EFFECTS OF WEATHER CONDITIONS AND ANTHROPOGENIC PRECURSORS ON GROUND-LEVEL OZONE CONCENTRATIONS IN MALAYSIA CITIES

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by

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This project report titled Effects of Weather Conditions and Anthropogenic Precursors on Ground-Level Ozone Concentrations in Malaysia Cities was prepared and submitted by Syaza Ezzati Binti Baidrulhisham (Matrix Number: 181132690) and has been found satisfactory in terms of scope, quality and presentation as partial fulfilment of the requirement for the Bachelor Environmental Engineering with Honours in Universiti Malaysia Perlis (UniMAP).

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KESAN KEADAAN CUACA DAN PRAPENANDA ANTROPOGENIK TERHADAP KEPEKATAN OZON ARAS BUMI DI BANDAR MALAYSIA

ABSTRAK

Ozon aras bumi (O_3) tidak dipancarkan terus ke atmosfera. Ia terhasil daripada tindak balas fotokimia antara prapenanda dan juga dipengaruhi oleh faktor cuaca seperti suhu. Oleh itu, kajian ini bertujuan untuk menyiasat variasi ozon aras bumi dan menganalisis prapenanda antropogenik yang ketara dan parameter cuaca yang dikaitkan dengan ozon aras bumi pada waktu siang dan malam di Kuala Terengganu, Perai dan Seremban dari tahun 2016 hingga 2020. Data sekunder diperoleh daripada Jabatan Alam Sekitar (JAS) yang kemudiannya diekstrak mengikut data setiap jam ubtuk O_3 dengan gas surih dan parameter cuaca. Data sekunder dianalisis menggunakan analisis temporal seperti statistik perihalan, plot kotak dan plot harian serta analisis ruang seperti plot kontur. Sekaitan Spearman dan regresi linear berganda (MLR) digunakan untuk mengenal pasti perkaitan O_3 dengan prapenanda O_3 dan parameter cuacanya. Keputusan menunjukkan bahawa kepekatan O_3 minimum adalah 0 ppm pada tahun 2016 hingga 2020. Manakala kepekatan O_3 maksimum ialah 0.103 ppm pada tahun 2017 di Seremban. Corak harian kepekatan O_3 mempunyai jumlah yang lebih tinggi pada tengah hari manakala prapenanda O_3 berkurangan pada waktu tersebut. Sekaitan Spearman dan analisis Regresi Lelurus menunjukkan bahawa variasi dalam kepekatan O_3 antara siang dan malam secara amnya bertepatan dipengaruhi oleh NO dan suhu. Pekali yang sangat kecil dikesan untuk parameter cuaca terutamanya suhu. Ini menunjukkan bahawa sangat minima hingga tiada korelasi parameter cuaca dengan aras O_3 yang telah dikenal pasti menggunakan MLR. Kesimpulannya, kepekatan NO yang lebih rendah akan meningkatkan jumlah kepekatan O_3 dan peningkatan jumlah kepekatan O_3 dipengaruhi oleh suhu persekitaran yang lebih tinggi.

EFFECTS OF WEATHER CONDITIONS AND ANTHROPOGENIC PRECURSORS ON GROUND-LEVEL OZONE CONCENTRATIONS IN MALAYSIA CITIES

ABSTRACT

Ground-level ozone (O_3) is not emitted directly into the atmosphere. It results from photochemical reactions between precursors and influenced by weather factor such as temperature. Therefore, this study aimed at investigating the variation of ground-level ozone and analysing the significant anthropogenic precursors and the weather parameters that associated with ground-level ozone during day time and night time at Kuala Terengganu, Perai and Seremban from 2016 to 2020. Secondary data were acquired from the Department of Environment (DOE) which then was extracted according for hourly data of O_3 with trace gases and weather parameter. The secondary data was analysed using temporal analysis such as descriptive statistics, box plot and diurnal plot as well as spatial analysis such as contour plot. Spearman correlation and multiple linear regressions (MLR) were used to identified association of O_3 with its precursors and weather parameters. The result showed that minimum O_3 concentration was 0 ppm during 2016 to 2020 year. Meanwhile, the maximum O_3 concentration was 0.103 ppm in 2017 at Seremban. The diurnal pattern of O_3 concentration has higher amount during midday while O_3 precursors decrease during that time. Spearman correlation analysis showed that variations in O_3 concentrations between day and night generally coincides influenced by NO and temperature. Very small coefficient was detected for weather parameters especially temperature. This indicate that very minimal to no correlation of weather parameters with O_3 level was identified using MLR. As conclusion, lower NO concentration will increased the amount of O_3 concentration and the increasing amount of O_3 concentration was influenced by the higher temperature of its surroundings.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

API	Air Pollution Index
CH_3O	Methyloxy Radical
CH_3O_2	Methylperoxy Radical
CH_4	Methane
CO_2	Carbon Dioxide
DOE	Department of Environment
GIS	Geographic Information System
IA	Index of Agreement
MLR	Multiple Linear Regression
NEM	North-East Monsoon
NMHC	Non-Methane Hydrocarbon
NO	Nitric Oxides
NO_2	Nitrogen Dioxides
NO_3	Nitrate
NO_x	Nitrogen Oxides
O	Oxygen Atom
O_2	Oxygen
O_3	Ozone
OH	Hydroxyl Radical
PM_{10}	Particulate Matter with Diameter 10 µm
RMSE	Root Mean Square Error
SO_2	Sulphur Dioxide
SWM	South-East Monsoon
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
UVB	Ultraviolet
VOCs	Volatile Organic Compound

CHAPTER 1

INTRODUCTION

1.1 Research Background

Ground-level ozone (O_3) has garnered a lot of attention in recent years since short-term ozone exposure has been linked to decreased lung function in young and elderly people with a history of respiratory disorders. The increased O_3 content in the Earth's surface has consequences for human health, natural ecosystems, and vegetation development (Cakmak et al. 2016). O_3 is primarily created by complex photochemical processes which is by anthropogenic precursors and this problem caused by human activities. The large percentage of ground-level ozone formation occurred in the presence of sunlight, typically the ultraviolet (UV) spectrum, when nitrogen oxides (NO_x), carbon monoxide (CO), non-methane hydrocarbons (NMHCs), methane (CH_4) and volatile organic compounds (VOCs) react in the atmosphere. Ozone absorbed radiation and thus works as a powerful greenhouse gas. Despite rising temperatures, O_3 affects evaporation rates, cloud formation, precipitation amounts, and atmospheric circulation. These effects are most noticeable in areas where ozone precursors are emitted (Kelly, Makar & Plummer, 2012).

Scientists employ the term "anthropogenic" in referring to environmental change caused or influenced by people either directly or indirectly. Anthropogenic effects processes, structures, or materials created from human activity are distinguished from those occurring in natural environments uninfluenced by humans. As example, mining, emission of industrial waste, burning of fossil fuels, primarily coal, insecticides, herbicides, and fertilisers are examples of anthropogenic activity (Ivanova, 2020). Anthropogenic global warming is caused by human behaviour, such as pollution and overexploitation of the earth's resources and ecosystems. However, it is formed as a consequence of the photochemical interaction of different NO_x with a diverse spectrum of VOCs such as solvent vapours and other hydrocarbons. Nevertheless, the contribution of VOCs to the formation of ozone varies depending on their reactivity and chemical composition (Melkonyan and Wagner, 2013).

For many years, it has been known that O_3 is significantly reliant on the weather. (Shen et al., 2015). The creation of O_3 is larger on dry, sunny days with stagnant air than on humid, cloudy, and windy days (Lee et al., 2012). The influences of weather and its precursors (i.e., NOx and VOC) by air flow, as well as the temperature and amount of sunlight, which both affect the chemical reaction rates of O_3 production and destruction. Malaysia has tropical weather with two distinct monsoonal seasons which are the northeast monsoon (NEM) from December to February and the southwest monsoon (SWM) from June to August, with inter-monsoon seasons in between. (Jamaluddin et al., 2017). The average temperature ranges from 21 to 32 degrees Celsius; the hottest months are April to May, while the coldest are December to January during the boreal winter season (Malaysia Meteorological Department., 2017).

In this research, the main aim was to analysed the variation of ground-level ozone concentration by using the spatio-temporal variability of O_3 concentrations with the help of the secondary O_3 data with the trace gases (i.e. NO_x, NO, NO_2, CO, SO_2, PM_{10}) and weather parameters (i.e. temperature, solar radiation, relative humidity and wind speed), taking into account the whole O_3 distribution. Next, this research also aim to analysed the association of ground-level ozone with its precursors and the weather parameter during day time and night time using non-linear corelation. Additionally, to develops model by using Multiple linear Regression (MLR) and to validate the model using performance indicators.

1.2 Problem Statements

Ground-level ozone is a significant source of air pollution mainly in most urban areas across the globe. The increasing population, industrial activities, and automobiles in Malaysia are concrete reason for significantly increased emissions of VOCs and NO_x. The atmospheric abundance of these compounds subsequently influences ozone production. During the day, sunlight plays an important role in starting reactions among O_3 precursors (Kulkarni et al., 2013; Latif et al., 2012). On the contrary, at night there is no sunlight to react with precursors forming ozone. Instead, through titration reactions with NO, O_3 is depleted, resulting in nitrogen dioxide (NO_2) and oxygen (O_2). The NO_2 produced can react along with O_3 and to produce nitrate (NO_3) also O_2 (Awang et al., 2015). Thus, the presence of NO_x at night should have a significant decreasing impact on the concentrations of O_3 in an area. Many studies focus on the effect of ground-level ozone in day time rather than night time due to O_3 significant with temperature.

The source of ground-level ozone is created by emissions from vehicles, power stations, industrial boilers, refineries, and chemical factories. As a result, it is critical to assess ground-level ozone at various places, particularly in urban areas. A lack of study about the ground-level ozone in Kuala Terengganu, Perai and Seremban which now the cities is high dense of the population. Moreover, there is less research focused on correlation factors that contribute ground-level ozone and its anthropogenic precursors in urban areas in Malaysia.

Most of the studies in Malaysia focused at Klang Valley which has mostly focused on variation in average ozone concentrations and predictions (Ghazali, Ramli &Yahaya, 2014). There are very limited research was conducted to investigate the relationship of anthropogenic precursors and weather parameter on ground-level ozone in Malaysia. It is important to understand the relationship of O_3 with its precursors and weather parameter.

This study is aimed to identify the factor that contribute of O_3 concentration at three cities in Malaysia. Besides that, the meteorology factors also been investigated to evaluate the increasing of O_3 concentration for both during day time and night time.

1.3 Research Objectives

The objectives of this research are as follows:-

1. To study the variation of ground-level ozone concentration in Kuala Terengganu, Perai and Seremban.
2. To analyse the significant anthropogenic precursors and the weather parameters that associates with ground-level ozone during day time and night time in Kuala Terengganu, Perai and Seremban using Spearman Correlation.
3. To develop the day time and night time O_3 level model using Multiple Linear Regression and accuracy of the model.

1.4 Scope of Research

The research focused on three urban cities in Malaysia, which are Kuala Terengganu, Seremban and Perai. Hourly data for ground level ozone concentration including Particulate Matter with 10μm (PM_{10}), CO, NO_x, NO, NO_2, sulphur dioxide (SO_2) and weather parameters UVB, temperature, humidity and wind speed from 2016 to 2020 were obtained from Department of Environment (DOE) Malaysia.

The study area has a highly dense population, which is more than 50,000 people. Based on the definition of an urban area, the minimum population is 50,000 people, or 1500 people within 1 km^2. In Seremban, the population was 608,700 in 2020. It is crystal clear that the study area has already changed from a sub-urban area to an urban area in 2020. While in Kuala Terengganu, the population was 261,300 in 2020. The study area in Penang was located at Seberang Perai Tengah, which means near to an industrial area and a high density of traffic with population about 428,500 in 2020 (Department of Statistics, 2020).

Values of the day-time period were used starting from 7:00 am to 7:00 pm and the night-time starting from 7:00 pm to 7:00 am. Firstly, the ground-level ozone was analysed by using temporal analysis. Descriptive statistics such as mean, median, minimum, maximum and standard deviation were used to describe O_3 level. Followed by, hourly data analysis and O_3 concentration with its precursor identified by using diurnal plot. Next, box plot was used to evaluate the annual, month, weekend and weekdays variation of ground-level ozone concentration at the cities during the study period. For spatial analysis, contour plots was plotted using ArcGIS software to compare the variation of O_3 level at Seremban, Kuala Terengganu and Perai.

Subsequently, the association of ground-level ozone with its precursors and weather parameter during day-time and night-time were determined using non parametric correlation which is Spearman Correlation. This corelation showed one dependent variable to one independent variable correlation among ozone with its precursors and the weather parameter using SPSS software. To support the analysis, MLR were used to model the prediction after 12 hours by using moderate correlation in spearman correlation.

1.5 Significance of The Project

Ground-level ozone can affected human health and create a variety of health problems. The main outcome of this study is to analyse the effects of weather parameter and anthropogenic precursors on ground-level ozone concentration in the three studied areas, namely Kuala Terengganu, Perai and Seremban. These three cities were chosen due to a scarcity of research on characteristics of ozone and its precursors. Then, with a result of the research it can be used as a reference for future mitigation plan since the weather parameters in the study area will be achieved by certain government or regulatory bodies. Moreover, this study can become a starting point for other researcher and authorities to develop a risk management plan. Besides that, this study is to reveal the significant relationships among multiple anthropogenic factors and ground-level ozone concentrations in Kuala Terengganu, Perai and Seremban which to assess the efficacy of O_3 control strategies and establish more appropriate standards for human health and environmental protection

CHAPTER 2

LITERATURE REVIEW

2.1 Stratospheric Ozone

Stratospheric ozone is an important component of the atmosphere because it shields living systems from the harmful effects of UV radiation from the sun. Ozone in the stratosphere shields humans from UV radiation from the sun. It absorbs the 99% of incoming UV radiation before it reaches the troposphere. The ozone molecules that absorb UVB rays subsequently re-radiate the energy as heat, warming the stratosphere. O_3 is formed in the stratosphere when a UVB photon from the sun collides with an O_2 molecule, splitting it apart (Ritchie & Roser, 2018). One of the atoms freed by this photodissociation process attaches itself to another O_2 molecule and converting it into O_3. The troposphere reaches all the way to the stratosphere, where 'good' ozone safeguards life on Earth. The concentration of stratospheric ozone is greatest between 10 and 15 kilometres above the earth's surface.

First, the absorption of solar UV radiation splits one oxygen molecule (O_2) into two oxygen atoms (O) (Equation 2.1). In a third body reaction, each oxygen atom interacts with an oxygen molecule to generate an ozone molecule (Equation 2.2) (Langematz, 2019) :

$$O_2 + h\nu \rightarrow O + O \quad \lambda \leq 242 \text{ nm} \tag{2.1}$$

$$O_2 + O + M \rightarrow O_3 + M \tag{2.2}$$

When solar UV light is accessible, photochemical ozone production happens in the stratosphere. The formation of stratospheric ozone is balanced by chemical destruction, in which an O_3 molecule is broken down into an oxygen molecule and an oxygen atom by solar UV radiation absorption (Equation 2.3). The oxygen atom then interacts with either another oxygen molecule or an ozone molecule to form a new O_3 molecule (Equation 2.2) and combines with an ozone molecule to rebuild two oxygen molecules (Equation 2.4):

$$O_3 + h\nu \longrightarrow O_2 + O \quad \lambda \leq 1180 \text{ nm} \tag{2.3}$$

$$O_3 + O \longrightarrow 2O_2 \tag{2.4}$$

The ozone layer in stratosphere typically absorbs 97% to 99% of incoming UVB radiation. Higher concentrations of ozone in the stratosphere is therefore essential to ensure life including humans at ground-level are not exposed to harmful concentrations of UVB radiation. The dynamic equilibrium between the generation and destruction of ozone today maintains the normal concentration of stratospheric ozone. Trace amounts of hydrogen, nitrogen, and halogen free radicals, particularly chlorine and bromine, catalyse the breakdown (Staunton-Sykes et al., 2021). These free radicals occur naturally, but industrial activities have considerably enhanced the concentration in recent decades. This has disturb the equilibrium and led to a sustained decline in stratospheric ozone concentrations. The Montreal Protocol's efficiency in averting major increases in UVB radiation (280–315 nm) at the Earth's surface has been proven by comparing UV observations at several clean-air sites to model simulations of the "World Expected" and "World Avoided" scenarios (Bernhard et al., 2020).

2.2 Ground-level Ozone

Ground-level ozone is one of the most common pollutants found in the earth's troposphere layers. It is therefore commonly referred to as 'bad' ozone. Troposphere ozone, also known as ground-level ozone, is a highly phytotoxic pollutant that is created primarily by photochemical reactions and the presence of its precursors, which are generally produced by human activities and natural processes (Awang et al., 2016). Ozone is an uncommon pollutant since it is not emitted directly into the environment. Ozone is formed when primary pollutants such as NOx and VOCs, as well as Non-Methane Hydrocarbons (NMHC), which are referred to as ozone precursors, react with solar in the troposphere (Sharma, 2021).

The transformation of land use from forest to agronomic, residential and town use has created a change in the O_3 precursor to rise up, which can be seen clearly between urban and rural areas (Kulkarni et al., 2016). This process usually results in the development of large concentrations of O_3 downwind and in suburban regions resulting higher anthropogenic precursors causing a high concentrations of O_3 (An et al., 2015). Thus, the concentration of ozone in Malaysia's urban, suburban, and industrial areas has been researched, with the emphasis mostly on the state of air quality and its sources. (Azmi et al. 2010). Previous research on land use and compliance found that major concerns with air quality only exist in heavily urbanised locations on the Malaysian Peninsular. This is due to the presence of dust, suspended particulate matter, and lead in the ambient air around public roadways (Afroz et al., 2003).

Ground-level ozone concentrations are also affected by elevation, with larger amounts being observed at locations in the unrestricted area. It's impossible to disperse a constant background O_3 concentration due to the various complicated natural and anthropogenically generated elements that impact present O_3 levels and variations (Roxanne, 2004). Ahamad et al. (2014) studies have shown that diurnal variations as well as weekdays and weekend time obviously give impact in determining O_3 concentrations. Previous studies has made by using cluster paths suggests that inter-continental influence and long-distance transport has led to high concentrations of O_3 to other areas (Latif et al., 2012).

2.3 Formation of Ground-level Ozone

Ozone is a greenhouse gas in the troposphere. It is a secondary pollutant produced by sunlight driven chemical interactions between NO_x and VOCs, which include CH_4, CO, and a variety of other more complex molecules (Daniela, 2014). According to studies by air quality researchers, O_3 level increase usually was influenced by the complex reaction between NOx and VOCs in the atmosphere produced by motor vehicles and industrial combustion processes (Ahamad et al., 2014). In urban areas in particular, the concentration of NO released from the traffic will affect the formation of NO_2. High concentration of NO produced by motor vehicles may result in reduced O_3 concentration in busy areas, but it will increase the concentration of NO_2.

High NO concentration will effectively titrate of atom (O) in urban areas due to emission from large amount of transportation. The formation of ground-level ozone started by formation of NO in (Equation 2.5). While NO react with O_2 and absence of sunlight will form NO_2 in (Equation 2.6). The titration of NO_2 with sunlight will form NO and O as shown in (Equation 2.7). Then, the radicals O that emitted by transporting downwind of NO will interact with the O_2 to form the O_3 (Equation 2.8) (Latif et al., 2016):

$$N_2 + O_2 \rightarrow 2\,NO \qquad (2.5)$$

The NO formed inside the vehicles engine reacts with O_2 in air to form NO_2 as in (Equation 2.6)

$$2NO + O_2 + hv \rightarrow 2NO_2 \qquad (2.6)$$

$$NO_2 + hv \rightarrow NO + O \qquad (2.7)$$

$$O + O_2 \rightarrow O_3 \qquad (2.8)$$

The equilibrium between chemical reactions that make and break ozone determines ozone abundances in the stratosphere and troposphere. The number of reactive gases in the atmosphere, as well as how the pace or efficacy of the various reactions vary with solar intensity, elevation in the atmosphere, temperature, and other factors, define the equilibrium (Latif et al., 2016). As atmospheric conditions change to O_3 producing reactions in a certain location O_3 concentration increase.

Besides that, NOx emissions are mainly come from combustion activities such as vehicles and industry while VOCs are emitted by both human activities and natural resources (Latif et al. 2016). The VOCs present in the atmosphere have several natural and anthropogenic origins, such as exhaust from vehicles, solvent evaporation, petroleum refining, bio decomposition of wastes, and different industrial processes. The formation of ozone in the troposphere, in the absence of VOCs, is presented in reactions (Equation 2.7 to Equation 2.9) (Geraldino et al., 2020):

$$NO_2 + h\nu \rightarrow NO + O \ (< 420 \text{ nm}) \tag{2.7}$$

$$O + O_2 + M \rightarrow O_3 + M \tag{2.8}$$

$$O_3 + NO \rightarrow NO_2 + O_2 \tag{2.9}$$

2.4 Air Pollutant in Malaysia

Pollutants in the air have a direct impact on our quality of life. The quality of the air might fluctuate from day to day, or even hour to hour. As a result, detecting polluted air is critical for providing an early warning system for air quality control and management, as well as public awareness. The air pollution index (API) was created as a reference measure for expressing air quality condition so that everyone may easily recognise and comprehend current events such as weather forecasts.

The API in Malaysia was designed using the API provided by the United States Environmental Protection Agency (USEPA), and it is based on the computation of sub-indices of five major pollutants. The pollutants which are particulate matter diameter 10 (PM_{10}), Ozone (O_3), carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) (Rahman & Lee, 2020). It can be used by government agencies to define the condition of air quality because API allows for easy assessment and normalization at any given site across countries (Sansuddin et al. 2011). API also assists the general population in simply understanding the air quality state for their personal health precautions. This information with different ranges are reflected as 'Good (0 to 50), Moderate (51 to 100), Unhealthy (101 to 200), Very Unhealthy (201 to 300) and Hazardous (301 and above)' (Leh et al. 2012). These ranges are used as a baseline for air quality control or for data analysis in decision-making processes (Afroz et al. 2003).

In Malaysia, there have been 76 continuous air quality monitoring in Malaysia recorded ambient air for gaseous pollutant such as PM_{10}, $PM_{2.5}$, O_3, CO, SO_2, NO , NO_x and NO_2 and weather parameter wind speed, wind direction, temperature, humidity and UVB (Ahmat et al., 2015) . Table 1.1 shown the New Ambient Air Quality Standard in Malaysia.

Table 2.1: New Ambient Air Quality Standard (Department of Environment, 2020)

Pollutants	Averaging Time	Ambient Air Quality Standard		
		IT-1 (2015) $\mu g/m^3$	IT-1 (2018) $\mu g/m^3$	IT-1 (2020) $\mu g/m^3$
PM_{10}	1 Year	50	45	40
	24 Hour	150	120	100
$PM_{2.5}$	1 Year	35	25	15
	24 Hour	75	50	35
SO_2	1 Year	350	300	250
	24 Hour	105	90	80
NO_2	1 Year	320	300	280
	24 Hour	75	90	70
O_3	1 Hour	200	200	180
	8 Hour	120	120	100
CO	1 Year	35	35	30
	8 Hour	10	10	10

Nowadays, due to expanding sources of its precursors, O_3 has become one of the most major air pollutants (Fuks, Woodby & Valacchi, 2019). Since ozone is a secondary pollutant formed by a chemical reaction that happens in air with the presence of sunlight, there are no significant primary emissions of O_3 in the atmosphere (Abdul-Wahab et al., 2005). When its precursors, such as NOx or VOCs, chemically interacted in the presence of UV radiation (hv 430nm) by sunlight, O_3 was formed in the ambient air. Ozone precursors can be produced by natural, mobile, and permanent sources such as vehicle, forest, and power plant emissions (Mohammed et al., 2012).

Urban areas such as Kajang faced severest O_3 pollution compared to sub urban, industrial and background areas. Urban citizen were exposed to higher concentration of ozone compared to other areas (Awang, Ramli, Mohammed &Yahaya, 2013). Ismail et al (2011) reported that the ozone level in the Kemaman area has been continuously rising and is expected to approach 40 ppb by 2019 if no effective interventions are implemented.

2.5 Impact of Ground-Level Ozone

Ozone may adversely affect human health, plant growth and environmental change and may contribute to global warming (Alghamdi et al., 2014). A prior study found that an increased ozone could induce health and mortality in humans (Xie, 2017). Larger premature mortalities are shown in cities in the eastern China due to high O_3 levels and large population (Lu et al., 2020). Air pollution may harm ecosystems, materials, structures, works of art, plants, and visibility, in addition to causing harm to human health (Ilyas et al., 2009).

Ground-level ozone at the lower atmosphere especially on hot sunny days can reach unhealthy levels and can harm the wellbeing since living things inhale regularly. Individuals whom with asthma, infant, older adults, and individual who are active outdoors, including the outdoor workers are the one with highest risk (Guo, Su, Zhou & Shi, 2014). Asthma has been attributed to O_3 pollution, and adolescents have been identified as the most vulnerable individuals when compared to non-smoking adults and the elderly (Gorai et al., 2016). Constant night time exposure to O_3 concentrations will likely pose a health risk for this weak individual (Sheffield et al., 2015). Breathing air containing O_3 can trigger several health issues including damage and inflammatory responses, coughing, reduces lung functions, throat irritation and asthma problems (Yang et al., 2014).

Previous studies have shown that O_3 can also affect and reduce production of agricultural crop such as paddy plant (Amin, 2014). O_3 can affects the plants, by damaging the membrane on leaves hence affecting the photosynthesis process (Emberson et al., 2018). For certain sensitive plant, O_3 can obstruct the capacity of the plants to deliver and store food. During normal gas exchange, ozone can enter plant leaves through the stomata (Ashmore, 2005). Ozone as a strong oxidant and its secondary by products may damage the vegetation which reducing the photosynthesis process and other important physiological functions will resulting in stunted plants, lesser crop quality, weaker, and decreased yields (Yi, Feng, Wang & Jiang, 2020). Many of previous studies focus on the effect of day time surface ozone they prove that O_3 has a direct negative impact on vegetation.

2.6 Relationship Ground-level Ozone With Weather Parameters

The ground-level ozone production is also influenced by weather conditions at the specific areas. The relationship between O_3 and meteorological had received greater consideration and have been done widely by many researcher. Previous research has found that the essential components influencing ground-level ozone concentrations are precipitation, air temperature, relative humidity, solar radiation, surface air pressure, and wind speed (Tang et al., 2012). Meteorological circumstances were the major determining elements throughout the year, which is consistent with previous study that meteorological factors play important roles in the formation of ground-level ozone (Cheng et al., 2019). Radiation, temperature, and humidity cause the chemical reactions that produce ozone, whereas boundary layer characteristics and the absence of wind, respectively, lead to the accumulation of precursors and limit their dispersion.

The concentration of O_3 was highest at middle of the day when the intensity of UVB was at the highest level. The formation of the O radical, which is required for the production of O_3 from its precursors such as NO_x and VOCs, is aided by a significant amount of sunlight (Xie et al., 2016). At midday, the concentrations of these precursors were very low due to their transformation into other secondary pollutants such as O_3 and the convective movement of pollutants to higher elevations (Latif et al. 2016). Kaniah et al. (2016) indicated that motor vehicle exhausts were the primary source of air pollution throughout that time period, with high emissions of trace gases largely during morning rush hours, but late evening peaks were mostly impacted by meteorological conditions such as low mixing height, which favours the build-up of aerosol and pollutants near the surface. The concentrations of the O_3 precursors peaked when people travel back home from work is due to emission of NO_x and VOC_s from vehicles and react with sunlight to form an O_3. The concentrations of O_3 precursors including NO, NO_2, NO_x and CO decreased less steeply during night because to increased air stability and the lack of sunshine, which reduced the scavenging response of photocatalytic oxidants (Awang et al., 2015). Most of the studies exposed that the ozone concentration has a positive correlation with temperature and negative correlation with humidity. Due to climate change, the surface ozone concentration is increasing since there are elevated in temperature that results in high reaction rate of the ozone precursors (Ozbay et al., 2011). Lu (2018) stated that the precursors involved such as NO_x, VOCs, carbon monoxide (CO) and Methane (CH_4). These substances react with sunlight at atmosphere surface to react with O_2 to form O_3. In other hand, irradiation, windspeed, temperature is also found to play a significant role in influencing ozone concentrations. Abdullah et al (2017), stated that maximum temperature had an impact on ozone concentration. Diurnal changes of daily maximum temperature and daily maximum ozone concentration were shown to be significantly different in long term variation. Cloudy weather with less solar irradiance influenced the O_3 concentration due to less UVB that can react with O_3 precursors. Furthermore, the elevated level of O_3 precursors variations in low level atmosphere could not be fully related with temperature only, but there are other meteorological factors that might be affecting the O_3 concentration.

Peninsular Malaysia is mainly affected by two different monsoon regimes namely the South West Monsson (May to August) and the North East Monsoon (November to February) (Tangang et al., 2012). During the NEM, north and east of Peninsular Malaysia receives heavy rainfall compare to other parts of the Malaysia. During the SWM, Peninsular Malaysia does have a dry and hot season with clearer sky and lower rainfall. Ground-level ozone production are very favourable under this situation as this increases photochemical production of O_3 (Wang et al., 2017). Hence, high humidity is typically associated with the frequency of rain events, which decreases the concentration of trace gases in the atmosphere owing to the wash-out processes of atmospheric particles. The association of humid days with enhanced cloud cover reduced the photochemical reaction that lead to O_3 formation (Xu et al., 2011). Consequently, there is a negatively correlated between humidity and O_3 in ambient air. The association of humidity with rain may decreased the emissions of O_3 precursors (Tawfik & Steiner, 2013).

The influence of meteorology condition on ozone concentrations includes transportation of ozone and its precursors by wind speed that will affecting the photochemical reaction rate of production and destruction of O_3 (Ghazali, Yahaya,Yusof, Sansuddin & Al Madhoun, 2010). The transportation of air pollutant by wind influenced the high concentration of O_3 in certain areas which the direction of wind come from polluted area which emission from industrial and urban area (Latif et al., 2016). The concentration of pollutant may reduce at place near to coastal regions due to the local scale wind system such as the land-sea breeze

2.7 Relationship of Ground-Level Ozone with Its Precursors

Ground-level ozone level had been increased since industrial that have been attributed primarily to increases in anthropogenic emissions of NO_x and CH_4 which is the latter of the most abundant reactive carbon species in the atmosphere (Stevenson et al.,2013). Previous research at the Klang Valley area was a developed industrial and economic zones in the Malaysia and heavy traffic flow was the main reason for the elevated atmospheric pollutants in this areas (Azmi et al., 2010). The association of O_3 to NO_x emissions from different modes of land transport, sea transport, and aircraft were most efficient at producing atom O from NO_x (Glasow, 2003). Ground-level ozone is formed as a result of a series of photochemical reactions between its precursors such as NO, NO_x, NO_2 and CO. As a result, once O_3 is formed, it is eliminated from the atmosphere via a variety of mechanisms, including photolysis in the presence of water vapour and chemical reactions with NOx, as well as dry deposition methods such as surface deposition and nitric titration (Abdul-Wahab & Al-Alawi, 2005). Ozone is formed when a combination of Nitrogen (N) and O_2 is exposed to UVB and occurs in contaminated air at lower atmosphere surface. The source of the oxygen atoms for ozone formation is provided by the photolysis of NO_2 in the (Equation 2.8) 'M' represents an unstable molecule such as nitrogen (N_2) or O_2, and O (^3P) represents an equilibrium state or low energy oxygen atom that interacts with molecular O_2 to produce O_3 (Harnung & Johnson, 2012):

$$NO_2 + h\nu \rightarrow NO + O\ (^3P) \qquad (2.7)$$

which is then followed by

$$O + O_2 + M \rightarrow O_3 + M. \qquad (2.8)$$

The nitric oxide formed in reaction (Equation 2.7) reacts rapidly with O_3 reforming NO_2

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (2.9)$$

As in the troposphere, this process does not result in net ozone gain, but rather maintains a dynamic equilibrium between O_3, NO, and NO_2 that is dependent on solar actinic radiation and nitrogen oxide concentration. Additional processes must be included in order to explain pollution episodes with elevated ozone concentrations. This is due to the simultaneous presence of NOx and VOCs, which causes the total response. (Harnung & Johnson, 2012):

$$NOx + VOC + h\nu \rightarrow O_3 + M \quad (2.10)$$

This equation is generally started by the reaction between one of the O_3 precursors and the hydroxyl radical OH which produces HO_2 that then reacts with nitrogen monoxide NO to produce NO_2. Without O_3 being consumed and thus bypassing reaction (Equation 2.11), the dynamic equilibrium between NO and NO_2 in reactions (Equation. 2.7) and (Equation 2.9) is thus perturbed and shifted towards NO_2, which upon photolysis produces O atoms and thus leads to the formation of ozone. As a result of the dynamic equilibrium formed by the fast photochemical cycling of NO, the O_3 concentration will increase. The equation is illustrated by the following chemical chain, which includes the precursor molecule CH_4. First, OH react with the methyl radical (Harnung & Johnson, 2012):

$$CH_4 + OH \rightarrow CH_3 + H_2O \quad (2.11)$$

which then reacts with molecular oxygen to form the methylperoxy radical (CH_3O_2)

$$CH_3 + O_2 + M \rightarrow CH_3O_2 + M \quad (2.12)$$

The methylperoxy radical combines with nitric oxide NO and produces a methyloxy radical CH_3O and nitrogen dioxide NO_2, followed with a consequent formation by photolysis of an oxygen atom that can react with O_2 producing O_3:

$$CH_3O_2 + NO \rightarrow CH_3O + NO_2 \quad (2.13)$$

Another sink for CH_3O_2 is the reaction with HO_2:

$$CH_3O_2 + HO_2 \rightarrow CH_3OOH + O_2 \quad (2.14)$$

The methoxy radical (CH_3O) undergoes reaction with O_2 to form formaldehyde (CH_2O) and HO_2 ($CH_3O_2 + NO \rightarrow CH_3O + NO_2$).

$$CH_3O+O_2 \rightarrow CH_2O + HO_2 \quad (2.15)$$

Formaldehyde can either photolyze in the two possible channels (Equation 2.16 and 2.17) to form respectively CHO radical or CO or react with OH to form CHO as well:

$$CH_2O + h\nu + O_2 \rightarrow CHO + HO_2 \quad (2.16)$$

$$CH_2O + h\nu \rightarrow CO + H_2 \quad (2.17)$$

$$CH_2O + OH \rightarrow CHO + H_2O \quad (2.18)$$

The CHO radical reacts with O_2 forming CO and HO_2 (Equation 2.19)

$$CHO + O_2 \rightarrow CO + HO_2 \quad (2.19)$$

Carbon monoxide is then oxidized through OH originating an ozone producing cycle which can be summarized as in (Equation 2.20)

$$CO + 2O_2 \rightarrow CO_2 + O_3 \quad (2.20)$$

and which proceeds by the following individual reaction steps (Equation 2.21 to Equation 2.25)

$$CO + OH \rightarrow H + CO_2 \quad (2.21)$$

$$H + O_2 + M \rightarrow HO_2 + M \quad (2.22)$$

$$HO_2 + NO \rightarrow NO_2 + OH \quad (2.23)$$

$$NO_2 + h\nu \rightarrow NO + O \quad (2.24)$$

$$O + O_2 + M \rightarrow O_3 + M \quad (2.25)$$

VOCs potentially lead to the formation of O_3 by a variety of photochemical events, such as hydroxyl radical (OH) initiated oxidation of VOCs, nitrogen cycling driven by peroxyl (RO_2) and hydroperoxyl (HO_2) oxidation and photolysis, and the pairing of oxygen atom O with oxygen atom O_2 (Lyu et al., 2016). In the case of NO_x rich air, the production of NO_2 takes place by reaction of NO with HO_2 or RO_2 (peroxy radicals), which ultimately helps ozone production. VOCs may come from either natural or anthropogenic sources. VOCs are naturally formed by trees and plants, forest fires caused by natural causes, and anaerobic marshy swamp processes. Metal surface degreasing, textile cleaning, food extraction, fertiliser and pesticide application, septic system, chlorination, fumigation, traffic, hydrocarbon fuel evaporation, petroleum storage, distribution and storage, landfill, printing, and construction are all examples of anthropogenic activities that produce VOCs. Other anthropogenic sources of VOCs include emissions from the chemical and petroleum industries and from organic solvents in small stationary sources such as dry cleaners (Ashfold et al., 2017). A long term study at Jerantut, Pahang on a background ground-level ozone monitoring site showed a positive ozone trend for the period between 1997 and 2011, associated with expanding anthropogenic activity in the surrounding area (Latiff et al., 2014). The adverse effects of VOC emissions on human health such as renal, haematological, neurological, hepatic, and mucosal irritation, as well as the reduction of stratospheric ozone and photochemical ozone formation at the surface level, are among the environmental and epidemiological issues caused by VOC emissions (Domingo & Nadal, 2009).

The ground-level ozone concentration react with CO at any location is measured by different physical and chemical process such as emissions, photochemical, transportation and deposition. Direct emission is a major source of CO near surface whereas hydrocarbon oxidation is an important source in the free troposphere (Drori et al., 2012). During the second half of the 20th century, tremendous economic growth and rapid industrialization in emerging countries resulted in a substantial increase in air pollution (Kim et al., 2013). Some emission assessments have been constructed to adjust for the impact of primary sources on CO concentrations (Granier et al., 2011). These measurements estimated that the regional CO limit is expanding across China and India as a result of uncontrolled industrialization and urbanisation (Granier et al., 2011).

Granier et al., (2011) estimated the manmade CO emissions increase over South Asia particularly over Indian. Given the negative impact of CO and its chemical derivative ozone on human health, considerable efforts have been made to comprehend the various processes that influence their surface and vertical distribution over the Indian subcontinent. Besides that, previous studies stated that the high values of CO over west region of Peninsular Malaysia were as result of various human and industrial activities. The high concentration CO at this area may be due to the area has high dense of the population, crowded city and large industrial area that cause CO emissions (Irwan, Amin & Akhir, 2020).

2.8 Modelling of Ground-level Ozone levels

Multiple linear regression analysis (MLR) is a method used in atmospheric sciences to express the dependency of a response variable on numerous independent (predictor) factors by fitting a linear equation to observed data. Linear regressions expressly require that the error term is normal and that the relationship between the response variable (in this example, O_3) and the covariates is linear. The Root Mean Square Error (RMSE) is a measure of the prediction error that gives an idea of the actual size of the square root of the mean of the squared deviations between predicted and observed values (Mahapatra, 2010), whereas the the index of agreement (IA) indicates how well the model fits the pattern of variation around the mean value (Elbir et al., 2011). The criteria for choosing original independent variables required a high loading with each principal component to substitute in the regression equation with a high coefficient of determination (Al-Alawi et al., 2008).

Li et al. (2019), used MLR to better understand the processes governing ozone trends in China from 2013 to 2017, they used a model to determine the primary meteorological variables driving the variability of daily ground-level ozone for each grid cell. Only the three locally dominant meteorological variables are regressed on a monthly basis. On a regional scale, they discover that the primary meteorological variables influencing ozone variability are consistent across grid cells.

Allu et al. (2020) predict the variability in ground-level ozone with precursors i.e. NO_x and CO including weather parameter i.e. temperature and humidity using MLR. The result stated that coefficients correlation for O_3 prediction through weather parameters which is more than 0.99 for all seasons in 2016 at Telangana, India. The model equation revealed that variables such as NO_x, CO, temperature and humidity influenced O_3 level significantly.

In addition, Abdullah et al. (2019) also developed model MLR to predict development of O_3 in urban areas located at Klang, Selangor. It was found that, the significant predictors were $O_{3,t-1}$, humidity, wind speed, SO_2, NO, NO_2 and temperature. O_3, temperature and wind speed have positive influence on O_3 levels while humidity, NO_2, CO, NO, and SO_2 have negative influence on O_3 levels.

Jing et al. (2016) conducted MLR model to analysed the relationship between O_3 and dry tropical weather separately for the two periods 1990–2003 and 2004–2014. The findings show that dry tropical weather contributed more to O_3 concentrations in 2004–2014 than in 1990–2003. The variation of O_3 seems to have become more strongly associated with dry tropical weather conditions in 2004–2014 than in 1990–2003. Jing et al. (2014) showed that O_3 became insensitive to NO_2 especially for high O_3 concentrations. Another factor is because, as the climate warms, temperature-related variables become more important in predicting the probability of dry tropical weather, and temperature is significantly related with O_3.

Awang et al. (2015) applicable of the MLR and PCR models during day-time, night-time and critical conversion time in predicting the variation in O_3 concentration. The selected variables that comprised NO_2, NO, SO_2, CO, PM_{10}, $O_{3,t+1}$, temperature, humidity, wind speed, and UVB were proven to explain the O_3 variability better during critical conversion time with 69.9%, compared with that during day-time (68.8%) and night-time (63.7%). MLR exhibited significantly better performance during day-time compared with that during night-time and critical conversion time.

Han et al. (2020) the MLR was used to determine the primary meteorological sources of ozone variability. According to the regression model, meteorology accounts for 18% of the rise in the local mean of middle summer seasons of ground-level ozone across eastern China from 2013 to 2018. Using the MLR, they were able to identify the primary climatic factors responsible for daily fluctuations in middle summer ground-level ozone in eastern China from 2013 to 2018. Relative humidity is the most important climatological variable in most parts of eastern China's centre and south, whereas temperature is the most significant aspect in the north.

In conclusion, most of the studies determined comparison of using MLR with others models to evaluate significant of O_3 precursors and weather parameter. Previous study mostly observed the variation of O_3 in certain seasons such as cold seasons and hot seasons. The limited of the study during day-time and night-time was concerned to this study to develop model using MLR.

CHAPTER 3

METHODOLOGY

Hourly data set of air pollutants and weather parameter were collected from DOE Malaysia which is from 2016 to 2020 (5 years). The location of monitoring station are at Seremban, Kuala Terengganu and Perai. The air pollutant parameters used in these studies were O_3, PM_{10}, CO, SO_2, NO_2, NO and NO_x. In addition, weather parameters, such as: wind speed, temperature, UV radiation and humidity also used.

Firstly, the data were sorted according to day, month and year. Then, the distribution of data was measured using descriptive statistics, boxplot and diurnal plot. The spatial characteristics was observed using contour plot . Next, the association of ozone with the weather and anthropogenic precursors in those three cities was analyesd using Spearman Correlation Analysis. Finally, Multiple Linear Regression (MLR) was used to develop model of day-time and night-time O_3 level. The summary of the research flowchart for this project is shown in Figure 3.1.

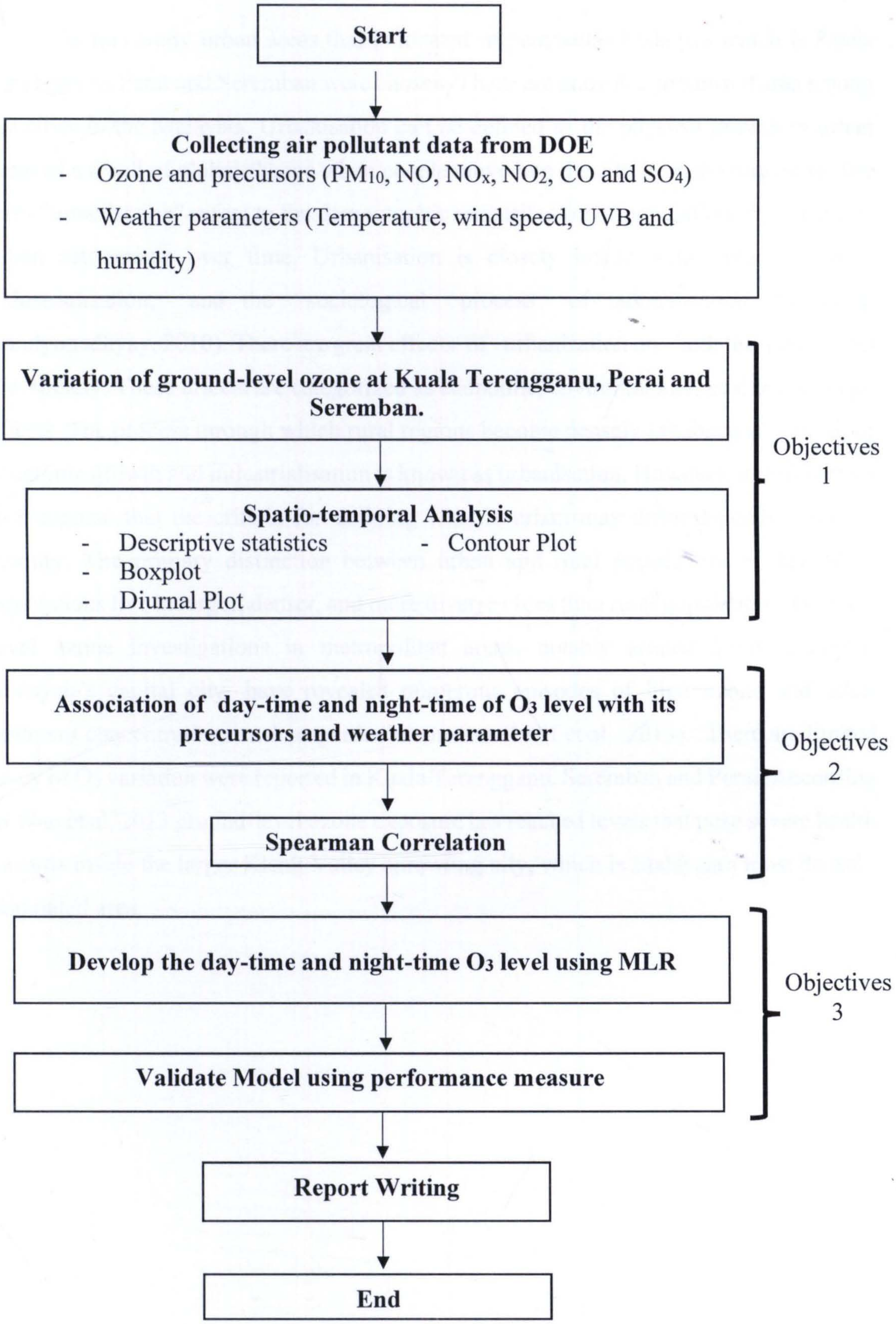


Figure 3.1: The research flowchart

3.1 Background of The Study Area

In this study urban areas that is located in peninsular Malaysia which is Kuala Terengganu, Perai and Seremban were chosen. Those are known as urbanized area among the cities in the Malaysia. Urbanisation can be defined as the physical growth of urban areas as a result of global change when people move into the city from the rural area. The term "urbanisation" refers to the demographic redistribution of populations from rural to urban settlements over time. Urbanisation is closely linked with modernisation, industrialisation, and the sociological process of rationalisation (Bhatta & Bandyopadhyay, 2010). There are great effects of urbanization on both the people and the society. These effects are categorized as economic, environmental, health and social effects. The process through which rural regions become densely inhabited as a result of economic growth and industrialisation is known as urbanisation. However, it is important to recognise that the criteria for defining what is urban may differ depending on the country. The primary distinction between urban and rural populations is that urban populations live in larger, denser, and more diverse cities than rural populations. Ground-level ozone investigations in metropolitan areas, notably around Kuala Lumpur, Malaysia's capital city, have revealed numerous episodes of high ozone and other pollutant concentrations such as particulate matter (Latif et al., 2013). There are limited study of O_3 variation were reported in Kuala Terengganu, Seremban and Perai. According to Wan et al, 2013 ground-level ozone exposure has reached levels that pose severe health hazards inside the larger Klang Valley sprawling city, which is Malaysia's most densely populated area.

3.1.1 Kuala Terengganu

Kuala Terengganu is located in the southern region of the South China Sea, the Western Pacific Ocean's largest semi-enclosed marginal sea. Terengganu is a constituent state of the Malaysian Federation, located in Peninsular Malaysia on the Asian continent's mainland. Kuala Terengganu is bounded to the north by Kelantan and to the south by Pahang. Terengganu population primarily resides in coastal towns and villages. Kuala Terengganu is Terengganu's principal political and economic centre. (Albani, 2013).Terengganu is located on the east coast of Malaysia with the total area of 210 km^2. The total population of the state in 2019 was 261,300 (Department of Statistics, 2020). The air quality monitoring stations is located in Kuala Terengganu at Sekolah Kebangsaan Pusat Chabang Tiga (5.3066, 103.1217). The location of the study area was depicted in Figure 3.2. The monitoring station is nearby to main road namely Jalan Kota Bharu and nearby to Mydin Mall about (2 km). There are many of the residential area around the monitoring area. The population are concentrated in this area due to its proximity to public facilities such as schools and towns.

The amount of rainfall varies according to the monsoon season. The monitoring area, Kuala Terengganu is an urban coastal location that experiences two main monsoons annually. The meteorological features for these two monsoons vary substantially, with the northeast monsoon (NEM) occurring from November to March and the southwest monsoon (SWM) occurring from May to September (Fong, Abdullah & Ismail, 2018). Meanwhile, the South China Sea breeze moderates humidity in offshore locations, while the height and lush forest trees and plants have cooled urban and rural areas (Besi, Nikong & Mustafa, 2019).

Figure 3.2: Location of monitoring station in Kuala Terengganu (Source: Google map, 2022)

3.1.2 Seberang Perai

The mainland part of the state of Penang is referred to as Seberang Perai. The Penang Strait separates it physically from Penang Island to the west. The Muda River forms the Penang-Kedah border to the north, while a little stretch of the Kerian River constitutes the Penang-Kedah border to the south. The land area of Seberang Perai is 751 km^2 (Department Of Statistics, 2020). Rapid urbanisation of Seberang Perai has increase the population due to greater industrial activity and the location of the Penang Bridge's terminus within the district. Seberang Perai has developed into a major economic hub for Peninsular Malaysia's northern area (Samat et al. 2011) The Central District, which includes Perai and Bukit Mertajam, has seen a greater concentration of manufacturing industries, making it the most industrialised district in Seberang Perai. Monitoring station is located at Sekolah Kebangsaan Seberang Jaya 2 (5.3979, 100.4043). The location of monitoring station in is shown in Figure 3.3. There are many of residency and housing near to the monitoring station and the whole Seberang Perai populated about 428,500 in 2020 (Department of Statistic, 2020). The Butterworth-Kulim Express highway and North-South highway is close to the monitoring area. Plus, industrial area which is Free

Industrial Zone (FIZ) also located within 5 km with the monitoring area. Hence, high air pollutants emission from vehicle can be expected.

Seberang Perai, like the rest of Malaysia, has a tropical rainforest environment, but it also has a tropical monsoon climate. Between December and February of the following year, Seberang Perai experiences slightly drier conditions. It receives approximately 2,477 millimetres (97.5 in) of precipitation per year, with the lowest being 60 millimetres (2.4 in) in February and the maximum being approximately 210 millimetres (8.3 in) between August and October (Tijs et al., 2019).

Figure 3.3: Location monitoring station in Seberang Perai (Source: Google map, 2022)

3.1.3 Seremban

Negeri Sembilan is a state in Malaysia which located at western coast of Peninsular Malaysia. Seremban is a capital of Negeri Sembilan It occupies a total land area of approximately 935.78 sq. km and includes the districts of Seremban town, Setul, Labu, Rasah, Ampangan, Rantau, Pantai, and Lenggeng with population of 608,700 in 2020 (Department Of Statistic, 2020). Seremban is situated about 60 km south of Kuala Lumpur which is the capital city of Malaysia and about 20 km from Putrajaya. Since the establishment of The Linggi River has played a significant part in the development of Seremban. The Linggi River served as an important transit route for tin dealers during the tin mining boom. Recent years, oil palm and rubber plantations is the major economy in Negeri Sembilan.

Negeri Sembilan is experiencing SWM, which has triggered variability in rainfall episode across district areas to form two significant features to the area on the west, which is Seremban of the highlands up to the coast, indicates an increase in annual rainfall, whereas the area on the east, which includes Jelebu and Kuala Pilah, indicates a decrease in rainfall (Rahmat, Ishak, Yahaya & Masrani, 2019). Figure 3.4 shows the location of monitoring station that is situated at Kolej Vokasional Ampangan (2.7250, 101.9708). The monitoring area is near to the main road that connect Seremban to Kuala Pilah. Many residential areas were located near to the monitoring area.

Figure 3.4: Location monitoring station at Seremban (Source: Google map, 2022)

3.2 Air Pollutant Dataset

Continuous hourly air quality data from 2016 to 2020 were obtained from the Air Quality Division of the Department of Environment. This study used 11 variables that were divided into two groups. One group comprised seven air pollutants, such as ground–level ozone O_3 (ppm), NO_x (ppm), NO (ppm), SO_2 (ppm), NO_2 (ppm), CO (ppm), and PM_{10} ($\mu g/m^3$). While weather parameters are wind speed (m/s), temperature (°C), humidity (%) and UVB (W/m^2). These data were sorted in Microsoft Excel according to diurnal cycle since O_3 level significantly varies during day time and night time.

3.3 Variation of ground-level ozone

A few analysis had been done to study the variation of ground-level ozone in the three study areas this analysis includes descriptive statistics, boxplot and diurnal plot.

3.3.1 Descriptive Statistics

In this work, descriptive statistics was calculating using Statistical Package for Social Science (SPSS) software. The results were presented in the table and box-plot was used to visualised the distribution of O_3 level in the three areas. The detail of boxplot was elaborated in the next section. The process of collecting, organizing, summarizing and presenting the data also part of the descriptive statistic. It interpreted the data by using central tendency such as mean, median, maximum, minimum and standard deviation the formula as stated in **Table 3.1** below.

Table 3.1: Descriptive statistics formula (Goos & Meintrup, 2015)

Descriptive Statistics	**Formula**	**Description**
Mean	$\bar{x} = \frac{\sum x}{n}$	x = Observations given n = Total number of observations
Median	Odd: $x = \frac{n+1}{2}$ Even: Median = n/2 and n/2+1	n = Total number observaion
Standard Deviation	$s = \sqrt{\frac{\sum(x-\bar{x})^2 - \bar{x}^2}{n-1}}$	x = Observations given $\bar{x}$ = Mean n = Total number of observations

3.3.2 Box Plot

Box plot analysis is a regularly used to show the distribution characteristics of group of dataset as well as level of scores (Thirumalai, 2017). Box plot will also interpret the descriptive statistics such as mean, maximum and minimum value of the data. It is a simple method to demonstrate the data spread through their quartiles which are lower quartile (Q1), median (Q2), upper quartile (Q3) and outliers. It gives an excellent review of data dispersion. Figure 3.5 show the box plot visualized median (Q2/50th Percentile) is the middle value of the dataset. The first quartile (Q1/25th Percentile) is the number in the midpoint of the dataset's smallest (not "minimum") and median values. The third quartile (Q3/75th Percentile) of a dataset is the value that falls between the median and the highest values "maximum". Meanwhile, the whiskers part is used to represent the maximum and minimum values. The highest score, excluding outliers, is given at the right whisker's end. The higher and lower whiskers show scores that are outside the middle 50%. i.e. the lower 25 percent of scores and the upper 25 percent of scores. The interquartile range (IQR) represents the middle 50% of all scores i.e. the range between the 25th and 75th percentile (McLeod, 2019).

In this research, box plot was used to visualised the distribution of O_3 concentration at the three different monitoring stations. The annual, monthly, weekdays and weekend of the O_3 level were observed using box plot that was constructed using SPSS software. Its displayed the skewness through displaying the data quartiles.

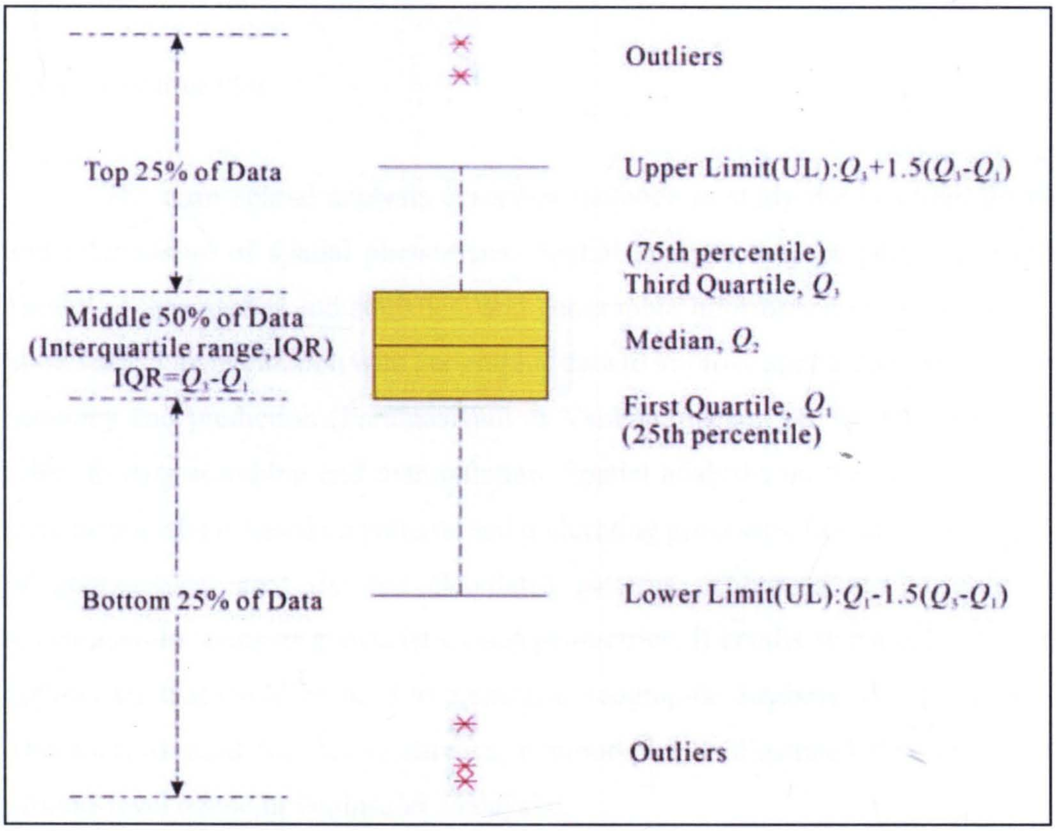


Figure 3.5: Visualized box plot (Zhang & Yao, 2020)

3.3.3 Diurnal Plot

The diurnal plot is used to identify behaviour by showing and averaging hourly values over a 24-hour period (Baxla, Roy,Gupta & Bandhopadhy, 2009). A diurnal cycle is anything that transpires on a daily basis. A diurnal profile in atmospheric chemistry depicts the patterns in a given concentration of gas through time at each hour of the day using an hourly scale. They are great for visualizing how a trace gases and O_3 changes in the atmosphere throughout the day. It can show the relationship and effect of ozone concentration towards its precursors, and show the variations were in hourly. In this research trace gases such as NO, NO_2, No_x and CO were used to visualized the data trend towards O_3 concentration. The trend visualized when the destruction of O_3 precursors to form and O_3 especially during day time. The plot is also capable of illustrating the exact time.

3.3.4 Contour Plot

The term spatial analysis describes methods to study the location, distribution, and relationship of spatial phenomena. Spatial analysis may be performed utilising a variety of approaches and statistical and geographic information systems (GIS). A GIS allows attribute interaction with geographic data to improve spatial analysis interpretation accuracy and prediction (Paramasivam & Venkatramanan, 2019). The term "analysis" refers to data searching and manipulation. Spatial analysis, on the other hand, refers to statistical analysis based on patterns and underlying processes. Location analysis is a type of geographical analysis that elucidates patterns of human attributes and spatial appearance in terms of geostatistics and geometrics. It entails statistical and processing approaches that could be used to a specific geographic database. (Cucala et al., 2018). The analysis used for this research is contour plot to illustrated the concentration of ground-level ozone in Peninsular Malaysia.

A contour plot is used to display a three-dimensional (3D) surface on a two-dimensional (2D) plane. The line is drawn to connect the x and y axes, and the contour value is z. The contour plot is used in this study to depict the monthly variation of ground-level ozone levels using hourly data. By using Microsoft Excel, the data of concentration O_3 were sorted by monthly average for 5 years at 3 different monitoring station ie. Seremban, Kuala Terengganu and Perai. Then, by using ArcGIS software, the types of GIS using for contour plot were interpolated and extracted. This approach predicts unidentified values for any geographical location data such as precipitation, height, depth, chemical parameter concentrations, pollution levels, and other factors. Inverse Distance Weighing (IDW) on of interpolation method to show weights observed as a reducing function of distance (Setianto & Triandini, 2013).

3.4 Spearman Correlation

A nonparametric measure of the relationship between two sets of ordinal ranked values is Spearman rank correlation (ρ) (Astivia & Zumbo, 2017). A Spearman coefficient is essentially a Pearson correlation coefficient calculated using the ranks of the values of the two variables rather than their actual values. (rho) or "r_s" is a typical abbreviation for a Spearman coefficient. The application of a Spearman coefficient is not confined to continuous variables because ordinal data can be ranked. The coefficient quantifies strictly monotonic correlations between two variables by calculating ranks. A nonlinear strictly monotonic connection is converted to a linear relationship by rating the data. A Spearman coefficient varies from −1 to +1, similar to the Pearson coefficient. It may be used to describe anything in the range of no relationship to strong association with (ρ = 0) to a perfect monotonic relationship (ρ = −1 or +1) (Schober, Boer & Schwarte, 2018). The negative value state that the relationship is negatively correlated while positive value indicates that the relationship is positively correlated. The same criteria apply to the interpretation of confidence intervals and P values for a Spearman coefficient as they do for a Pearson correlation. The correlation and association of ozone concentration and its precursors and weather parameter can be identified using Spearman Correlation Analysis (Equation 3.1) (Jia et al., 2020):

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{3.1}$$

ρ = Spearmen's Correlation coefficient

d_i = difference between two ranks of each observation

n = number of observation

In this research, Spearman Correlation was used to analysed the significant precursors and weather parameter towards O_3 concentration. The analysis was divided into two different time which is day time (7:00 am to 7:00 pm) and night time (8:00 pm to 6:00 am). The result were displayed in form of heat matrix to visualized the correlation of O_3 precursors and weather parameters with O_3 level. The heat matrix were conducted using Microsoft Excel and the Spearman Correlation analysis using SPSS software.

Because the correlation is an effect size, the absolute value of "ρ" of the correlation can be described informally using the following guide. Table 3.2 shows the description of correlation using the following guide for the absolute value of "ρ" (Mukaka, 2012):

Table 3.2: Shows the description of correlation related to the value of ρ

Value of ρ	**Description**
0.00 – 0.19	Very weak
0.20 – 0.39	Weak
0.40 – 0.59	Moderate
0.60 – 0.79	Strong
0.80 – 1.0	Very Strong

3.5 Multiple Linear Regressions (MLR)

MLR is a conventional method used to model air pollutants. MLR offers modelling the connection between two or more independent variables and a dependent variable by fitting a linear equation to the observed data. Multiple linear regression analysis is a statistical technique that can be used to examine the relationship between a single dependent (criterion) variable, y, and several independent (predictor) variables, x's. A random response y relating to a set of independent variables x1, x2,..., xk based on the multiple regression model. MLR act as a predictive analysis and used to describe the relationship between one dependent variable with more than two independent variables. The application of regression analysis and bivariate techniques has been used to predict O_3 concentration for next 12 hour. Thus, this studies conducted two different time of O_3 concentration which is day time (7:00 am to 7:00 pm) and night time (8:00 pm to 6:00 am) for 3 monitoring station at Seremban, Kuala Terengganu and Perai. By using Rapid Miner software, the coefficient result were displayed in form weight bar graph. MLR also can show variability association between the independent variable and the dependent variable by fitting the observed data into a linear equation (Equation 3.2) (James, Witten, Hastie & Tibshirani, 2015):

$$Y_i = \beta_0 + \beta_1 X_1 + ... + \beta_k X_i + \epsilon_i \quad (3.2)$$

Where, for i = n

observations :

Y_i = dependent variable

X_i = explanatory variable

B_0 = y-intercept (constant term)

B_k =slope coefficients for each explanatory variable

ϵ = the model's error term (also known as the residuals

Where B_i are the regression coefficient X; are the independent variables and is the an error. Assumptions for multiple linear regression:

(i) The term error represented by and is usually distributed with mean and variance.

(ii) ϵ is assumed to be uncorrelated.

(iii) There will be k independent variables and n observations.

3.6 Performance Measures

Performance measures are used to evaluate predictive model MLR. Performance indicators (PI) were used to assess the models applicability in predicting future O_3 concentrations and to pick the best-fitting model. There are two categories of performance indicators (Table 3.3), one that measures the errors which are the normalized absolute error (NAE), mean absolute error (MAE) and root mean square error (RMSE), and the one that measures the accuracy of the prediction are the coefficient of determination (R^2) and index of agreement (IA).

Table 3.3: Performance indicators (Ul-Saufie et al., 2012)

Performance Indicators	Equation	Better Predictability if
NAE	$NAE = \frac{\sum_{i=1}^{n} \lvert P_i - O_i}{\sum_{i=1}^{n} O_i}$	Closer to 0
MAE	$MAE = \frac{\sum_{i=1}^{n} \lvert P_{i\_} O_i}{n}$	Closer to 0
RMSE	$RMSE = \frac{1}{n-1}\sum_{i=1}^{n}(P_i - O_i)^2$	Closer to 0
R^2	$R^2 = \left(\frac{\sum_{i=1}^{n}(P_i - \bar{P})(O_i - \overline{O})}{n. S_p. S_O}\right)$	Closer to 1
IA	$IA = \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n} \lvert P_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert^2}\right]$	Closer to 1

Where;

n = total number of annual measurements at particular site

P_i = predicted values of a single set of annual monitoring data

O_i = the observed values from a single set of annual monitoring records

$\bar{P}$ = the mean of one set of annual monitoring records' predicted values

$\bar{O}$ = the average of the observed values from a single set of annual monitoring data

S_P = denotes the standard deviation of predicted values from a single set of annual monitoring data.

S_O = standard deviation of one set of annual monitoring records' observed values

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results and provides a discussion on variations of ground-level ozone concentration and anthropogenic precursors in three difference cities i.e. Perai, Kuala Terengganu and Seremban from 2016 to 2020. The reaction of O_3 level with the trace gases such as and also weather parameter i.e. wind speed, temperature, UVB and humidity were also investigated. The discussion is divided into 3 subsection including, the variation of ground level ozone, spatial analysis of seasonal variation of O_3 level, association of O_3 level with its precursors and weather parameter using Spearman correlation and modelling of O_3 levels using Multiple Linear Regression (MLR).

4.2 Spatio-temporal Variation of Ground-level Ozone Level

In this study data of hourly ozone concentration with its precursors and weather parameter in Seremban, Kuala Terengganu and Perai was chosen for analysed. Hourly data of ground-level ozone with the trace gases (i.e., NO_2, NO, NO_x, CO, SO_2 and PM_{10}) and the weather parameter (i.e., wind speed, temperature, relative humidity and UVB) from 7.00 a.m to 7.00 p.m (day time) and during night time (7.00 p.m. to 7.00 a.m) were recorded. The whole duration for monitoring was 12 hours throughout day time and 12 hours throughout night time. There were totally different variety of analysis that was employed in order to achieve objective of this study such as descriptive method, box plot, diurnal plot and contour plot were achieved.

4.2.1 Descriptive Statistics of Ground-level Ozone

Table 4.1 represent the concentration of ground-level ozone in the three difference cities for 5 years. Overall, the mean concentration of ozone level for Perai, Kuala Terengganu and Seremban are below the limit (0.1 ppm) as postulated in Malaysian Ambient Air Quality Guidelines (MAAQG). The maximum O_3 level in 2018 was recorded as the highest value compared to all study areas during these five years period. The highest ozone concentration reading in Perai was 0.095 ppm in 2018 with the mean of 0.0175 ppm while the lowest maximum value was 0.080 ppm in 2020 with mean value of 0.01718 ppm. From mean concentration, Perai and Seremban shows increment trend from 2015 to 2019 whereas Kuala Terengganu shows decrement trend of O_3 level. As the result, smallest range of data was observed i.e 0 ppm to 0.009 ppm. Seremban recorded the highest concentration of O_3 starting from 2018 with the mean value of 0.022 ppm. Lower concentrations were recorded in Kuala Terengganu and the lowest was in Perai. The standard deviation indicates that the O_3 measurement records was less variables and smaller range of O_3 level in Kuala Terengganu.

Table 4.1: Descriptive Statistic of Ground Level Ozone Concentration in Perai, Seremban and Kuala Terengganu

Study Area	Year		2016	2017	2018	2019	2020
Perai	N	Valid	8237	5513	8260	8350	8292
		Missing	547	1303	500	410	492
	Mean		0.01543	0.01629	0.01749	0.01757	0.01718
	Median		0.01100	0.01050	0.01140	0.01090	0.01185
	Std. Deviation		0.014710	0.16441	0.017208	0.017544	0.015890
	Minimum		0.000	0.000	0.000	0.000	0.000
	Maximum		0.091	0.085	0.095	0.093	0.080
Seremban	N	Valid	6478	5886	8327	8356	8373
		Missing	2306	928	426	406	409
	Mean		0.01686	0.01748	0.02030	0.02194	0.01943
	Median		0.01200	0.012	0.01600	0.01930	0.01680
	Std. Deviation		0.014792	0.016436	0.017167	0.016930	0.014807
	Minimum		0.000	0.000	0.000	0.000	0.000
	Maximum		0.097	0.103	0.100	0.095	0.094
Kuala Terengganu	N	Valid	8335	5975	8215	8320	8337
		Missing	449	836	558	440	447
	Mean		0.01981	0.01776	0.01739	0.01559	0.01412
	Median		0.01800	0.01670	0.01600	0.01520	0.01350
	Std. Deviation		0.013018	0.012303	0.012521	0.011184	0.009916
	Minimum		0.000	0.000	0.000	0.000	0.000
	Maximum		0.076	0.082	0.069	0.058	0.057

Figure 4.1 represents the box plot of hourly O_3 concentration in Seremban, Perai and Terengganu from 2016 to 2020. O_3 level in Seremban and Perai were higher variability in 2018 and 2019. The result show that, as the maximum concentration was 0.103 ppm. The lowest result in Seremban show in 2020 with the maximum value 0.094 ppm.

The highest concentration in Perai was 0.095 ppm in 2018 while the concentration decreases in 2019 and 2020 with the maximum value of 0.093 ppm and 0.80 ppm respectively. The data distribution for all years at Perai were skewed to the right which means positive skew.

Conversely, concentration of O_3 at Kuala Terengganu was lowest compared to Perai and Seremban. The maximum value O_3 concentration was 0.082 ppm in 2017 while the lowest was 0.057 ppm in 2020 as illustrated in Figure 4.1. Kuala Terengganu experiencing decrement of O_3 concentration value by year starting from 2016 to 2020. It was observed that O_3 level in Kuala Terengganu was less variable compared to Seremban and Perai. Kuala Terengganu has less number of vehicles compared to other studies area. In 2018, Kuala Terengganu recorded 457,549 and increase to 471,740 number of the vehicles in 2019. While in Seremban the number of vehicle is 732,783 in 2018 and increase to 742,923 number of vehicles in 2019. This is crystal clear that Kuala Terengganu is the less polluted compared to other study areas.

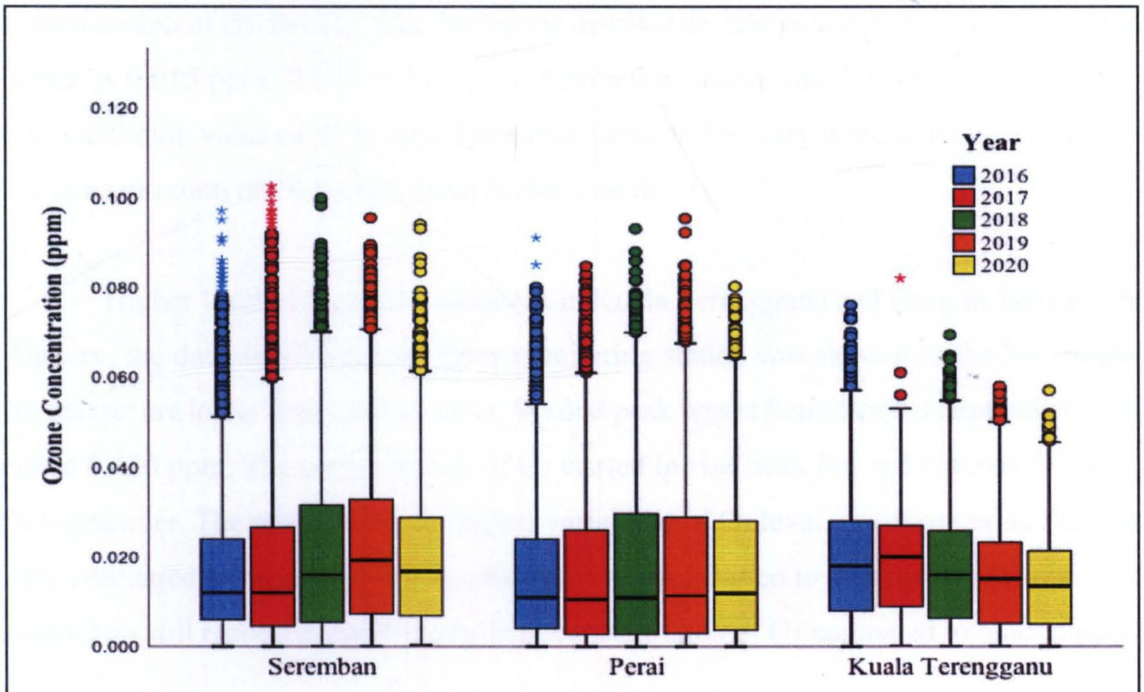


Figure 4.1: Hourly box plot

Overall, the distribution of O_3 level in all study areas were skewed to the right which indicate that extreme concentration occurred. Seremban was observed to have high exceedance of O_3 level especially in 2017. Those monitoring station have a decrement in 2020 due to less of using transportation and factory shutdown because of epidemic transmission of the Covid-19. Malaysia response to the Covid-19 pandemic has resulted in unprecedented reductions in economic activity in 2019 to 2021 (Venter et al., 2020). After accounting for weather changes, lockdown events lowered population-weighted concentrations of NO_2 and particulate matter by around 60% and 31%, respectively, as well as O_3 concentrations. Reductions in transportation sector emissions are largely responsible for the NO_2 variances. The different result in three monitoring station are believed to be influenced by variations in temperature, humidity and wind speed.

4.2.2 Monthly Variation of O_3 Level

Figure 4.2 displays monthly clustered box plot of ground-level ozone in three cities which is Kuala Terengganu, Seremban and Perai. O_3 concentrations show a clear seasonal effect the distribution shows bimodality with peaks can be observed in March and September. First peak was at Seremban in March which is 0.028 ppm the highest concentration of O_3. Besides that, the lowest distribution shown was in November at Perai which is 0.015 ppm. While in May, the distribution shown small differences minimum and maximum value of O_3 level at Seremban same as February at Perai its indicates that the concentration of O_3 remain equal in that month.

Higher level of O_3 can be observed in Kuala Terengganu and Perai in January. In January, the data distribution for three monitoring station was skewed to the left means all dataset are lower than median value. Second peak was at Seremban on September with value 0.026 ppm. The concentration of O_3 started tp rise from Jun and reached the peak in September. The result show, the higher variability of O_3 level was observed in Perai in July compared to other places. Even though, O_3 level started to decrease on October but Seremban still recorded significantly high concentration of O_3 compared to other places.

Overall, high concentration of O_3 level are recorded during the month of Northeast Monsoon (NEM) i.e January to March and Southwest Monsoon (SWM) i.e May to September (Fong, Abdullah & Ismail, 2018) which wind that will bring the pollution from the neighbour country to Malaysia. Cloudy and precipitation weather conditions during end and May to June of the year result in very low UV radiation in the monitoring area, which reduce photochemical ozone formation (Bais et al., 2015).

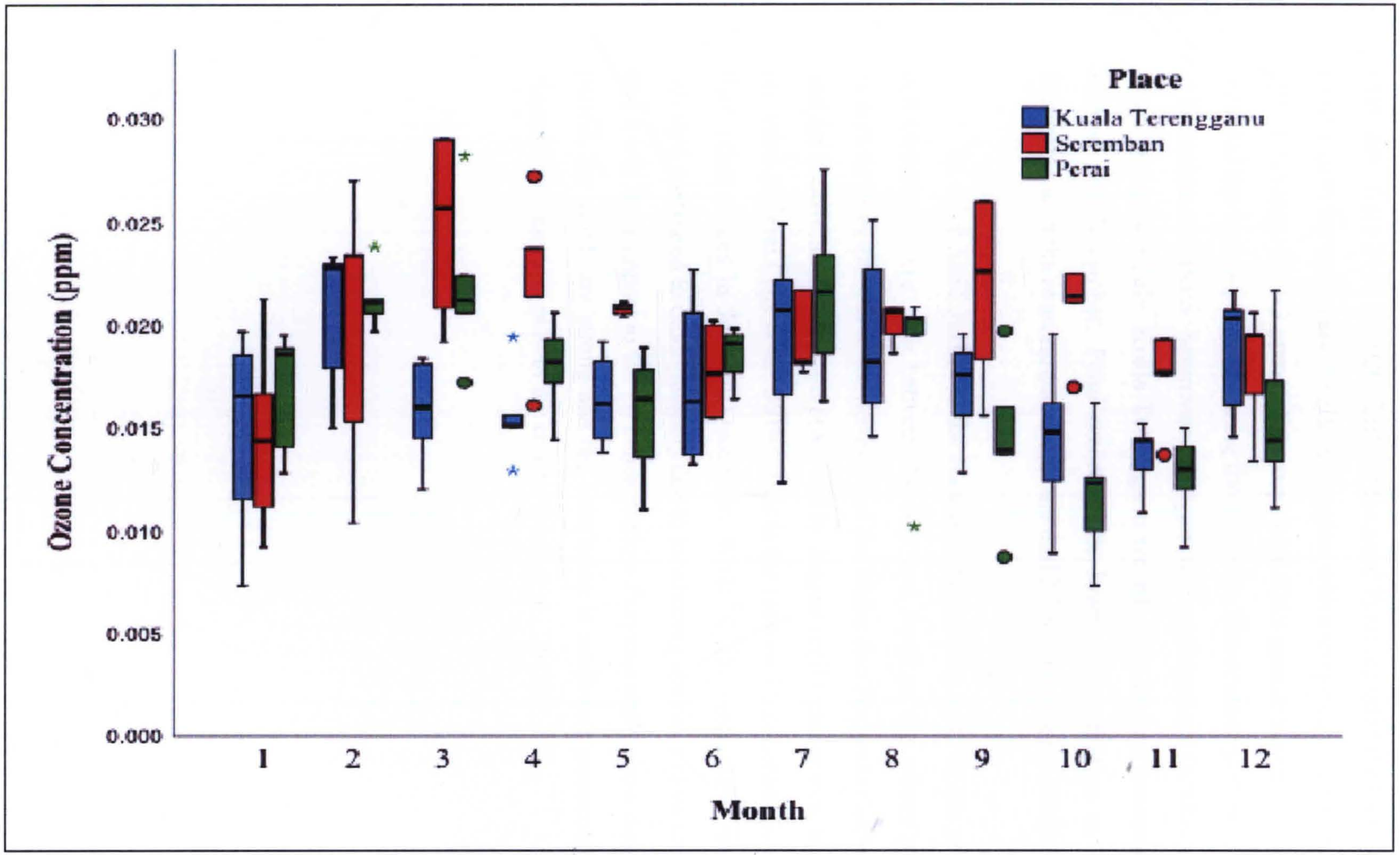


Figure 4.2: Monthly box plot of ground-level ozone in Kuala Terengganu, Seremban and Perai.

Figure 4.3 shows the monthly contour plots O_3 concentrations for five years of all the three study areas. The averaged of monthly contour plot of O_3 concentration of all the study area from 2016 to 2020. Early of the year, Perai recorded the highest concentration compared to Seremban and Kuala Terengganu with average concentration value is 0.0168 ppm in January, 0.0213 ppm in February and 0.0219 ppm in March. However, Seremban recorded the lowest polluted during those month. The contour plot shows bimodal peak at Seremban and Perai. Seremban rise again in September and October while Perai rise again in Jun and July. Kuala Terengganu recorded the highest concentration of O_3 in August and December. Perai recorded the lowest concentration in November and December with the concentration value are 0.0127 in November and 0.0156 in December.

In other hand, recorded the high pollutant during early of the year is due to O_3 concentrations were high between January and April as the winter monsoon brings pollutants from the area to the northeast of the Malaysian Peninsular including Indochina and the South China Sea. (Latif et al., 2012). August until October were high precipitation recorded at Perai (Tijs et al., 2019). This is the reasons O_3 concentration at Perai lower than other places in July till December. While Kuala Terengganu recorded the less polluted compared to other places is due to monitoring station is close to the coastal area and it will have impact to the O_3 concentration. Previous study show during June to July period, the winds are strong and the circulation is southwest monsoon that brings the clean marine airmass over to the coastal (Nair et al., 2018).

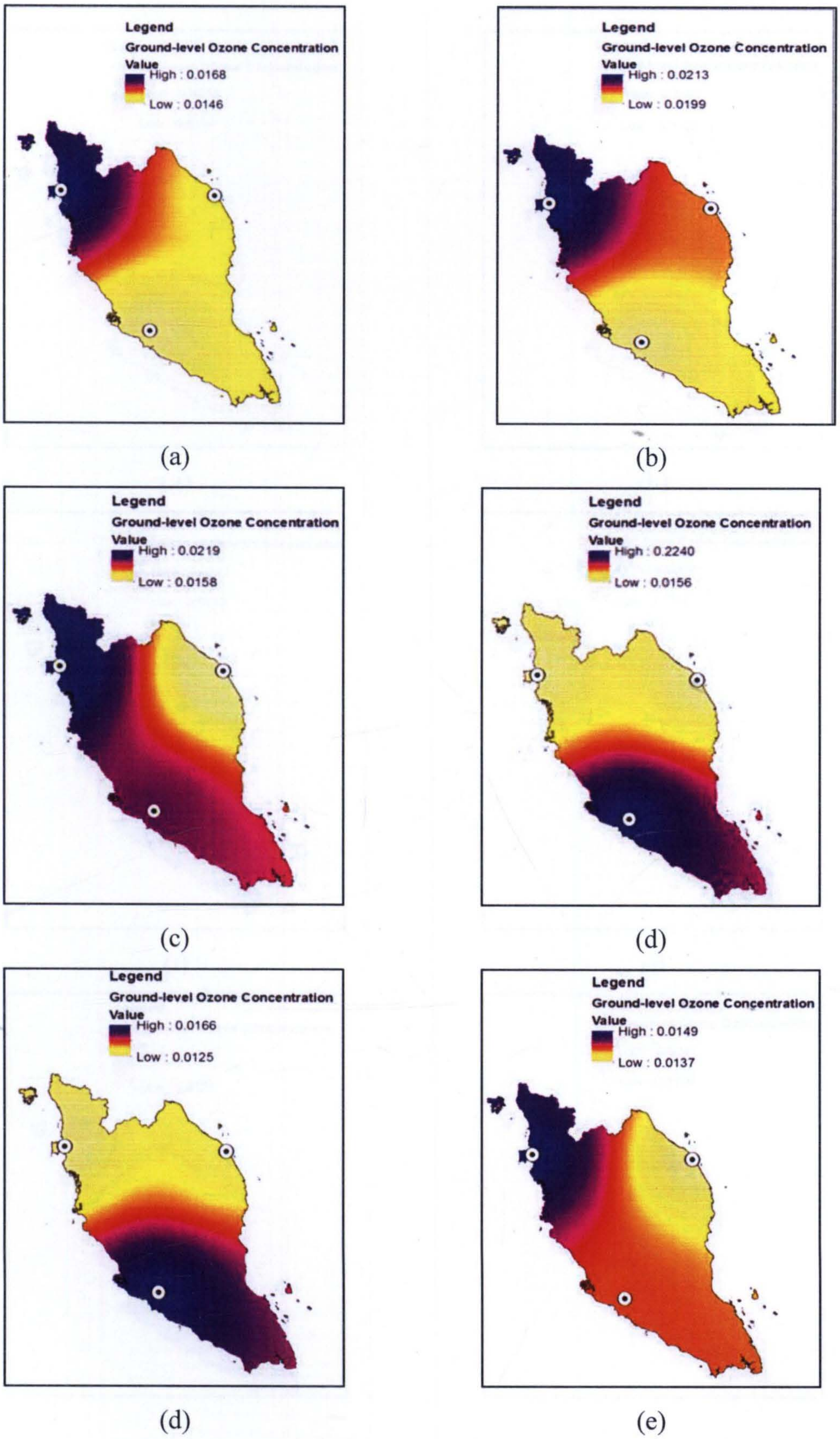


Figure 4.3: Monthly contour plot of ground-level O_3 in Seremban, Kuala Terengganu and Perai (a) January, (b) February, (c) March, (d) April, (e) May, (f) Jun, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December

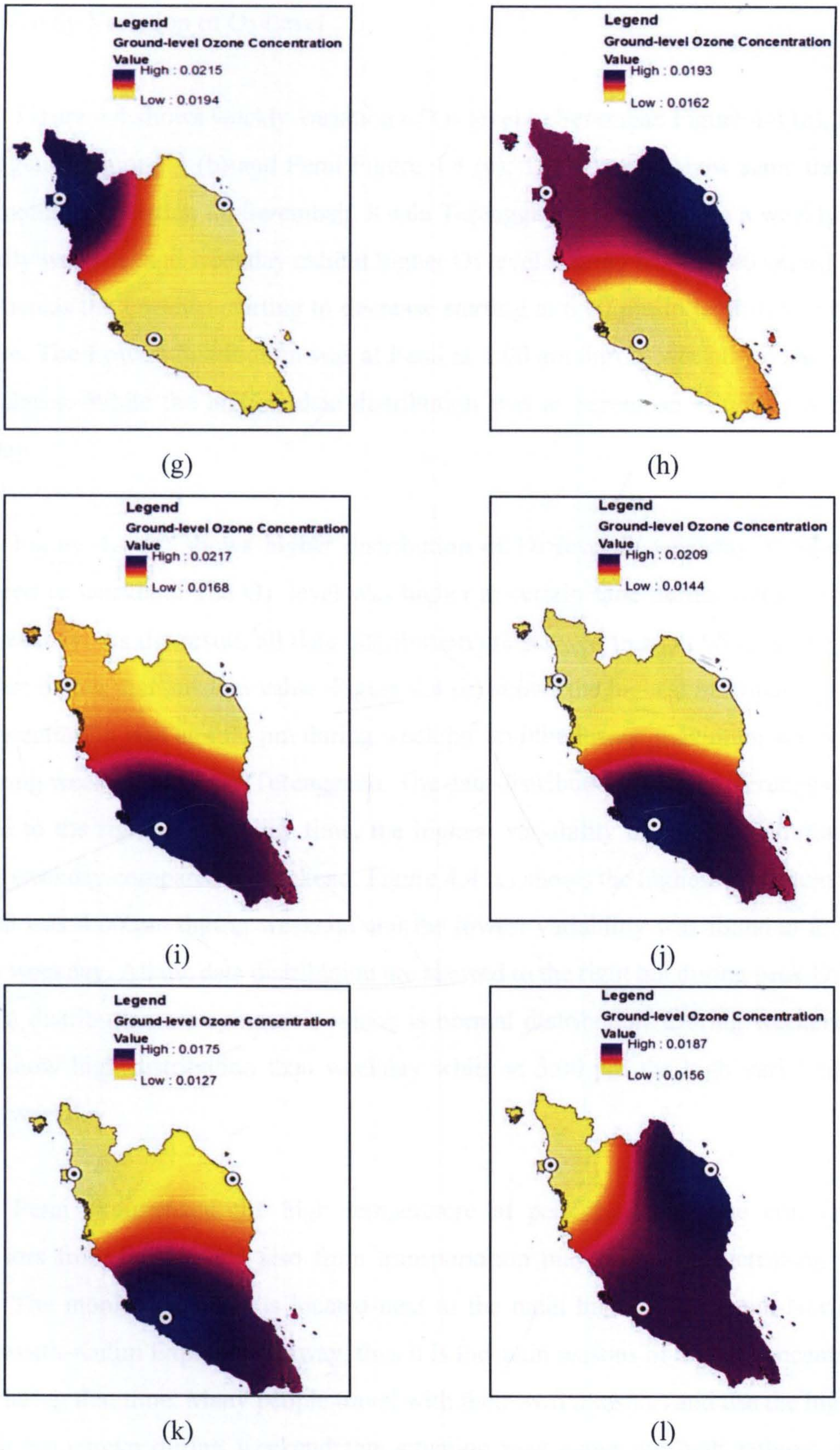


Figure 4.3: Monthly contour plot of ground-level O_3 in Seremban, Kuala Terengganu and Perai (a) January, (b) February, (c) March, (d) April, (e) May, (f) Jun, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December (Continued)

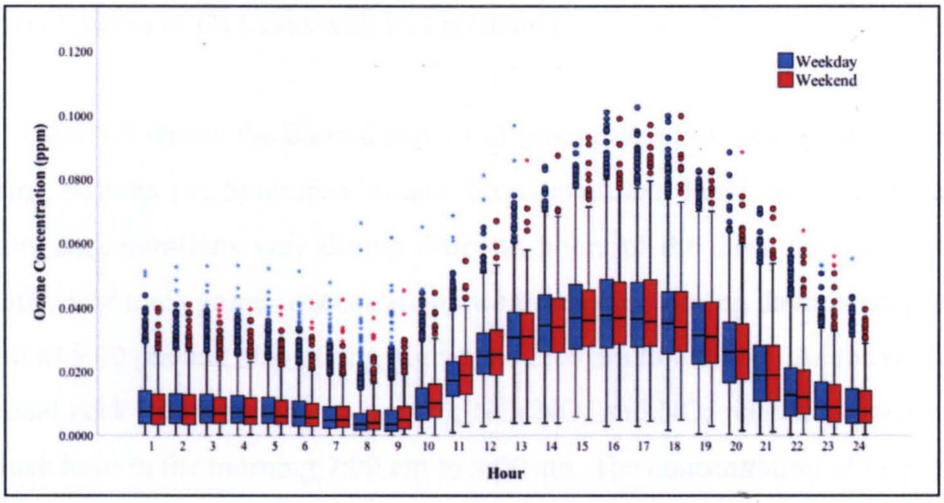
4.2.3 Weekly Variation of O_3 Level

Figure 4.4 shows weekly variation of O_3 level in Seremban Figure 4.4 (a), Kuala Terengganu Figure 4.4 (b) and Perai Figure 4.4 (c). The box plot show same trend for three monitoring station i.e Seremban, Kuala Terengganu and Perai. On a weekly basis generally weekend and weekday exhibit higher O_3 level starting from 10:00 am till 17:00 pm, whereas the O_3 level starting to decrease starting at 6:00 pm to tomorrow morning 9:00 am. The Lowest distribution was at Perai at 8:00 am during weekday compared to other places. While the highest data distribution was at Seremban at 5:00 pm during weekday.

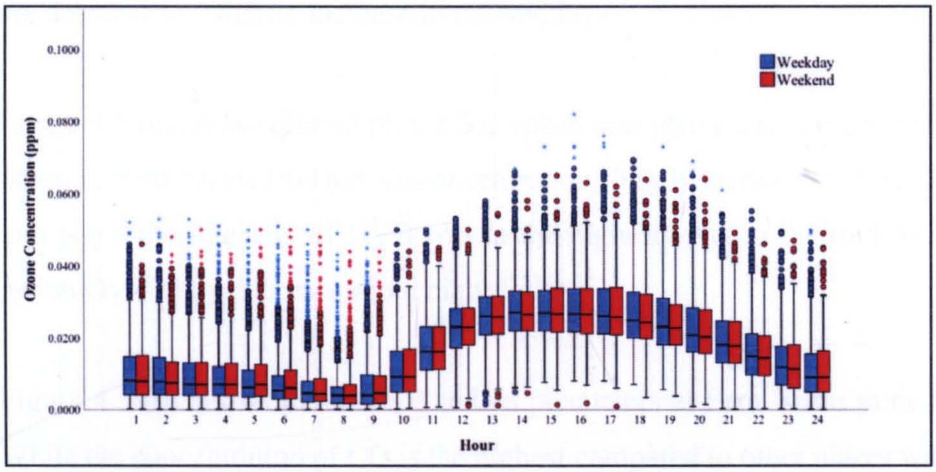
Figure 4.4 (a) shows higher distribution of O_3 level in weekday at Seremban compared to weekend. The O_3 level was higher at certain time during weekend rather than weekday. As the result, all data distribution are skewed to right whereas the mean value are higher than median value. Figure 4.4 (b) shows the highest maximum value of O_3 concentration was at 4:00 pm during weekday and the lowest maximum was at 8:00 am during weekday at Kuala Terengganu. The data distribution at Kuala Terengganu are skewed to the right. During day time, the highest variability of O_3 concentration was during weekday compared to weekend. Figure 4.4 (c) shows the highest maximum value at Perai was 4:00 pm during weekend and the lowest variability was found at 8:00 am during weekday. All the data distribution are skewed to the right but during peak O_3 level the data distribution are symmetric which is normal distribution. During weekend, the result show high distribution than weekday while at 3:00 pm the high variability are during weekday.

Perai experienced the high temperature at peak hour and the emission of precursors from factory and also from transportation may cause the increasing of O_3 levels. The monitoring areas is located next to the main highway of South-North and Butterworth-Kulim Express Highway, thus it is the main reasons of higher concentration of O_3 during that time. Many people travel with their own transport and use the highway to their hometown during weekend this situation may cause the high volume of the transportation at that time. Moreover, the concentration of ozone decrease after 17:00 hours till next morning it's probably due to less UVB and lower temperature due to no sunlight and no titration NO to O_3 by emission of precursors from the vehicles. Therefore, the maximum ozone concentrations are normally observed during the morning and evening traffic peak hours, while the minimum concentrations are observed at night due to low traffic and in the mid-afternoon due to photochemical ozone formation (Coyle et al., 2002).

This phenomenon may be caused by the differences in the number of vehicles used during the weekends and weekdays. Residents in suburban area may not go out on weekends compared to residents in urban and industrial area. This result differs from the study by Banan and Latif (2011) which found that O_3 concentration during the weekend was higher compared to weekdays. A high level of ozone on the weekend is a well-known phenomenon known as the "ozone weekend effect" (OWE) (Jenkin, 2008). Low levels of traffic on weekends are thought to be the primary source of OWE, as low levels of NO emission reduce local ozone elimination. The greater amount of ozone compared to other weekdays is most likely due to the residual effect of ozone from the weekend. Ozone concentrations in all cities follow a similar twenty-four hour cycle, with lower levels during the night and early morning hours and higher levels during the day. The largest concentrations are obtained in the afternoon from 12:00 to 17:00 hours, most likely due to photochemical ozone generation as a result of increased UV radiation during these hours. This effect is most likely produced by early morning traffic, which generates NO, which immediately reacts with ozone, reducing O_3 concentrations even further.



(a)



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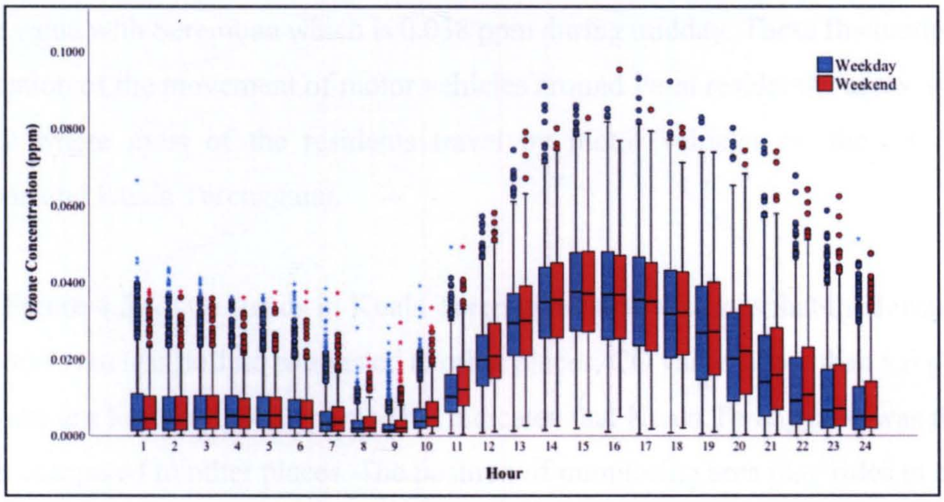


(c)

Figure 4.4: Weekday and Weekend box plot of hourly ground-level ozone concentration (a), Seremban (b), Kuala Terengganu, and (c) Perai

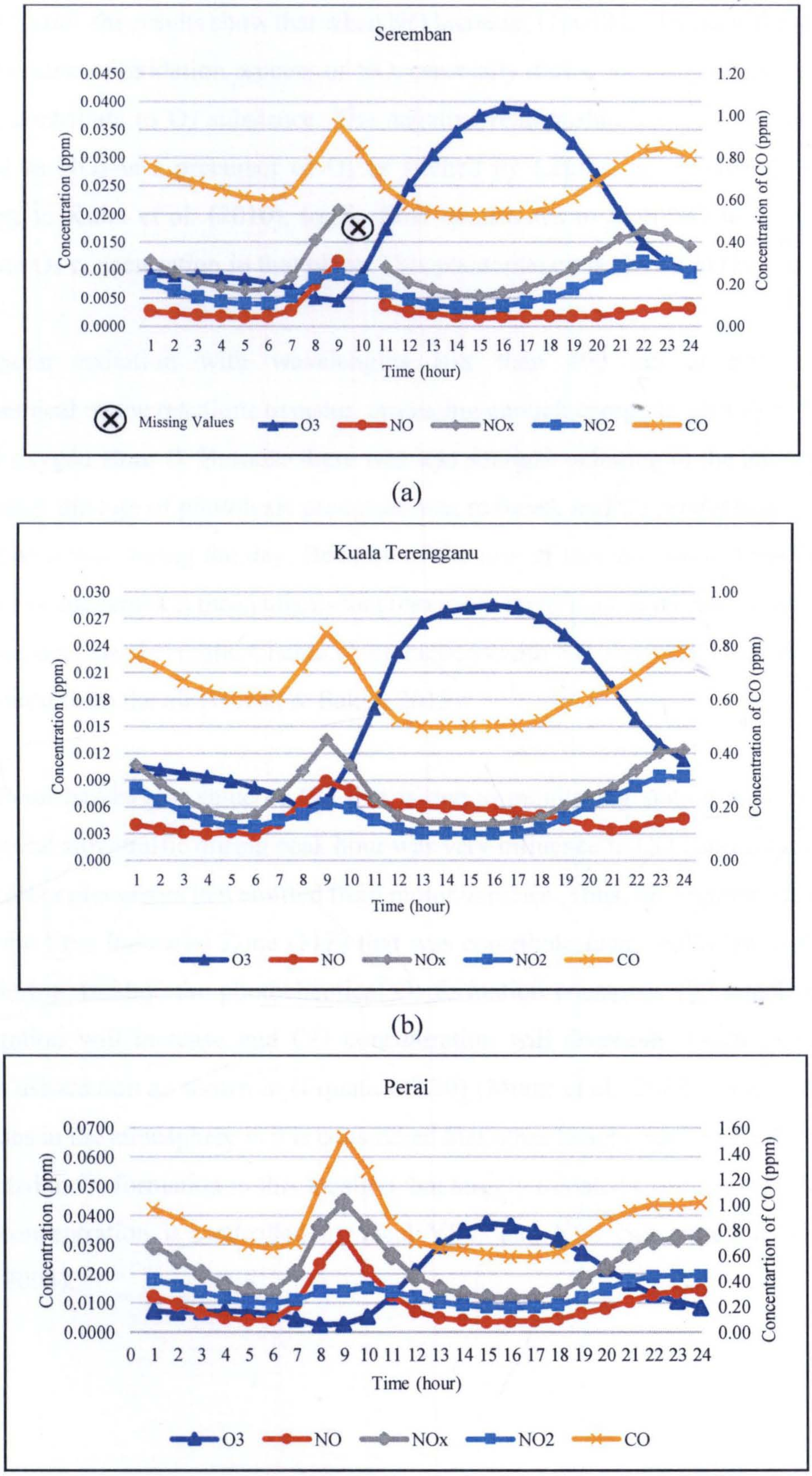
4.3 Association of O_3 Level with Its Precursors

Figure 4.5 shows the diurnal pattern of ground-level O_3 and its precursors at all monitoring stations i.e. Seremban, Kuala Terengganu and Perai. Time variation plots show how concentrations vary during different hours of the day-time and night-time. Expectedly, low trace gases concentrations were observed during daytime starting from 12:00 pm to 5:00 pm and also during night time 2:00 am to 6:00 am. As the result show, the bimodal peak of O_3 precursors i.e. CO, NO, NO_x and NO_2 related by traffic pattern during rush hour in the morning 7:00 am to 9:00 am. The concentration of O_3 precursors peak again in the evening 6:00 pm to 10:00 pm when people travel back to home from work. There is negative correlation with O_3 concentration as result show when O_3 precursors decrease O_3 slightly increase in the midday.

Figure 4.5 (a) shows diurnal plot at Seremban seem have a missing value of NO_x and NO starting 9:00 am to11:00 am. O_3 concentration slightly increase starting 10:00 am to 5:00 pm when the intensity of UVB was at the highest level in the midday and the concentration O_3 slightly decrease when night falls.

Figure 4.5 (b) shows trend of O_3 and its precursors at Perai seem same as other places. While the concentration of CO is the highest compared to other places with value 1.58 ppm. In addition, other precursors i.e. NO, NO_x and NO_2 also have high level concentration compared to other places. While the O_3 concentration value seems same average value with Seremban which is 0.038 ppm during midday. These fluctuations give an indication of the movement of motor vehicles around Perai residential areas and main highway where most of the residents travel by motor vehicles on the outskirts of Seremban and Kuala Terengganu.

Figure 4.5 (c) O_3 trends in Kuala Terengganu demonstrates that the formation of precursors is the less pollute contrasted to other places. CO value is low than 1.0 ppm and other gases are low than 0.002 ppm. This indicates that Kuala Terengganu was the least polluted compared to other places. The position of monitoring area play roles to affected with concentration of O_3 and its precursor.



(a)

(b)

(c)

Figure 4.5: Diurnal plot of O_3 precursors in (a) Seremban, (b) Kuala Terengganu and (c)Perai

Overall, the results show that when NO increase, O_3 will be decrease for all places. This is because of oxidation process of NO, especially during the daytime produces NO_2 that can contribute to O_3 substance. The negative relationship between O_3 and NO_2 is expected as NO_2 is a precursor of O_3 as studied by Latif et al., (2016). In addition, according to Kuhn et al. (2010), traffic flow contributes to high NO levels that have contribute O_3 concentration in that place. This phenomenon is shown in (Equation 2.9).

Solar radiation with wavelengths less than 400 nm is favourable for photochemical ozone reactions to occur, producing enough energy to photolyze NO_2 into NO and oxygen atom O. Because there was less sunlight radiating in the atmosphere in the evening, the rate of photolysis processes was reduced, and O_3 production was not as efficient as it was during the day. Because of the low of temperature and the improved efficiency of the removal mechanisms that remove the pollutant in the atmosphere, ozone generation decreased at night. Chemical interactions with NO and VOCs would eliminate the pollution from the air (Ghosh & Sakar, 2013).

Perai has largest value of CO that is due to monitoring station located at main highway and slow traffic during peak hour was very influence to CO concentration. Plus, same as other precursors that emitted from motor vehicles. Thus, the location also located near to the Free Industrial Zone (FIZ) that was contribute many pollution in that area. While during midday, the photochemical O_3 formation consumes CO which make O_3 concentration will increase and CO concentration will decrease, which explains the negative association as shown in (Equation 2.20) (Munir et al., 2012). The oxidation of trace gases in the atmosphere is it is considered that other factors, such as VOC, probably contributed to O_3 formation in this location that largely initiated by reaction with the OH whose concentration is controlled by local VOC and NO_x concentrations (Heard & Pilling, 2003).

4.4 Association of O_3 Level with Other Trace Gases and Weather Parameters

Figure 4.6 illustrates the Spearman Correlation heat matrix to show of relationship between the two variables in Perai, Kuala Terengganu and Seremban. There are two different time which was day time 7:00 am to 7:00 pm and night time 7:00 pm to 7:00 am. O_3 concentrations were negatively correlated with its precursors i.e NO_2, NO_x, NO and CO for all places during day and night time. While for weather parameter, the most correlated parameter temperature followed by windspeed, UVB and humidity. All weather parameter are positively correlated with O_3 but only humidity negatively correlated.

Figure 4.6 (a) shows the association of O_3 with its precursors and weather parameter at Seremban. The strong correlate with O_3 was temperature ($\rho = 0.605$) during day-time followed by humidity that has moderate correlation with the value of $\rho = -0.052$ but its negatively correlated with O_3 concentration. For O_3 precursors, was moderately correlated with NO. The trend of association of O_3 with its precursors and weather parameter seems the same with night time but the ρ value were smaller. NO ($\rho = -0.549$) is the moderate correlated with O_3 during night time followed by temperature and wind speed.

Figure 4.6 (c) and (d) shows the parameter that were most correlated with O_3 were humidity and temperature at Kuala Terengganu. Temperature was positively correlated while humidity was negatively correlated. The O_3 precursors also shown negative correlation during day time and night time. At day time, NO is strongly correlated to the O_3 with $\rho = -0.52$ compared to night time followed by No_x ($\rho = -0.41$) which demonstrating that rise up in O_3 level. In the nighttime NO moderate correlated with O_3 with $\rho = -0.591$. However, for weather parameter that negatively moderate correlated with O_3 is humidity with value ($\rho = -0.578$) while temperature ($\rho =0.479$) and wind speed ($\rho = 0.453$) are positively moderate correlated with O_3.

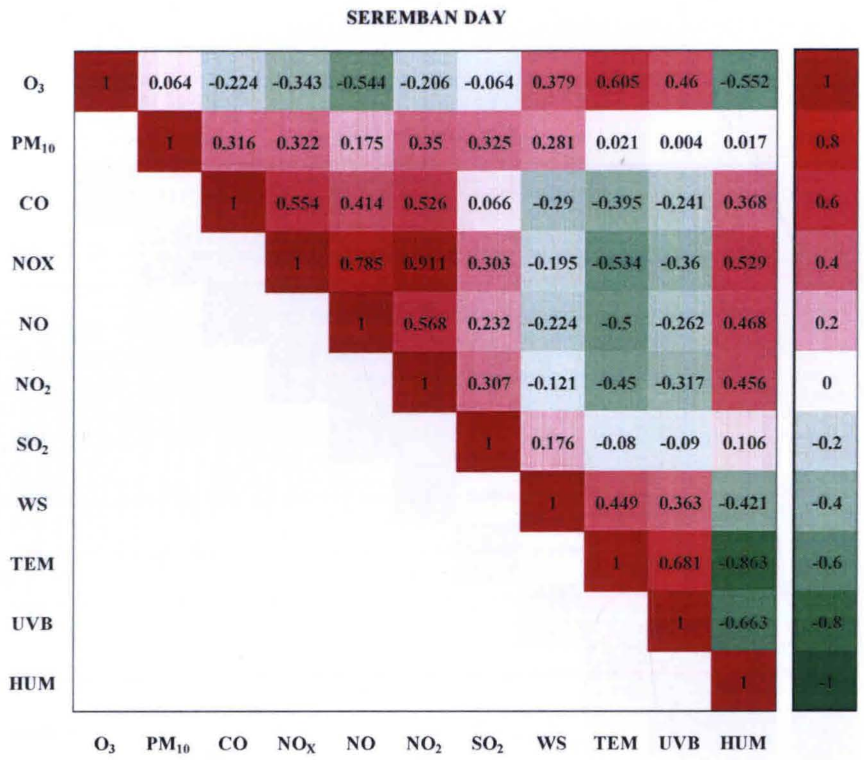
Figure 4.6 (e) and (f) show heat matrix of association O_3 with its precursors and weather parameter at Perai. Among these three places, Perai recorded the highest value correlation of CO with O_3 concentration and the value is ($\rho = -0.468$). During day time, the strong negative correlation was observed with NO ($\rho = -0.704$) followed by weather parameter which are temperature and humidity with value (ρ = -0.742) and (ρ =-0.684) respectively. While during night time the negatively strong significant is NO (ρ = -0.591). NO_x recorded moderate correlation with O_3 that has (ρ = -0.467). while weather parameter that moderate correlated is humidity with value of (ρ = -0.523).

Overall, high temperature will contribute to photochemical ozone chemistry which significant in the generation of secondary aerosols such as sulphate (SO_4^{-2}) and nitrate (NO_3^{-}) that generated from SO_2 and NO_x. (Ding et al., 2013). This mechanism most likely reduces the negative link between the two species over time. NO is significantly associate with O_3 concentration and three different places this is due to studies by air quality researchers, O_3 concentration increase is usually influenced by the complex reaction between NOx and VOCs in the atmosphere produced by motor vehicles and industrial combustion processes (Ahamad et al., 2014). Humidity negatively correlated with O_3 is influenced by humid days with enhanced cloud cover and thus reduced photochemistry (Xu et al., 2011). A decreasing in humidity is typically accompanied by increasing temperatures and hence will formed O_3 in Malaysia (Latif et al., 2014). Obviously in Perai, the SO_2 concentration is among the highest associated with O_3 compared to other places is due to industry area is near to the monitoring station. According Mohtar et al., (2018), the fluctuations of SO_2 in the study area may due to the contributions of SO_2 from local and regional sources of biomass burning. As the location Penang Port is near to the monitoring areas, its influenced the high concentration of SO_2 at that place. The distribution of SO_2 usually from shipping port that will transfer SO_2 to the nearer area (Mohtar et al., 2018).

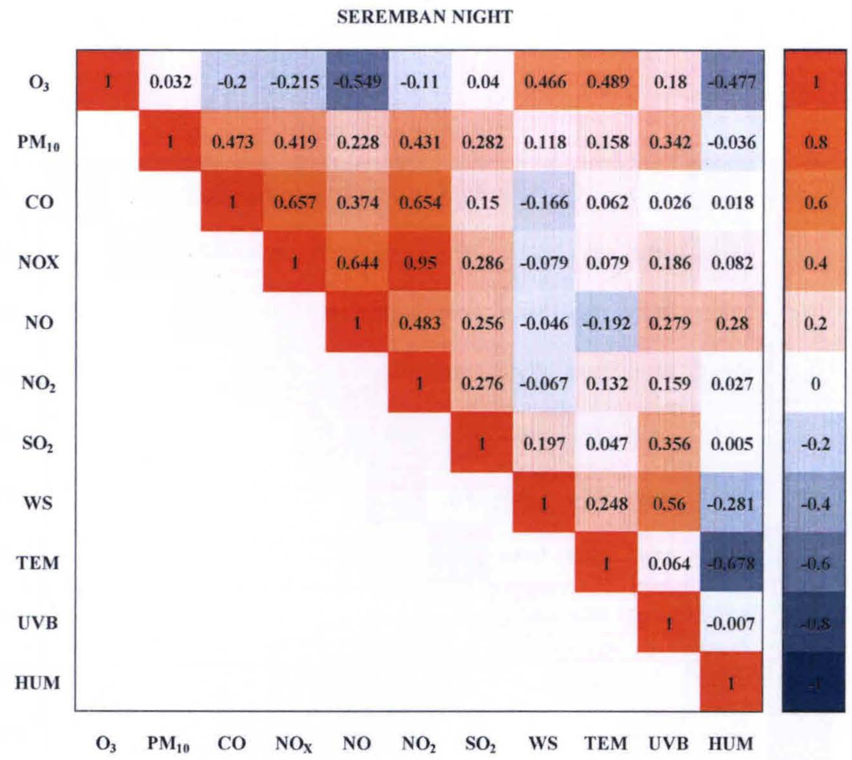
In conclusion, the parameters that had moderate and strong correlation ($\rho \geq 0.4$) were choosen for modelling day time and night time using MLR. Table 4.2 summarize the parameters used as the input for MLR model.

Table 4.2: The moderate correlation of O_3 with its precursors and weather parameter

Time	Seremban	Kuala Terengganu	Perai
Day-time	Parameter	Parameter	Parameter
	NO	NO_x	CO
	Temperature	NO	NO_x
	UVB	Wind Speed	NO
	Humidity	Temperature	Temperature
		UVB	UVB
		Humidity	Humidity
Night-time	NO	NO	NO_x
	Wind Speed	Wind Speed	NO
	Temperature	Temperature	Temperature
	Humidity	Humidity	Humidity

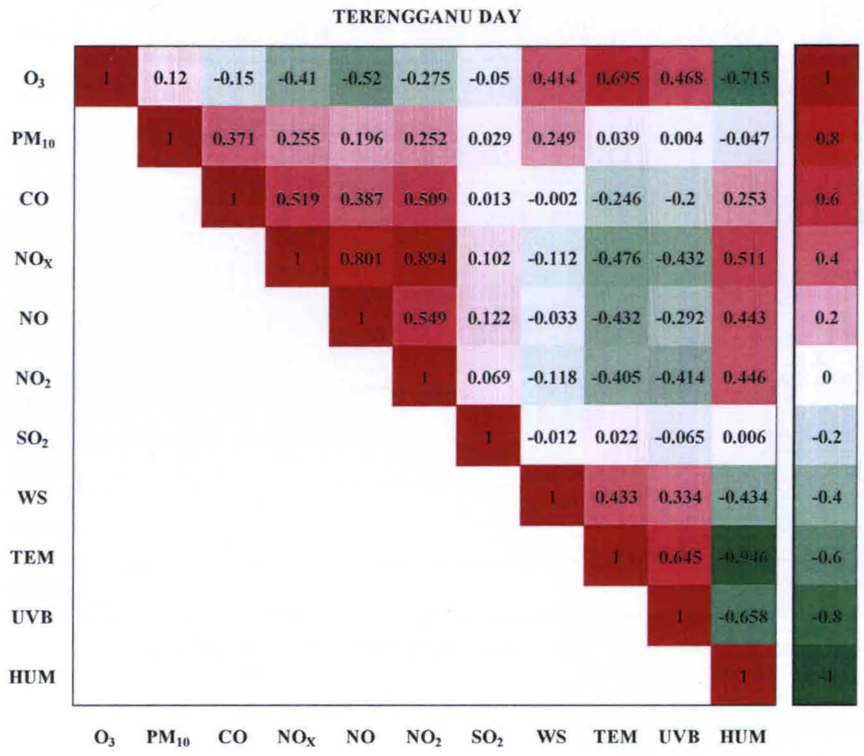


(a)



(b)

Figure 4.6: Spearman correlation matrix of O_3 with the trace gases and weather parameter (a) Seremban day time, (b) Seremban night time, (c) Kuala Terengganu day time, (d) Kuala Terengganu night time, (e) Perai day time and (f) Perai night time



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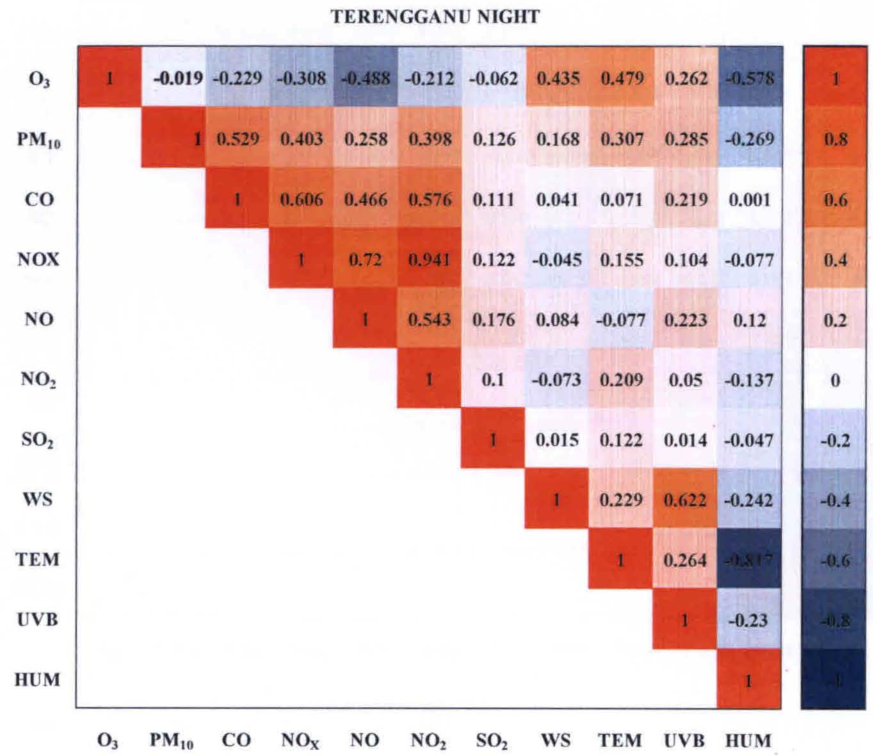
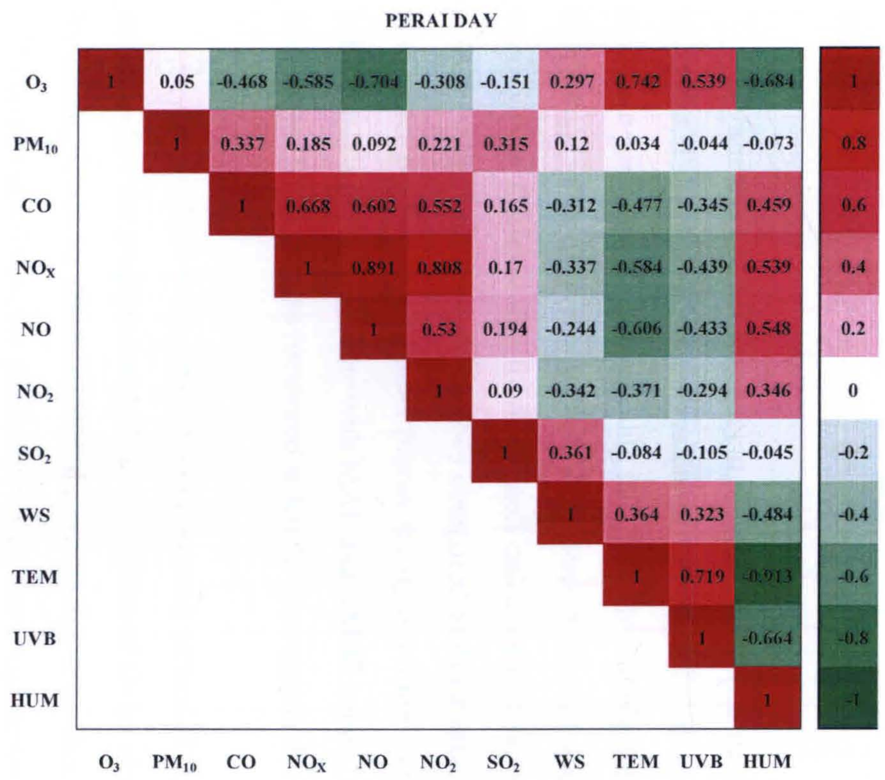
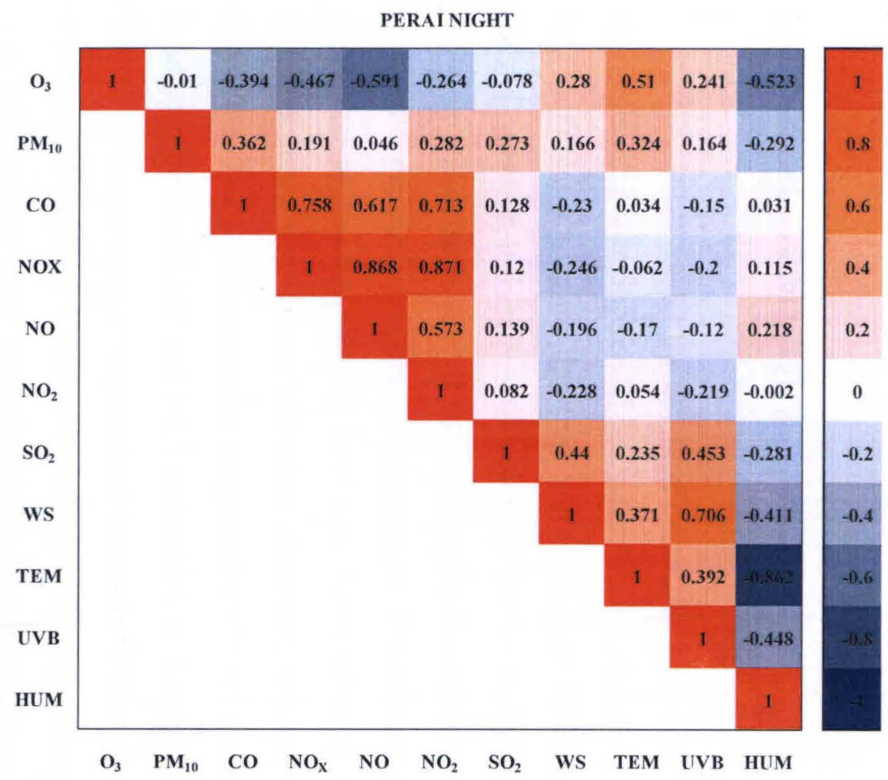


(d)

Figure 4.6: Spearman correlation matrix of O_3 with the trace gases and weather parameter (a) Seremban day time, (b) Seremban night time, (c) Kuala Terengganu day time, (d) Kuala Terengganu night time, (e) Perai day time and (f) Perai night time (Continued)



(e)



(f)

Figure 4.6: Spearman correlation matrix of O_3 with the trace gases and weather parameter (a) Seremban day time, (b) Seremban night time, (c) Kuala Terengganu day time, (d) Kuala Terengganu night time, (e) Perai day time and (f) Perai night time (Continued).

4.5 Modeling of O_3 Levels using MLR

The MLR model for day-time and night-time at all study areas were developed using parameters that were moderately correlated ($\rho > 0.4$) with O_3 level. (Refer Table 4.2 in Section 4.6) Table 4.3 shows the day-time and night-time MLR model for each of the study areas. Overall, positive influence was observed for O_3 and NO_x concentration whereas negative influence was detected for NO and temperature. In addition, very small coefficient was detected for weather parameters especially temperature. This indicate that very minimal to no correlation of weather parameters with O_3 level was identified using MLR. NO is significant predictor variables during day-time at Seremban. However, NO and temperature are significant during night-time. The O_3 concentration decreased 0.027 units when the one unit of NO decreasing during daytime and 0.042 and 0.001 units of NO and temperature during night-time. In addition, Kuala Terengganu indicates increase of one unit of NO_x will increase of 0.331 units of O_3 during day time and decrease 0.024 of NO during night-time. Perai shows the increase of one unit of NOx will increase 0.197 unit of O3. The O_3 concentration decreased about 0.002 and 0.325 when the one unit of CO and NO decreasing.

Validation of MLR model at all study areas was performed using several performance measures. Table 4.4 shows the results of validation for all study areas. Generally, MLR shows moderate performance in predicting the day-time and night-time O_3 level in all study areas with the average value of IA around 0.4. Very weak prediction was detected in Perai once estimating the day-time O_3 level due to very small calculated value of IA (0.285) and noticeable error (MAE =0.061 and RMSE = 0.064) compared to other areas. As for Seremban, MLR models give better prediction than other places during day-time. Perai shown the weakest fitted of the MLR models during day-time with MAE and RMSE value 0.061 and 0.064 respectively. While the highest IA value was measured at Kuala Terengganu during day-time with value of 0.470.

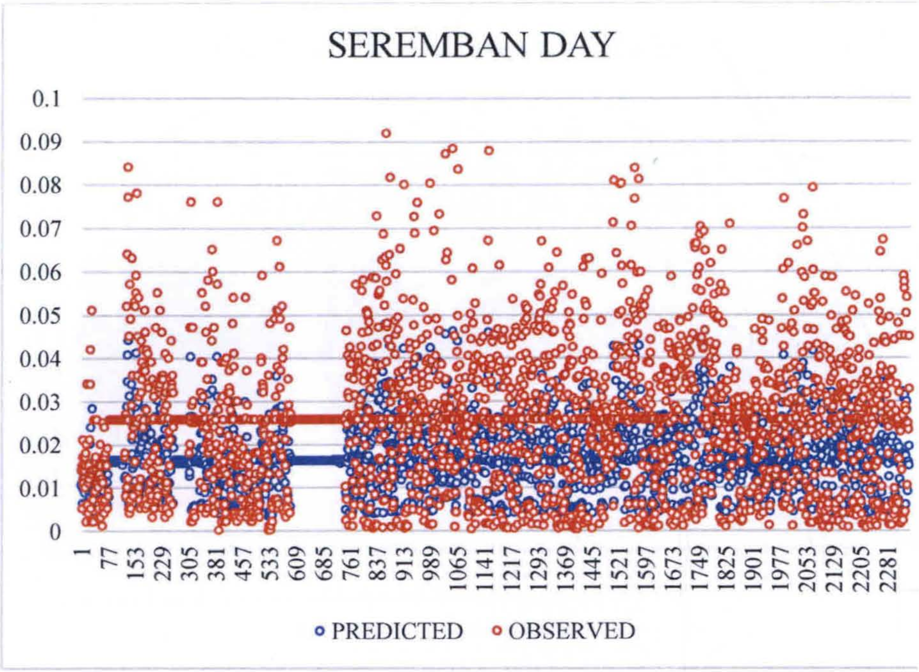
To illustrate the predicted and observed values of O_3 level, Figure 4.7 shows the time series plot of the predicted and observed values of O_3 level day and night at all study areas. In Seremban, it can be observed that the overestimate prediction for day-time O_3 concentration and during night-time, the predicted values were underestimated if compared to the observed values. While in Kuala Terengganu, the prediction for day-time O_3 level was underestimated than observed and for night-time was overestimated of the prediction compared to observed values. However, in Perai it can be observed for both time i.e. day-time and night-time were underestimated if compared to observed values.

Table 4.3: Summary model for O_3 level predictions

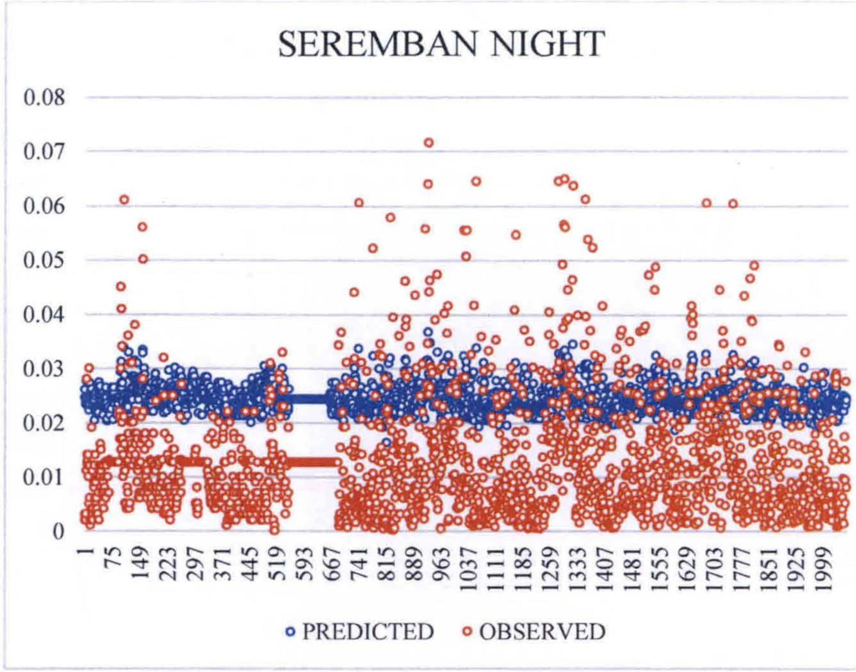
Study Area	Time	Predict Hour	Model
Seremban	Day-time	Next 12 hours	$O_{3,t+12} = 0.004 + 0.477O_3 - 0.027NO + 0T + 0UVB + 0H$
	Night-time	Next 12 hours	$O_{3,t+12} = 0.047 + 0.276O_3 - 0.042NO + 0WS - 0.001T + 0H$
Kuala Terengganu	Day-time	Next 12 hours	$O_{3,t+12} = 0.022 + 0.453\ O_3 + 0.311NO_X - 0.449NO + 0WS + 0T + 0UVB + 0H$
	Night-time	Next 12 hours	$O_{3,t+12} = 0.001 + 0.487O_3 - 0.024NO + 0WS + 0T + 0H$
Perai	Day-time	Next 12 hours	$O_{3,t+12} = 0.09 + 0.403O_3 - 0.002CO + 0.197\ NO_X - 0.325NO + 0T + OUVB + 0H$
	Night-time	Next 12 hours	$O_{3,t+12} = 0.44 + 0.207O_3 + 0.002NO_X - 0.091NO - 0.001T + 0H$

Table 4.4: Performance comparison of O_3 prediction models

Study Area	Time	Performance Indicator		
		MAE	RMSE	IA
Seremban	Day-time	0.015	0.019	0.442
	Night-time	0.014	0.015	0.437
Kuala Terengganu	Day-time	0.014	0.017	0.472
	Night-time	0.016	0.021	0.443
Perai	Day-time	0.061	0.064	0.285
	Night-time	0.012	0.013	0.446

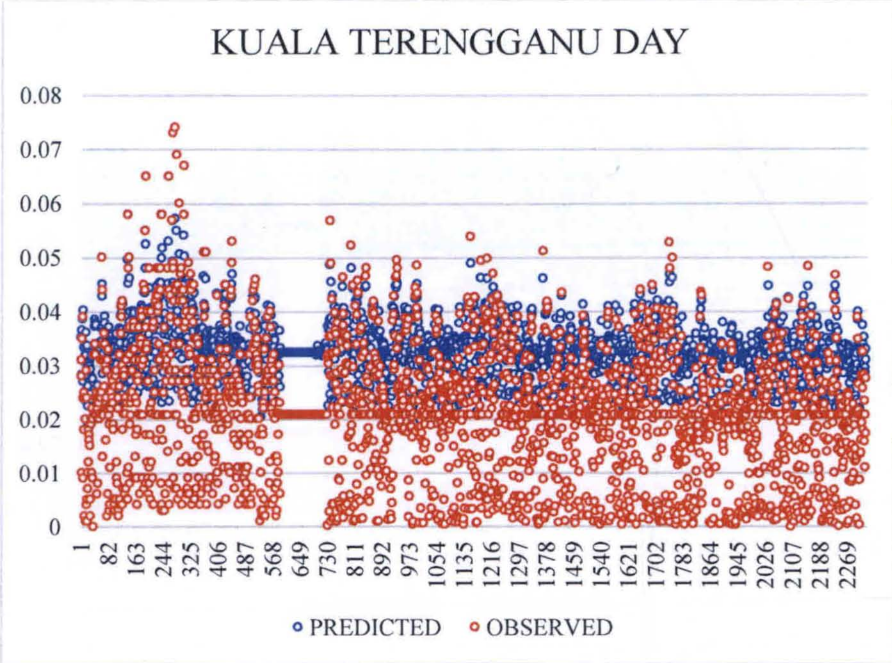


(a)



(b)

Figure 4.7: Time series plot of the relationship between observed and predicted value of O_3 concentration (a) Seremban day-time, (b) Seremban night-time, (c) Kuala Terengganu day-time, (d) Kuala Terengganu night-time, (e) Perai day-time and (f) Perai night-time.



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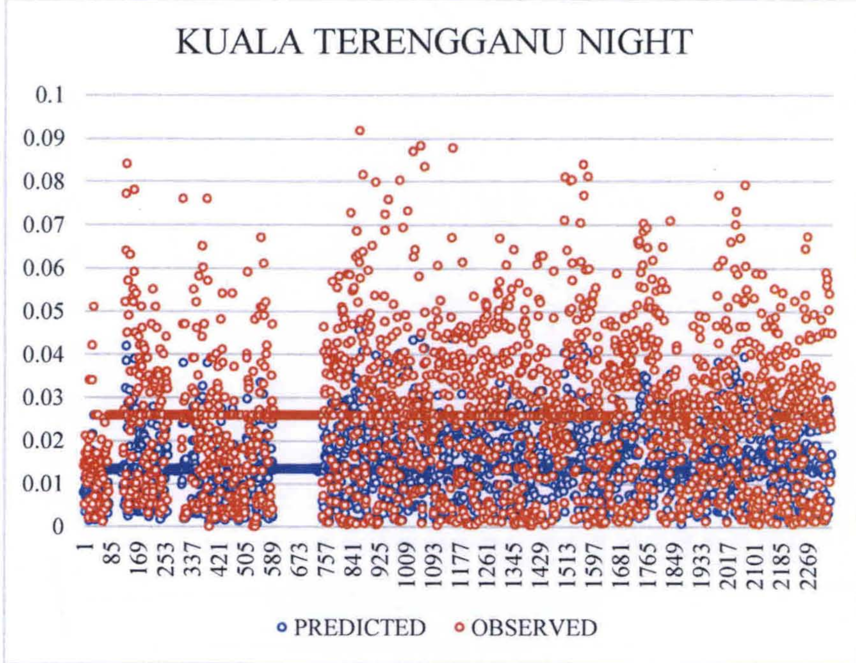
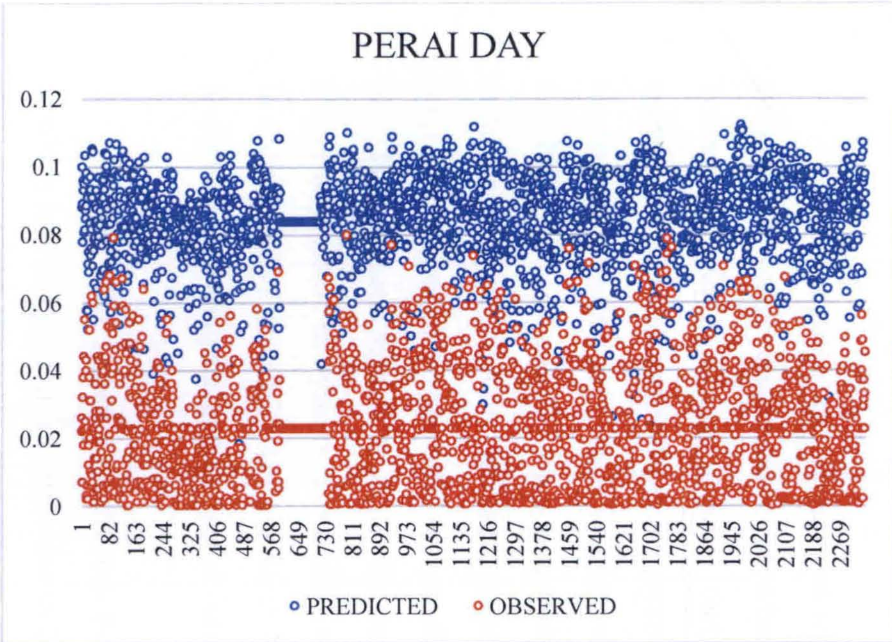
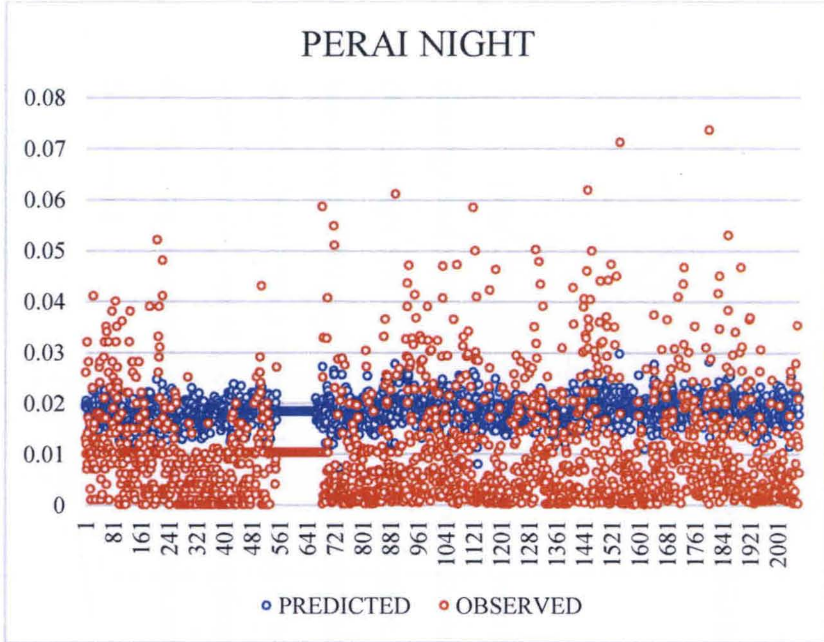


(d)

Figure 4.7: Time series plot of the relationship between observed and predicted value of O_3 concentration (a) Seremban day-time, (b) Seremban night-time, (c) Kuala Terengganu day-time, (d) Kuala Terengganu night-time, (e) Perai day-time and (f) Perai night-time. (Continued)



(e)



(f)

Figure 4.7: Time series plot of the relationship between observed and predicted value of O_3 concentration (a) Seremban day-time, (b) Seremban night-time, (c) Kuala Terengganu day-time, (d) Kuala Terengganu night-time, (e) Perai day-time and (f) Perai night-time. (Continued)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This chapter summarises the whole final year project, focusing on the main findings and contributions of the project. Further work has been suggested in the light of the findings and constraints of this project. Section 5.1 is the conclusion of the project was carried out and what are the main contributions of the project to the field of air quality, particularly ground level ozone in urban areas and section 5.2 describes the main recommendations of the project for the future work, which is the work that could not be done in this project due to data, time and resources constraints or was out of the scope of this project.

5.1 Conclusion

The main aim of this project was to study the spatial and temporal variability of ground-level ozone concentration at urban monitoring sites which are Perai, Kuala Terengganu and Seremban. Besides that, this project also to analysed significant anthropogenic precursors and weather parameters that associates with ground-level ozone concentration during daytime and night time. The parameter of this study are O_3, NOx, CO, NO_2, NO, SO_2 and PM_{10} and meteorological variables which are temperature, solar radiation, relative humidity and wind speed. All the data are from DOE Malaysia. The project mainly employs graphical presentations such diurnal plot, box plot, and scattered plot. Then, general statistics such as Spearman Rank Correlation analysis, and Multiple Linear Regression analysis by using SPSS software to do most of the statistical analysis. In addition, MS Excel 2020, Google Earth 2022 and ARCGIS have also been used in the project for data analysis, getting spatial data and mapping procedure.

Descriptive statistics results state that the maximum concentration is at Seremban in which is 0.103 ppm maximum value in 2017 compare to other study areas. Seremban has exceeding the limitation that stated by MAAQG for two years which is in 2017 and 2018 the maximum value is 0.103 ppm and 0.1 ppm respectively. The statistical models display the lowest concentration of ozone is at Kuala Terengganu which is 0.057 ppm in 2020. Moreover, mean for all study areas is below than standard MAAQG which is less than 0.18 ppm. Therefore, different number of population and monitoring areas is affected the value concentration of ozone. Box plot presents three different time scale which are hourly, monthly and weekly of the concentration ground-level ozone. For hourly, the result shown the concentration of ozone at Seremban is the highest follow by Perai and Kuala Terengganu. The median value at Perai remain same range every year while in Seremban the value increase by year and start decrease in 2020. Besides that, result for Kuala Terengganu decrease by year and has highest median value compare to Perai and Seremban in 2017. This is can conclude that in 2020 has less emission of VOCs and NO_x due to total lockdown in Malaysia caused by Covid-19. The diurnal plot is to analysed trend of the ozone concentration with its precursors (NO_x, NO, NO_2 and CO). The trends of the concentration has been proved in literature review same as result which is the ozone higher during peaks hour (12:00 pm till 18:00 pm) and decrease start night-time until next morning. VOCs react with ozone precursors during photochemical reaction and increasing concentration of ozone while decreasing the precursors concentration.

The association of ozone and its precursors including weather parameter was test using non parametric correlation. Spearmen correlation is used to analysed the relation of ozone with one independent variable. The result indicates that there are strong correlation between ozone with temperature with rho = 0.605 at Seremban during day-time while night-time shows moderate correlation with NO. Kuala Terengganu shows strong correlated between O_3 and humidity with rho = -0.715 during day-time followed by temperature rho =- 0.695 while and moderate correlated of humidity with rho = -0.578. In addition, the strong correlated with O_3 are NO and temperature during day-time. While in night-time indicates that NO and humidity were moderate correlated with O_3 levels.

Multiple Linear Regression is used to model for day-time and night-time at all study areas were developed using parameters that were moderately correlated ($\rho > 0.4$) with O_3 levels. 12 hours predictions were made and the result in Seremban was the best fit model for both time during day-time (MAE = 0.015, RMSE = 0.019 and IA=0.442). Perai shows the weakest prediction with IA=0.285 during day-time. Prediction of O_3 level in Kuala Terengganu was underestimated than observed while during night-time indicates overestimated

In conclusion, this study can be a database for further research and can be used as reference for future development to DOE. They can take precautions measures of the ground-level ozone to protect environment and human due to ozone can effects human health and bad effects to the environment such as crops and agricultures.

5.2 Recommendations

Ozone is a complicated air pollutant and its concentration in the atmosphere is dependent on many factors, including meteorological variables (temperature, solar radiation, relative humidity, wind speed, wind direction, cloud cover, the amount of precipitation), other air pollutants (NOx, NO, NO_2, CO, SO_2,and PM_{10}, and VOCs), the sources of ozone precursors are road traffic and other combustion processes. Hence, further study can be conducted to see the effect of different vehicle categories (cars, vans, buses, articulated heavy vehicles and motorcycles) and also type of manufacturing factory on ozone concentration. Hence, the effect of different fuel types (e.g., petrol, diesel, alternative fuel types) has not been considered in this project and required for further research. Furthermore, nonmethane hydrocarbon (NMHC) need to be investigated in further study due to NMHC such as ethane, ethene, propane, propene, and isoprene are trace atmospheric constituents that play important roles both in providing a sink for hydroxyl radicals and in controlling ozone concentrations.

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Descriptive Statistics For Year 2020

Study Area	Parameter		O_3 (ppm)	CO (ppm)	NO_X (ppm)	NO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (µg/m3)	Windspeed (m/s)	Humidity (%)	Temperature (°C)	UVB (W/m^2)
Perai	N	Valid	8292	8283	8059	8059	8059	8338	8750	8765	8765	8765	8765
		Missing	492	501	725	725	725	446	34	19	19	19	19
	Mean		.01718	.69210	.02001	.00843	.01158	.00098	25.26	.77	78.17	27.78	145.35
	Median		.01185	.62100	.01630	.00470	.01050	.00090	23.46	.48	80.02	27.44	.40
	Std. Deviation		.015890	.329763	.014184	.010211	.006550	.000344	12.053	.665	12.588	2.996	219.615
	Minimum		.000	.049	.000	.000	.000	.000	2	0	37	22	0
	Maximum		.080	3.187	.152	.119	.047	.007	138	7	97	37	914
Seremban	N	Valid	8373	8375	8328	8328	8328	8344	8344	8751	8767	8767	8767
		Missing	409	407	454	454	454	438	438	31	15	15	15
	Mean		.01943	.56129	.00720	.00166	.00555	.00186	.00	18.40	.92	79.70	27.59
	Median		.01680	.52600	.00520	.00070	.00420	.00120	.00	17.22	.62	82.53	26.93
	Std. Deviation		.014807	.169210	.006184	.002835	.004566	.002482	.002	8.307	.792	12.171	3.017
	Minimum		.000	.083	.000	.000	.000	.000	0	1	0	39	22
	Maximum		.094	1.807	.073	.045	.041	.057	0	105	5	97	39
Kuala Terengganu	N	Valid	8337	8290	8167	8167	8167	8286	8763	8720	8735	8735	8730
		Missing	447	494	617	617	617	498	21	64	49	49	54
	Mean		.01412	.50712	.00595	.00167	.00428	.00113	23.30	1.28	84.40	26.80	120.19
	Median		.01350	.47100	.00460	.00090	.00350	.00110	21.44	1.14	86.11	26.41	.00
	Std. Deviation		.009916	.185743	.004763	.002618	.003022	.000405	12.659	.657	10.380	2.588	213.987
	Minimum		.000	.044	.000	.000	.000	.000	2	0	48	21	0
	Maximum		.057	2.180	.057	.048	.024	.008	168	12	99	35	1381

Descriptive Statistics For Year 2019

Study Area	Parameter	O_3 (ppm)	CO (ppm)	NO_X (ppm)	NO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (μg/m3)	Windspeed (m/s)	Humidity (%)	Temperature (°C)	UVB (W/m^2)
Perai	N Valid	8350	8356	8224	8224	8200	8313	8704	8754	8755	8755	8755
	Missing	410	404	536	536	560	447	56	6	5	5	5
	Mean	.01757	.89973	.02521	.01008	.01516	.00115	28.37	.83	77.86	27.46	164.23
	Median	.01090	.81050	.02070	.00540	.01360	.00100	25.49	.55	79.75	27.12	.14
	Std. Deviation	.017544	.392687	.017695	.012678	.008004	.000841	14.848	2.080	12.754	2.987	247.690
	Minimum	.000	.226	.001	-.001	.000	.000	1	0	1	0	0
	Maximum	.093	3.632	.154	.136	.057	.018	239	183	96	35	964
Seremban	N Valid	8356	8316	8289	8289	8290	8347	8758	8758	8760	8760	8760
	Missing	406	446	473	473	472	415	4	4	2	2	2
	Mean	.02194	.68041	.00872	.00158	.00714	.00139	29.41	1.01	77.66	27.69	163.77
	Median	.01930	.63100	.00690	.00070	.00580	.00100	23.47	.67	80.55	26.98	.18
	Std. Deviation	.016930	.240618	.007040	.003559	.005185	.001697	22.445	.911	12.333	3.079	243.970
	Minimum	.000	.100	-.001	.000	.000	.000	1	0	36	21	0
	Maximum	.095	2.390	.210	.177	.051	.042	222	8	97	36	1006
Kuala Terengganu	N Valid	8320	8310	8178	8178	8178	8205	8750	8538	8540	8540	8540
	Missing	440	450	582	582	582	555	10	222	220	220	220
	Mean	.01559	.56769	.00708	.00183	.00525	.00077	28.86	1.26	81.85	27.29	228.10
	Median	.01520	.52600	.00560	.00090	.00440	.00070	24.31	1.11	83.96	26.86	.01
	Std. Deviation	.011184	.235607	.005295	.002800	.003517	.000523	19.129	0.732	11.213	2.805	332.057
	Minimum	.000	.093	.000	.000	.000	.000	0	0	45	21	0
	Maximum	.058	2.292	.050	.043	.030	.015	204	5	99	35	1420

Descriptive Statistics For Year 2018

Study Area	Parameter		O_3 (ppm)	CO (ppm)	NO_X (ppm)	NO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (µg/m3)	Windspeed (m/s)	Humidity (%)	Temperature (°C)	UVB (W/m^2)
Perai	N	Valid	8260	8342	8161	8161	8165	8325	8704	8755	8755	8755	8755
		Missing	500	418	599	599	595	435	56	5	5	5	5
	Mean		.01749	.98488	.02388	.00873	.01517	.00113	28.45	.64	76.64	27.89	174.19
	Median		.01140	.88800	.02000	.00480	.01380	.00110	25.96	.45	78.30	27.58	.36
	Std. Deviation		.017208	.418864	.015600	.010742	.007661	.000564	16.852	.539	12.921	3.120	262.843
	Minimum		.000	.317	.001	.000	.000	.000	0	0	26	21	0
	Maximum		.095	5.029	.145	.118	.058	.008	229	8	96	37	961
Seremban	N	Valid	8327	8343	8283	8283	8266	8323	8520	8741	8744	8742	8742
		Missing	426	410	470	470	487	430	233	12	9	11	11
	Mean		.02030	.71848	.00917	.00192	.00726	.00119	23.52	1.06	78.17	27.25	154.33
	Median		.01600	.68000	.00740	.00070	.00610	.00090	21.43	.69	82.60	26.42	.06
	Std. Deviation		.017167	.218381	.006774	.003568	.004902	.001094	11.718	3.758	11.400	3.038	234.375
	Minimum		.000	.130	-.001	.000	.000	.000	1	0	2	21	0
	Maximum		.100	2.399	.083	.062	.034	.020	118	337	95	36	1057
Kuala Terengganu	N	Valid	8215	8237	8109	8109	8071	8048	8429	8600	8617	8620	8522
		Missing	558	536	664	664	702	725	344	173	156	153	251
	Mean		.01739	.63276	.00748	.00193	.00556	.00060	25.20	1.26	26.48	82.98	185.77
	Median		.01600	.58700	.00580	.00080	.00470	.00060	22.63	1.09	25.89	85.50	.00
	Std. Deviation		.012521	.224602	.006034	.003551	.003763	.000337	17.502	.771	2.793	11.150	280.298
	Minimum		.000	.082	-.001	-.001	.000	.000	1	0	18	0	0
	Maximum		.069	5.000	.077	.072	.028	.003	906	8	34	98	1152

Descriptive Statistics For Year 2017

Study Area	Parameter		O_3 (ppm)	CO (ppm)	NO_X (ppm)	NO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (µg/m3)	Windspeed (m/s)	Humidity (%)	Temperature (°C)	UVB (W/m^2)
Perai	N	Valid	5513	6248	5933	5933	5426	6258	6632	6699	6697	6699	4343
		Missing	1303	568	883	883	1390	558	184	117	119	117	2473
	Mean		.01629	.83013	.02431	.01050	.01368	.00174	31.20	1.88	75.48	27.61	157.84
	Median		.01050	.74000	.01920	.00540	.01240	.00120	28.96	1.23	76.93	27.30	.00
	Std. Deviation		.016441	.434115	.018454	.014147	.006974	.002315	15.121	1.746	13.855	2.735	244.232
	Minimum		.000	.120	.000	.000	.000	.000	1	0	31	21	0
	Maximum		.085	13.745	.213	.169	.067	.077	110	11	100	34	1082
Seremban	N	Valid	5886	6214	6525	6525	5737	5779	6622	6485	5765	5530	4337
		Missing	928	600	289	289	1077	1035	192	329	1049	1284	2477
	Mean		.01748	.72370	.01381	.00518	.00890	.00147	27.98	1.70	79.78	27.01	134.86
	Median		.01200	.68900	.01000	.00140	.00780	.00100	26.79	.92	83.33	26.31	.00
	Std. Deviation		.016436	.384101	.023394	.023657	.005669	.002128	12.476	1.927	12.485	3.196	212.306
	Minimum		.000	.000	-.002	-.001	.000	.000	1	0	40	19	0
	Maximum		.103	10.550	.554	.592	.044	.049	130	15	110	36	1039
Kuala Terengganu	N	Valid	5975	4496	6100	6100	5324	6039	6489	6772	6776	6779	4310
		Missing	836	2315	711	711	1487	772	322	39	35	32	2501
	Mean		.01776	.63813	.00729	.00201	.00529	.00074	28.42	3.10	82.44	26.78	135.88
	Median		.01670	.61500	.00560	.00100	.00440	.00070	25.82	1.48	85.13	26.20	.00
	Std. Deviation		.012303	.267136	.005959	.003375	.003642	.000616	15.521	3.519	11.803	2.893	239.714
	Minimum		.000	.000	.000	.000	.000	.000	1	0	42	21	0
	Maximum		.082	2.063	.057	.044	.036	.007	165	17	98	35	1118

Descriptive Statistics For Year 2016

Study Area	Parameter	O_3 (ppm)	CO (ppm)	NO_X (ppm)	NO (ppm)	NO_2 (ppm)	SO_2 (ppm)	PM_{10} (µg/m3)	Windspeed (m/s)	Humidity (%)	Temperature (°C)	UVB (W/m^2)
Perai	N Valid	8237	8297	8177	8177	8177	8246	8667	8718	8718	8718	0
	Missing	547	487	607	607	607	538	117	66	66	66	8784
	Mean	.01543	.80071	.01952	.00887	.01065	.00353	36.17	3.92	68.19	28.77	
	Median	.01100	.70000	.01500	.00500	.00900	.00300	33.00	3.50	68.00	28.60	
	Std. Deviation	.014710	.360613	.016138	.011239	.007073	.003033	16.614	1.661	15.452	2.717	
	Minimum	.000	.220	.000	.000	.000	.000	5	1	25	22	
	Maximum	.091	3.300	.161	.105	.078	.059	194	11	100	37	
Seremban	N Valid	6478	8169	8170	8170	8170	8111	8581	8208	5236	7103	0
	Missing	2306	615	614	614	614	673	203	576	3548	1681	8784
	Mean	.01686	.69682	.01293	.00339	.00953	.00295	38.32	3.84	79.63	27.41	
	Median	.01200	.65000	.01100	.00200	.00800	.00200	35.00	2.30	82.00	26.70	
	Std. Deviation	.014792	.310841	.009344	.005257	.006156	.002795	17.114	3.461	20.100	4.058	
	Minimum	.000	.000	.000	.000	.000	.000	6	1	22	19	
	Maximum	.097	3.120	.101	.076	.043	.066	295	20	110	38	
Kuala Terengganu	N Valid	8335	8006	7923	7924	7923	8188	8524	7801	6818	6817	0
	Missing	449	778	861	860	861	596	260	983	1966	1967	8784
	Mean	.01981	.81647	.00868	.00273	.00595	.00083	38.87	5.33	79.59	28.16	
	Median	.01800	.80000	.00700	.00200	.00500	.00100	35.00	4.60	84.00	27.30	
	Std. Deviation	.013018	.405743	.005961	.003351	.003853	.000878	16.877	3.375	14.082	3.417	
	Minimum	.000	.000	.001	.000	.000	.000	5	1	40	23	
	Maximum	.076	4.230	.059	.043	.030	.017	194	18	100	37	