ASSESSMENT OF HIGH NIGHTTIME GROUND-LEVEL OZONE CONCENTRATION IN KEMAMAN, TERENGGANU

by

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DECLARATION

I declare that this thesis entitled “Assessment of High Nighttime Ground-level Ozone Concentration in Kemaman” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Ground-level ozone was a pervasive air pollutant due to its harmful effect on living things. In this research, the concentration of nighttime ground-level ozone and its precursors were determined, starting from 7 p.m. to 7 a.m. using descriptive analysis, box and whisker plot and time-series plot in Kemaman, Terengganu. Besides, diurnal plot was also used to illustrate the mechanism of nighttime ground-level ozone removal chemistry. Multiple Linear Regression was used to fit the data obtained from site to predict the response outcome of selected variable to ground-level ozone concentration. This study showed that the concentration of ground-level ozone has a mean of 16.11 ppb in Kemaman. Diurnal plot illustrated that the concentration of ground-level ozone had decreased over time while the concentration of adjusted nitrogen dioxide still remained high. Along the period of monitoring, the highest concentration of ground-level ozone recorded was 51 ppb in Kemaman. The R^2 value for primary data was moderate, which was 0.408, indicating the selected variables have explained less possibilities in variation of ground-level ozone concentration. The concentration of ground-level ozone in Kemaman monitored was lower than the nitrogen dioxide because it was raining along the monitoring period and also because of the nighttime ground-level ozone removal chemistry. On the other hand, the R^2 value for secondary data was low, 0.052, which indicates the selected variables have explained less possibilities in variation of ground-level ozone concentration. This was probably due to a lot of missing data.

ABSTRAK

Ozon paras tanah adalah pencemar udara yang meluas kerana kesannya yang berbahaya terhadap makhluk hidup. Dalam kajian ini, kepekatan ozon paras tanah dan pra-penanda ditentukan, mula dari pukul 7 petang hingga pukul 7 pagi dengan menggunakan analisis deskriptif, kotak dan plot kumis dan plot siri masa di Kemaman, Terengganu. Selain itu, plot diurnal juga digunakan untuk menggambarkan mekanisme kimia penyingkiran ozon paras tanah pada waktu malam. Regresi linier berganda digunakan untuk menyesuaikan data yang diperoleh dari tapak pemantauan untuk meramalkan hasil tindak balas pemboleh ubah terpilih dengan kepekatan ozon. Kajian ini memperlihatkan bahawa kepekatan ozon paras tanah di Kemaman mempunyai purata yang 16.11 ppb. Plot diurnal telah menunjukkan kepekatan ozon paras tanah menurun pada waktu malam manakala kepekatan nitrogen dioksida masih kekal pada tahap yang tinggi. Sepanjang tempoh pemantauan, kepekatan tertinggi ozon paras tanah yang dicatatkan ialah 51 ppb. Nilai R^2 untuk data primer adalah sederhana, iaitu 0.408, menunjukkan pemboleh ubah yang dipilih telah kurang menjelaskan kemungkinan dalam variasi kepekatan ozon paras tanah. Kepekatan ozon paras tanah dipantau di Kemaman adalah lebih rendah daripada nitrogen dioksida kerana berlakunya hujan sepanjang tempoh pemantauan dan juga disebabkan oleh kimia penyingkiran ozon paras tanah pada waktu malam. Sebaliknya, nilai R^2 untuk data sekunder adalah rendah, 0.052, menunjukkan pemboleh ubah yang dipilih lebih kurang kemungkinan menjelaskan variasi kepekatan ozon paras tanah. Ini berkemungkinan disebabkan oleh banyak kehilangan data.

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LIST OF ABBREVIATIONS

a.m.	Ante meridiem
CO	Carbon monoxide
DOE	Department of Environment, Malaysia
DW	Durbin-Watson
H_2O	Water
HACA	Hierarchical Agglomerative Cluster Analysis
HNO_3	Nitric acid
LPG	Liquified petroleum gas
M	Stabilizing agent
MLR	Multiple Linear Regression
N_2	Dinitrogen
N_2O_5	Dinitrogen pentoxide
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_3	Nitrate
NO_x	Nitrogen oxides
O	Oxygen atom
O_2	Oxygen gas
O_3	Ozone
p.m.	Post meridiem
PM_{10}	Particulate matter which aerodynamic diameter less than 10 micrometers

$PM_{2.5}$	Particulate matter which aerodynamic diameter less than 2.5 micrometers
SO_2	Sulphur dioxide
USEPA	United States Environmental Protection Agency
UVB	Ultraviolet B
VIF	Variance inflation factor
VOCs	Volatile organic compounds
WHO	World Health Organization

LIST OF SYMBOLS

%	Percent
$\mu g/m^3$	Microgram per cubic meter
nm	Nanometre
+	Plus
λ	Wavelength
$\rightleftharpoons$	Reversible reaction
ppm	Parts per million
N	North
E	East
km^2	Kilometre square
mm	Millimetre
°	Degree (angle)
‘	Minute (angle)
±	Plus or minus
<	Less than
ºC	Temperature (degree Celsius)
ppb	Parts per billion
σ	Sigma

CHAPTER 1

INTRODUCTION

1.1 Background Study

Ambient air refers to the mixture of gases, which compromises 78% of nitrogen, 21% of oxygen, 0.03% of carbon dioxide and a small amount of argon and other gases. When these composition changes due to dust, aerosols or fumes, air pollution occurs. These changes will also cause respiratory and cardiac diseases because they were tiny particles and may attack the internal organs when inhaled.

Outdoor (ambient) air pollution refers to air pollution with unrestricted portion of air in the atmosphere (WHO, 2019). It can be originated from natural or anthropogenic sources. However, the major ambient air pollution was contributed by anthropogenic sources. For example, fuel combustion from vehicles, power generation and residential waste disposal (WHO, 2000). Anthropogenic air pollution has become a hot topic and receive high public health concern. It existed since the knowledge on using fire and in this generation, it was further worsen by industrialization (Katsouyanni, 2003). Human activities will directly affect ambient air quality. For examples, burning of fossil fuels and release of chemical pollutants from industry (Bruneekreef & Holgate, 2002).

According to World Health Organization (2000), there were five significant air pollutants, which were ozone (O_3), carbon monoxide (CO), particulate matter (PM_{10}

and $PM_{2.5}$), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). Ozone, nitrogen dioxide and sulphur dioxide were the main pollutants in Malaysia. These air pollutants can cause adverse effects on health effects as well as threatening flora and fauna at ambient level.

The standard that is used to determine the safe level is the New Malaysia Ambient Air Quality Standard, which was established in year 2013 to replace the previous standard, Malaysia Ambient Air Quality Guideline 1989. In this new standard, six air pollutants are included in the criteria: PM_{10}, $PM_{2.5}$, sulphur dioxide, nitrogen dioxide, ground-level ozone and carbon monoxide. The threshold level for ozone concentration in 1 hour was 92 ppb while in 8 hours was 51 ppb for year 2019 (DOE, 2013).

Ozone can bring benefits or negative impacts and it depends on where it was found. Ozone can be produced naturally in the stratosphere or as a secondary pollutant in the troposphere. Stratospheric ozone functions as protecting all the living things from ultraviolet radiation from the sun and therefore it was classified as "good" ozone. On the other hand, ground-level ozone or in another word, tropospheric ozone was classified as "bad" because it may cause adverse effects to the environment and living things (USEPA, 2018). The main precursor of the formation of ground-level ozone was nitrogen dioxide. According to Ghazali *et al.* (2010), nitrogen dioxide is produced from nitric oxide (NO) by reacting with oxidised hydrocarbons. Meanwhile, nitric oxide originated from the emission of vehicles. Nitrogen dioxide will release oxygen atom (O) through photolysis process. Then, oxygen will be taken by oxygen gas (O_2) molecules to form ozone. Ozone will then react with nitric oxide. The by-products of this chemical reaction are nitrogen dioxide and oxygen. After that, the cycle repeats (Teixera *et al.*, 2009).

High concentration of ozone can cause negative impacts to human health and vegetation such as damage to lung tissues and cardiovascular disease (Yahaya *et al.*, 2017). It reduces lung function and cause difficulties in breathing. Therefore, it also aggravates asthma. Furthermore, people that were active in outdoor activities were more vulnerable to ozone exposure due to increased intake of ozone. Besides, it also damage plants, disturbing their photosynthesis process as well as their production (Lichtfouse, 2015). This causes the vegetation were forced to adapt to the new environment and further leads to change in genetic in the plants. Therefore, the plants that reproduced were with poor quality such as stunted growth, low productivity and reduced shoot growth (Davidson & Barnes, 1998).

Since this reaction requires ultraviolet radiation, it results in higher ozone concentration during daytime due to the higher formation rate of ozone. It was further enhanced at noon due to the high intensity of sunlight (USEPA, 1996). Meanwhile, it drops significantly starting from 3 p.m. because of the reduction of light intensity (Awang & Ramli, 2017). Since it was photochemically driven, the ozone concentration should be lower during nighttime because there was no formation of ozone during nighttime. Furthermore, the ozone concentration will be reduced during nighttime due to depletion of ozone by the reaction between ozone and nitric oxide (Dueñas *et al.*, 2002). Since ground-level ozone was a secondary pollutant, which was unsafe for human, environment and plants, it has to be further determined to investigate its variation.

1.2 Problem Statement

Ground-level ozone, a co-contaminant plays an important role as oxidant and also greenhouse gas, which can be found in stratosphere and troposphere (Muhamed-Noor *et al.*, 2018). However, tropospheric ozone is a secondary pollutant, forming by the reaction between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) through a series of chemical reaction with the presence of ultraviolet rays of sunlight (Padgett, 2010).

High concentration of ozone causes adverse effect to vegetation and ecosystems such as forest, wilderness areas and crops production. It inhibits the growth of the crops, which indirectly affect the income of the farmers. Besides, ozone poses significant risk to human health. According to Lippmann (2012), the only significant exposure to ozone was through inhalation. Therefore, people who active in outdoor activities were more vulnerable to ozone because ozone penetration increases with both volume and flowrate.

According to Ghazali *et al.* (2010), ozone exhibits strong day-to-day variations. Meanwhile, ozone's precursor and ultraviolet radiation were the main factor that alters the formation and destruction of ozone. Ozone can be removed from ambient air via chemical reactions with nitrogen oxides. It was further removed during nighttime because of the insufficient ultraviolet light for the formation of ozone (USEPA, 2018).

Awang *et al.* (2015a) found that the ozone concentration has a peak value during noontime due to the maximal ultraviolet radiation. Ozone concentration in Kemaman was low and stable due to the deposition processes and chemical reactions (Sousa *et al.*, 2011). However, the mean nighttime of ozone concentration in Kemaman was much higher than the other stations and yet the concentration of its precursor, nitrogen

dioxide were not measured. The real reason and factor for this scenario was still a myth. Therefore, this problem was investigated critically.

1.3 Objectives

i. To determine the concentration of ground-level ozone and nitrogen dioxide during nighttime in Kemaman.

ii. To investigate the relationship between the ozone concentration and its precursors during the nighttime.

iii. To determine the effect of precursors on high nighttime ground-level ozone concentration in Kemaman.

1.4 Scope of Study

In this research, the nighttime concentration of ground-level ozone and its precursors were determined from 7 p.m. to 7 a.m. in Kemaman, Terengganu. Kemaman was chosen as the study area because the nighttime ground-level ozone concentration was abnormally high where it should not be. Therefore, primary data were collected at this area. Besides, secondary data on hourly basis were also obtained from Department of Environment (DOE) for the year 2006 - 2010. There were some analysis used in this study such as descriptive analysis and time-series plot, which used to describe the features of data. Besides, diurnal plot also used to visualize the hourly average data. The last analysis used was Multiple Linear Regression to illustrate the characteristics and patterns of ground-level ozone and its precursor over 24 hours.

1.5 Significance of Study

Long-term exposure to high concentration of ozone during nighttime poses a risk to environment and human health. Therefore, high nighttime ground-level ozone concentration should be studied to further understanding the abnormal behaviour of the ground-level ozone concentration. The factors for the accumulation of nighttime ground-level ozone were investigated in order to mitigate the side effects from the ozone.

CHAPTER 2

LITERATURE REVIEW

2.1 Ground-level Ozone

Unlike stratospheric ozone, which forms naturally and acts as a protection from harmful ultraviolet rays of the sun. Ground-level ozone also known as tropospheric ozone is an air pollutant, which can be found in troposphere, the closest layer to the Earth with average height of 18 km (USEPA, 2018). Through the chemical reactions between nitrogen oxides and volatile organic compounds with the presence of sunlight, ground-level ozone will be formed. Ozone starts accumulating when the production rate is higher than the destruction rate. Furthermore, sea breezes promote the accumulation of ozone. This happens because of the circulation of air that induced by temperature, it traps smog-producing compounds (Souza, 2017). It was also related to the degradation of air quality worldwide (Chattopadhyay & Chattopadhyay, 2012).

2.2 Ozone Trend

2.2.1 Ozone Trend in Worldwide

According to Wang *et al.* (2007), China expands its economic growth by increasing in higher consumption of fossil fuels. This further result in increasing in nitrogen oxides. Generally, the concentration of ozone in rural area was higher than

that of suburban area and urban area in Guangzhou (Zhou & Feng, 2001). The concentration of ozone was also affected by seasons. During winter season, it was found that the concentration of ozone was significantly lower while concentration of ozone was high during summer (Luo *et al.*, 2000; Wang *et al.*, 2003). Besides, the concentration of ozone also show an increasing trend in summer season, reflecting the ozone production was the highest during summer (Lin *et al.*, 2000). Furthermore, increase the use of vehicle also increase local vehicle traffic, which indirectly caused an increment in ozone concentration (Lin *et al.*, 2000). According to Bytenerowicz (2002), the average ozone concentrations decrease in Vychodna during mid-August, where the concentration rarely exceed 40 µg/m^3. The diurnal pattern can also be observed where the minimum value of concentration occurred in early morning while the highest concentration was determined in the afternoon. Although the ozone concentration in August and September was particularly lower, the general daily pattern of ozone does not change.

2.2.2 Ozone Trend in Malaysia

Ground-level ozone was known to exhibit daily variation strongly, which indirectly leads to complexity pollutants' analysis and predictions (Awang *et al.*, 2015b). Figure 2.1 showed the diurnal plot of ozone, nitrogen dioxide and nitric oxide concentration in Kota Bharu.

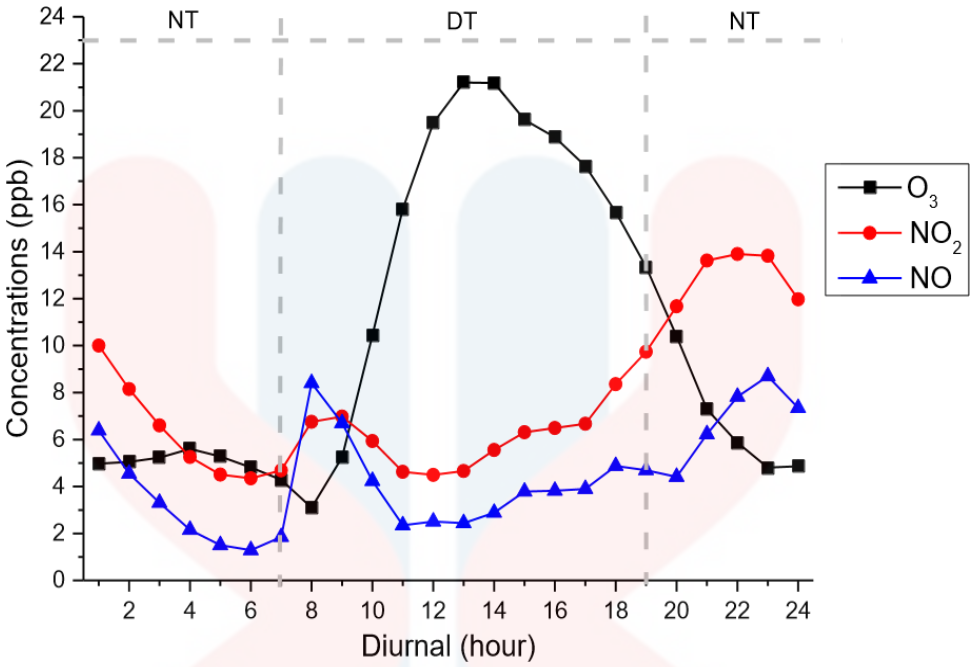

Figure 2.1: Diurnal plot of ozone, nitrogen dioxide and nitric oxide concentration in Kota Bharu (Awang & Ramli, 2017).

Based on Figure 2.1, the concentration of ozone was indirectly proportional to the concentration of nitrogen dioxide and nitric oxide. There were a lot of other researches which show the concentration of ozone, nitric oxide and nitrogen dioxide were similar trend all over Malaysia (Abdullah *et al.*, 2012; Banan *et al.*, 2013; Zainordin *et al.*, 2017).

Since Malaysia is not a four-season country, it was not affected by seasons (Khoder, 2008). However, it is affected by monsoon. According to Tan *et al.* (2014), north-east monsoon and south-west monsoon will affect the variation of ozone. The lowest concentration of ozone was recorded during north-east monsoon while a few peaks were recorded during inter-monsoon season, which was April and October and also south-west monsoon.

2.3 Ozone Chemical Reactions

2.3.1 Daytime Tropospheric Chemistry

Generally, the concentration of ozone was affected by the concentration of nitrogen oxides, volatile organic compounds and the intensity of solar radiation. In tropospheric layer, nitrogen dioxide photolyzes in sunlight to form nitric oxide and oxygen atom at wavelength shorter than 400 nm as shown in Equation 2.1.

$$NO_2 + hv\ (\lambda < 400\ nm) \rightarrow NO + O \quad (2.1)$$

Oxygen atom will react with O_2 to produce ozone. This oxygen atom will then combine with O_2 with the presence of stabilizer, M to form ozone as shown in Equation 2.2.

$$O + O_2 + M \rightarrow O_3 + M \quad (2.2)$$

Therefore, the concentration of ground-level ozone were on peak during noontime due to the strongest light intensity. Emissions from transportation vehicles exhaust or industries are also major sources of nitrogen oxides and volatile organic compounds (Seinfield & Pandis, 2016). This phenomenon is more obvious in urban areas (The World Bank Group, 1998). However, according to researches, the peak concentration were found usually last for less than three hours.

2.3.2 Nighttime Tropospheric Chemistry

The nighttime ground-level ozone is a continuous reaction of photochemical reactions. Nitrogen oxides that is produced in the daytime is an ingredient to continue the reaction during the nighttime as shown in Equation 2.3.

$$O_3 + NO \rightarrow O_2 + NO_2 \quad (2.3)$$

Since there is no sunlight available during nighttime, nitrogen dioxide combine with ozone to produce nitrate radicals to form unstable nitrate (NO_3) and O_2 as shown in Equation 2.4.

$$NO_2 + O_3 \rightarrow NO_3 + O_2 \quad (2.4)$$

They can further turn into dinitrogen pentoxide (N_2O_5) (Somers *et al.*, 2007). However, N_2O_5 was unstable, which can be disassociate back into NO_3 and nitrogen dioxide as shown in Equation 2.5.

$$NO_3 + NO_2 \rightleftharpoons N_2O_5 \quad (2.5)$$

2.4 Effects of Ground-Level Ozone on Humans, Animals and the Environment

In addition, N_2O_5 can react with water (H_2O) to form nitric acid (HNO_3), where it deposits on the surface of ocean and reduce photochemical reaction, preventing them from involving in the next reaction as shown in Equation 2.6.

$$N_2O_5 + H_2O \rightarrow 2HNO_3 \quad (2.6)$$

Besides, it was also the key ingredient for the formation of acid rain (Awang *et al.*, 2016a). Therefore, ground-level ozone was a harmful air pollutant. It causes side effects to humans, animals, crops and also the environment. According to The World Bank Group (1998), the main health concern of exposure was the consequences and effects on living organisms especially the respiratory system. This was because ozone irritate humans' lungs. Factors that may cause the severity of the disease were

concentration of ozone, duration of exposure to ozone, volume of air breathed in and the length interval between the exposures. Besides, long-term exposure to ozone may cause respiratory diseases such as malfunction of lungs (Banan *et al.*, 2013).

On the other hand, ozone damages the leaves and shoots of plants. This indirectly reduces the production yield of the crops and inhibits their growth. Moreover, this lowers the resistance of the crops and reduces the quality of the crops. Ozone can reduce the amount of carbon dioxide during plants photosynthesis and indirectly disturbing the process, reducing the rate of photosynthesis (Ashmore, 2005). Frequency of exposure to ozone, duration of exposure to ozone and concentration of exposure to ozone were all major factors to manipulate the impacts of the exposure.

2.5 Factors that Affect the Concentration of Ground-Level Ozone

2.5.1 Effects of Precursors on Ground-Level Ozone

Ground-level ozone is not emitted directly into the air but through chemical reactions between nitrogen oxides and volatile organic compounds in the presence of heat and sunlight. The photochemical reaction can only be completed with the presence of ultraviolet B (UVB) (Tiwary and Colls, 2009). Nitrogen oxides and volatile organic compounds were ozone precursors, where the concentration of nitrogen oxides was the main manipulated variable for the changes of concentration of ground-level ozone. Nitrogen oxides were usually emitted from industrial facilities, electric utilities, motor vehicles exhaust, chemical solvents and gasoline vapors.

According to Stevenson *et al.* (2006), ozone has short atmospheric lifetime, which was about 30 minutes but the lifetime extends to several weeks when the concentration of its precursors were high. The net chemical production occurs when

precursor concentrations were high, and in troposphere where the destruction of ozone was slow (Tiwari & Agrawal, 2018). Cheng *et al.* (2009) also found that the formation of ozone will be suppressed by high concentration of nitric oxide.

2.5.2 Effects of Meteorological Factors on Ground-Level Ozone

Meteorological effects also affect the concentration of ozone too. Certain meteorological conditions are required for the accumulation of the ozone concentration For example, winds, high temperatures and solar radiation (MacKenzie *et al.*, 1995).

According to Dueñas *et al.* (2002), temperature, wind speed, wind direction and relative humidity are important for the change in concentration of ozone. Temperature plays a role as promoting the propogation rate of radical chain and also a demoting role on the termination rate of the chain (Ruiz-Suarez *et al.*, 1995). Generally, the higher the temperature, the higher the concentration of ozone. Wind speed and wind direction were vital for the dispersion of ozone precursors from one place to another. Sea breeze as well as land breeze contribute to the distribution and dispersion of ozone. Liu *et al.* (2002) stated that land breeze may transport the produced ozone together with its precursor over the sea while the accumulated ozone can return to the land with sea breeze. Therefore, it depends on the sources and direction of the wind to cause an accumulation or elimination of the ozone concentration. Liu *et al.* (2002) stated that relative humidity play a role in overall reactivity system in terms of chain terminating reactions or producing wet aerosols. This will further affect the ultraviolet actinic flux, a radiant quality used for calculating the rate of photodissociation (Camalier *et al.*, 2007).

Whereas, high relative humidity can promote the cleaning of ozone due to the wet conditions. In addition, wind acts as an agent to help dispersing the air pollutants (Dueñas *et al.*, 2002). The peak concentration of ozone were found to exist in the summer season due to high solar radiation (Wild & Palmer, 2008).

2.6 Sources of Precursors

2.6.1 Nitrogen Dioxide

Nitrogen dioxide is a coloured gas but its colour varies with the atmosphere's condition. It is pungent in odour and relatively toxic and corrosive due to its highly oxidation rate. It is a vital air pollutant, which was the main contribution factor for the formation of smog. It gives adverse effect on human health. Mobile sources such as personal cars and public transportation were the biggest source of nitrogen dioxide. Other sources such as power-supply stations, fuel burning by industries and production processes of industries also contribute significant pollutants in Malaysia (Afroz *et al.*, 2003). Song *et al.* (2010) stated that ship emission was also a contributing factor for emission of nitrogen dioxide. Besides, nitrogen dioxide can be produced through atmospheric process but in slow and direct oxidation reaction as shown in Equation 2.7 (Godish, 2004).

$$2NO + O_2 \rightarrow 2NO_2 \qquad (2.7)$$

In this research, adjusted nitrogen dioxide was used because the nitrogen dioxide trapped by the equipment contains ground-level ozone (Jhun *et al.*, 2014), where the formula was shown as below:

[Adjusted nitrogen dioxide] = [Nitrogen dioxide] – [Ground-level ozone]

2.6.2 Nitric Oxide

Nitric oxide was tasteless, odourless, colourless and relatively non-toxic. It can be produced naturally through biological nitrification process or transport from stratosphere to troposphere. It can be produced at high temperature combustion as shown in Equation 2.8.

$$N_2 + O_2 \rightarrow 2NO \quad (2.8)$$

Nitric oxide was also environmental concern because it serves as precursor molecules for many other atmospheric reactions, which concentration increases significantly according to human activities (Godish, 2004).

2.7 Common Analysis Method

Awang *et al.* (2016b) used statistical analysis, mean, minimum, median, maximum and standard deviation to overview the overall distribution of the continuous data. Besides, cluster analysis was also widely used in order to assemble objects with similar characteristics. Awang *et al.* (2015a) used Hierarchical Agglomerative Cluster Analysis (HACA) to nine monitoring stations to illustrate the variability of nighttime ozone. Moreover, Multiple Linear Regression (MLR) was also a common method in predicting the concentration of particulate matters. Ul-Saufie *et al.* (2013) used Multiple Linear Regression to predict the next two-day and next-three day concentration of PM_{10} at the same site. It was very important as residual analysis determines the adequacy of the statistical model as if the error were in regular patterns, the model does not show systematic information. Based on the reports of Ul-Saufie *et al.* (2013), the future PM_{10} concentration prediction models illustrated no errors with multicollinearity.

CHAPTER 3

MATERIALS AND METHODS

3.1 Research Flowchart

Figure 3.1 showed the procedure that was done in the research. The title of the research was "Assessment of High Nighttime Ground-level Ozone Concentration in Kemaman" There are two types of data collection, which are primary data on July in Kemaman and secondary data from year 2006 – 2010. The total duration of monitoring in Kemaman was 72 hours, starting from 23rd July to 26th July 2019. However, only the nighttime data were calculated and tabulated. The primary data was collected at 7.10 a.m. everyday. The raw data was one value per minute. Then, the data were calculated to average to hourly data. The equipment used were Aeroqual series 500 with ozone sensor 0-0.5 ppm and nitrogen dioxide sensor 0-1 ppm. On the other hand, the secondary data used was from year 2006 – 2010 from DOE. The analysis used were statistical descriptive, box and whisker plot, time-series plot, diurnal plot and Multiple Linear Regression.

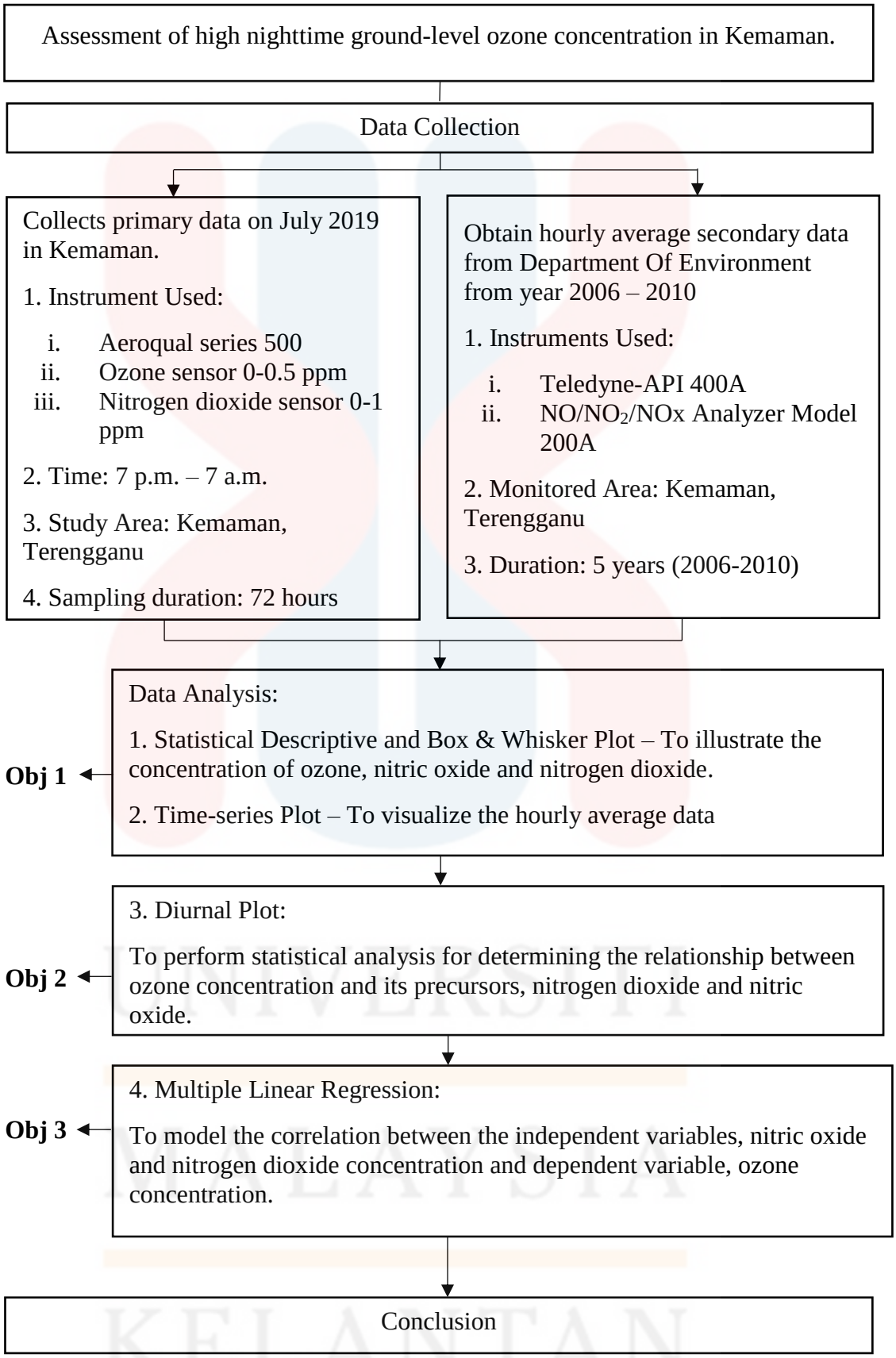

Figure 3.1: Research flow of research methodologies

3.2 Study Area

The study area is located at Kemaman, Terengganu, Malaysia. Kemaman is one of seven districts of Terengganu. It is in coordinates of 4°16′N 103°23′E. The total area was about 2535.60 km^2. The population of Kemaman is about 137070 while the average annual temperature in Kemaman was 26.5°C. Annual rainfall recorded was about 239 mm while average rainfall was about 2882 mm (Ekhwan *et al.*, 2009). Kemaman's geographical area can be divided into three main groups, which were coastal, inland and foothill area. It is mainly capacited with oil palm plantation and timber. So, the residents were focusing more on local economic activities, farming or fishing. Besides, there were also steel industries, oil discovery in the offshore in Kemaman. Petronas also own liquified petroleum gas (LPG) in Kemaman Port as an export terminal, which makes and supports the economic growth in Kemaman. On the other hand, there were also parks, beaches and mini zoo found in Kemaman. Figure 3.2 showed the map of monitoring area.

Figure 3.2: Location of study area, Kemaman. (Source: Google Map, 2019).

3.3 Monitoring Equipment

3.3.1 Secondary Data

The secondary data for Kemaman, Terengganu were obtained from Department of Environment (DOE) from year 2006 – 2010. The instruments used to obtain the data were Teledyne-API 400A and $NO/NO_2/NO_x$ Analyzer model 200A starting from 7 p.m. to 7 a.m., where the data were recorded hourly. Teledyne-API 400A or Model 400A UV Absorption Ozone Analyzer was a microprocessor-controlled analyser used to measure ozone concentration in ambient air based on Beer-Lambert law. Ultraviolet light signal with wavelength of 254 nm is used in this system. The light passes through the sample cell containing ozone. Measurement between sample stream and sample that had been scrubbed by ozone was alternated by switching valve every three seconds. This device is suitable to detect the concentration of ozone within the range of 0 - 10 ppm (Cherokee, 2019). The $NO/NO_2/NO_x$ Analyzer model 200A uses chemiluminescence detection to provide sensitivity and stability for the monitoring of nitric oxide, nitrogen dioxide and total nitrogen oxides. It is suitable to detect the concentration of nitrogen dioxides within the range of 0 – 50 ppb to 0 – 20 ppm (Teledyne Monitor Lab, 2016).

3.3.2 Primary Data

The concentration of ozone, nitric oxide and nitrogen dioxide were collected in Kemaman, Terengganu by using Aeroqual series 500 with two different types of sensors, which were Ozone Sensor Head 0-0.5 ppm and Nitrogen Dioxide Sensor Head 0-1 ppm. The Aeroqual series 500 was set up under a waterproof shelter to prevent it from getting wet. These Aeroquals were placed at 1.5 m elevation above the ground

level, which was an average height for humans' respiration take place. The charger of the Aeroqual were switched on every two hours to prevent the battery of both Aeroqual from going depleted. The Aeroqual sensors inlets were positioned just under the waterproof shelter for the sampling of freely flowing ambient air. In this research, the data were collected for three days continuously from 7 p.m. to 7 a.m. The data were all collected in parts per million (ppm). Table 3.1 showed the sampling range and details of the Ozone Sensor Head 0-0.5 ppm while Table 3.2 showed the details of Nitrogen Dioxide Sensor Head 0-1 ppm. Both sensors recorded the readings in ppm and were required to convert to ppb for the ease of interpretation.

Table 3.1: Details of Ozone Sensor Head 0-0.5 ppm.

Sensor Code	OZL / OZL2/ OZL4
Range	0 – 0.5 ppm
Sensor Type	GSS
Minimum Detection Limit	0.001 ppm
Accuracy of Factory Calibration	< ± 0.008 ppm 0 – 0.1 ppm < ± 10% 0.1 – 0.5 ppm
Resolution	0.001 ppm
Response Time	60 seconds
Temperature	0 to 40ºC
Relative Humidity	10 to 90%

(Source: Aeroqual, 2019a)

Table 3.2: Details of Nitrogen Dioxide Sensor Head 0-1 ppm.

Sensor Code	ENW / ENW2
Range	0 – 1 ppm
Sensor Type	GSE
Minimum Detection Limit	0.005 ppm
Accuracy of Factory Calibration	< ± 0.02 ppm 0 – 0.2 ppm < ± 10% 0.2 – 1 ppm
Resolution	0.001 ppm
Response Time	30 seconds
Temperature	0 to 40ºC
Relative Humidity	15 to 90%

(Source: Aeroqual, 2019b)

3.4 Data Analysis

The data collected were analysed. Methods that were used for data analysis were descriptive analysis, time-series analysis, diurnal plot and linear regression. Descriptive analysis were used in this research to illustrate the concentration of ozone, nitric oxide and nitrogen dioxide because it provides a simply summary for the samples and the measures with graphical analysis. Besides, time-series plot was used to visualize the data points at all intervals of time in order to see the changes of hourly average data. Furthermore, diurnal plot was also good to perform a statistic for determining the relationship between ozone concentration and its precursors. In order to predict a variable on a continuous dependent variable, linear regression analysis were used.

3.4.1 Treatment of Data

The data collected was during nighttime, which was from 7 p.m. to 7 a.m. The monitoring period was 72 hours. The data were transformed into hourly average from every minute raw data. Therefore, there were a total of 36 sets of hourly average data. These data were further analysed by analysis methods mentioned before.

3.4.2 Descriptive Analysis

Descriptive statistics were used in data analysis to describe the basic features of the data. Basis of the quantitative analysis data can be visualised from the simple graphics analysis. It was used in this research to analyse the concentration of nighttime ozone, nitric oxide and nitrogen dioxide. Mode, mean, median and standard deviation

were determined so that the maximum and minimum concentration can be observed obviously.

The formula for mean was shown in Equation 3.1.

$$Mean = \frac{sum\ of\ the\ values}{the\ number\ of\ values} \quad (3.1)$$

The formula for median was shown in Equation 3.2.

$$Median = \frac{(n+1)^{th}}{2}\ value \quad (3.2)$$

The formula for standard deviation was shown in Equation 3.3.

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{N-1}} \quad (3.3)$$

Where,

σ = standard deviation

$\sum$ = summation of

$\bar{x}$ = sample mean

N = Total number of scores in sample

Whereas, mode can be observed directly from the graph, where the highest frequency or weightage of the data was the mode. Maximum point was determined when the data achieved a highest peak while the minimum point was determined when the data achieved a lowest peak.

3.4.3 Time-series plot

Time-series graph was used to visualize the hourly average data. So, the changes of nighttime ozone concentration as well as its precursors can be observed over the time taken.

3.4.4 Diurnal plot

The diurnal plot was used to analyse the concentration of ozone, nitric oxide and nitrogen dioxide to characterise the characteristic and pattern of these components over 24 hours.

3.4.5 Multiple Linear Regression

Multiple Linear Regression was used to determine the relationship of independent variable and dependent variables. It was used in this research in order to predict the contributions of ground-level ozone precursors to ground-level ozone variations (Abdul-Wahab *et al.*, 2005). In this research, the independent variable will be the nitric oxide and nitrogen dioxide concentration while the dependent variables will be ozone concentration (Gvozdic *et al.*, 2011; Borcherds, 2012). The equation of the linear regression was shown in Equation 3.4.

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \qquad (3.4)$$

where,

y_i = Dependent variable

x_i = Independent variable

$\beta_0 =$ y – intercept (constant term)

$\beta_p =$ Slope coefficients for each explanatory variable

On the other hand, the R^2 value indicates the model could have lesser variability of the predicted data. Value which approaching 1 will indicate more variability of the data related to the observed values (Abdul-Wahab *et al.*, 2005; Elbayoumi *et al.*, 2014). Thus, higher R^2 value will have better results.

Durbin-Watson (DW) statistic was also used as a test for autocorrelation in the residuals from statistical regression analysis. (Chatterjee *et al.*, 2013) The Durbin-Watson will always fall between 0 to 4, where 2.0 was the midpoint, which means that there was no autocorrelation found in the sample (Ul-Saufie *et al.*, 2013). However, value that approaching zero represented positive correlation while the value approaching four represented negative correlation in the sample. (McAuliffe, 2005). Variance inflation factor (VIF), was the quotient of the variance with more than one terms by the variance of a model with a single term alone (James *et al.*, 2017). It was used to evaluate multicollinearity by using least squares regression. The developed model should not encounter multicollinearity problems as the variance inflation factor was less than 10 while the multicollinearity was considered high if it was more than 10 (Kutner *et al.*, 2004; Sheather, 2009).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data of Descriptive Statistics

Table 4.1 showed the descriptive statistics of secondary data, which were the concentration of ozone, nitric oxide and nitrogen dioxide from year 2006 to 2010 in Kemaman, Terengganu. Based on Table 4.1 and Figure 4.1, the mean concentration for three parameters, ground-level ozone, nitric oxide and nitrogen dioxide were below the MAAQG. The mean concentration of ground-level ozone in year 2008 was the highest, which was 21.89 ppb while the lowest was recorded in year 2010, which was 13.40 ppb. The maximum concentration of ground-level ozone has not exceeded MAAQG in year 2006, which was 83 ppb. The minimum concentration of three parameters were around 0 ppb but for the maximum concentration was about 25 ppb. Based on the result, the mean of nighttime nitrogen dioxide concentration in Kemaman, Terengganu was low, which were around 3 ppb throughout these 5 years, where it does not exceed the MAAQG. The maximum nitrogen dioxide concentration was 34 ppb, recorded in year 2006. On the other hand, the minimum nitrogen dioxide concentration for these 5 years were the same, which was 0 ppb.

Table 4.1: Descriptive statistic of ozone, nitric oxide and nitrogen dioxide in Kemaman, Terengganu

Descriptive Statistics Table					
Date	Nighttime (NT)				
	Parameters	Minimum	Maximum	Mean	SD
2006	O_3 (ppb)	0.00	83.00	15.03	10.97
	NO (ppb)	0.00	22.00	0.98	1.42
	NO_2 (ppb)	0.00	34.00	3.40	2.84
2007	O_3 (ppb)	1.00	66.00	20.53	13.35
	NO (ppb)	0.00	21.00	0.85	1.29
	NO_2 (ppb)	0.00	22.00	2.84	2.55
2008	O_3 (ppb)	0.00	71.00	21.89	14.22
	NO (ppb)	0.00	60.00	1.01	3.96
	NO_2 (ppb)	0.00	23.00	3.24	3.09
2009	O_3 (ppb)	0.00	74.00	15.80	11.54
	NO (ppb)	0.00	38.00	0.41	1.34
	NO_2 (ppb)	0.00	25.00	3.28	3.07
2010	O_3 (ppb)	0.00	61.00	13.40	9.54
	NO (ppb)	0.00	33.00	0.83	1.71
	NO_2 (ppb)	0.00	23.00	3.08	2.69
Average 2006 - 2010	O_3 (ppb)	0.20	71.00	17.33	11.92
	NO (ppb)	0.00	34.80	0.82	1.94
	NO_2 (ppb)	0.00	25.40	3.17	2.85

Figure 4.1 showed the box and whisker plot of the concentration of nighttime ground-level ozone, nitric oxide and nitrogen dioxide from year 2006 – 2010.

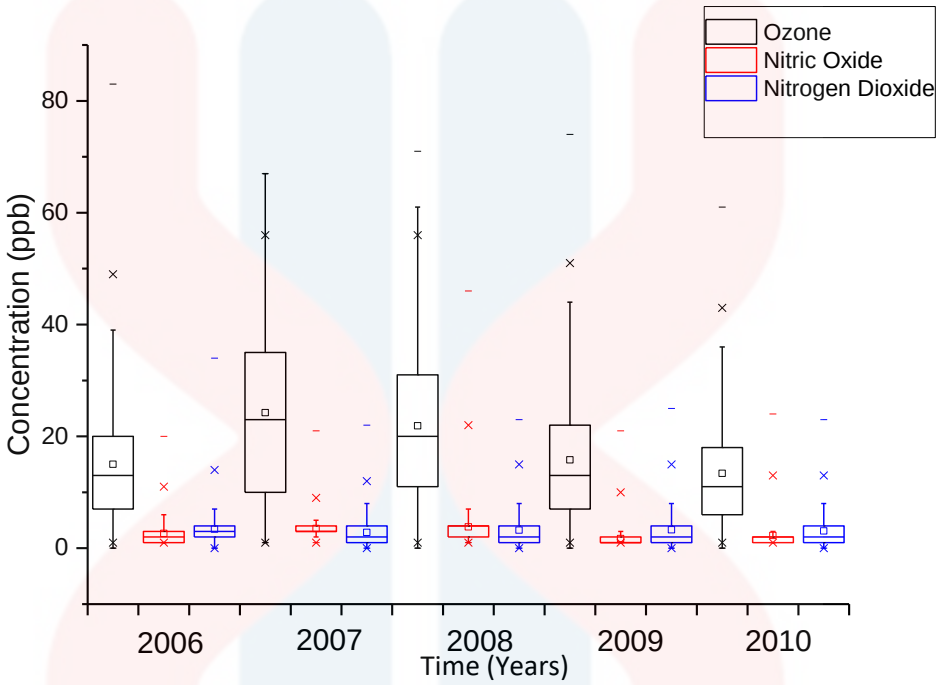

Figure 4.1: Concentration of secondary data in Kemaman, Terengganu.

In overall, the mean concentration of nighttime ground-level ozone, nitric oxide and nitrogen dioxide were 17.33 ppb, 0.82 ppb and 3.17 ppb respectively. This was because of the absence of sunlight during nighttime. This directly affect the production of ground-level ozone because there was no photochemical reaction (Awang *et al.*, 2015a; Awang & Ramli, 2017). Moreover, there were less vehicles during nighttime. Therefore, there were less vehicle emissions such as nitrogen oxides.

Table 4.2 showed the descriptive statistics of primary data of ozone and nitrogen dioxide from 23rd July to 26th July 2019 in Kemaman, Terengganu.

Table 4.2: Descriptive statistics of ozone and nitrogen dioxide in Kemaman, Terengganu

Descriptive Statistics Table					
Date	Nighttime (NT)				
	Parameters	Min	Max	Mean	SD
Day 1	O_3 (ppb)	0.00	23.00	11.55	4.79
	NO_2 (ppb)	23.00	56.00	36.71	6.31
Day 2	O_3 (ppb)	5.00	51.00	25.31	11.29
	NO_2 (ppb)	8.00	51.00	30.07	7.18
Day 3	O_3 (ppb)	0.00	27.00	11.47	5.61
	NO_2 (ppb)	22.00	67.00	39.62	8.18
Average	O_3 (ppb)	1.67	33.67	16.11	7.23
	NO_2 (ppb)	17.67	58.00	35.47	7.22

Figure 4.2 showed the box & whisker plot of the concentration of nighttime ground-level ozone and adjusted nitrogen dioxide during the monitoring period.

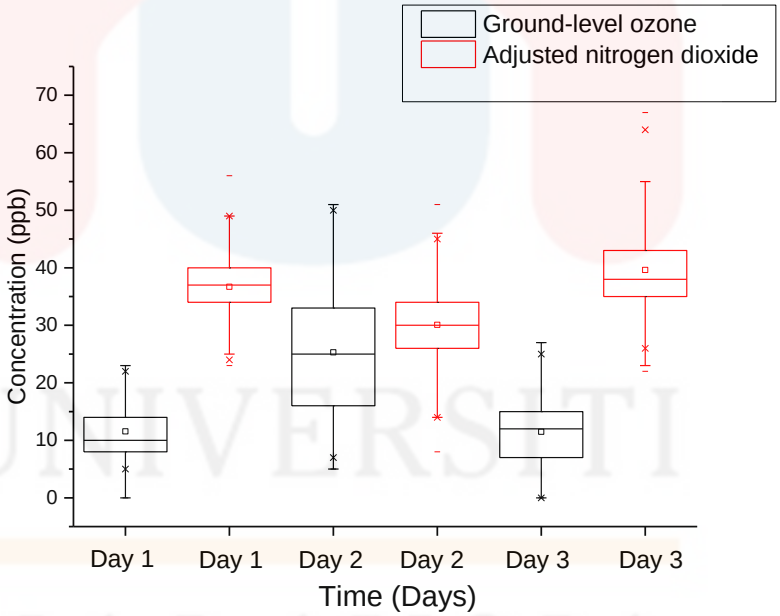

Figure 4.2: Concentration of primary data in Kemaman, Terengganu.

Based on the Table 4.2 and Figure 4.2, the mean of nighttime ground-level ozone concentration in Kemaman was high, which was 11.55 ppb on Day 1. During the monitoring period, there was construction site nearby the sampling site. Therefore, the pollutants contributed may be increased.

On Day 1, it was raining starting from 1 a.m. to 2 a.m. and 6 a.m. to 7 a.m. while on Day 2, it rained at 9 a.m. to 10 a.m. and 10 p.m. to 11 p.m. On the last day, it started to rain at 7 p.m. to 7.30 p.m. and continued to rain from 1 a.m. to 6.30 a.m. The result showed that the mean concentration on Day 1 was quite similar with Day 3 because both days experienced raining during nighttime. The mean concentration of nitrogen dioxide was 48.28 ppb, with minimal changes and differences during these three days of monitoring period.

The maximum concentration of ground-level ozone was 51 ppb on Day 2 as there was a little rainfall during nighttime and in the morning, starting from 9 a.m. to 10 a.m. and also 10 p.m. to 11 p.m. However, it still did not exceed the Malaysia Ambient Air Quality Guideline (MAAQG), which was 92 ppb. Rainfall during the daytime has significantly reduce the concentration of ground-level ozone. However, unlike Day 1 and Day 3, where the rainfall happened during nighttime, the mean concentration of nighttime ground-level ozone was the highest during the monitoring period. Due to there was no rainfall during nighttime, the minimum concentration of three parameters were different compared to other days, where the minimum concentration of ground-level ozone was 5 ppb.

On Day 3, there was a short period of raining from 7 p.m. to 7.30 p.m. and a long period of raining during 1 a.m. to 6.30 a.m. The mean concentration of ground-level ozone was 11.47 ppb, which was the lowest among these three days while the maximum concentration on Day 3 was only 27 ppb. On the other hand, the minimum concentration of ground-level ozone recorded were quite consistent, which were 0 ppb on Day 1, 5 ppb on Day 2 and 0 ppb on Day 3. The reason for the result shown was because of the nighttime removal chemistry. Ground-level ozone concentration will be reduced in the night because of insufficient of sunlight for the formation of ground-

level ozone. In addition, it was lost through nitrogen oxides titration in nighttime (Awang *et al.*, 2015a; Awang & Ramli, 2017). Therefore, the minimum value of the concentration can go up to 0 ppb.

4.2 Data of Time-series Plot

Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6 and Figure 4.7 below showed the time-series plot of concentration of ground-level ozone, nitric oxide and nitrogen dioxide from year 2006 to 2010 in Kemaman, Terengganu respectively.

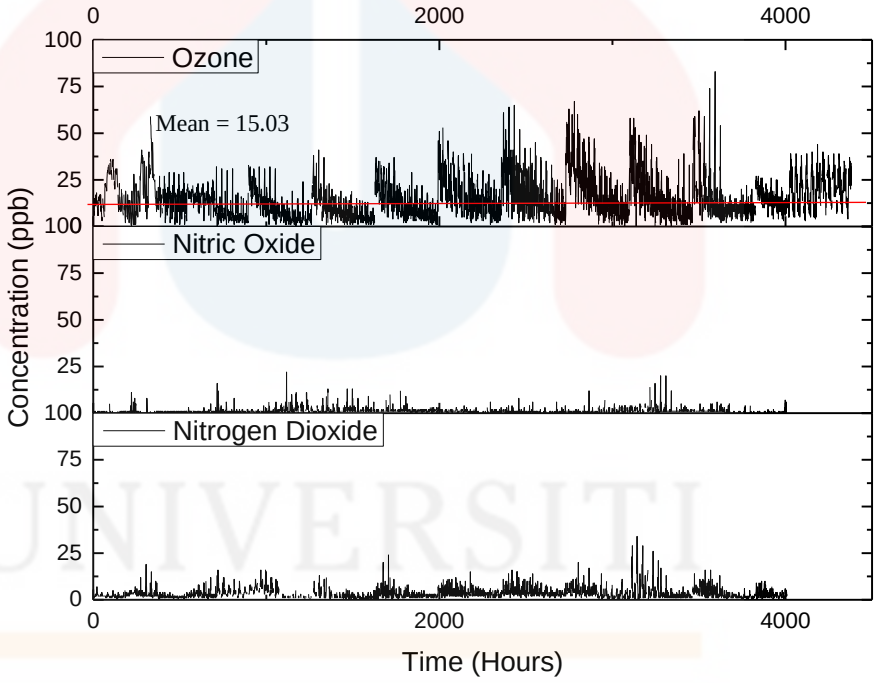

Figure 4.3: Time-series plot for secondary data in Year 2006.

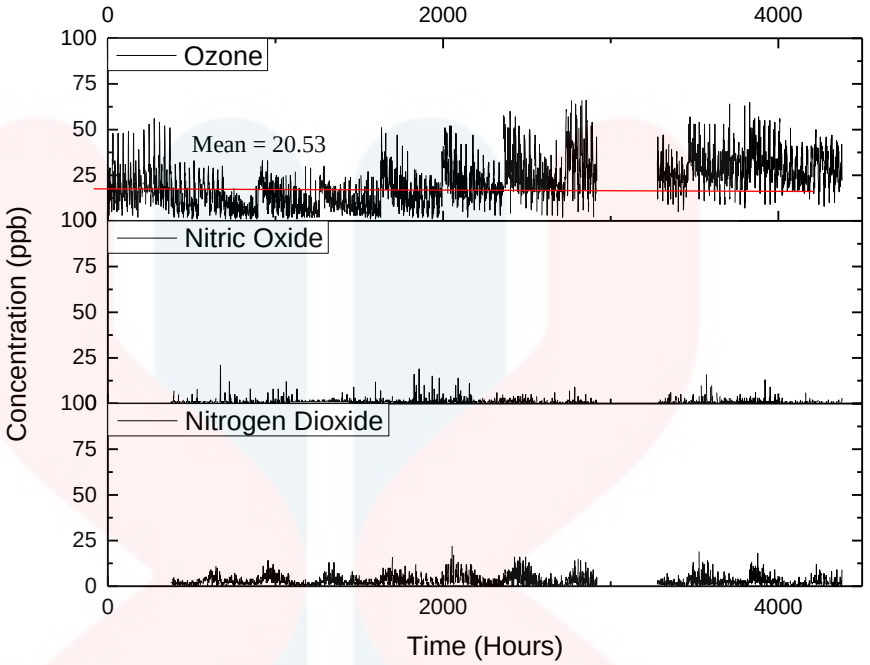

Figure 4.4: Time-series plot for secondary data in Year 2007.

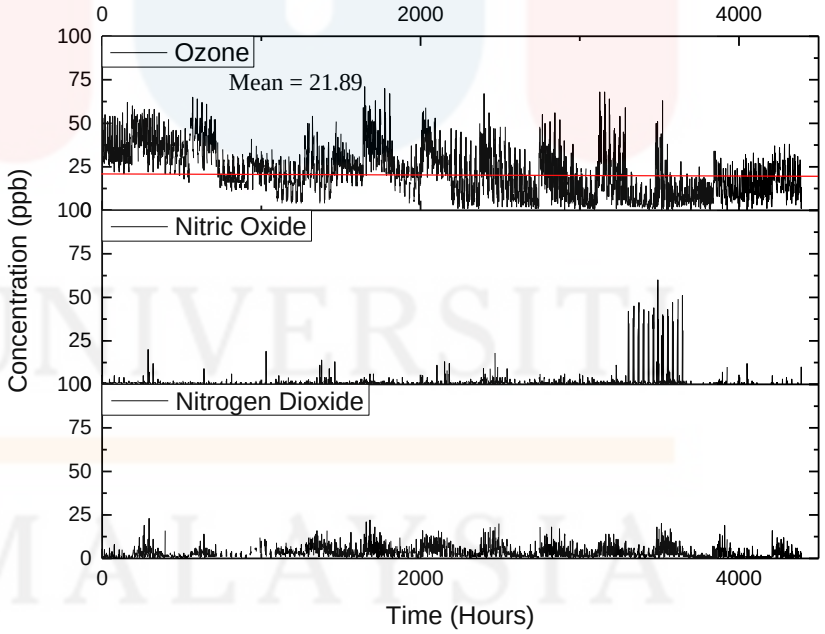

Figure 4.5: Time-series plot for secondary data in Year 2008.

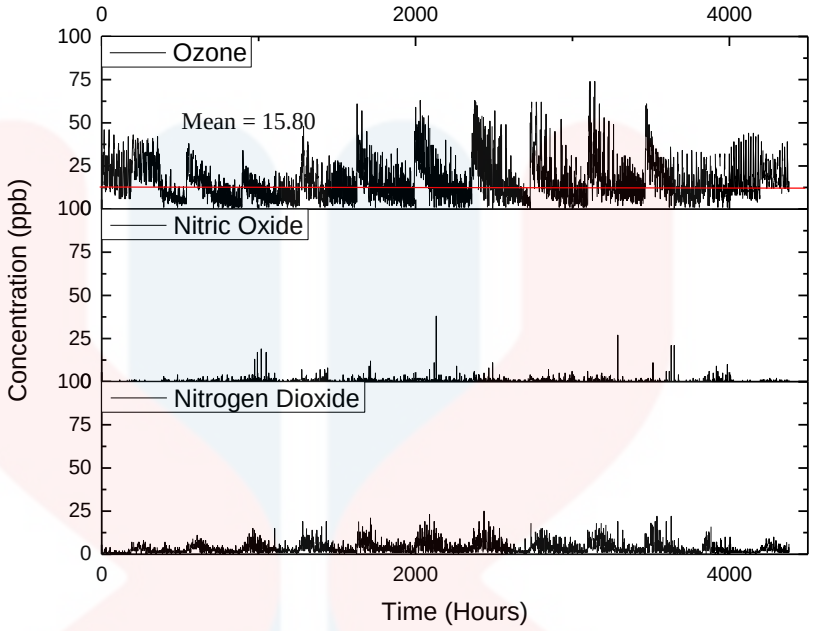

Figure 4.6: Time-series plot for secondary data in Year 2009.

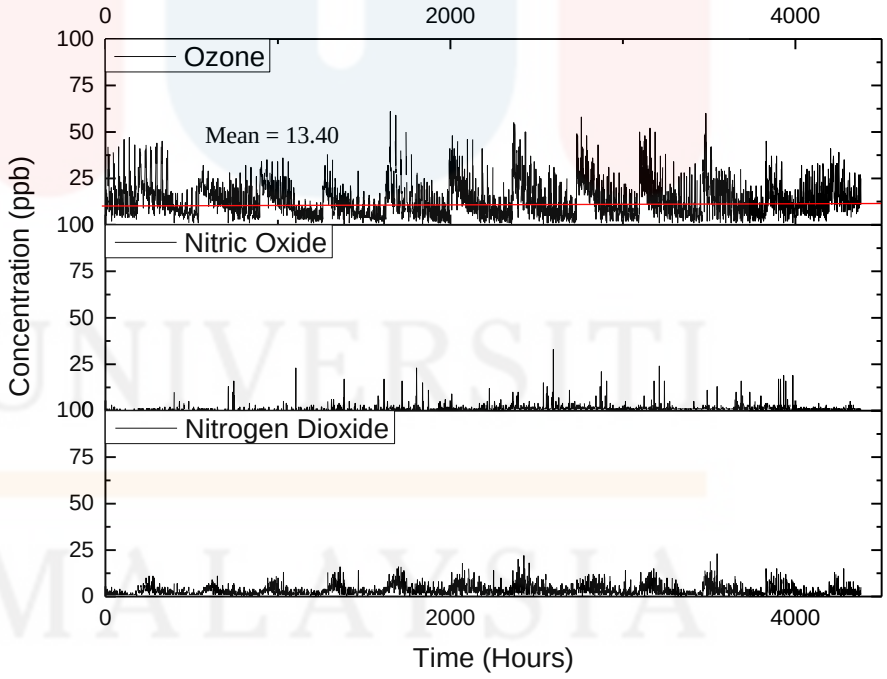

Figure 4.7: Time-series plot for secondary data in Year 2010.

Based on the figures above, the concentration of ground-level ozone from 2006 – 2010 does not exceed the MAAQG but it was considered high compared to the other places in Malaysia (Awang *et al.*, 2015a). The high ground-level ozone concentration in Kemaman, Terengganu can be due to the high emission of pollutant gases from anthropogenic sources such as traffic jams and industrial development. There were quite a lot of industrial areas along the coastline such as steel industries, petroleum industry and others (Sugiyanto & Malkhamah, 2018). Besides the significant source of pollutants, ineffective ground-level ozone removal was another cause for the high concentration due to insufficient sunlight to promote the removal mechanism (Awang *et al.*, 2015a). Besides, the nitric oxide concentration was also extremely low based on the time-series plot. Indirectly, the nitric oxide titration will be reduced and allowing ground-level ozone to stay remain in the atmosphere. In addition, the concentration of nitrogen dioxide will also be affected, where reducing as the concentration of nitric oxide decreased (Awang *et al.*, 2015a).

The mean for these five years were in the range of 13-22 ppb, it did not exceed the MAAQG but it was considered high for nighttime. There was a big blank in the time-series plot, where this blank space was reported as missing values (referring to Figure 4.3 and Figure 4.4). It was due to the maintenance of the monitoring equipment. Therefore, the data for that particular month were not recorded.

The hourly variations of concentration of ground-level ozone and nitrogen dioxide from 23rd July 2019 to 26th July 2019 were illustrated using time-series analysis as shown in Figure 4.8, Figure 4.9 and Figure 4.10 respectively.

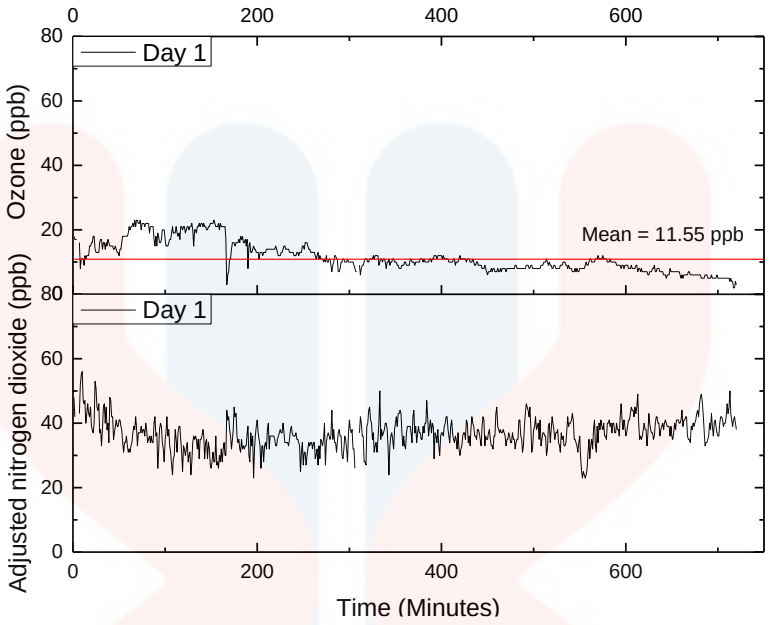

Figure 4.8: Time-series plot for primary data from 7 p.m. 23rd July 2019 to 7 a.m. 24th July 2019

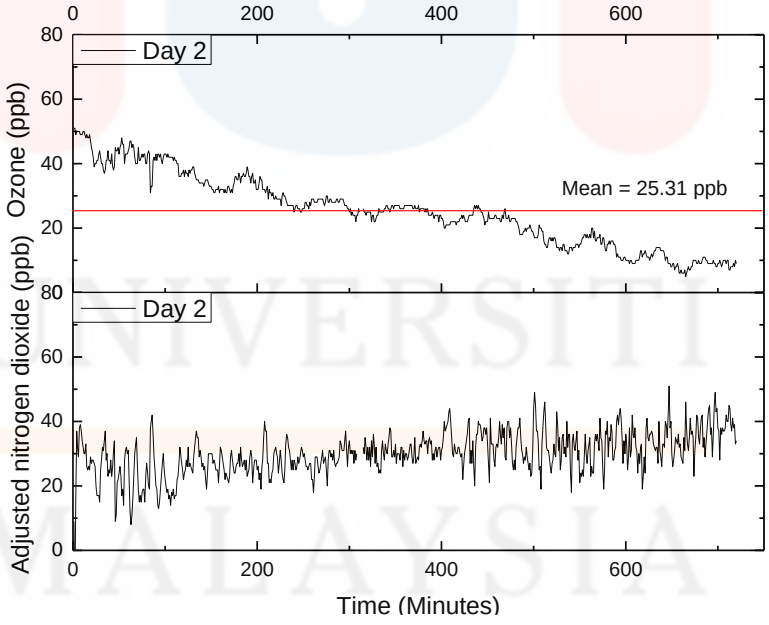

Figure 4.9: Time-series plot for primary data from 7 p.m. 24th July 2019 to 7 a.m. 25th July 2019

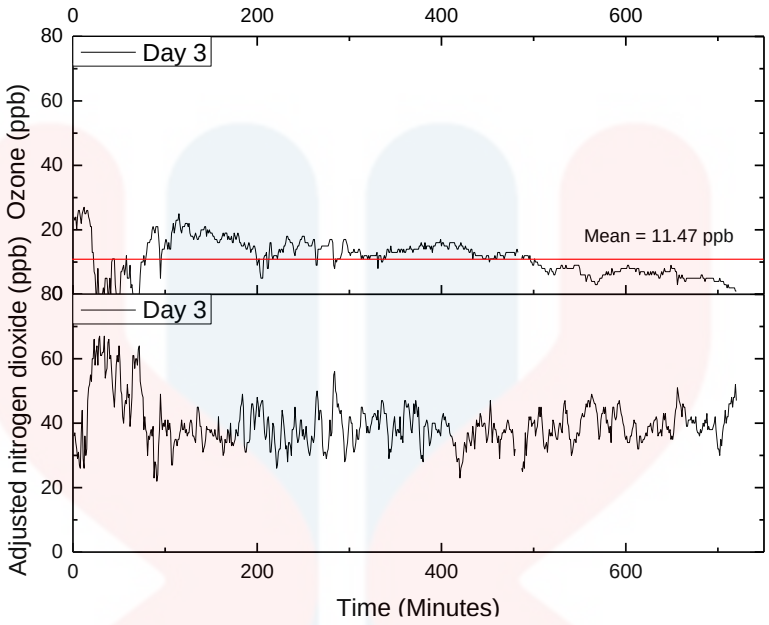

Figure 4.10: Time-series plot for primary data from 7 p.m. 25th July 2019 to 7 a.m. 26th July 2019

Based on the research, the trend of ground-level ozone concentration was more or less similar throughout the monitoring period, where the nighttime ground-level ozone concentration was high at the beginning and reducing after a period, eventually become nearly zero value in the end. This was because of the decreasing in production of ground-level ozone in the absence of sunlight during nighttime. In addition, this enhanced nighttime removal chemistry of ground-level ozone. In other word, ground-level ozone were effectively been reduced during nighttime. Ground-level ozone were reacted with nitric oxide to produce nitrogen dioxide and oxygen gas (Awang *et al.*, 2015b; Awang & Ramli, 2017). In short, the ground-level ozone concentration was decreased while nitrogen dioxide was increased. On Day 3, there was a short period of raining from 7 p.m. to 7.30 p.m. and a long period of rain pour during 1 a.m. to 6.30 a.m. This was the reason that the concentration of the ground-level ozone drops suddenly at the beginning and was significantly low. However, the trend was almost the same, where the ground-level ozone was dropping constantly.

On the other hand, there was no rainfall during nighttime on Day 2. This was the reason why the concentration of ground-level ozone was higher than the other day at the beginning. To conclude, the condition of these three days were consistent and stable, no huge differences during the monitoring period.

4.3 Data of Diurnal Plot

Figure 4.11, Figure 4.12, Figure 4.13, Figure 4.14 and Figure 4.15 showed the diurnal plot for average concentration of ground-level ozone, nitric oxide and nitrogen dioxide from year 2006 to year 2010 in Kemaman, Terengganu respectively.

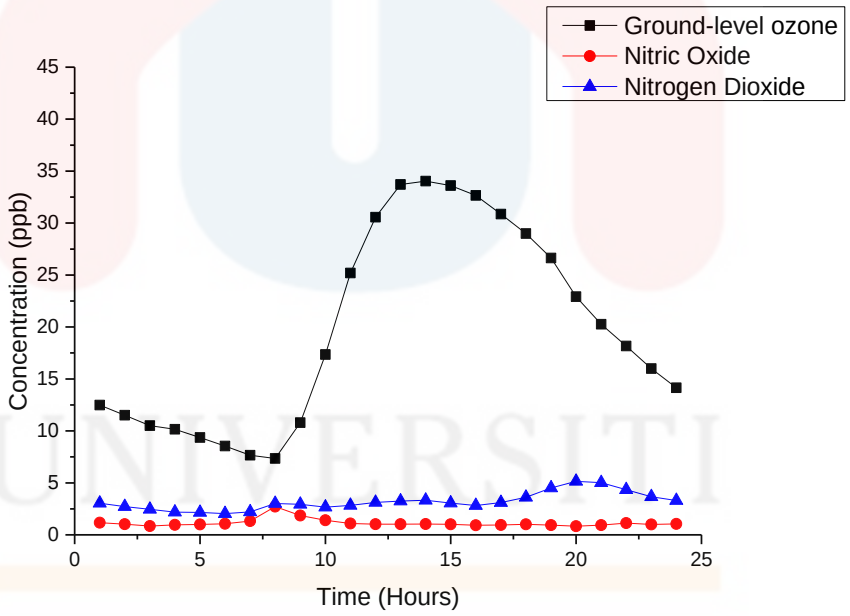

Figure 4.11: Diurnal plot for secondary data in Year 2006.

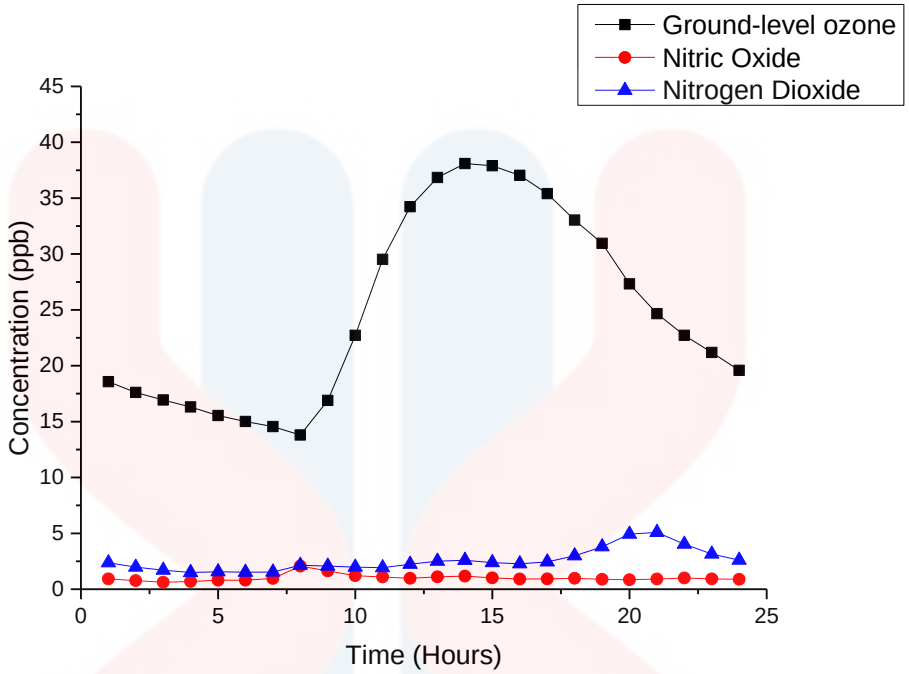

Figure 4.12: Diurnal plot for secondary data in Year 2007.

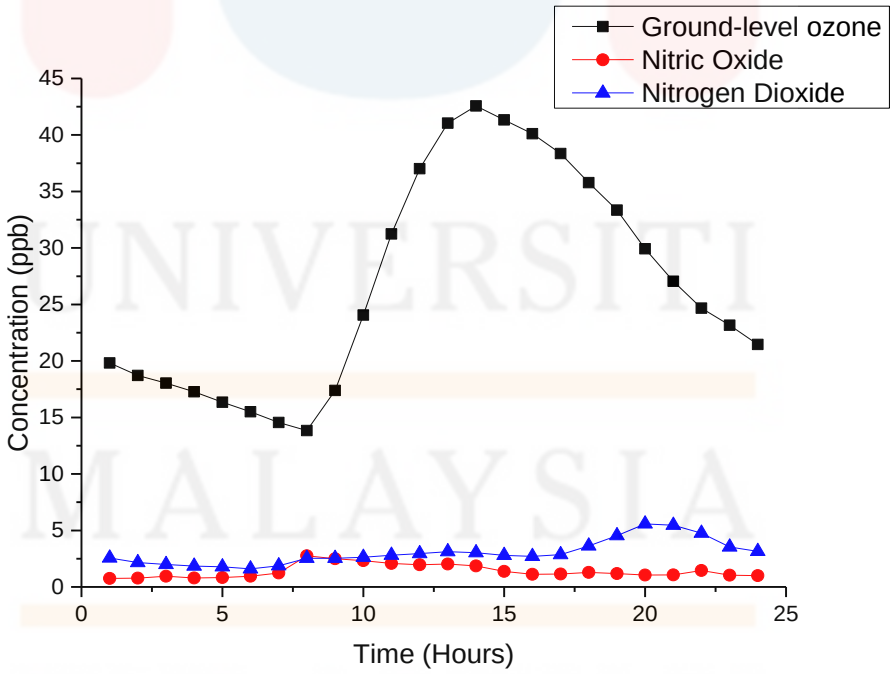

Figure 4.13: Diurnal plot for secondary data in Year 2008.

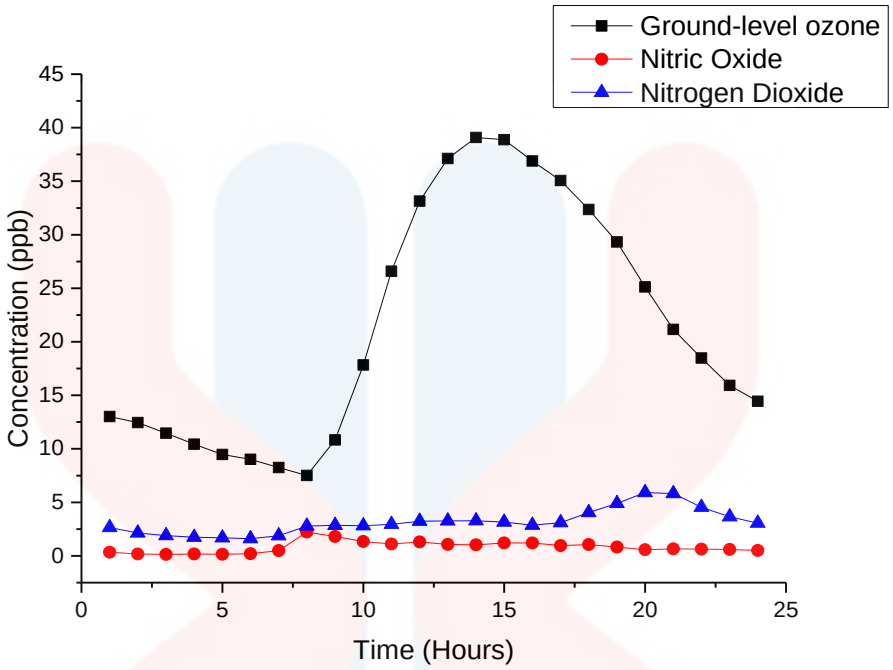

Figure 4.14: Diurnal plot for secondary data in Year 2009.

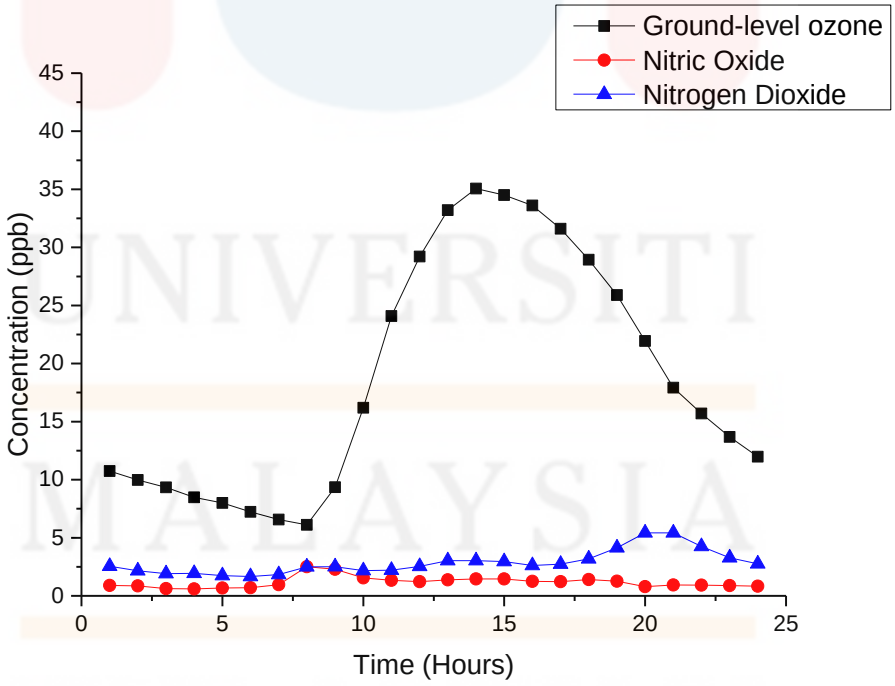

Figure 4.15: Diurnal plot for secondary data in Year 2010.

The figures above illustrated that the trend of concentration for nighttime ground-level ozone, nitric oxide and nitrogen dioxide were almost similar throughout these five years. Banan *et al.*, (2013) stated that the pattern of concentration of nitric oxide in diurnal trends were more or less similar to the pattern of nitrogen dioxide while the concentration of ground-level ozone was like a bell-shape curve. There was no significant fluctuations in the concentration of nitric oxide and adjusted nitrogen dioxide. This may because of less emission from vehicles during nighttime. On the other hand, the concentration of ground-level ozone during nighttime also showed a decreasing trend. The lowest reading of ground-level ozone concentration was at 6 a.m. However, Awang *et al.*, (2015a) reported that the concentration of ground-level ozone in Kemaman was considered because of lack of efficiency of nitrogen oxides titration during nighttime removal reaction.

Diurnal plot was also used to illustrate the nighttime chemistry of ground-level ozone and its precursor for primary data and secondary data. Figure 4.16, Figure 4.17 and Figure 4.18 below showed the diurnal plot of adjusted nitrogen dioxide and ground-level ozone for Day 1, Day 2 and Day 3 respectively, which were 23rd July 2019 to 26th July 2019 in Kemaman, Terengganu.

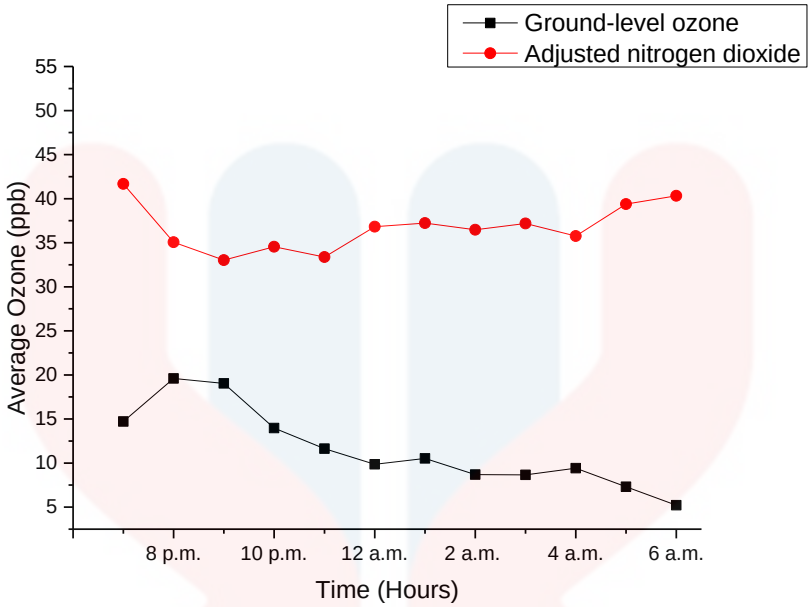

Figure 4.16:

Diurnal plot for primary data on Day 1.

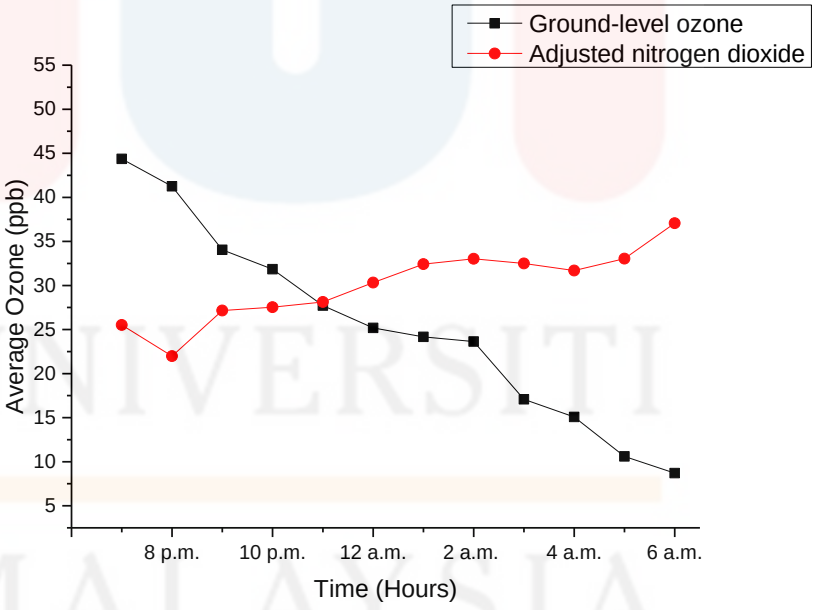

Figure 4.17: Diurnal plot for primary data on Day 2.

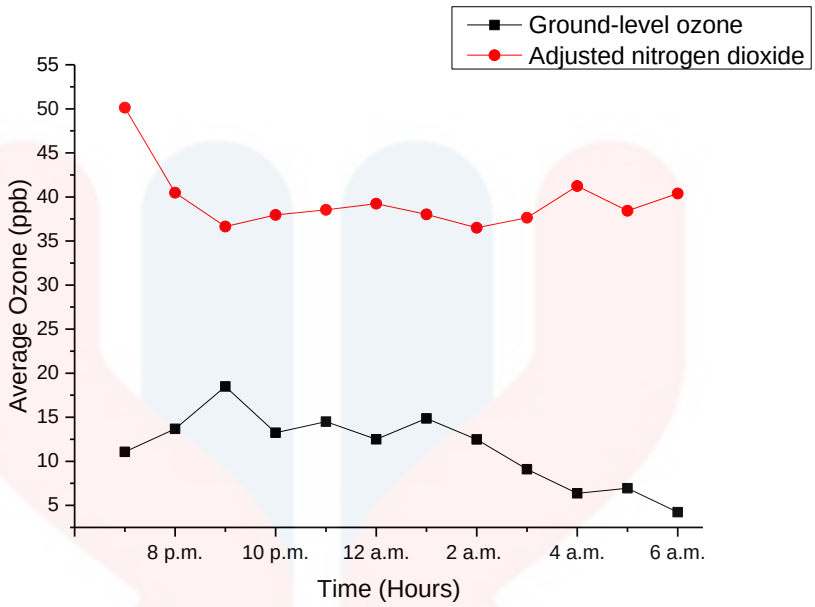

Figure 4.18: Diurnal plot for primary data on Day 3.

Figure 4.16, Figure 4.17 and Figure 4.18 showed that the concentration of ground-level ozone dropped generally during nighttime. The diurnal plot on Day 1 in Kemaman showed that the concentration of ground-level ozone decreased significantly during nighttime. The lowest concentration of ground-level ozone was monitored at 6 a.m. This was because of the insufficient of ultraviolet light, which promotes the production of ground-level ozone during nighttime and high efficiency of nitrogen oxide titration. High nitrogen dioxide concentration was monitored throughout these three days because of the nighttime removal reaction. Since ground-level ozone reacted with nitric oxide to produce nitrogen dioxide and oxygen, the increment of nitrogen dioxide concentration can be related to low concentration of ground-level ozone. This proves that the occurrence of nighttime removal reaction during nighttime in Kemaman (Sillman, 1999; Awang *et al.*, 2015a). The result indicating that the trend for ground-level ozone concentration showed decreasing trend

and had lowest concentration on 6 a.m. while the concentration of adjusted nitrogen dioxide was always higher than that of ground-level ozone.

4.4 Data of Multiple Linear Regression

Table 4.3 showed the summary Multiple Linear Regression models in Kemaman using original parameters. Durbin-Watson and variance inflation factor were used to evaluate multicollinearity and autocorrelations that existed in the models.

Table 4.3: Summary models of ground-level ozone concentration during nighttime using original parameters for Multiple Linear Regression.

	R^2	Models	VIF	Durbin-Watson
Primary Data	0.408	$O_3 = 48.667 – 0.921\ NO_2$	1.000	0.209
Secondary Data	0.052	$O_3 = 15.243 + 0.632\ NO_2 – 0.759\ NO$	1.039	0.714

From Table 4.3, the R^2 value for secondary data was 0.052, which was very low, indicating very less possibilities in variations of ground-level ozone concentration (Awang *et al.*, 2015b). This was probably because of the existing of missing values. The R^2 value for primary data was 0.408, which considered moderate. This explained that the model illustrate lesser variability of the predicted data since it was approaching zero, performing moderate performance. In other words, the selected variables have illustrated 40.8% of the variations of ground-level ozone concentration.

The Durbin-Watson value for secondary data was 0.714. On the other hand, the Durbin-Watson value for primary data was 0.209, which means there was a slightly positive correlation. Since both of these values did not exceed the value of 10, there were no corrections made in this research. For secondary data, the most significant factor that affect the nighttime removal chemistry was nitric oxide as it had the highest gradient value of 0.759 while for the primary data was nitrogen dioxide, 0.921.

4.5 Wind Rose

Wind rose was used as a tool to graphic the display of wind speed and wind direction in Kemaman over these 3 days. Based on Awang *et al.*, (2015a), wind rose can be used to determine the potential contributing sources over the area based on the wind speed and wind direction monitored. This was because that the air pollutants can be carried away by wind. Figure 4.10 below showed the wind rose produced in Kemaman.

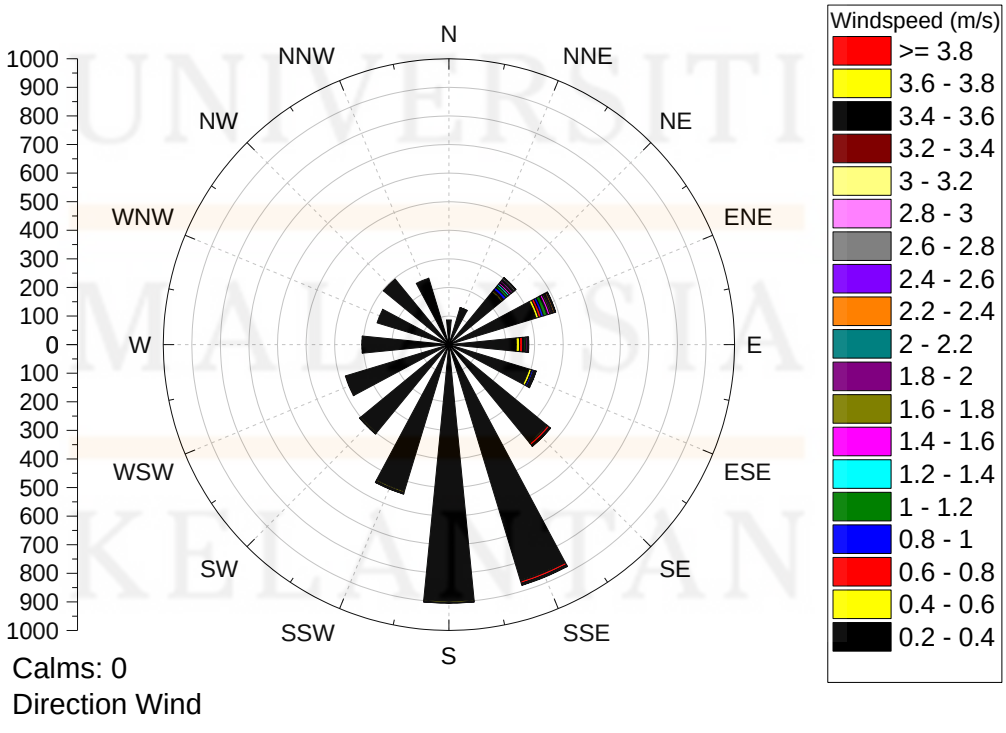

Figure 4.19: Wind rose of Kemaman from 23rd July 2019 to 26th July 2019.

Based on Figure 4.19, most of the wind came from south side, which was the residential area. However, the wind speed from south and south-southeast were only 0.2 – 0.4 m/s. There were strong wind coming from northeast and north-northeast side, which was industrial areas. It was believed that both these areas contributed significant sources for the high concentration of ground-level ozone during nighttime in Kemaman.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The concentration of nighttime ground-level ozone in Kemaman, Terengganu was presented in this research. The research showed that the concentration of nighttime ground-level ozone in Kemaman decreases during nighttime as shown in Figure 4.16, Figure 4.17 and Figure 4.18. Besides, the data did not tally with the secondary data based on the diurnal plot as the concentration of nitrogen dioxide was much higher than that of secondary data. The mean concentration of nighttime ground-level ozone for secondary data for five years was 17.33 ppb while the mean concentration of nighttime ground-level ozone for primary data was 16.11 ppb. However, the mean concentration of adjusted nitrogen dioxide was higher in primary data compared to the secondary data, where it surpassed the concentration of ground-level ozone. This was probably because of the effect of raining throughout the monitoring period as there were raining during the monitoring period. It was raining quite often and construction was in progress nearby during the monitoring period. It may due to the uncalibrated instruments too.

Furthermore, the trend of the concentration of the decrement of concentration of ground-level ozone also affected by nighttime ground-level ozone removal reaction. Whereas this reaction was affected by its precursors, nitrogen dioxide and nitric oxide. Based on the result, the mean concentration of nighttime ground-level ozone and adjusted nitrogen dioxide were 16.11 ppb and 35.47 ppb respectively in Kemaman.

The concentration of nitrogen dioxide increases significantly while the concentration of ground-level ozone decreases, which indicates the reaction of nighttime ground-level ozone removal chemistry was not effective. The mean concentration of adjusted nitrogen dioxide was relatively higher than that of ground-level ozone. The decrement on the concentration of ground-level ozone due to the rainfall also decreased the chemical removal reaction of ozone and therefore the adjusted nitrogen dioxide accumulated.

Multiple Linear Regression showed a slightly positive correlation for both primary and secondary data while no multicollinearity existed as the variance inflation factor did not exceed 10. This showed that the data was reliable, predicted precisely and had low standard errors. The R^2 value for primary data was considered moderate, 0.408, which indicates the selected variables illustrated 40.8% of the variations of ground-level ozone concentration. On the other hand, R^2 value for secondary data was very low, 0.052 due to abundant of missing data.

5.2 Recommendations

Atmospheric studies should have longer duration and period of monitoring as it was changing continuously. Therefore, longer period of monitoring should be done in future studies. The concentration of ground-level ozone can be determined precisely by extending the duration of study. Besides, the limitations of this study is that the instrument should be updated or calibrated.

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APPENDICES

APPENDIX A

Equipment set up in monitoring site

APPENDIX B

Monitoring station of Department of Environment

APPENDIX A

Equipment set up in monitoring site

Figure A1: Aeroqual series 500 (ozone and nitrogen dioxide sensor) set up in monitoring site under a canopy umbrella

Figure A2: Weather station set up in monitoring site

APPENDIX B

Monitoring station of Department of Environment

Figure B2: Monitoring station of Department of Environment in Kemaman