INVESTIGATION OF NIGHTTIME GROUND LEVEL OZONE CONCENTRATIONS IN INDUSTRIAL AND RURAL AREA

by

TEH SI YONG

A report submitted in fulfilment of the requirements for the degree of Bachelor of Applied Science (Sustainable Science) with Honours

FACULTY OF EARTH SCIENCE

UNIVERSITI MALAYSIA KELANTAN

2019

DECLARATION

I declare that this thesis entitled “Investigation of Nighttime Ground Level Ozone Concentrations in Industrial and Rural Area” is the result on my own research except as cited in the references. The thesis has not been accepted for any degree and is not currently in candidature of any other degree.

Signature : _____

Name : _____

Date : _____

ACKNOWLEDGEMENT

I am highly grateful to Faculty of Earth Science for providing this opportunity to carry out the Final Year Project at University Malaysia Kelantan (UMK) Jeli Campus.

The constant guidance and encouragement received from my supervisor, Dr. Norrimi Rosaida Bt Awang has been of great help in carrying out the project work and are acknowledged with appreciative thanks. Without her wise counsel and guidance, it would have been impossible to complete the project in this manner.

I would like to express a deep sense of gratitude to my Final Year Project coordinator, Dr. Amal Najihah Binti Muhamad Nor for her kindness in sharing the information regarding to the project.

Last but not the least, I wish to take this opportunity to express my sincere appreciation to my friends and family for supporting me both on and off water. To those who have helped me survive all the stress and lent me their hand whenever I met problems while completing my project, a special debt of gratitude is due.

Investigation of Nighttime Ground Level Ozone Concentrations in Industrial and Rural Area

ABSTRACT

Ground level ozone (O_3) is the most pervasive global air pollutant due to its adverse effect on human health and crop yields. In this study, the variation of nighttime ground level ozone concentration was determined in Jeli, Kelantan and Kemaman, Terengganu. The concentration and the variation of nighttime O_3, NO_2, NO and meteorological factors were determined using the descriptive analysis and time-series analysis. Besides that, the mechanism of nighttime O_3 removal chemistry was investigated using the diurnal plot. The most significance factor to enhance the nighttime removal chemistry was identified using multiple linear regression (MLR). The MLR model was used to fit the observed data obtained from monitoring sites. The study showed the nighttime O_3 concentration in Jeli was lower than that for Kemaman due to the high efficiency of NO_x titration. Over the monitoring period, the highest nighttime O_3 concentration recorded was 35.87 and 150 ppb in Jeli and Kemaman, respectively. The presence of nighttime O_3 removal reaction in Jeli contributed to the low O_3 concentration. In contrast, the low rate of nighttime O_3 removal reaction in Kemaman probably due to low NO_2 and NO concentrations as the main factor to control the nighttime O_3 removal chemistry. The R^2 for primary and secondary data was moderate (0.73 and 0.67), indicating the selected variables have explained more possibilities in the variation of O_3 concentrations.

Penyiasatan terhadap Kepekatan Ozon Paras Tanah Waktu Malam di Kawasan Perindustrian dan Luar Bandar

ABSTRAK

Ozon paras tanah (O_3) adalah pencemar udara global yang meluas akibat kesan buruknya terhadap kesihatan manusia dan hasil tanaman. Dalam kajian ini, variasi kepekatan ozon paras tanah ditentukan di Jeli, Kelantan dan Kemaman, Terengganu. Dalam kajian ini, kepekatan dan variasi waktu malam O_3, NO_2, NO dan faktor meteorologi telah ditentukan menggunakan analisa deskriptif dan siri masa. Di samping itu, mekanisme kimia penyingkiran O_3 waktu malam disiasat menggunakan plot diurnal. Faktor yang paling penting untuk meningkatkan pengyingkiran kimia waktu malam telah dikenalpasti menggunakan regresi linear berganda (MLR). Model MLR digunakan untuk menyesuaikan data yang diperoleh dari kawasan cerapan. Kajian menunjukkan kepekatan O_3 pada waktu malam di Jeli adalah rendah kerana kecekapan tinggi titrasi NO_x manakala kepekatan O_3 di Kemaman lebih tinggi daripada di Jeli. Sepanjang tempoh pemantauan, kepekatan O_3 waktu malam yang tertinggi direkodkan ialah masing-masing 35.87 ppb dan 150 ppb di Jeli dan Kemaman. Kadar tindakbalas penyingkiran O_3 pada waktu malam yang tinggi yang diperhatikan di Jeli menyebabkan kepekatan O_3 rendah. Manakala, kadar tindakbalas penyingkiran O_3 yang rendah pada waktu malam di Kemaman ditunjukkan oleh kepekatan O_3 pada waktu malam yang tinggi mungkin disebabkan oleh kepekatan NO_2 dan NO yang rendah di Kemaman merupakan faktor utama yang mengawal kimia penyingkiran O_3 waktu malam. Dapatan model MLR menunjukkan R^2 untuk data primer dan sekunder adalah sederhana (0.73 dan 0.67) menggambarkan bahawa pemboleh ubah yang dipilih mampu menerangkan lebih banyak kemungkinan dalam variasi kepekatan O_3.

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LIST OF ABBREVIATIONS

NO_x	Nitrogen oxides
VOC	Volatile Organic Compounds
SO_2	Sulphur dioxide
CO	Carbon monoxide
NO	Nitrous oxide
NO_2	Nitrogen dioxide
O_3	Ground level ozone
NO_3	Nitrate
N_2O_5	Dinitrogen pentoxide
UVB	Ultraviolet B
HNO_3	Nitric acid
DOE	Department of Environment, Malaysia
N	North
E	East
MLR	Multiple Linear Regression
MAAQG	Malaysia Ambient Air Quality Guideline

LIST OF SYMBOLS

%	Percentage
+	Plus
°	Degree
°C	Temperature (degree Celsius)
±	Plus or Minus
<	Less Than
σ	Sigma
÷	Division

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Ambient air was vital to all organisms for survival. Ambient air was the natural state of the atmospheric air. It was the things that breathe by all organisms when there was no contamination of air-borne pollutants in the atmosphere. Ambient air was the mixture of gases comprising 78% of nitrogen, 21% of oxygen and the 1% of gases including carbon, helium, methane, argon and hydrogen. Human activities could directly affecting the quality of ambient air. Example of man's activities which were the manufacturing processes and the burning of fossil fuels that could release high level of industrial and chemical pollutants to the atmosphere which directly affected the ambient air quality (Brunekreef & Holgate, 2002).

Air pollution is occurring when the changing in the ambient air composition and it caused by smoke, dust, fumes, aerosols and odorous substances from a range of including transportation, power generation, industries, domestic sources and others. Therefore, the poor air quality can causing some health problems, particullarly respiratory and cardiac diseases. Besides that, there were some air pollutants categorised as carcinogens including benzene (Monks *et al*., 2009).

Malaysia has been affected by the air pollution for many years. The haze is considered serious in recent years which caused by the air pollutant. The haze which

was as choking smoke is caused by the open burning of forests and peat bogs. The uncontrolled agriculture burning which is happening in Indonesia annually may hindered activities in surrounding countries was one of the significant cases. It caused unhealthy air pollution levels in many parts of Malaysia (Sastry, 2002). Therefore, most of the schools were closed and illnesses were widespread, especially among the elderly and those with breathing difficulties. Malaysia also has the problems which were local industrial and vehicular pollutions contribute to the situation. The issues of air pollution in Malaysia were mainly due to human activities including the used of motor vehicles, development activities, land clearing and open burning at solid waste disposal sites (Afroz, Hassan, & Ibrahim, 2003; Yan *et al*, 2016).

Urban air pollution referred to the air pollution that experienced by human populations living in or around the urban areas, typically around or in cities. The sources from the product of the anthropogenic precursor emissions which have been contributed heavily to the ozone in the troposphere globally. Both mobile' sources such as stationary sources and cars such as smoke stacks have given significant contributions to urban outdoor air pollution. There were other major sources comprising emissions from the manufacturing facilities in factory, exhaust fumes from the vehicles and emission power generation for examples smoke stacks of coal fired power plants (Banan & Latif, 2013).

In urban air pollution, recently the ozone pollution was considered more serious. Ozone that found in the troposphere was called as ground level or bad ozone. At ground level, ozone was an air pollutant that damages human health and vegetation. This was due to ground level ozone is produced from the reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) with the presence of sunlight. This reaction is called photochemical reaction (Atkinson, 2000).

Many urban areas exhibited high concentration of ground level ozone. This was because of the major sources of anthropogenic carbon dioxide emissions from the burning of fossil fuels; from industrial processes; transportation of people and goods, and other emissions are in urban areas (Gál *et al*., 2009). However, the rural areas were also tending to increase in ozone levels due to the winds that could transport the ozone and the pollutants that formed it to hundreds of miles away from the sources. The process of the carrying of ozone and pollutants was called transport. Regardless of how the ground level ozone got to the cities, it could pose health threats to all the inhabitants, people, animals and plants (Sousa, Alvim-Ferraz, & Martins, 2011). Ozone causing damage to plants. For example, the ozone causes some spots to appear on the tips of leaves (Akimoto, 2006).

1.2 Problem Statement

Ground level ozone was not emitted directly into the air. However, it was created by the chemical reactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOC) that produced by cars, industrial boilers and other sources that chemically reacted with the presence of sunlight. Ozone pollution would affect the sensitive vegetation and ecosystems which included forests, parks and wilderness areas. Especially, ozone pollution harmed the sensitive vegetation during the growing season (United States Environmental Protection Agency, 2003). Therefore, there was a standard to know whether the pollutants are in safety level which was the New Ambient Air Quality Standard. This standard has adopted 6 air pollutants criteria which include 5 existing air pollutants which including ground level ozone (O_3) and nitrogen dioxide (NO_2). The Malaysia Ambient Air Quality Standard for ground level

ozone (O_3) is 100 ppb per hour and 60 ppb per 8 hours (Department of Environment Malaysia (DOE), 2018).

Nighttime ozone chemistry could remove O_3 from the ambient air via chemical reactions with NO_x. In daytime, ozone production was reduced when there were less nitrogen oxides in the atmosphere, and the reduction could be further reduced through the nighttime reaction and significantly lower O_3 concentration in the next day. The reacted nitrogen oxides could be removed and they would not involve again in ozone-forming chemistry in the next day (Brown *et al*., 2007). However, the efficiency of nighttime ozone removal chemistry was relatively un quality and the information were relatively scarce due to limit research focusing on this aspect of O_3. The information would be crucial in understanding this noxious air pollution. Thus, this study embarks to critically study nighttime ozone chemistry in industrial area of Kemaman and the verification study has been conducted in Jeli to gather initial information about nighttime ozone removal chemistry.

1.3 Objective

1. To determine the variation of nighttime ground level ozone concentration in selected industrial and rural area.
2. To investigate the mechanism of nighttime ground level ozone removal chemistry.
3. To identify the most significance factor that could enhance the nighttime removal mechanism.

1.4 Scope of Study

In this research, the concentration of ground level ozone at nighttime had been examined in Jeli, Kelantan and Kemaman, Terengganu. Besides that, the mechanism of nighttime ground level ozone removal chemistry onto reduced one of the main pollutants that form ground level ozone, NO_x had been examined. The gas products, NO_2 had been examined to confirm the nighttime reaction as an indicator the reduction of O_3 concentration in the atmosphere. The factors that may influenced the removal mechanism comprising nitrous oxide (NO), nitrogen dioxide (NO_2), UVB rays, temperature and relative humidity had been studied to determine the significant factor that could enhance the nighttime ozone removal mechanism.

1.5 Significant of Study

The ground level ozone pollution was considered a serious environmental problem especially in urban area due to the development of industrial sectors and the increase of use of vehicles. The nighttime mechanism for ground level ozone removal chemistry was the mechanism that could help to reduce the pollutants that would produce ground level ozone on next day. The significance factor of the removal mechanism may help to enhance the efficiency of the mechanism to make the mechanism more effective and efficient to reduce the ground level ozone.

CHAPTER 2

LITERATURE REVIEW

2.1 Ground Level Ozone

Ozone can be found in the stratosphere and troposphere. The closest layer to the surface of Earth was troposphere while the stratosphere was above the ground between 12.9 and 48.3 km. Therefore, the air in the troposphere was the air that people breathe in daily. Ground level ozone was also found in the troposphere which is called tropospheric ozone too (Tobergte & Curtis, 2013).

Ground-level ozone was produced through the photochemical reaction that required the presence of sunlight and the precursors which was nitrogen oxides. Besides that, there were other pollutants that produced ground level ozone such as volatile organic compounds (VOCs) that were photochemically reactive hydrocarbons may also cause the ground level ozone. Generally, ozone concentrations have been influenced by the absolute concentrations of NO_x and VOCs, the ratio between NO_x and VOCs and the intensity of solar radiation. Moreover, the accumulation of ground level ozone also would occur with sea breezes due to the circulation of air over an area or when the components that produce smog are trapped by the temperature-induced air inversions (Atkinson, 2000; Akimoto, 2006).

Therefore, the peak concentrations of ground level ozone have been studied by the World Health Organisation (WHO). According to WHO, the peak concentrations

of ground level ozone are measured in the afternoon because it was the time that has the strongest sunlight in the day. Besides that, the mean concentrations were highest during the summer generally. However, the peak concentration of ground level ozone was rarely last for more than two to three hours with the highest 1-hour average value was amounts to 238 μg/m³. Typically, an 8-hour average value of 120 μg/m³ can only be exceeded on 25 days on average. In the most recent averaging period of 2015 to 2017 (Minkos, Dauert, & Feigenspan, 2018).

Ozone at ground level was considered as a harmful air pollutant. The sources such as pollutants that emitted by cars, power plants and fuel combustion reacted chemically with the presence of sunlight to cause the ozone formed. The primary sources of NO_x and VOCs are the emissions from motor vehicle exhaust, gasoline vapours, chemical solvents, industrial facilities and electric utilities which also caused the ozone produced actively (Akimoto, 2006; Gál *et al*., 2009)

2.2 Effects of Ground Level Ozone

In fact, the high concentrations of ground level ozone could be harmful to people, animals, crops, and other components. Ozone may irritated people's respiratory system and caused people start coughing. Ozone also aggravated asthma which has inflamed and damaged cells that line people's lungs. In addition, ozone aggravated chronic lung diseases which were emphysema and bronchitis. Then, it also reduced the respiratory immune system to fight off bacterial infections in the respiratory system. Lastly, ozone caused permanent lung damage too (United States Environmental Protection Agency, 2003; Akimoto, 2006).

Vulnerable people were at higher risk when exposed to the ozone through the respiratory inhalation including those with asthma, older adults, children, and people who are active at outdoors, especially outdoor workers. Besides that, people with some genetic characteristics and people with less intake of specific nutrients, such as vitamins C and E were also at greater risk from ozone exposure. Children were in risk when they exposed to ozone due to their lungs were still developing and they were more likely to be active outdoors which increased their exposure when ozone levels are high (Akimoto, 2006).

For the environment, ozone lead to the reduction of agricultural crop and commercial forest yields, reducing of up growth and survivability of tree seedlings, and the increasing of susceptibility to diseases, pests and other stresses such as harsh weather. Ozone inhibited the plants' ability to open the microscopic pores on their leaves to breathe which damaged vegetation and ecosystems. It disturbed the photosynthesis process by reducing the amount of carbon dioxide the plants that could process and released as oxygen (Ashmore, 2005; Akimoto, 2006).

2.3 Nighttime Tropospheric Chemistry

Ground-level ozone was considered as a by-product due to the emissions of NO_x and VOCs which present in the atmosphere. In short, ozone was produced by the reaction between oxygen atom (O) and oxygen molecule (O_2) to produce O_3. In the troposphere, nitrogen dioxide photolyzed in the presence of sunlight to form NO and O. This O then instantaneously combined with O_2 in the surrounding atmosphere to form O_3. NO continued to cycle back to NO_2 and O_2 through reactions with O_3 (Sillman, 1999).

However, the nighttime ground level ozone reaction was different from daytime ground level ozone reaction due to the ozone photochemical reaction. The nighttime reaction was a continuous reaction of photochemical reactions. NO_2 that produced in daytime and the emission of NO_2 in daytime are used to continue the nighttime reaction (Somers *et al*., 2007). The formation of NO_2 in daytime as shown in equation (2.1):

$$O_3 + NO \longrightarrow O_2 + NO_2 \qquad (2.1)$$

There was no sunlight in the night. Hence, the concentration of OH was almost zero in nighttime (Somers *et al*., 2007). Remaining NO_2 continued and involved in nighttime reaction. NO_2 combined with O_3 to produce nitrate radicals which were shown in equation (2.2):

$$NO_2 + O_3 \longrightarrow NO_3 + O_2 \qquad (2.2)$$

According to Ghosh *et al*. (2013), the reaction between NO_3 and NO_2 was thermally unstable and had possibility to disassociate back from N_2O_5 to NO_3 radicals and NO_2. Thus, the reversible with the form of as shown in equation (2.3):

$$NO_3 + NO_2 \rightleftharpoons N_2O_5 \qquad (2.3)$$

Then, N_2O_5 may reacted with H_2O to form nitric acid (HNO_3). When the water vapour is increased in nighttime which meant the relative humidity was high, this enhanced the reaction (Awang *et al*., 2015). The formation of nitric acid was shown in equation (2.4):

$$N_2O_5 + H_2O \rightarrow 2HNO_3 \qquad (2.4)$$

The nitric acid then deposited and sink in the surface of the ocean. This can reduced the precursors of the photochemical reaction and prevented them from

involving in next day morning reaction (Tung, Ko, Rodriguez, & Dak Sze, 1986; Awang *et al*., 2015)

2.4 Meteorological Factors that Influence Ground Level Ozone Concentration

The air pollution problems might vary with the geographical, demographic and socio-economic conditions of an area that in turn will determine the types of source and emission rate of pollutants. The climate and topography of a region could affected the distribution of pollutants and the atmospheric processes. Therefore, in the past decade, several studies have shown that air quality is integrated with various meteorological factors. The meteorological factors are included wind speed and its direction, solar radiation, precipitation, humidity and temperature (Nadir, 2007).

2.4.1 Relative Humidity

Relative humidity was the amount of water vapour present in the air expressed as a percentage of the amount needed for saturation at the same temperature. It was also play important role in affecting the concentration of ground level ozone (Kgabi & Sehloho, 2012). Relative humidity affected the concentrations of air pollutants. According to Li *et al*. (2007), there was an increase in relative humidity may lead to decrease in average concentrations of ozone. The relationship between O_3 and the relative humidity was negatively correlated (Kgabi & Sehloho, 2012).

2.4.2 Temperature

Ground level ozone was formed through a series of complex photochemical reactions among its anthropogenic precursors in the presence of sunlight and

temperature. The highest monthly O_3 concentrations were observed in the summer months which was from June to August while the lowest concentrations were observed in the winter months which was from December to February (Khoder, 2008). This meant that the concentration of ground level ozone has become high when the temperature was high because the high temperature could promote the photochemical generation of O_3 (Kgabi & Sehloho, 2012).

According to Khoder (2008), O_3 concentrations were positively correlated with temperature in the study, suggesting that high temperature leads to an increase in the formation of O_3. Higher temperatures were often associated with intense solar radiation, which would have a significant effect on the photochemical reactions.

2.4.3 Solar Radiation Intensity

The photochemical reaction of ozone production involved in several chemical processes that required sunlight. The increase of O_3 production was directly proportional to the intensity of solar radiation. The solar radiation was needed in photochemical reaction. The O_3 formed through the reaction between NOx and VOCs under the solar radiation intensity. The photochemical reaction needed the solar intensity with between 300 and 400 nm of UV radiation to photolyze NO_2 into NO and O. Therefore, more or high O_3 production was caused by the higher solar radiation during summer (Dickerson *et al*., 1997; Singh *et al*., 2016).

2.5 Ground Level Ozone Precursors

The precursors for the ground level ozone were NO_x gases which included NO and NO_2 that was emitted by both mobile and industrial sources. The effective production of O_3 was the result of precursor emissions and meteorological factors, but it also depended on the proportion of precursors (Shao *et al*., 2009; Wałaszek, Kryza & Werner, 2017).

The level of ozone concentration was the highest levels during the daytime and lowest levels in the nighttime. This was due to higher emissions of ozone precursors through industrial activities, motor vehicles exhaust and other anthropogenic activities during the daytime and there was less or no industrial activities and lower traffic density in nighttime. This caused the reduction in the concentrations of NO_x in the atmosphere for the photochemical reaction (Shao *et al*., 2009; Wałaszek, Kryza, & Werner, 2017; Awang *et al*, 2018).

Conversely, ground-level ozone concentrations could be determined based on source and sink mechanisms that depended on the prevailing levels of ozone precursors (nitrogen oxides and volatile organic compounds) and the meteorological conditions including temperature, solar radiation and relative humidity. NO titration was the process that involves the immediate removal of O_3 by reacting with primary NO. NO titration was the important part of the nighttime ground level ozone removal chemistry (Khoder, 2008).

2.6 Multivariate Analysis

Multivariate data analysis was a technique used to analyse data with more than one outcome variables. There were two types of multivariate analysis methods,

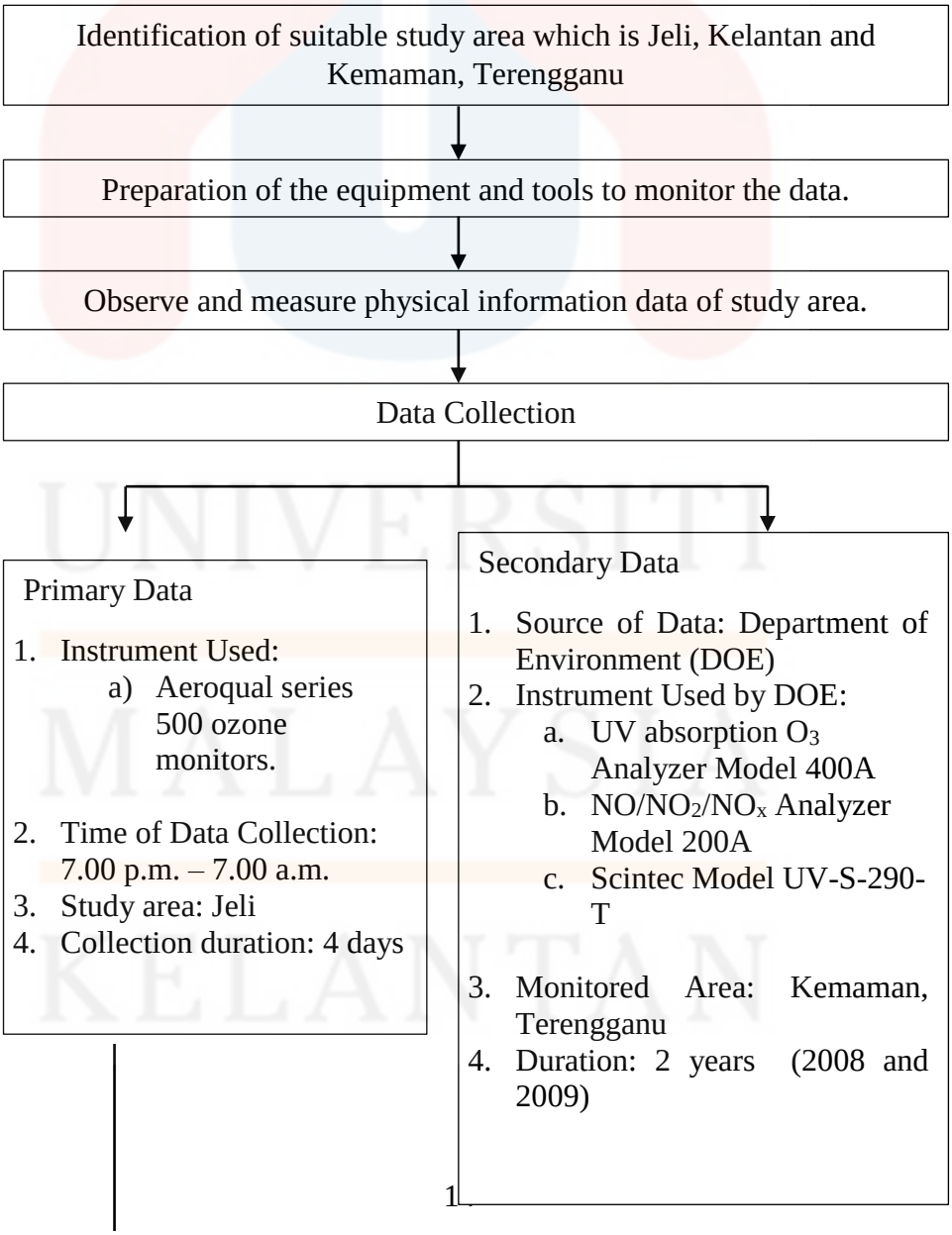
comprising analysis of dependence and analysis of interdependence. Linear regression was one of the most common analysis used to analyse air quality data. However, linear regression was sensitive to extreme values and may cause difficulties in handling data below the detection limits, which was commonly encountered in environmental studies (Baldasano, Delgado, & Calbo, 1998; Dominick, Juahir, Latif, Zain, & Aris, 2012; Awang *et al*., 2015). Interpreting regression coefficients using multiple predictors was more complicated because the interpretation of any given coefficient depended in part on other variables in the model. Multiple linear regression was one of the modelling techniques for studying the relationship between a dependent variables and two or more independent variables. It was a generalization of a simple linear regression model (Awang *et al*., 2015).

CHAPTER 3

MATERIALS AND METHODS

3.1 RESEARCH FLOW

Flow in Figure 3.1 shown the procedures and data analyses that have been conducted in this research.



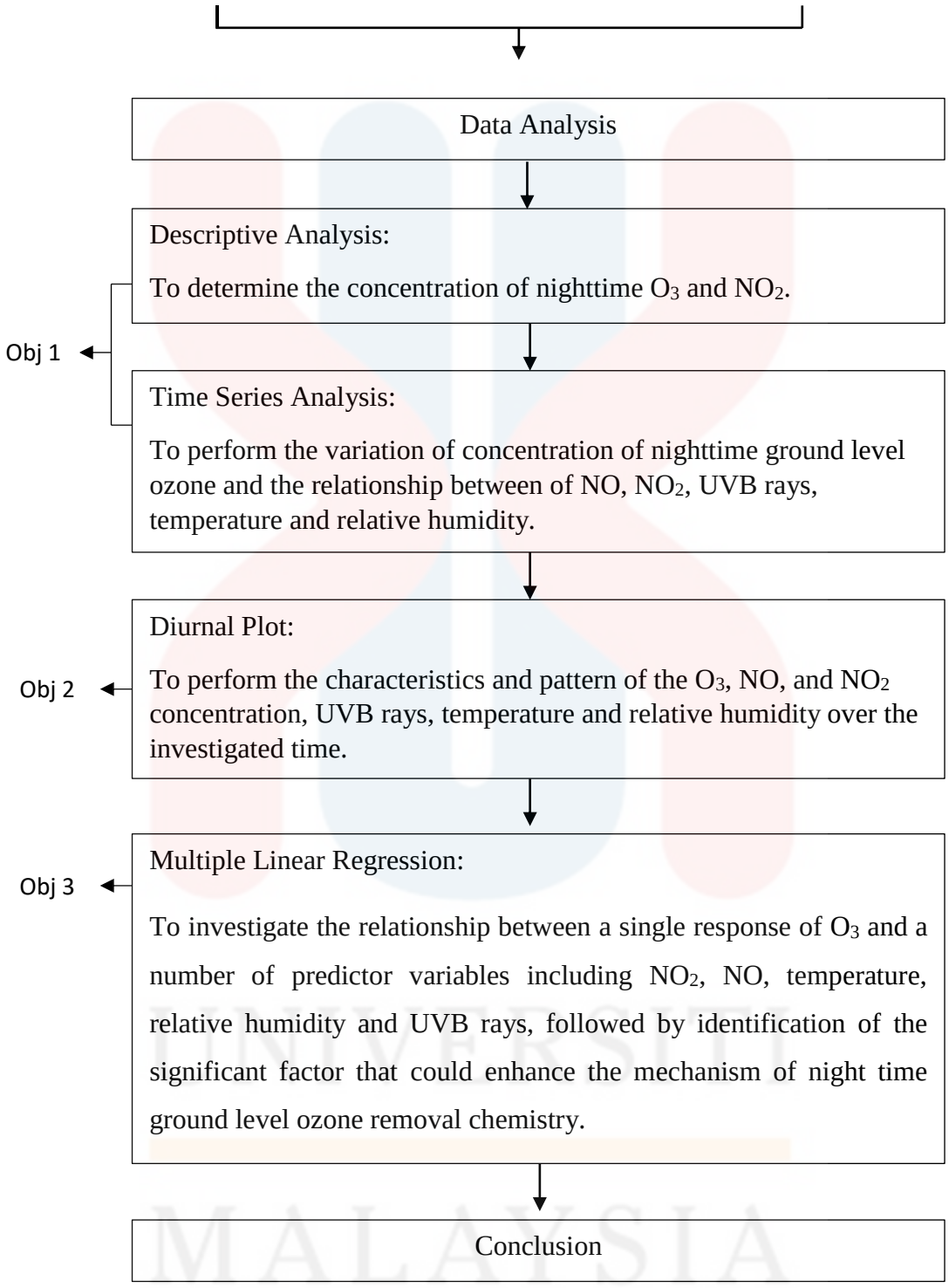


Figure 3.1: Research flow of research methodologies

3.2 Study Area

Jeli, Kelantan was selected as the location to collect the primary air pollution data. Meanwhile Kemaman, Terengganu was chosen for the secondary measurement in this study. Classification of the type of air monitoring stations was based on DOE classification due to locations, which the stations were established.

3.2.1 Study Area Description

a. Jeli, Kelantan

This research was conducted in town Jeli with coordinates of latitude 5^0 45' 55" and 5^0 48' 35" N and longitudes 101^0 52' 55" - 101^0 55' 35" E. Jeli was a district and parliamentary constituency in western Kelantan, Malaysia. The population of the area is estimated at 42,882. Jeli was managed by the Jeli District Council. Jeli borders with state of Perak in the west, borders with Thailand in the north, Tanah Merah in the northeast, and Kuala Krai in the southeast. Most of Jeli's people were rubber tappers. Rubber plantations belonging to local people also attracted foreigners to work. Batu 13 Jeli was the wettest place in Malaysia with annual rainfall of over 6,000 mm. In 2011, the average rainfall in Batu 13 Jeli was 8,596 mm (Adriansyah *et al*., 2015). The location of Jeli across Kelantan, Malaysia map was shown in Figure 3.2.

Figure 3.2: Location of Jeli across Kelantan, Malaysia map. Source: Google, 2018. (Map is not up to scale.)

b. Kemaman, Terengganu

The secondary data were collected by the DOE was conducted in Kemaman which was one of seven districts of Terengganu. Kemaman was in coordinates of latitude 4° 16’ and 4° 38’ N; longitudes 103° 23’ and 103° 31’ E. Total area of Kemaman was 2,535.60 km^2. The annual rainfall in Kemaman has averaged 239 mm with a maximum rainfall amount of 757 mm and a minimum of 50.7 mm. The annual temperature in Kemaman was almost the same throughout the years and averaged 27°C with a uniform comparative humidity average at 81% (Ekhwan, Toriman, & Mokhtar, 2009). The location of Kemaman across Terengganu, Malaysia map was shown in Figure 3.3.

Figure 3.3: Location of study area, Kemaman across Terengganu, Malaysia map.
Source: Google, 2018. (Map is not up to scale.)

3.3 Monitoring Equipment

3.3.1 Primary Data

Two portable Aeroqual series 500 with ozone monitor were used to monitor the concentrations of ground level ozone and NO_x gases (NO and NO_2), temperature and relative humidity at nighttime in Jeli town, Kelantan. The two portable Aeroqual series 500 ozone monitors were set up under a weatherproof plastic shelter at ~1.5 m elevation above the ground. The Aeroqual sensor inlets were positioned therefore the sensor heads will be levelled with the lower edge of the waterproof shelter and sampled freely flowing ambient air if the monitoring sites are under the waterproof shelter.

In this study, the period for the data collection was from 7 p.m. until 7 a.m. for a duration of the data collection was in 4 days. In this study, the sensor head that used in this study was ozone sensor head with 0-0.5 ppm and the nitrogen dioxide sensor head with 0-1 ppm were used. The measurement units were used in ppm or mg/m^3. The details of these two sensor heads had distributed in Table 3.1 and Table 3.2 (Laurinavičienė, 2009; Lin *et al*., 2015).

Table 3.1: Details of Aeroqual 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 40°C
Relative Humidity	10 to 90%

Table 3.2: Details of Aeroqual 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 40°C
Relative Humidity	15 to 90%

3.3.2 Secondary Data

The secondary data for Kemaman, Terengganu was collected by the Department of Environment (DOE). The instruments used by DOE to obtain these data are UV absorption Ozone Analyzer Model 400A and $NO/NO_2/NO_x$ Analyzer model 200A. The time frame for the data from DOE was from 7 p.m. to 7 a.m. The duration of the obtained secondary data was about two years which was 2008 and 2009.

Lastly, Scintec Model UV-S-290-T was used to monitor the UVB rays. This device was used to measure UVB radiation. This accurate device was operated with a wavelength ranging from 280 nm to 315 nm. Besides that, the device was also used to record the minimum and maximum of the reading of the UVB radiation. Scintec Model UV-S-290-T used a Teflon diffuser under the quartz dome in front of the filters. This device measured UVB radiation in J/m^2h (Awang *et al*., 2016 & 2016b).

3.4 Data Analysis

In this research, the data were collected and continued with data analysis. The data were proceeded in descriptive analysis and statistical analysis. The method of data analysis that were used are descriptive analysis, time series analysis and diurnal plot.

3.4.1 Mean Top-bottom Imputation Method

Imputation was performed when there was missing of data which the repeated '0' value is less than 4. The imputation was done by using formula of the previous value before '0' value add with the next value after '0' value and divide by two. The answer from the formula will apply and substitute the '0' value. If there was more than 4 repeated '0' value, the '0' value was just remained in '0' value (Noor, 2018).

The formula for mean top-bottom imputation method was shown in (3.1):

$$y_i = \frac{1}{2} (y_{n1} + y_{n1+1}) \quad (3.1)$$

3.4.2 Treatment of Data

The data were collected for 24-hours period from 7 p.m. to 7 a.m. for a duration of 4 days which were from 12th to 16th August 2018. The data were transformed into hourly average from 1 minute average of raw data. Hence, there were 12 sets of hourly data per day.

3.4.3 Descriptive analysis

Descriptive analysis referred to the systematic observation and description of the characteristics or properties of objects or events. In this study, the descriptive analysis was conducted based on the IBM SPSS Statistic version 20. From the data collection, the descriptive analysis was used to analyse the concentration of nighttime O_3 and NO_2. By using the SPSS, the mean, maximum, minimum and standard deviation of the concentration of nighttime ground level ozone and NO_2 were identified. Therefore, the minimum, maximum of the concentrations, central tendency and the skewed of the graph were observed clearly (Zott *et al.*, 2010; Shodganga, 2013).

The formula for mean as shown in (3.2):

$$Mean = \frac{sum\ of\ the\ values}{the\ numbers\ of\ values} \quad (3.2)$$

The formula for standard deviation as shown in (3.3):

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

Where:

σ = standard deviation

Σ = sum of

$\bar{x}$ = sample mean

N = number of scores in sample

3.4.4 Time-series plot

The time series graph was used to perform the data of the concentration of nighttime ground level ozone and the relationship between of NO, NO_2, UVB rays, temperature and relative humidity. This was because that the concentrations were observed more detailed across the time taken.

3.4.5 Diurnal plot

The O_3, NO, and NO_2 concentration, UVB rays, temperature and relative humidity over the period investigated were analysed by using diurnal plot. The characteristics and pattern of these components were observed in detailed across the time taken by using the diurnal graph analysis.

3.4.6 Multiple Linear Regression (MLR)

Multiple Linear Regression was the common techniques used in the air pollution studies due to its capabilities to predict the effects of independent variables

on the dependent variable (Anwar & Mikami, 2011; Özbay *et al*., 2011; Ul-Saufie *et al*., 2011; Awang *et al*., 2015). In this study, the independent variables comprising NO_2 and NO concentration, temperature, relative humidity and UVB rays while the dependent variable was the O_3 concentration. According to Awang *et al*. (2015), the model was fitted by using the least squared method.

The general equation of MLR as shown in (3.4):

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \ldots + \beta_{p-1} X_{i,p-1} + \varepsilon_i \quad (3.4)$$

Where:

Y_i = Dependent variable

X_i= Independent variables

β = Unknown coefficient

ε_i = Error term

i = 1, 2..., n

CHAPTER 4

RESULT AND DISCUSSION

4.1 Descriptive Statistics

The total hours of monitoring were 48 hours which was 12 hours per day. The raw data was one value per minute and calculated to get average 1 hour. Results showed that the nighttime O_3 concentration in Jeli, Kelantan were generally very low, with the mean values of 6.07 ppb on day 1, 5.04 ppb on day 2, 7.86 ppb on day 3 and 11.52 ppb on day 4. Over the period investigated, the highest maximum nighttime O_3 concentration was 35.87 ppb on day 1; that do not exceed the Malaysia Ambient Air Quality Guideline (MAAQG) of 100 ppb. This is due to in the generally calm condition on day 1, with the emission from the vehicles in the surrounding that contributed to the O_3 formation. The maximum nighttime O_3 concentrations recorded on day 2, day 3 and day 4 were 18.97 ppb, 17.37 ppb and 29.62 ppb, respectively, which are still under MAAQG of 170 ppb. Meanwhile, the minimum nighttime O_3 concentration recorded were almost the same which are 0.04 ppb on day 1, 0 ppb on day 2 and 3, and 0.10 ppb on day 4. The O_3 concentration had been reduced at nights due to the nighttime removal chemistry. There is no formation of O_3 and loss through NO_x titration in nighttime (Sanford Sillman, 1998; Sillman, 1999; Awang *et al.*, 2015; Awang & Ramli, 2017). In addition, there were nighttime O_3 removal chemistry that could remove O_3 during the night and thus significantly reduce the O_3 concentrations

in the ambient air. Therefore, the minimum nighttime O_3 concentrations were almost zero values.

Meanwhile, the results also showed that the mean of nighttime NO_2 concentrations in Jeli were relatively high comprising 45.09 ppb on day 1, 39.79 ppb on day 2, 38.17 ppb on day 3 and 34.84 ppb on day 4. The highest maximum nighttime NO_2 concentration was 49.78 ppb on day 1 but not exceeded the MAAQG. The maximum NO_2 concentration recorded on day 2, day 3 and day 4 were 44.78 ppb, 44.48 ppb and 42.13 ppb, respectively; these values are well below the MAAQG limit with 170 ppb. Meanwhile, the minimum NO_2 concentration recorded on day 1, day 2, day 3 and day 4 were 26.12 ppb, 27.88 ppb, 29.36 ppb and 23.73 ppb respectively. The NO_2 concentration increased were probably due to NO_x titration in the nighttime removal chemistry. There is also because of less emission of vehicle to produce NO_x gases in nighttime (Sanford Sillman, 1998; Sillman, 1999; Awang *et al*., 2015; Awang & Ramli, 2017).

Table 4.1 showed the descriptive statistics of the primary data of air pollutants and meteorological parameters from 12th August 2018 to 16th August 2018 in Jeli town.

Table 4.1: Descriptive statistic of air pollutants and meteorological parameters in Jeli, Kelantan

Day	Parameters	Minimum	Maximum	Mean	Std. Deviation
Day 1	O_3 (ppb)	0.04	35.87	6.07	10.96
	NO_2 (ppb)	26.12	49.78	45.09	6.49
	Temperature (˚C)	22.89	30.46	25.84	2.47
	Relative Humidity (%)	64.13	80.50	74.43	5.06
Day 2	O_3 (ppb)	0.00	18.97	5.04	6.96
	NO_2 (ppb)	27.88	44.78	39.79	4.95
	Temperature (˚C)	23.17	31.80	26.42	2.77
	Relative Humidity (%)	55.59	81.60	73.50	7.73
Day 3	O_3 (ppb)	0.00	17.37	7.86	6.49
	NO_2 (ppb)	29.36	44.48	38.17	4.21
	Temperature (˚C)	23.95	31.42	26.67	2.44
	Relative Humidity (%)	60.35	81.74	73.89	6.76
Day 4	O_3 (ppb)	0.10	29.62	11.52	9.74
	NO_2 (ppb)	23.73	42.13	34.84	5.53
	Temperature (˚C)	24.27	31.13	27.06	2.12
	Relative Humidity (%)	62.88	82.63	74.92	6.28

Table 4.2 showed that the nighttime O_3 concentrations in Kemaman, Terengganu were generally high comprising mean values of 20.36 ppb and 14.18 ppb for year 2008 and 2009, respectively. The mean values of nighttime O_3 concentrations in Kemaman, Terengganu were twice or triple higher than the mean of nighttime O_3 concentration in Jeli, Kelantan. In these 2 years, the highest maximum nighttime O_3 concentration was 150 ppb in year 2009 that had exceeded the MAAQG. According to Awang *et al*. (2015), the high nighttime O_3 concentration in Kemaman, Terengganu were due to the lack of efficiency in NO_x titration. The maximum nighttime O_3 concentration recorded for year 2008 was 70 ppb which is still under MAAQG. Meanwhile, the minimum nighttime O_3 concentration were the same for 2008 and 2009 with 1.00 ppb. This is due to the decreased of vehicle emissions and the absence of sunlight in nighttime for the photochemical reaction to produce O_3 (Sanford Sillman, 1998; Sillman, 1999; Awang *et al*., 2015; Awang & Ramli, 2017).

In addition, results also showed that the nighttime NO_2 concentrations in Kemaman, Terengganu were relatively low with the mean values of 3.12 ppb in year 2008 and 3.09 ppb in year 2009. The highest maximum nighttime NO_2 concentration was 25.00 ppb in year 2009 but not exceeded the MAAQG. The maximum NO_2 concentration recorded was 23.00 ppb which was also under MAAQG in year 2008. Meanwhile, the minimum NO_2 concentration recorded were the same at 0.00 ppb for both year 2008 and 2009.

Table 4.2 showed the descriptive statistics of secondary data of air pollutants and meteorological parameters from 2008 to 2009 in industrial area.

Table 4.2: Descriptive statistic of air pollutants and meteorological parameters from 2008 to 2009 in Kemaman, Terengganu

Parameters	Year	Minimum	Maximum	Mean	Std. Deviation
O_3 (ppb)	2008	1.00	70.00	20.36	12.95
	2009	1.00	150.00	14.18	10.51
NO_2 (ppb)	2008	0.00	23.00	3.12	2.92
	2009	0.00	25.00	3.09	2.90
NO (ppb)	2008	0.00	51.00	1.22	4.38
	2009	0.00	38.00	0.58	1.46
Temperature (˚C)	2008	20.20	25.50	22.84	1.09
	2009	20.00	29.20	23.67	1.72
RH (%)	2008	64.00	100.00	90.64	9.22
	2009	20.00	86.00	73.53	8.60
UVB rays (J/m^3)	2008	0.00	1.00	0.07	0.25
	2009	0.00	4.00	0.05	0.24

4.2 Time Series Analysis

The hourly variations of O_3, NO_2 concentration, temperature and the relative humidity over the 4 days from 12th August 2018 to 16th August 2018 were illustrated based on the time series analysis as shown in Figure 4.1. Similarly, the hourly variations of O_3, NO_2, NO concentration, temperature, relative humidity and UVB rays throughout the year 2008 and 2009 were illustrated using the time series analysis as shown in Figure 4.2 and Figure 4.3, respectively.

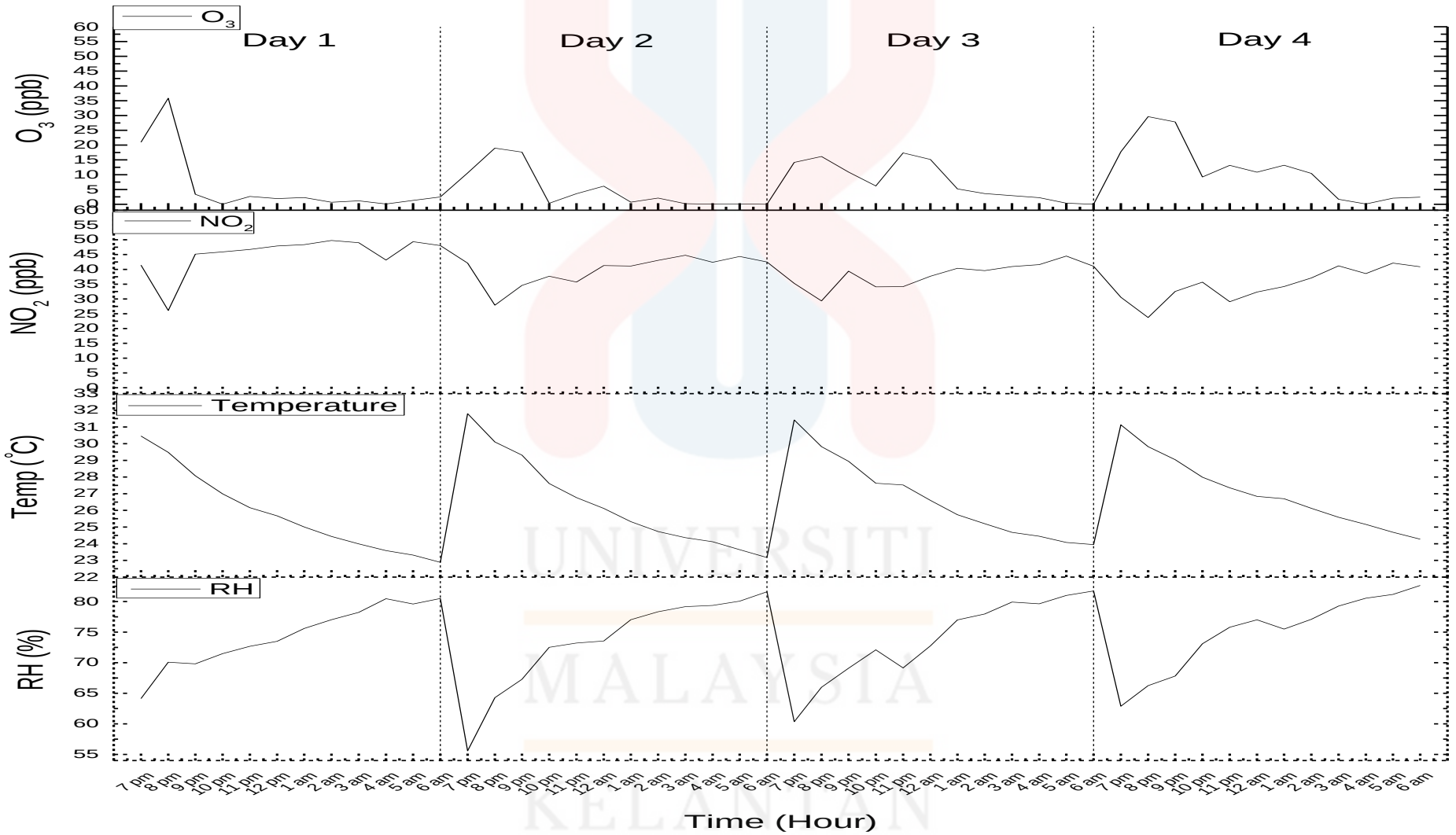


Figure 4.1: Time series plot for the concentrations of O_3, NO_2, temperature and relative humidity from 12th until 16th August 2018 at nighttime in Jeli, Kelantan

Figure 4.1 showed the O_3 concentration is high from the beginning and become low or zero value at the end in the duration from 7 p.m. to 7 a.m. This is due to the reduced or no production of O_3 in the absence of sunlight. The absence of sunlight also improved the efficiency of the nighttime removal chemistry of O_3 to reduce the O_3 concentration in nighttime. In nighttime, the O_3 is reacted with NO to produce NO_2 and O_2 for the nighttime removal reaction (Sanford Sillman, 1998; Sillman, 1999; Somers *et al*., 2007; Awang *et al*., 2015; Awang & Ramli, 2017). Therefore, the O_3 is decreased when the NO_2 is increased. The trends of O_3 concentration were consistent over the 4 days in Figure 4.1. This is due to the weather condition and the surrounding condition were almost the same with no rain and other activities including construction process at the site.

Meanwhile, the trends of temperature were the same over the period investigated with the highest at 7 p.m. and low at 7 a.m. This is due to there is no sunlight in night that can cause the temperature to decrease. Besides that, the relative humidity also showed increasing trends from 7 p.m. to 7 a.m. with the lowest at 7 p.m. and highest at 7 a.m. Relative humidity increased is because of the amount of water vapour present in air is high in night due to low temperature and no sunlight. The readings of relative humidity did not exceeded 90% due to no precipitation in these 4 days (Dickerson *et al*., 1997; Singh *et al*., 2016).

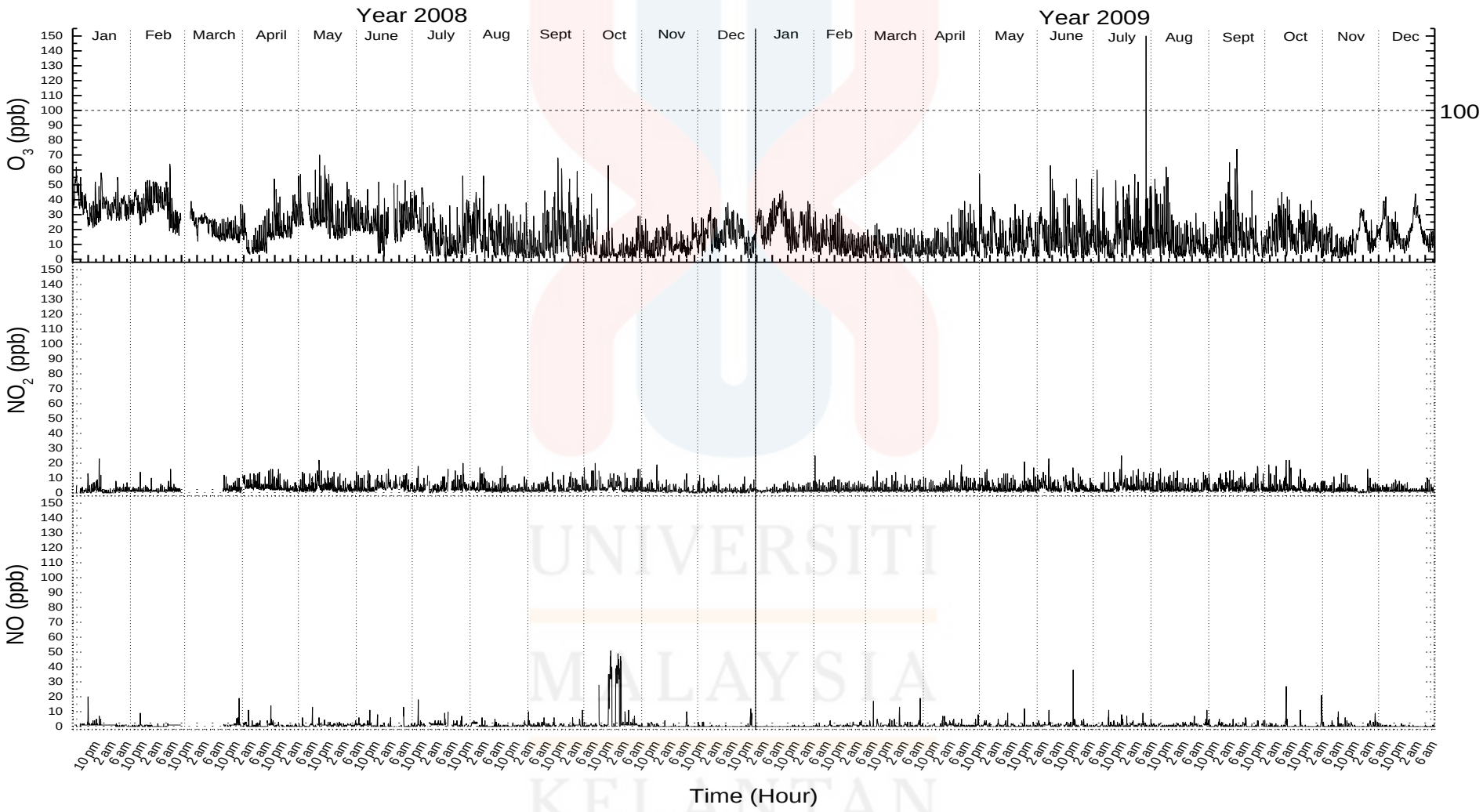


Figure 4.2: Time series analysis for the concentrations of O_3, NO_2 and NO in nighttime for year 2008 and 2009

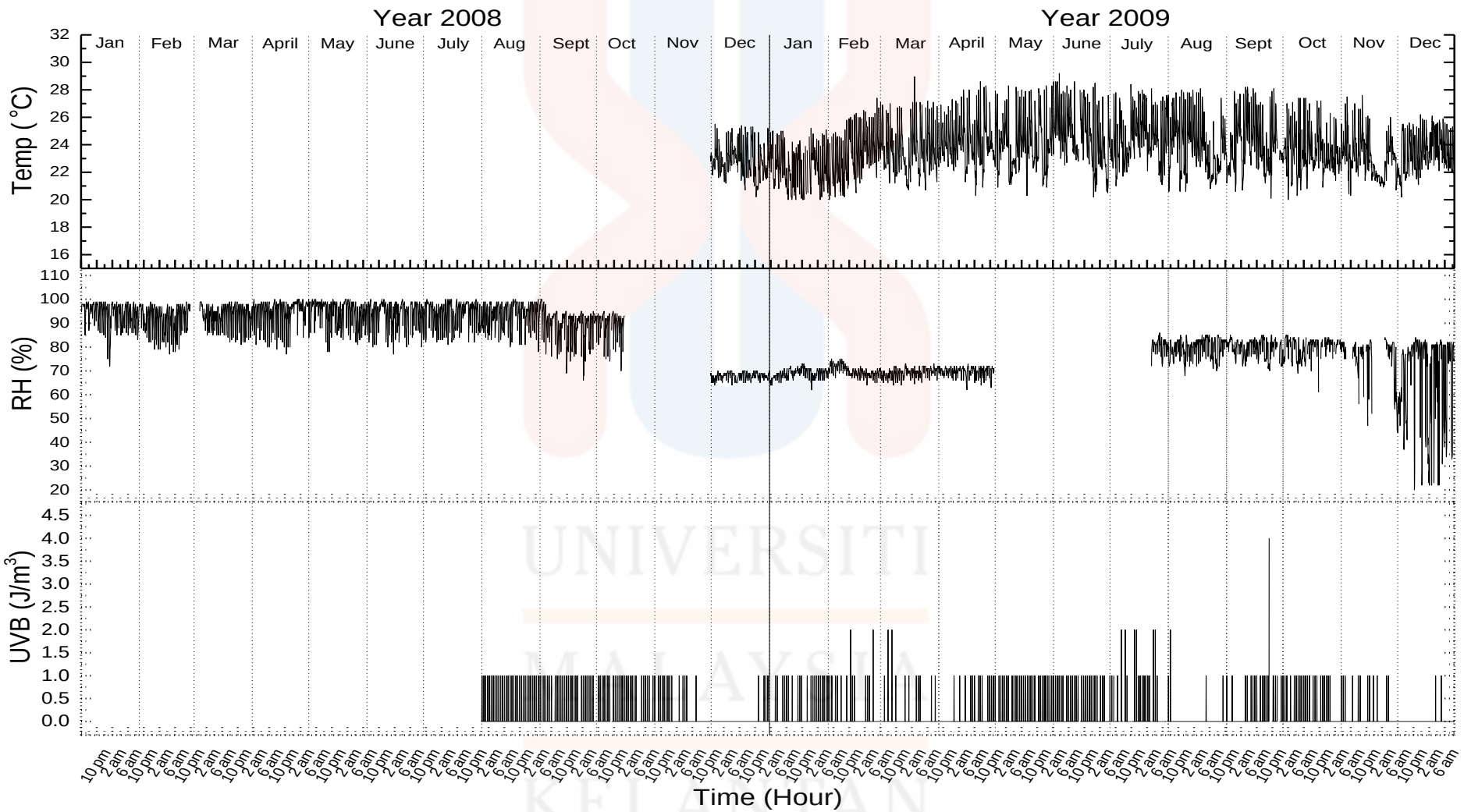


Figure 4.3: Time series analysis for temperature, relative humidity and UVB for year 2008 and 2009 in nighttime

Despite the different study periods and durations, Kemaman, Terengganu had relatively higher nighttime O_3 concentration compared to Jeli, Kelantan. Result in Figure 4.2 showed that the nighttime O_3 concentration in Kemaman, Terengganu is exceeded the MAAQG with 150 ppb in July, 2009. The high O_3 concentration in Kemaman, Terengganu is probably due to there is more emission of gases from anthropogenic sources including higher traffic density and industrial establishment. This is because the district of Kemaman, Terengganu except for the areas that along coastline which were sited with steel and petrochemical plants is relatively underdeveloped (Sugiyanto & Malkhamah, 2018).

Through time series plot in Figure 4.2, the monthly concentration of O_3 in January was the highest. Then, the O_3 concentration was decreased gradually from February to April. The O_3 concentration increased from May to September and decreased from October to November, then increased again from December to January. However, the highest hourly average concentration of O_3 in nighttime was observed which is 150 ppb in July, 2009 which exceeded the MAAQG. According to Awang *et al*. (2015), inefficient removal mechanism was the main cause to the high concentration of O_3 in nighttime.

Meteorological factors also played an important role in affecting concentration of O_3. There are four monsoon seasons changes in Malaysia which are northeast monsoon, southwest monsoon, first and second intermonsoon (Suhaila, Deni, Zawiah Zin, & Jemain, 2010). The northeast monsoon occurred between November to March. Nighttime O_3 concentration in Figure 4.2 showed the concentration in November were generally low. According to Suhaila *et al*. (2010), the influence of the northeast monsoon in the eastern coastal areas of Malaysia is more prominent than other areas. The increase in rainfall intensity promotes the wet deposition process in the

atmosphere which minimizing the concentration of pollutants in the ambient air while the strong turbulent wind speed promotes the transportation of air pollutants to other places (Grima, Micallef, & Colls, 2002). Result also showed the low nighttime O_3 concentration from April to May for first intermonsoon and from October to November for second intermonsoon. The concentration of O_3 in nighttime is low during intermonsoon. This is due to the occurrence of thunderstorms in late afternoon during the intermonsoon are observed (Majid *et al*, 2012; I. Ramli *et al*., 2015).

In accordance to O_3 concentration, NO_2 concentration in Kemaman, Terengganu showed in Figure 4.2 is lower than the NO_2 concentrations in Jeli, Kelantan. The NO_2 concentration in Kemaman did not exceed 170 ppb as listed in MAAQG. Temperature low in January and increased from February to October and decreased from November to December which is due to the monsoon season. Relative humidity in year 2008 was recorded the readings exceeded 90% which means that there is rainfall in year 2008. UVB radiation showed in Figure 4.3 is considered normal and stable. Result showed the first peak reading of UVB rays was in early evening which was from 7 p.m. to 8 p.m. and second peak was from 6 a.m. to 7 a.m. This is due to the sunset in early evening and sunrise in the morning.

The blank space in the time series analysis was reported as missing values in Figure 4.3. The presence of the missing value were caused by the maintenance of the monitoring equipment. This caused the data of the day could not be collected.

4.3 Diurnal Plot

Diurnal plot was produced for the primary and secondary data to monitor the occurrence of nighttime chemistry. The diurnal plot showed the average concentration of O_3, NO_2, temperature and the relative humidity from 12th August 2018 until 16th August 2018 in nighttime in Jeli, Kelantan (Figure 4.4) and the average concentration of NO_2, O_3, NO, temperature, relative humidity and UVB for year 2008 and 2009 in nighttime in Kemaman, Terengganu (Figure 4.5).

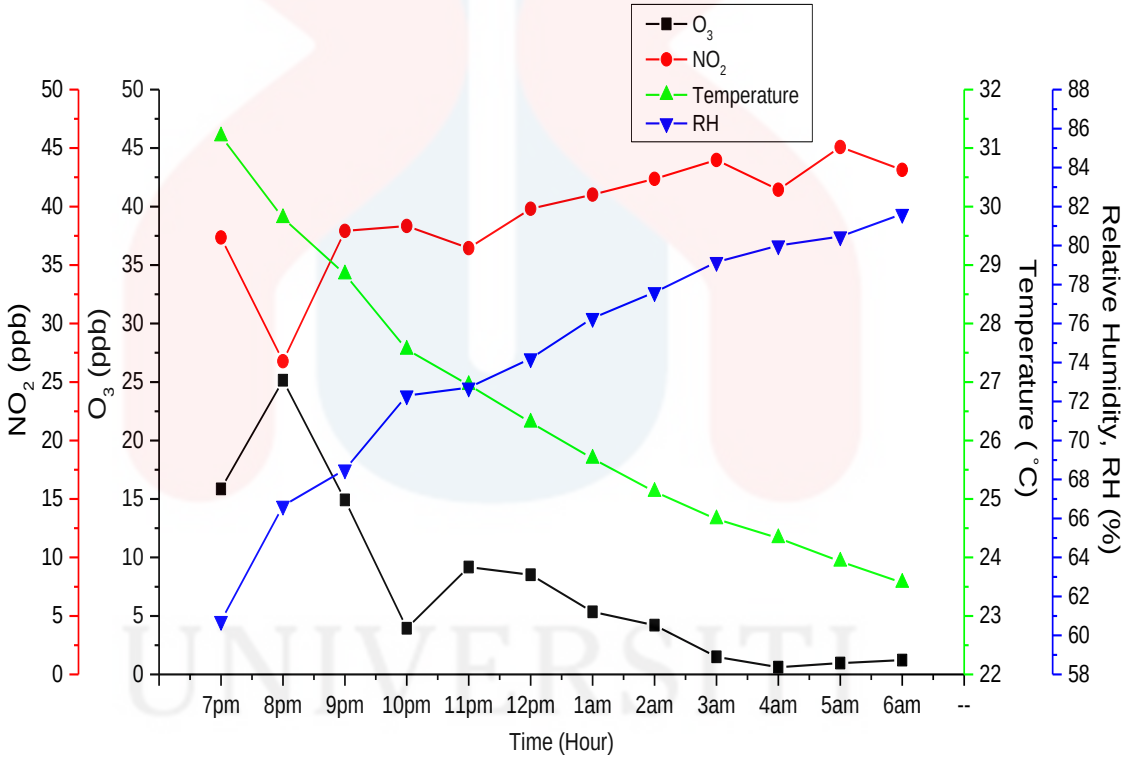


Figure 4.4: Composite diurnal plot for average concentration of O_3, NO_2, temperature and relative humidity in Jeli.

Figure 4.4 showed the O_3 concentration was decreased obviously after sunset. The lowest O_3 concentration was monitored at 4 a.m. in the early morning. The O_3 concentration slightly increased again from 5 a.m. This is due to the absence of sunlight which caused no production of O_3 in nighttime and the high efficiency of NO_x

titration. Ghosh *et al*. (2013) reported that concentration of O_3 in nighttime in Kolkata, India has similar finding which was relatively low and constant.

Figure 4.4 showed the NO_2 concentration increased significantly after 8 p.m. The high NO_2 concentration in Jeli is due to the nighttime removal reaction. In nighttime removal reaction, there was one reaction which is O_3 react with NO to produce NO_2 and O_2. This reaction is the cause that the high concentration of NO_2. The increased of NO_2 concentration can related to the low concentration of O_3, indicating the occurrence of the nighttime removal reaction in nighttime in Jeli (Sillman, 1998; Sillman, 1999; Awang *et al*., 2015; Awang & Ramli, 2017).

The temperature was decreased in nighttime after sunset. The O_3 concentration was positively correlated with the temperature. Temperature decreased due to the absence of sunlight in nighttime. On the other hand, relative humidity was increased after sunset. The relative humidity was negatively correlated with O_3 concentration. Besides that, the temperature also negatively correlated with relative humidity which was the relative humidity increased when the temperature decreased (Khoder, 2008; Kgabi & Sehloho, 2012).

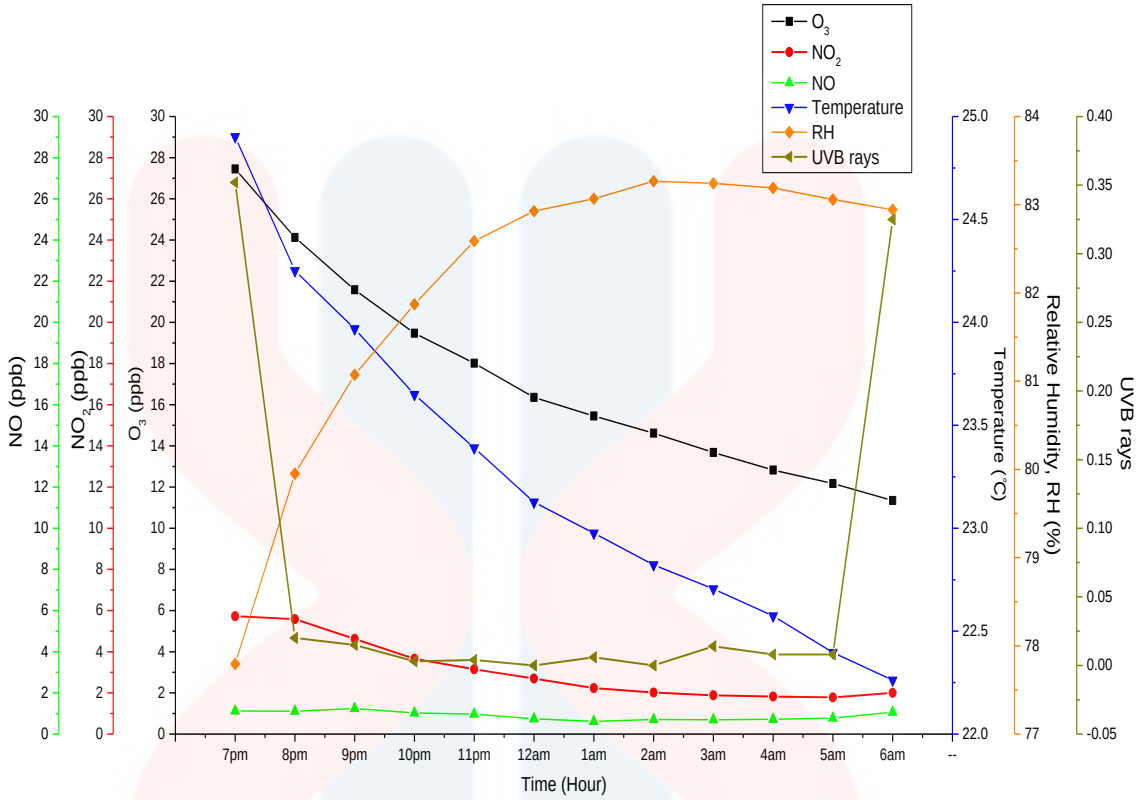


Figure 4.5: Composite diurnal plot for average concentration of nighttime NO_2, O_3, NO, temperature, relative humidity and UVB in Kemaman.

Figure 4.5 showed the trend for NO_2 and NO concentration were almost the same. This has been proven by the paper written by Banan *et al*. (2013), the pattern of concentration of NO in diurnal trends are typically similar to the pattern of concentration of NO_2 diurnal trends. The trend for NO_2 and NO concentration did not in high fluctuation. The concentration of NO_2 and NO was low due to less emission from vehicle and industries. The NO concentration was relatively lower than the NO_2 concentration.

Besides that, Figure 4.5 showed the decrease trend of O_3 concentration from 7 p.m. to 7 a.m., most likely due to the absence of sunlight and no production of O_3 in nighttime. The highest reading of O_3 concentration was at 7 p.m. and the lowest reading of O_3 concentration was at 6 a.m. However, the O_3 concentration were considered high in nighttime. The high nighttime O_3 concentration was proven. Awang

et al., (2015) reported that the high nighttime concentration of O_3 is due to the lack of efficiency of NO_x titration in nighttime removal reaction.

Result also showed the decrease trend of the temperature in nighttime in Figure 4.5. The O_3 concentration was positively correlated with the temperature, with decreasing temperature in absence of sunlight in nighttime. On the other hand, relative humidity was in the trend of increasing. The relative humidity was negatively correlated with O_3 concentration. Besides that, the temperature also negatively correlated with relative humidity which was the relative humidity increased when the temperature decreased (Khoder, 2008; Kgabi & Sehloho, 2012). For the UVB rays, the readings were almost constant during the period from 8 p.m. to 5 a.m. The first peak reading of the UVB rays was in the early evening which was from 7 p.m. to 8 p.m. due to the sunset while second peak was from 6 a.m. to 7 a.m. which due to the sunrise.

4.4 Multiple Linear Regression (MLR) Analysis

Table 4.3 showed the summary of the MLR models that developed for the primary data in Jeli and the secondary data at Kemaman using original parameters as input. Durbin-Watson (DW) and variance inflation factor (VIF) were used to evaluate multicollinearity and autocorrelations that existed in the models. From Table 4.3, the DW value fall in the range between 1.37 and 1.56, with the value of DW should always be between 0 and 4 in DW statistic (Table 4.3). The value of 2 indicates that there is no autocorrelation in residual (Nerlove & Wallis, 1966). A value approaching 0 represented positive autocorrelation whereas the value approaching 4 represented negative autocorrelation in the residual (McAuliffe, 2005). Therefore, the DW values showed slightly positive autocorrelation in the models.

Table 4.3: Summary models of O_3 concentration during nighttime using original parameters for Multiple Linear Regression

Sources of Data	R^2	Models	Range of VIF	Durbin-Watson
Primary Data	0.73	$O_3 = 111.56 – 0.90\ NO_2 - 0.60\ T - 0.71\ RH$	3.22 - 24.42	1.37
Secondary Data	0.67	$O_3 = -118.46 + 0.37\ NO_2 - 0.41\ NO + 4.99\ T + 0.07\ RH + 2.96\ UVB$	1.05 - 1.54	1.56

Besides that, R-squared (R^2) statistic is the method that used to determine the degree of the models fit the data and the R^2 statistic is always between 0 and 1. The value approaching 0 indicates the model could explain lesser variability of the predicted data while the value approaching 1 indicates the model could explain more variability of the predicted data (Abdul–Wahab *et al*., 2005). Hence, the higher the R^2

value, the better the model fits the data. Besides that, according to Abdul-Wahab *et al*. (2005), the R^2 also used as the ability of the variables indicator to explain the concentration of O_3 variations in a certain period. The result showed that the R^2 value in primary data was 0.73 indicating the optimal performance. This means that the selected variables have explained 73% of the variations of the O_3 concentration. For the secondary data based MLR model, the R^2 value was 0.67 which was considered moderate. This indicated the selected variables have explained more possibilities in the variations of O_3 concentration (Anwar & Mikami, 2011; Özbay *et al*., 2011; Ul-Saufie *et al*., 2011; Awang *et al*., 2015).

The result showed no multicollinearity in the secondary data but multicollinearity existed in primary data with the value of VIF exceeded 10. The value of VIF exceeding 10 means multicollinearity exists and that correction is required (Anwar & Mikami, 2011; Özbay *et al*., 2011; Ul-Saufie *et al*., 2011; Awang *et al*., 2015). However, no correction has been done in this study. The result for the primary data also showed the most significance factor that enhance the nighttime removal reaction in primary data was NO_2 with the highest gradient value of 0.90. Meanwhile, the significance factor that enhance the nighttime removal reaction in the secondary data was temperature with the highest gradient value of 4.99.

CHAPTER 5

CONCLUSION

This study analysed the variation of nighttime O_3 concentration in Jeli, Kelantan and Kemaman, Terengganu. The study showed that the nighttime O_3 concentration in Jeli, Kelantan were highest around sunset (7 p.m. to 8 p.m.) and become low around sunrise (6 a.m. to 7 a.m.) due to the high efficiency of NO_x titration. Meanwhile the nighttime O_3 concentration in Kemaman, Terengganu were low at the beginning of the year from January to March and at the end of the year from November to December due to the northeast monsoon season in Malaysia.

Besides that, this study also determined the presence of nighttime O_3 removal reaction based on the effects of NO_2 and NO on the nighttime O_3 concentration. In Jeli, Kelantan, the presence of nighttime O_3 removal reaction was observed through the significant decreased of O_3 concentration and the increased of NO_2 concentration. However, the absence of nighttime O_3 removal reaction in Kemaman, Terengganu was observed through the high nighttime O_3 concentration and low NO_2 and NO concentration.

The developed MLR model showed a slightly positive autocorrelation problem and the secondary data model showed no multicollinearity existed while the primary data model showed multicollinearity existed which the value of VIF was exceeded 10. The R^2 for the primary data (0.73) is considered higher than secondary data (0.67), indicating the selected variables have explained 73% and 67% of the variations of the O_3 concentration, respectively. In addition, the results indicate the most significance

factor to enhance the nighttime removal chemistry for the primary data and secondary data were NO_2 and temperature, respectively.

5.1 Recommendations

The trend of the atmospheric study needs to have long duration of monitoring period. Therefore, a long duration of monitoring period is favourable in the future study. This is due to the trend of the concentration of O_3 can be observed more detail by extending the duration of study. Although the high nighttime concentration of O_3 was identified in this study, the causes that the low NO_x concentration in Kemaman, Terengganu was not found in this study which can have further study on that issue. Besides that, the study of wind direction is also suggested to predict the concentration of O_3 as the primary pollutant will be brought to the monitoring station from the other places.

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