EMCO phase and keep on increasing to the peak during CMCO by 3.801. Then, starting from CMCO, the NO_2 column concentration decrease to 3.537 during RMCO.

4.5.3 Urban Land Use Types and Nitrogen Dioxide (NO_2) Column Concentration Produced by Sentinel-5P

Table 4.7 shows the descriptive statistic of Nitrogen Dioxide (NO_2) column concentration retrieved from TROPOMI Sentinel-5P on urban land use type where mean, standard deviation, minimum and maximum concentration of NO_2 is generated in Microsoft Excel software. The unit for NO_2 column concentration retrieved is displayed in 10^{15} molec/cm^2.

Table 4.7
Descriptive statistic of Nitrogen Dioxide (NO_2) Column Concentration retrieved from Sentinel-5P on urban land use type

NO_2 Column Concentration (10^{15} molec/cm^2)	Land Use: Urban				
	Before MCO	MCO	EMCO	CMCO	RMCO
Mean	3.128	3.131	3.310	4.875	4.401
Standard Deviation	0.962	0.550	0.926	1.188	1.368
Minimum	2.369	2.565	2.530	3.402	2.411
Maximum	5.548	4.426	5.146	6.912	6.721

According to the table, the minimum concentration of NO_2 at urban land use type before MCO is 2.369 and its maximum value is 5.548. During MCO, the minimum concentration increases to 2.565 and decrease back to 2.530 after the MCO phase. Meanwhile, the maximum concentration decreases to 4.426. Then, the concentration increases back to 5.146 after the MCO phase ended. The highest concentration of NO_2 recorded at the sub-urban land use type is 6.912 where it occurs after the implementation of MCO, during CMCO.

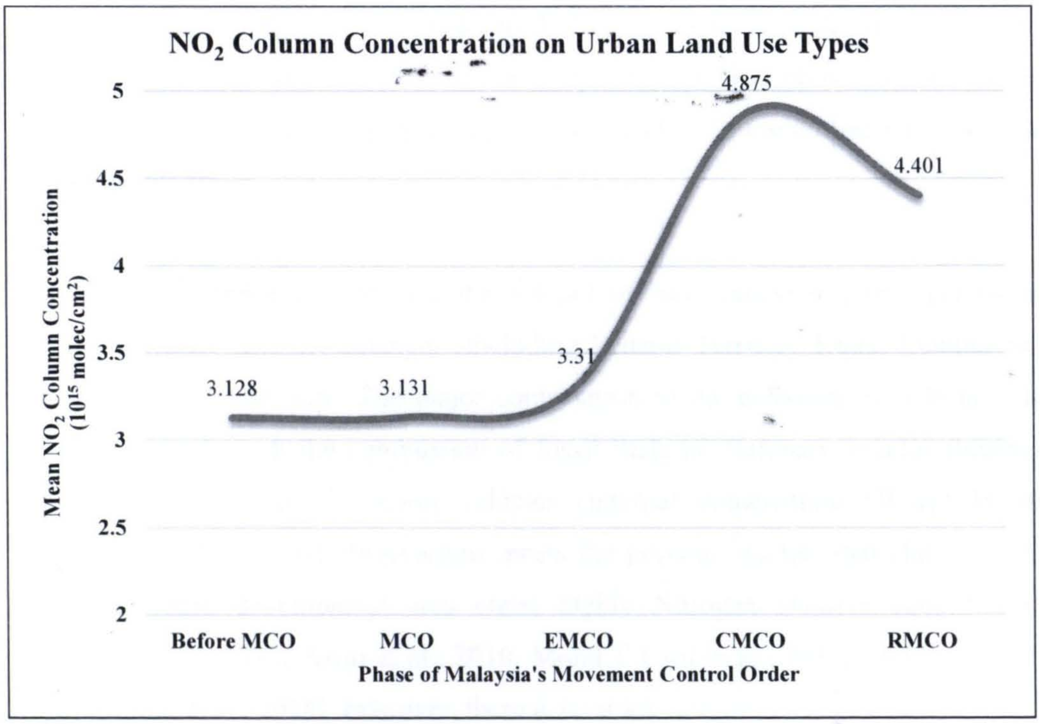


Figure 4.12 The mean of NO_2 column concentration on urban land use types for each Malaysia's MCO phase

Figure 4.12 shows the mean of NO_2 column concentration on urban land use type for each Malaysia's MCO phase that have been plotted into a scatter chart with smooth lines. The purpose of the chart is to observe the increment of the mean of NO_2 column concentration. From the figure, the line remains flat of the chart as NO_2 column concentration only experience a slight of change from 3.128 to 3.131, before to during MCO. Then, the concentration slightly increases to 3.310 after the MCO during EMCO phase and sharply increase to the peak during CMCO by 4.875. Then, starting from CMCO, the NO_2 column concentration decrease to 4.401 during RMCO.

4.6 Discussion

This study demonstrates the feasibility of monitoring the NO_2 emission over peninsular Malaysia during the implementation of Malaysia's Movement Control Order where the movement of motor vehicular and production of industrial were being halted with the generated map of NO_2 column concentration map of peninsular Malaysia. Therefore, the high correlation between ground CAQM NO_2 concentration and the TROPOMI NO_2 column concentration in this study illustrates the reliability of Sentinel-

5P data in monitoring the NO_2 emission. Using the extracted data of NO_2 column concentration from Sentinel-5P data, the comparison of NO_2 emission between the phases in peninsular Malaysia shows that the NO_2 concentration during MCO is lower than the other phase.

The method also identified the hotspot of NO_2 emission within peninsular Malaysia, which falls on Selangor (including Federal Territory Kuala Lumpur and Putrajaya) and Johor state. The major contribution to the emission of NO_2 into the atmosphere is through the combustion of fossil fuels in stationary sources (heating, power generation) and in motor vehicles (internal combustion) (World Health Organization, 2000). The observations meets the previous studies that claims Klang Valley as rapid development area emits highly Nitrogen Dioxide concentration (Abdullah et al., 2012; Azmi et al., 2010; Mohd T Latif et al., 2015; Masseran et al., 2016; Mohtar et al., 2018). However, there is no study related to the air quality in Johor and the spatial distribution of NO_2 emission does not follows the pattern as observed in peninsular Malaysia and Selangor. Therefore, the factor that influence the NO_2 concentration Johor is probably due to the meteorological factor, wind speed.

The mean NO_2 column concentration shown in the three (3) different land use types determined the influence of land use types towards the emission of NO_2. Urban land use types are identified to have the highest NO_2 mean concentration followed by the industrial land use types, both values 4.875 and 4.274 in 10^{15} molec/cm^2. Mohd T Latif et al., (2015) provided a commentary regarding the influence of urban area towards the emission of NO_2.

4.7 Chapter Summary

This chapter comprises the results and discussion of Nitrogen Dioxide (NO_2) column concentration extracted from TROPOMI Sentinel-5P. The Nitrogen Dioxide (NO_2) column concentration mapping for six (6) different dates are produced first before correlation analysis with ground CAQM NO_2 concentration is done. With the TROPOMI Sentinel-5P extracted data is proved to be highly correlated with surface monitoring concentration, the NO_2 column concentration before, during and after Malaysia's MCO are compared according to three (3) study areas; peninsular Malaysia, Selangor and Johor. Lastly, the relationship between land use types and the NO_2 column concentration are determined using statistical analysis.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Introduction

This final chapter highlighted the overall concept, process and analysis which had been conducted in this study. Recommendations for further work and references also being disclosed in this chapter for better understanding and improvements

5.2 Conclusion

The main purpose of this study is to analyse the impact of Malaysia's Movement Control Order (MCO) towards air quality Nitrogen Dioxide concentration in peninsular Malaysia had led to the exploration of Sentinel-5P application using remote sensing and geographical information system (GIS). Both method of GIS and remote sensing applied in completing this study are crucial.

Based on the results and analysis, this study demonstrates the first result of Sentinel-5 Precursor in the observation of NO_2 over peninsular Malaysia before, during and after the Malaysia's Movement Control Order (MCO). The high correlation of $R^2 = 0.692$ between the ground CAQM NO_2 concentration and the TROPOMI NO_2 column concentration in this study indicate the reliability of Sentinel-5P data in monitoring the air quality of NO_2 emission.

The extracted data of NO_2 column concentration from Sentinel-5P data is used to compare the NO_2 emission between the phases in peninsular Malaysia. Each of the classified area is extracted its value and calculated into percentage for comparison method. The results show that the NO_2 concentration during MCO is low and experience sudden increase in NO_2 concentrations during the conditional MCO in peninsular Malaysia. Hotspots are observed in the Selangor and Johor state as a result of rapid urban development and probably influenced by the meteorological factor, wind speed.

The mean NO_2 column concentration shown in the three (3) different land use types determined the influence of land use types towards the emission of NO_2. The value is extracted from the production of NO_2 column concentration map of Sentinel-5P data according to the category of CAQM stations. Urban land use types are identified to have the highest NO_2 mean concentration followed by the industrial land use types, both values 4.875 and 4.274 in 10^{15} molec/cm^2 occurred during the conditional MCO.

In conclusion, the remote sensing data and geographical information system techniques are utterly beneficial in monitoring air quality especially in mapping the air quality during this pandemic season. The observation of air quality can still be performed without having to collect data on-field. Although it is generally known that the data on field is highly accurate than other primary source of data, the high correlation of satellite image and ground data determined the reliability of using this method in extracting information. Furthermore, this method can save cost and time if proper techniques starting from pre-processing until data analysis is recognizes.

5.3 Recommendation

Various technical problems is encountered during the extraction process of air quality data from Sentinel-5 Precursor. The most important thing is the selection of data product. Sentinel-5P provided 71 data of various types of column concentration for Nitrogen Dioxide, including the latitude and longitude data file. Although the user documentation published by the European Space Agency (ESA) as an initiative to provide guidance for Sentinel-5P user to use Nitrogen Dioxide total column concentration for NO_2 data extraction, it is advisable for user to conduct correlation analysis between the provided satellite data and existing surface concentration data on the same date. The coherence between the satellite and surface concentration is crucial in determining the reliability of the map produced.

The unit involved in this study is molec/cm^2 from satellite data extraction and parts per million (ppm) unit from the CAQM data. The universal unit to measure the concentration of Nitrogen Dioxide is $\mu g/m^3$. Even so, most studies use molec/cm^2 portray the concentration of NO_2. However, with an appropriate amount of time, method and techniques, the algorithm to convert the unit universally could be obtained.

Due to the limited time given, this study only focused on the product of Sentinel-5P. Based on previous studies, there are other instruments on satellites which is utilized to monitor the air quality over study area such as Ozone Monitoring Instrument (OMI), Landsat 7 ETM+ and MERRA-2. Comparison of data can be made to identify which instruments can produce the most accurate and reliable result in monitoring air quality over study area.

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APPENDICES

APPENDIX 1

Table of Cross tab by station ID for parameter Nitrogen Dioxide (NO_2) (ppm) (Hourly)

DATE/TIME	CA01R	CA02K	CA03K	CA04K	CA06P	CA07P	CA08P	CA10A	CA11A	CA12A
20/6/2018 0:00	0.0093	0.0017	0.0133	0.0214	0.0234	0.0279	0.0229	0.0113	NA	0.0137
20/6/2018 1:00	0.0038	0.0012	0.0092	0.0172	0.0245	0.0235	0.0141	0.0098	NA	0.0146
20/6/2018 2:00	0.0013	0.0031	0.0005	0.0144	0.0268	0.018	0.0098	0.0077	NA	0.0112
20/6/2018 3:00	0.0011	0.0017	0.0017	0.0119	0.0162	0.0028	0.0021	0.0076	0.0107	0.0098
20/6/2018 4:00	0.0017	0.0012	0.0006	0.0008	0.0104	0.004	0.0023	0.0046	0.0133	0.0111
20/6/2018 5:00	0.0009	0.0007	0.0026	0.0021	0.007	0.0032	0.002	0.0034	0.0027	0.0099
20/6/2018 6:00	0.0014	0.0009	0.0026	0.0034	0.0136	0.0038	0.0017	0.005	0.0025	0.0097
20/6/2018 7:00	0.0024	0.002	0.0022	0.0047	0.0174	0.006	0.0058	0.006	0.0043	0.0105
20/6/2018 8:00	NA	NA	NA	NA	NA	NA	0.0097	0.0088	0.0057	0.0107
20/6/2018 9:00	0.0025	0.0039	0.0045	0.0086	0.0116	0.0134	0.0106	0.0076	NA	0.0134
20/6/2018 10:00	0.0018	0.0032	0.0046	0.0069	0.0129	0.0128	NA	0.0045	0.0045	NA
20/6/2018 11:00	0.0018	0.0007	0.0035	0.0055	0.0133	0.0058	0.0153	NA	0.0033	0.0181
20/6/2018 12:00	0.0017	0.0006	0.0036	0.0062	0.0152	0.004	0.0058	0.0048	0.0033	0.0097
20/6/2018 13:00	0.0018	0.0014	0.0045	NA	0.0165	0.0021	0.0045	0.0043	0.006	0.0039
20/6/2018 14:00	0.0016	0.0041	0.003	0.0032	0.0177	NA	0.0038	0.0076	0.007	0.0032
20/6/2018 15:00	0.001	0.0043	0.0026	0.0038	0.0156	0.0053	0.0059	0.0056	0.0068	0.0026
20/6/2018 16:00	0.001	0.0028	0.0026	0.0024	0.0066	0.0044	0.0041	0.0077	0.0065	0.0022
20/6/2018 17:00	0.0013	0.0032	0.0025	0.0033	0.0047	0.0057	0.0034	0.0088	0.0081	0.0026
20/6/2018 18:00	0.0013	0.004	0.0026	0.0038	0.0051	0.0048	0.004	0.002	0.0096	0.0022
20/6/2018 19:00	0.0015	0.0062	0.0028	0.0043	0.0102	NA	0.0039	0.0039	0.014	0.003
20/6/2018 20:00	0.0022	0.0081	0.0038	0.0052	0.0156	0.0084	0.0057	0.0206	0.0209	0.0056
20/6/2018 21:00	0.002	0.0058	0.0061	0.0078	0.0349	0.0127	0.0098	0.0111	0.0188	0.007

DATE/TIME	CA13A	CA14A	CA15W	CA16W	CA17W	CA18B	CA19B	CA20B	CA21B	CA22B
20/6/2018 0:00	NA	0.0117	0.0312	0.0334	0.0133	NA	0.0429	0.0302	0.0288	0.0138
20/6/2018 1:00	NA	0.0084	0.0298	0.031	0.0137	NA	0.0412	0.0248	0.0256	0.0129
20/6/2018 2:00	NA	0.0089	0.0249	0.0303	0.014	NA	0.0389	0.0203	0.0244	0.0147
20/6/2018 3:00	NA	0.0075	0.0193	0.0245	0.0135	NA	0.0324	0.0251	0.021	0.0162
20/6/2018 4:00	NA	0.0053	0.0184	0.0212	0.0122	NA	0.0272	0.0297	0.0234	0.011
20/6/2018 5:00	NA	0.0057	0.017	0.0182	0.0118	NA	0.0248	0.0251	0.0167	0.0032
20/6/2018 6:00	NA	0.0062	0.0164	0.0205	0.0061	NA	0.0247	0.0201	0.007	0.0029
20/6/2018 7:00	NA	0.0045	0.018	0.0135	0.0039	NA	0.0156	0.0108	0.0101	NA
20/6/2018 8:00	NA	NA	NA	NA	NA	NA	0.0191	NA	0.0134	NA
20/6/2018 9:00	NA	0.0068	0.0176	0.0129	0.0091	NA	NA	0.0168	NA	0.0063
20/6/2018 10:00	NA	0.0051	0.0182	0.0106	0.0075	NA	0.0217	0.0162	0.0115	0.0074
20/6/2018 11:00	NA	0.0096	0.0154	0.0078	0.0058	NA	0.0177	0.0158	0.0122	0.0066
20/6/2018 12:00	NA	0.0066	0.0088	0.0064	0.004	NA	0.0203	0.0118	0.0129	0.0063
20/6/2018 13:00	NA	0.0039	0.0086	0.0079	0.004	NA	0.0219	0.0121	0.0092	0.0061
20/6/2018 14:00	NA	0.0023	0.006	0.0061	0.003	NA	0.016	0.0108	0.0081	0.0107
20/6/2018 15:00	NA	0.0023	0.0095	0.0063	0.0035	NA	0.0098	0.0132	0.0055	0.0052
20/6/2018 16:00	NA	0.0023	0.0151	0.0058	0.0041	NA	0.0072	NA	0.0098	0.0178
20/6/2018 17:00	NA	0.0034	0.0139	0.0046	0.0052	NA	0.0068	0.0098	0.0065	0.0097
20/6/2018 18:00	NA	0.0024	0.0189	0.0074	0.0045	NA	0.0085	0.0157	0.0063	0.0066
20/6/2018 19:00	NA	0.0047	0.0289	0.0112	0.0055	NA	0.0141	0.0198	0.0143	0.0083
20/6/2018 20:00	NA	0.0111	0.024	0.0102	0.0054	NA	0.0136	0.025	0.0142	0.0094
20/6/2018 21:00	NA	0.0107	0.0242	0.0139	0.0059	NA	0.0162	0.0219	0.0166	0.0125

DATE/TIME	CA23N	CA24N	CA25N	CA27M	CA28M	CA30J	CA33J	CA34J	CA36J	CA39C
20/6/2018 0:00	0.0235	0.0095	0.0054	0.0115	0.0104	NA	0.013	0.017	0.0049	0.0048
20/6/2018 1:00	0.0205	0.0074	0.0054	0.0109	0.0098	NA	0.0119	0.0164	0.0048	0.004
20/6/2018 2:00	0.0141	0.0051	0.0072	0.0095	0.0076	NA	0.011	0.0169	0.0051	0.0042
20/6/2018 3:00	0.0121	0.0046	0.0023	0.013	0.0063	NA	0.0115	0.017	0.0052	0.0036
20/6/2018 4:00	0.0105	0.0032	0.0024	0.0089	0.0079	NA	0.0105	0.0139	0.0043	0.0031
20/6/2018 5:00	0.0106	0.0047	0.0031	0.0078	0.0072	NA	0.007	0.0118	0.0041	0.0033
20/6/2018 6:00	0.0122	0.0054	0.0022	0.0078	0.0073	NA	0.0096	0.0119	0.0052	NA
20/6/2018 7:00	0.0097	0.0074	0.0013	NA	0.0081	NA	0.0081	0.0117	0.0039	0.0034
20/6/2018 8:00	NA	NA	NA	NA	0.0055	NA	NA	NA	NA	0.0038
20/6/2018 9:00	0.0132	0.0063	0.003	NA	0.0037	NA	0.0196	0.0192	0.0058	0.0027
20/6/2018 10:00	0.0138	0.0079	0.0018	NA	0.0088	NA	0.015	0.0359	0.0063	0.0022
20/6/2018 11:00	0.0129	0.0072	0.0018	NA	0.0079	NA	0.0078	0.0162	0.0023	0.0024
20/6/2018 12:00	0.0155	0.0085	0.0015	0.0061	0.0062	NA	0.0107	0.019	0.002	0.0019
20/6/2018 13:00	0.0189	0.0064	0.0012	NA	0.0014	NA	0.0155	0.0209	0.0027	0.0016
20/6/2018 14:00	0.0178	0.0049	0.001	0.0062	0.0022	NA	0.0156	0.0295	0.0047	0.0009
20/6/2018 15:00	0.0139	0.0046	0.0009	0.0049	0.0033	NA	0.0142	0.0335	0.0041	0.0006
20/6/2018 16:00	0.0151	0.0032	0.0011	0.0034	0.0017	NA	0.005	0.0292	0.0083	0.0005
20/6/2018 17:00	0.012	0.0044	0.0019	0.0087	0.0041	NA	0.0071	0.0147	0.0079	0.0004
20/6/2018 18:00	0.0196	0.0055	0.0099	0.01	0.0064	NA	0.0142	0.0213	0.0059	0.0006
20/6/2018 19:00	0.0186	0.0076	0.012	0.0145	0.0093	NA	0.0143	0.024	0.0069	0.0026
20/6/2018 20:00	0.0208	0.0119	0.0066	0.0186	0.0078	NA	0.0156	0.0283	0.0125	0.0037
20/6/2018 21:00	0.023	0.0136	0.0062	0.0169	0.0117	NA	0.0162	0.0253	0.0147	0.0045

DATE/TIME	CA40C	CA41C	CA42T	CA43T	CA44T	CA46D	CA47D
20/6/2018 0:00	0.0102	0.01	0.0038	0.0033	0.0064	0.0071	0.0122
20/6/2018 1:00	0.0033	0.0083	0.0043	0.003	0.0048	0.0052	0.0082
20/6/2018 2:00	0.0024	0.0065	0.0036	0.0034	0.0062	0.0035	0.0069
20/6/2018 3:00	0.0041	0.0038	0.0032	0.0032	0.0043	0.0031	0.0066
20/6/2018 4:00	0.0033	0.004	0.0027	0.0032	0.0038	0.0029	0.0049
20/6/2018 5:00	0.0024	0.0044	0.003	0.0026	0.0037	0.0017	0.0052
20/6/2018 6:00	0.0036	0.0039	0.0022	0.0027	NA	NA	NA
20/6/2018 7:00	0.0041	0.004	0.0024	NA	0.0033	0.0022	0.0048
20/6/2018 8:00	0.0046	0.0047	0.0029	0.0027	0.0033	0.0017	0.0026
20/6/2018 9:00	NA	0.0044	NA	0.0024	0.0036	0.0014	0.0039
20/6/2018 10:00	0.0037	NA	0.0029	0.0025	0.0044	0.0012	0.0038
20/6/2018 11:00	0.004	NA	0.0022	0.002	0.0024	0.0006	0.0024
20/6/2018 12:00	0.002	0.0017	0.0023	0.0018	0.0016	0.0004	0.0016
20/6/2018 13:00	NA	0.0022	0.0031	0.0017	0.0021	0.0002	0.0015
20/6/2018 14:00	NA	0.0016	0.0057	0.0018	0.0021	0.0005	0.0001
20/6/2018 15:00	NA	0.0012	0.0037	0.0024	0.0024	0.0042	NA
20/6/2018 16:00	NA	0.0007	0.0027	0.0029	0.0038	0.0071	0.0001
20/6/2018 17:00	0.0009	0.0004	0.0013	0.0031	0.0045	0.0068	NA
20/6/2018 18:00	0.0023	0.0004	0.0009	0.0032	0.0058	0.0079	NA
20/6/2018 19:00	0.0029	0.0015	0.0013	0.0016	0.0102	0.0132	0.0001
20/6/2018 20:00	0.0105	0.004	0.003	0.0013	0.0119	0.0085	0.0011
20/6/2018 21:00	0.0136	0.0066	0.0044	0.0018	0.014	0.0056	0.0026

APPENDIX 2

Table of correlation coeffecient between surface NO_2 monitoring concentration and TROPOMI NO_2 column concentration

ID	Station ID	Ground (ppm)	Total Column (molec/cm^2)
1	CA01R	0.001972727	3.2047
2	CA02K	0.002763636	2.9157
3	CA03K	0.003609091	2.7906
4	CA04K	0.006222727	3.3328
5	CA06P	0.014509091	5.0335
6	CA07P	0.007663636	4.3907
7	CA08P	0.006690909	3.9112
8	CA10A	0.006940909	4.0309
9	CA11A	0.006727273	4.6373
10	CA12A	0.007940909	3.6651
11	CA14A	0.005881818	4.3552
12	CA15W	0.017459091	7.3928
13	CA16W	0.013804545	7.1436
14	CA17W	0.007090909	5.2784
15	CA19B	0.020027273	7.2652
16	CA20B	0.017045455	6.7799
17	CA21B	0.013522727	4.6037
18	CA22B	0.008527273	4.3818
19	CA23N	0.014922727	4.0087
20	CA24N	0.006331818	4.0126
21	CA25N	0.003554545	3.7058
22	CA27M	0.006572727	3.3490
23	CA33J	0.011518182	5.2104
24	CA34J	0.019709091	4.7202
25	CA36J	0.005527273	3.1537
26	CA39C	0.002490909	3.0907
27	CA40C	0.003540909	3.0497
28	CA41C	0.003377273	2.9767
29	CA42T	0.002800000	3.1833
30	CA43T	0.002390909	3.1923
31	CA44T	0.004754545	3.3321
32	CA46D	0.003863636	3.2935
33	CA47D	0.003118182	2.9077