ASSESSMENT OF EXTREME PARTICULATE MATTER (PM_{10} & $PM_{2.5}$) AND METEOROLOGICAL PARAMETERS IN THE PENINSULAR MALAYSIA AND ITS RELATION WITH CLIMATE EXTREMES VIA EXTREME QUANTILE ANALYSIS

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PENILAIAN PARTIKEL YANG EKSTREM (PM_{10} & $PM_{2.5}$) DAN PARAMETER METEROLOGI DI SEMENANJUNG MALAYSIA DAN HUBUNGANNYA DENGAN ANALISIS KUANTIL EKSTREM

ABSTRAK

Kejadian partikel ekstrem mendapat perhatian besar di seluruh dunia terutamanya di Asia Tenggara yang selalu menghadapi akibat dari peristiwa semasa Monsun Barat Daya. Sebatian dominan yang dijumpai semasa kejadian jerabu adalah bahan partikel yang terdiri daripada PM_{10} & $PM_{2.5}$ dipercayai melumpuhkan kesihatan awam dan persekitaran ekosistem. Oleh itu, penting untuk memberi perhatian lebih pada konsentrasi PM_{10} dan $PM_{2.5}$ kerana mudah dipengaruhi oleh parameter meteorologi. Data set kepekatan setiap jam PM_{10} & $PM_{2.5}$ dan parameter cuaca di Petaling Jaya dan Shah Alam pemantauan udara selama 4 tahun (2015 - 2018) data diperolehi dari Jabatan Alam Sekitar (JAS) Malaysia. Kajian ini bertujuan untuk meramalkan kepekatan bahan zarah yang melampau lebih awal semasa kejadian zarah ekstrem. Kaedah yang digunakan untuk menentukan ramalan model terbaik partikulat ekstrem adalah regresi linier berganda dan regresi kuantil dan pengukuran prestasi digunakan untuk menguji validasi model.Analisis temporal untuk zarah dan parameter cuaca dinilai dengan menggunakan statistik deskriptif, siri masa dan boxplot. Hasil kajian menunjukkan bahawa tahun 2015 mengalami kejadian partikulat yang tinggi berbanding tahun lain di kedua-dua kawasan kajian. Analisis trend PM_{10} & $PM_{2.5}$ di Petaling Jaya dan Shah Alam menunjukkan bacaan tertinggi pada bulan September 2015 disebabkan oleh kebakaran di Sumatera dan Kalimantan, Indonesia dan bacaan terendah dicatatkan pada tahun 2017 dan 2018. Korelasi positif yang kuat ditunjukkan antara PM_{10} & $PM_{2.5}$ ($r = 0.8$ & $r = 0.9$) dan korelasi positif yang lemah diperhatikan dengan suhu dengan nilai r dalam lingkungan 0.1 hingga 0.04. Bagaimanapun, korelasi negatif yang kuat dicatat untuk kelembapan dan korelasi negatif yang lemah untuk kelajuan angin. Model regresi kuantil menunjukkan model terbaik berbanding dengan Regresi Linier Berganda (MLR) kerana bacaan ralat mutlak min rendah (MAE) dan ralat kuasa dua punca min (RMSE) dan bacaan pekali

penentuan yang tinggi (R^2) dan indeks perjanjian (IA). Oleh itu, model kuantil regresi (QR) paling sesuai digunakan untuk meramalkan kepekatan PM_{10} semasa kejadian jerebu.

ASSESSMENT OF EXTREME PARTICULATE MATTER (PM_{10} & $PM_{2.5}$) AND METEOROLOGICAL PARAMETERS IN THE PENINSULAR MALAYSIA AND ITS RELATION WITH CLIMATE EXTREMES VIA EXTREME QUANTILE ANALYSIS

ABSTRACT

Extreme particulate events receive great attention worldwide especially in Southeast Asia that constantly faced the consequences of the event during Southwest Monsoon. The predominant compound found during high particulate event was particulate matter PM_{10} & $PM_{2.5}$ were believed severely to harm public health and environment. Therefore, it was important to give more attention on PM_{10} and $PM_{2.5}$ concentration as it was easily influenced by meteorology variables. The hourly dataset of PM_{10} & $PM_{2.5}$ concentration and weather variable at Petaling Jaya and Shah Alam air monitoring for 4 years period (2015 – 2018) data were obtained from Department of Environmental (DOE) Malaysia. This study aim to predict extreme particulate matter concentration ahead early during extreme particulate event. The method that used to determine best model forecast extreme particulate matter was multiple linear regression and quantile regression and performance measurement was used to test the validation of model. The temporal analysis for particulate matter and weather parameter was evaluated by using descriptive statistic, time series and boxplot. The result shown that 2015 experiences extreme high particulate event compare to other years for both study areas. The trend analysis of PM_{10} & $PM_{2.5}$ in Petaling Jaya and Shah Alam showed highest reading in September 2015 due to wildfire in Sumatra and Kalimantan, Indonesia and lowest reading recorded in 2017 and 2018. A strong positive correlation shown between PM_{10} & $PM_{2.5}$ ($r = 0.8$ & $r = 0.9$) and weak positive correlation was observed with temperature with r value in range 0.1 to 0.04. However, strong negative correlation was recorded for humidity and weak negative correlation for wind speed. The quantile regression model (QR) was selected as best model when the compared to Multiple Linear Regression (MLR) as QR low reading of mean absolute error (MAE) and root mean square error (RMSE) and high reading of coefficient of determination (R^2) and index of

agreement (IA). Thus, Quantile Regression (QR) model is more suitable to be applied for predicting PM_{10} concentration during extreme particulate event.

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LIST OF SYMBOLS

°C	Degree Celsius
%	Percentage
x_1	PM_{10} Concentration
x_2	Temperature (°C)
x_3	Relative Humidity (%)
x_4	Wind Speed (m/s)
$\bar{O}$	Means of observed values
O_i	Observed values
$\bar{P}$	Mean of predicted values
P_i	Predicted values
σ_O	Standard deviation of observed values
σ_P	Standard deviation of predicted values
$\mu g/m^3$	Micron gram per meter cubic
N	Sum of annual measurement at particular site
y	Next 24 hours of PM_{10} concentration ($\mu g/m^3$)
τ	Tau / quantile coefficient
$argmin$	Argument of minimum
ρ_τ	Absolute value of function

LIST OF ABBREVIATIONS

API	Air Pollution Index
ASEAN	Association of South-East Asian Nations
CAQM	Continuous Air Quality Monitoring
DOE	Department of Environmental
H	Relative Humidity
IA	Index of agreement
IT	Interim Target
MAAQS	Malaysia Ambient Air Quality Standard
MEA	Mean absolute error
MLR	Multiple Linear Regression
NE	Northeast Monsoon
PCA	Principle Component Analysis
PM	Particulate Matter
QR	Quantile Regression
RMSE	Root Mean Square Error
SW	Southwest Monsoon
SA	Source of Apportionment
T	Temperature
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WS	Wind Speed

NO_2	Nitrogen Oxide
O_3	Ozone
PM_{10}	Particulate matter with a diameter of less than 10μm
$PM_{2.5}$	Particulate matter with a diameter of less than 2.5μm
R^2	Coefficient of Determination
SO_2	Sulphur Oxide
CO	Carbon monoxide

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Rapid development in technology and urbanization increases the influence of a country and strengthen the economy. Hence, improving the living standards of the public. However, the development rise the contribution of air pollution locally or regionally. Air pollution is defined as all destructive effects of any source which contribute to the pollution of the atmosphere and/or deterioration of the ecosystem (Ghorani, Riahi & Balali, 2016). According to World Health Organization (WHO) (2018), nine out of ten people in the world breathe polluted air. Every year, approximately 7 million people die as a result of exposure to ambient and household air pollution.

Air pollution has harmed human health, visibility, ecosystems, and agricultural production in Southeast Asia (SEA) (Kumar, Adelodum, Khan, Krisnawati & Garcia, 2020). The development and increased use of vehicles, combined with the industrial revolution, resulted in increased cases of air pollution. At the same time, the wildfires in Indonesia's Sumatra and Kalimantan have exacerbated air pollution and contributed to intense extreme particulate event. Extreme particulate event also known as Haze. Extreme particulate event is characterized as an increase in atmospheric aerosol load that reduces visibility significantly. The absorption and scattering of light by gases and particles in the ambient air reduces visibility (Seinfeld & Pandis, 2016). Extreme particulate event is one of air pollutant which contributes to the major air pollution. Extreme particulate event occurred due to uncontrolled timberland fires from the Indonesian territory of Sumatra during the farm or forest clearing season that delivered a territorial fog scene that influenced the ASEAN nation, particularly Malaysia (Hashim, Noor & Annas, 2018).

Extreme particulate event was indeed composed of particulate matter and chemically mixed pollutant or trace pollutant, which contributes to an increase in the toxicity of the haze phenomenon. Particulate matter with a diameter of less than 10 μm (PM_{10}) has been identified as one of the major air pollutants (Mohd Kalkausar et al., 2019; Liew, Latif & Tangang, 2017). As PM_{10} air pollutant which was a mixture of solid particles and liquid droplets that existed in the atmosphere. It has a large group of coarse particle pollutant which comprises the fine particles ($PM_{2.5}$) and ultrafine particles ($PM_{0.1}$) (Anderson, Thundiyil & Stolbach, 2016). Instead of PM value, there are some air pollutant sources such as Ozone (O_3), Carbon Monoxide (CO), Sulphur Oxide (SO_2), and Nitrogen Oxide (NO_2), which important in measuring the air pollutant index (API). Inhalation of these atmospheric pollutants increases the hospitalization due to serious illness such as breading difficulties, cardiovascular disease, etc. This was supported by Pavani and Rao (2017) reported that emission of toxic gases such as carbon monoxide (CO), nitrogen dioxide (NO_2) carbon dioxide (CO_2) and particulate matter (PM) are leading to severe impact on the health of the general public with symptoms such as coughing, wheezing and asthma. The extreme haze also causes the descending economy of the country as most industries and businesses need to stop operating.

As meteorology is a key factor influence the concentration of particulate matter (PM_{10} and $PM_{2.5}$) during the extreme particulate events. The meteorology variables such as temperature, humidity and wind speed significantly affects the dispersion and removal of the atmospheric pollutant from the atmosphere. Extreme weather is classified as higher the temperature, the lower the humidity and wind speed which cause the increase the concentration of particulate matter. Malaysia has a unique tropical seasonal which is dry and wet all year long. According to Asmat, Tarmizi and Zakaria (2018), Malaysia is located near the equator and has a hot and humid climate all year. These established that Malaysia has four distinct seasons, namely the Southwest Monsoon (May to September), the Northeast Monsoon (November to March), and two brief transitional periods (April to May and October to November) (Abdul Hamid, Hanafi Rahmat & Aisyah Sapani, 2018). As an extreme particulate event hits Malaysia in 2015 record extreme poor air quality as the escalation of wildfire in Indonesia by an El Nino event. El- Nino is a non-regular phenomenon in the tropical Pacific region that exists when surface water in the equatorial Pacific warms above average and east winds blow weaker than usual (NOAA, 2015).

This study focused on analyzing the relation of extreme particulate event with extreme weather condition. The research was conducted at two air monitoring stations in Klang Valley, namely Petaling Jaya and Shah Alam. The parameters that used in this research were particulate matter (PM_{10} and $PM_{2.5}$) and meteorology parameter such as temperature, relative humidity, and wind speed.

1.2 Problem Statement

The extreme particulate event in Malaysia is usually attributed to land clearing activity occur in neighbor country Indonesia and anthropogenic activity that happened locally. Khan et al., (2020) reported that agricultural land clearing activity in Sumatra and Kalimantan, Indonesia combined with El Nina phenomena, exacerbated the wildfire, causing a worse haze event to hit Southeast Asia, particularly Singapore and Malaysia. Along with Harvard and Columbia University research, the 2015 haze was responsible for over 90 000 early deaths in the SEA (Koplitz et al., 2016).

Moreover, research regarding the correlation of particulate matter (PM_{10} & $PM_{2.5}$) together with other pollutant and weather parameter during extreme particulate event was not yet discovered in Malaysia recent research. Chooi and Yong (2016) having problem to distinguish the air quality index in Malaysia and Singapore as Singapore added the $PM_{2.5}$ reading in their air quality index (AQI) in 2014 whereas Malaysia implement of $PM_{2.5}$ reading in air pollution index (API) in 2017 (DOE, 2018).To resolve this issue, the assessment of extreme particulate matter (PM_{10} and $PM_{2.5}$) and metrological variable combined with other pollutant during extreme particulate event were discussed in this project. Most of the research focused on association of air pollutants and weather parameters during non-haze season. The influence of particle matter and weather parameter in urbanization region become distress as increase number of hospitalization (Alifa, Bolster, Mead, Latif & Crippa, 2020; Sentian, Jemain, Gabda, Franky & Wui, 2018).

Multiple Linear Regression (MLR) model merely concentrated on the mean concentration of dependent variables. This is not suitable for extreme particulate concentration modeling. Ng and Awang (2017) and Mohd Kalkausar et al., (2019) discussed that MLR was found out incoherent in finding of correlation of extreme particulate matter with weather variable during high particle event in Malaysia as MLR only predicted direct association of dependent and independent variables.

Thus, this project developed quantile regression model to analyze relation of the extreme particulate matter (PM_{10} and $PM_{2.5}$) together with meteorological variable. Then, the model test for validation by using performance measures like root mean square error (RMSE), Mean absolute error (MEA), Index of agreement (IA) and coefficient of determination (R^2).

1.3 Research Objective

The following objective of studies are planned in several phases along the course of research:

i. To study the temporal characteristics of particulate matter and meteorology variables.
ii. To compare the extreme trend of particulate matter concentration with weather variables.
iii. To develop the model and validate the extreme particulate matter concentration using extreme quantile regression analysis.

1.4 Scope of the Study

In this research, the hourly measurement data of particulate matter (PM_{10} and $PM_{2.5}$), other pollutants and meteorology parameter of air monitoring station in Petaling Jaya and Shah Alam which located in Klang Valley, Selangor were collected from 2015 to 2018 from the Department of Environmental (DOE).

Firstly, the temporal characteristics of particulate matter and the meteorological variable were studied. To achieve this objective, the variation of particulate matter hourly concentration and meteorology parameters ware analysed using descriptive statistics and boxplot where the trend of particulate matter and weather parameters were evaluated. Additionally, the extreme particulate matter (PM_{10} and $PM_{2.5}$) data and extreme weather variable like temperature, relative humidity and wind speed data for 2015 to 2018 were sorted according to 95th percentile as high and 5th percentile as low. The particulate (PM_{10} and $PM_{2.5}$) and temperature were sorted in accordance to 95th percentile. The relative humidity together with wind speed sorted based on 5th percentile.

Secondly, the extreme trend of particulate matter concentration with the extreme weather variables been compared and correlated. Pearson Correlation coefficient were used to investigate the relationship of extreme trend of particulate matter with chosen meteorology variables. Finally, the prediction model were developed via multiple linear regression model (MLR) and quantile regression (QR) model based on the obtained correlation previously. The performance and validation of the model were evaluated using performance measurement i.e. root mean square error (RMSE), Mean absolute error (MEA), coefficient determination (R^2) and Index of agreement (IA). In this study, it was proven that the quantile regression model to successfully evaluate the correlation of extreme particulate matter (PM_{10} & $PM_{2.5}$) with the extreme weather parameter.

1.5 Organization of Research

This thesis is divided into five chapters. Chapter 1 provide an overview of air quality in Malaysia during the extreme particulate event and the influence of co-pollutant and meteorology variable in the concentration of particulate matter during haze episode.

Chapter 2 reflects on the literature review which has defined the extreme particulate event in Malaysia and discusses the impact of extreme particulate matter on the health of the public, environment and economy. Hence, the influence of particulate matter (PM_{10} and $PM_{2.5}$) concentration with co-pollutant and meteorology variables. In addition, this chapter compare the studies related to the prediction models estimating PM_{10} concentration.

Chapter 3 explain the method involved in this study to achieve the objective of the study. This chapter described the study area and method used to characterize the particulate matter and weather parameters. Furthermore, this chapter also described the development of the regression models used to correlate of extreme particulate matter with weather parameters.

Chapter 4 result and discussion which cover all the graphical illustration table like box plot, times series graph were explained. The result of the analysis of extreme particulate matter and extreme weather were discussed and the development of the regression models and the performance measure used to evaluate the performance of the model in order to achieve the objective.

Chapter 5 deliberate the conclusion of the overall thesis and provide a suitable recommendation for this research to aid future analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Malaysia Air Quality Monitoring

Malaysia installed nationwide air quality monitoring networks to keep track of air quality in various places such as residential areas, industrial areas, commercial areas, roadside areas and reference areas. The Department of Environment (DOE) of Malaysia contracted out national air quality monitoring to a private company, Alam Sekitar Malaysia (ASMA) Sdn Bhd. The company provides continuous ambient air and manual air quality monitoring using 52 continuous and 25 manual monitoring stations around Malaysia (Murad & Pereira, 2019; DOE, 2018). Figure 2.1 and Table 2.1 show the list of 36 continuous air quality monitoring station across Peninsular Malaysia with three different type of station such as sub urban, urban and industrial.

Air Pollutant Index (API) calculation is based on Pollution Standard Index (PSI) that has been recognized at the international level by the United States Environmental Protection Agency (USEPA). The Air Pollutant Index (API) is a measurement of the air pollutant concentration such as particle matter < 10 micrometers and < 2.5 micrometer (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), Sulphur dioxide (SO_2), nitrogen oxide (NO_2) and ozone (O_3). To calculate the API for a specific time period, the sub-index values (including all five air pollutants in the API System) were estimated based on the average concentration. The API was chosen as the maximum sub-index of all five pollutants, and the specific responsible primary pollutants for the API value have been reported to indicate the relevant health effect category and actions to be taken (DOE, 2018).

In 2017 Measurement of $PM_{2.5}$ concentration was included in the National Air Quality Monitoring Station Network (DOE, 2018). The API range can be classified into

5 categories that are blue (good), green (moderate), yellow (unhealthy), orange (very unhealthy) and red (hazardous). Table 2.2 shows the range of API categories with color differentiated for better understanding of emergency and health.

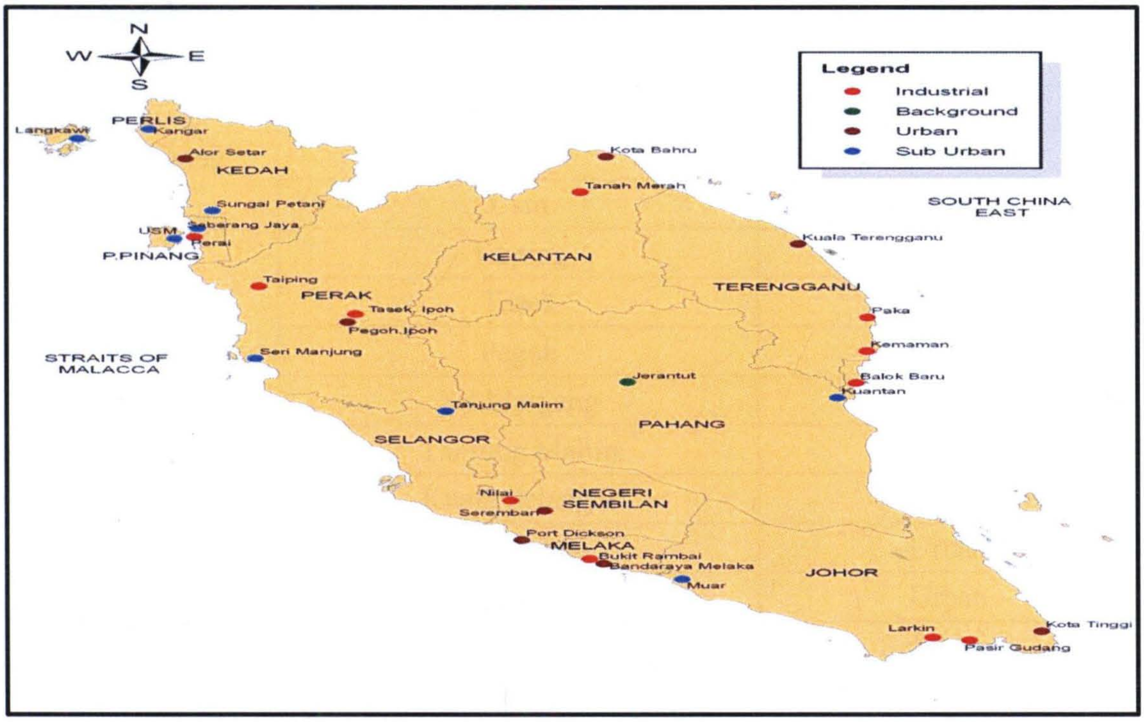


Figure 2.1: Location of CAQM location in Peninsular Malaysia (DOE, 2018)

Table 2.1: Location of CAQM station and types in Peninsular Malaysia

State	Location	Type of Station
Perlis	Kangar	Sub Urban
Kedah	Sungai Petani	Sub Urban
	Alor Setar	Urban
	Langkawi	Sub Urban
Pulau Pinang	Sebarang Jaya	Sub Urban
	Perai	Industrial
	Usm	Sub Urban
Perak	Taiping	Industrial
	Tasek	Industrial
	Pegoh	Urban
	Sri Manjung	Sub Urban
	Tanjung Malim	Sub Urban
Selangor	Kuala Selangor	Sub Urban
	Shah Alam	Urban
	Port Klang	Urban
	Banting	Sub Urban
	Putrajaya	Urban
	Petaling Jaya	Industrial
Kuala Lumpur	Cheras	Urban
	Batu Muda	Urban
Negeri Sembilan	Seremban	Urban
	Port Dickson	Urban
	Nilai	Industrial
Melaka	Bukit Rambai	Industrial
	Bandaraya Melaka	Urban
Johor	Muar	Sub Urban
	Larkin	Industrial
	Pasir Gudang	Industrial
Pahang	Jerantut	Background
	Kuantan	Sub Urban
	Balok Baru	Industrial
Terengganu	Kemaman	Industrial
	Paka	Industrial
	Kuala Terengganu	Urban
Kelantan	Tanah Merah	Industrial
	Kota Bharu	Urban

Table 2.2: The range of API categories with color differentiation (DOE, 2020a)

Colors	Value of API index	Level of distress	Meaning
Blue	0 to 50	Good	The air quality is satisfactory, and there is little or no risk of pollution.
Green	51 to 100	Moderate	The air quality is satisfactory. However, some people would be at risk, particularly those who are extremely sensitive to air pollution.
Yellow	101 to 200	Unhealthy	Some members of the general public may suffer from health effects, while members of vulnerable groups may suffer from more serious health effects.
Orange	201 to 300	Very unhealthy	Health warning: the risk of side effects has been increased for everyone.
Red	›301	Hazardous	Everyone is more likely to be affected by an emergency health condition.

2.1.1 Malaysia Ambient Air Quality Standard

Ambient air quality guidelines for air pollutants were formulated by the Malaysian Department of the Environment (DOE) in 1989. The Malaysia Air Quality Standard (MAAQS) defined concentration limits of selected air pollutants that might adversely affect the public's health and welfare (Rani, Azid, Khalit & Samsudin, 2018). The new Ambient Air Quality Standard adopts 6 air pollutants criteria that include 5 existing air pollutants with is particulate matter with the size of < 10micron (PM_{10}), sulphur dioxide (SO_2), carbon dioxide (CO), nitrogen dioxide (NO_2), ground level ozone (O_3) as well as one additional parameter which is particulate matter with the size of < 2.5 microns ($PM_{2.5}$).

The concentration of atmospheric pollutants has limit reinforce in stage until 2020. Three interim targets were set which include target 1 (IT-1) in 2015, interim target 2 (IT-2) in 2018 and the implementation of the standard in 2020 (DOE, 2018). Table 2.3 shows the New Malaysia Ambient Air Quality Standard (MAAQS) in comparison to the standard stipulated by World Health Organization (WHO) and United States Environmental Protection Agency (USEPA).

Table 2.3: New Malaysia Air Quality Standard (MAAQS) (DOE, 2018)

Pollutants	Average time	Ambient Air Quality Standard				
		IT-1 (2015)	IT-2 (2018)	Standard (2020)	WHO	USEPA
		µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3
PM_{10}	1 Year	50	45	40	20	-
	24 Hour	150	120	100	50	150
$PM_{2.5}$	1 Year	35	25	15	10	15
	24 Hour	75	50	35	25	35
SO_2	1 Hour	350	300	250	-	-
	24 Hour	105	90	80	20	-
NO_2	1 Hour	320	300	280	40	100
	24 Hour	75	75	70	200	-
O_3	1 Hour	200	200	180	-	235
	8 Hour	120	120	100	100	140
CO	1 Hour	35	35	30	-	40
	8 Hour	10	10	10	-	10

2.2 Air Quality Status in Klang Valley

Klang Valley have high levels of air pollution because it was Malaysia's main economic region, with physically demanding infrastructure development, industrialization, and urbanization. (Ming, Yu-Lin, Hamid & Latif, 2018). The air monitoring station in Petaling Jaya categorized as industrial background as it was surrounded by industrial, resident and commercial areas. Meanwhile, Shah Alam station categorized as urban background as it was located in a residential region and near to the busy road.

Asmat et al., (2018) research on Klang Valley air quality monitoring found that the Petaling Jaya station records the lowest mean of humidity (72 .42 %) compared to Hulu Langat station recorded higher (80.19 %) mean humidity. Klang station recorded a higher mean temperature (28.44 °C) compared to Gambak Station recorded the lowest mean temperature (26.60 °C). Also, the wind speed at Kuala Selangor station recorded higher which 5.27 km/h compared with other stations was.

Based on Wong, Mohamed Noor and Mohamad Hashim (2018) studies Shah Alam recorded highest PM_{10} concentration followed by Kuala Terengganu and Melaka from May until October. This was due to the location of Shah Alam at southwest coastal area which near to Indonesia as hot wind brought by southwest monsoon. Besides, Mohtar et al., (2018) stated that Petaling Jaya station recorded higher annual mean of CO and NO_2 concentration as it was located in industrial area with high traffic emission. Annual average of O_3 concentration in Shah Alam station recorded higher as it was placed nearby in industrial sites. However, Klang station recorded higher PM_{10} and SO_2 concentration as the location of the station near to the shipping port where, the concentration of SO_2 higher than NO_2.

2.3 Extreme Particulate Event

Extreme particulate event phrase often used to describe haze event due to high concentration of suspended particle in the atmosphere exceeding the standard. Since 1982, this haze pollution has become almost an annual occurrence in Southeast Asia, with the worst episodes being in the period of 1997-1998 and 2006-2007 (Varkkey, 2017). However, the haze episode that occurred in 2015 was noted to be the worst after the 1997 Asian Haze (Koplitz et al., 2016).

The number of hospitalization surge due to cardiovascular and respiratory diseases in end of year (Aug – Dec) and the beginning of year (Jan – Feb) in year 2015 (Tajudin et al., 2019). Geriatric with age 65-74 recorded higher mortality due to exposure of PM_{10} from extreme particulate event 1997 at South East Asian (Sastry, 2016), while nine year old and 15-month old baby dead dues to haze smoke exposure and more than 100,000 people exposure extreme particulate event in 2015 (BBC, 2015). In 16 week haze periods over two years, 28 admission for breathing difficulties for each week compare with 16 cases per week during non-haze days and most of patient having pre-existing condition like asthma or chronic obstructive pulmonary diseases in 2015 high particulate event (Lisa, 2015).

According to the Department of Environment in 2015, an extreme particulate event occurs when particles in the air are two times higher than normal while visibility is less than one kilometer (km) and air humidity is less than 95 percent (Abdul Hamid et al., 2018). Most area in Malaysia air quality reach unhealthy air limit where, worst API reading were recorded in Shah Alam was hit hazardous limit of 308 API reading (The Malay Mail, 2015). Education Ministry urged closure school temporarily in four state: Sarawak, Selangor, Negeri Sembilan and Malacca suggested to wear face mask and also limit outside activities (The Malay Mail, 2015; Star, 2015).

There have been two categories of sources that contribute to the increase of occurrence of haze which is natural and anthropogenic sources. The natural source normally includes erupted volcanoes, accidental fires in forestry, ashes storm and road ashes. At the same time, anthropogenic sources are commonly produced by the emission from industrial factories, power stations and fuel burning. As in Malaysia, serious haze happened due to uncontrolled open burning of forestry and plantation at a neighbour country as the particulate matter has been transported by the southwesterly wind from Sumatra and Kalimantan (Mohd Zahid, Abdul Malik & Kassim, 2018). During the normal period, the level of particulate matter is mostly influenced by local biomass burning, traffic and industries (Lawrence & Lelieveld, 2016).

Extreme particulate event is more than a visual obstruction phenomenon; it is also pollution with the potential to cause significant harm to the atmospheric environment and human health, a factor that is difficult to detect directly from visibility (Pui, Chen & Zuo, 2016; Tainio et al., 2015).

2.4 Impact of Extreme Particulate Event

The following subtopic briefed the impacts of the extreme particulate event towards the health and economy impact.

2.4.1 Health Impact

The particulate pollutant is the main culprit during a haze phenomenon. Due to their small aerodynamic size that originates from a different source and wide chemical characteristics impose different health problem. Exposure to poor air which contains a widespread of particulate matter will result in serious health problems. The extremely small size of particulate matter increases the possibility of access to the human body compared to large particles. The particles with 10 micrometers diameter or smaller may cause serious health effects as those sizes are able to pass through the nose and throat (Mohd Zahid et al., 2018).

During extreme particulate event in 2015, the fire season background PM concentration increased by a factor of 30-100 in the region, with an estimated 185 million people persistently exposed to PM_{10} concentrations exceeding WHO guidelines, and contributed to 11880 excess around deaths worldwide (Crippa et al., 2016). During extreme particulate event, risen the number of hospitalization due to respiratory distress. Tajudin et al., (2019) research stated the increase of hospitalization due cardiovascular and respiratory disease during hazy season than normal days in urbanized area at Kuala Lumpur, Malaysia. The particulate pollutant might be contaminated with chemicals due to it is originated from emissions from industrial and combustion of motor vehicles. Ghorani et al., (2016) report that SO_2 is very harmful to living organisms as people with lung disease, children, older people and those who are exposed to sulphur dioxide are at higher risk of the skin and lung diseases.

Overall, the seasonal transboundary haze problem severely impacts public health and increased the rate of mortality during haze episodes than normal period. Particulate pollutant considers toxic or hazardous pollutants as they originated from a different source and smaller in size which easily penetrate to the human body especially in the alveoli of lungs and cause illness. The pedestrian, low immunity people and children are prone to get sick during haze episodes.

2.4.2 Economic and other impact

The extreme particulate event hit hard on health and also the economy of the country. Hanafi et al., (2019) reported that countries that were affected by haze would incur productivity losses as a result of haze-related illnesses suffered by the population. Productivity losses occurred in terms of foregone production opportunities during the idled workdays of hospital admission and sick leaves obtained by a fraction of the population at risk, as well as reduced activity days (Dahlui & Hafiz, 2017).

People prone to get illness during haze phenomena especially old people and children which relatively increase hospitalization admission and cost fee as haze relates to disease. Latif et al., (2018) collected data on the daily hospitalization of 14 diseases related to haze pollution from four hospitals in Malaysia in 2005, 2006, 2008 and 2009 respectively, and assessed the economic loss caused by haze pollution in the area. It was estimated that the average economic loss due to haze pollution was about the US $91,000 for each hospitalized patient. Meanwhile, Hanafi et al., (2019) accumulate the health risk analysis of PM_{10} concentration in the ambient air of haze and non-haze period of 2014, 2015 and 2016 in Pasir Gudang Larkin. He found out that the average annual economic loss due to the outpatient health impact of haze were value at RM 83233 and RM 107486 for Pasir Gudang and Larkin respectively. The tourism sector also severely impact as most of international event was postponed like 2015 Malaysia motorcycle Grand Prix was under threat of 2015 event and also Kucing, Sarawak airport was temporarily closed due to extreme particulate event (Star, 2015).

Haze phenomena also impact ecosystem as sunlight penetration is affected, trees and flowering plant reproduction will also likely to be changed. These also cause disturb the food chain of the ecosystem and also reduce crop production. Social activity has also been reduced as haze events cause serious illness. As to avoid health problem due to vision impaired, haze also cause social and productivity problem as the school had to be closed and outdoor activity has to be reduced which also cause reduce income from tourism activity and loss of income due to reducing productivity (Djamil, Lee, Tien Dat & Kuwata, 2017; Quah & Varkkey, 2017).

2.5 Source of Apportionment of Particulate Matter

Particulate matter (PM_{10} and $PM_{2.5}$) is one of major component found in air pollution. The particulate matter normally documented as most hazardous component as it is easily penetrated into human respiratory systems and cause severe illness such as asthmatic problem, lungs infection and etc. The sources apportionment of particulate matter was vital in order to studies the classification of air pollutant during extreme particulate event. As source apportionment (SA) has been commonly used to provide quantitative data about the source contribution of PM to enable in air quality control and management (Hopke, 2016).

Based on Ryou, Gon, Heo and Kim (2018) research on PM_{10} and $PM_{2.5}$ sources of apportionment in South Korea the PM was reclassified PM sources into six categories such as motor vehicle, secondary aerosol, soil dust, combustion/industry, natural resource and other. According this research, motor vehicle sources was mainly contribute the production of PM_{10} and $PM_{2.5}$ in metropolitan areas. Soil dust sources were reported as the main source of PM_{10} and $PM_{2.5}$ across all regions, but with high influences in a few areas, particularly for $PM_{2.5}$. However, this research didn't focus on PM source of apportionment during extreme particulate event and the research focus on dense populated metropolitan areas only.

The research executed by Chen et al., (2018) the result obtained from the study inferred that the highest concentration of $PM_{2.5}$ was observed during haze episodes. In the analysis of this research, on haze days the organic matter and elemental carbon concentrations were higher more than four times than on non-haze days. Secondary sulphide, secondary nitrate, and secondary organic aerosol were much higher on haze days than on non-haze days, indicating that secondary particulate matter formation was the dominant reason for high particle concentrations on haze days.

These concluded that the sources of appointment was necessary in order to evaluate the fingerprints of PM during extreme particulate event. The influence of chemical composition during haze season attributes to the source of particulate matter production.

2.6 Particulate Matter (PM_{10} and $PM_{2.5}$)

The air pollutant that mostly affects Southeast Asia during haze contained particulate matter. Particulate matter is a mixture of solid particles and liquid droplets, also known as aerosol when it is suspended in the air. The presence of particulate matters in the atmosphere cause aesthetic and visibility problem (Mohd Zahid et al., 2018). Particulate matter normally came from various forms of shape as it originates from different sources. Particulate matter (PM) is one of the most harmful air pollutants in the form of dust, soot, dirt, smoke and liquid droplet in the ambient air (Ceylan & Bulkan, 2018). Due to their smaller size, these particles easily penetrate the human body and cause serious illness.

Particulate matter was different based on their size and densities. There was two sources contributed the formation of particle matter which was natural and anthropogenic sources. Natural source normally from volcano eruption, roadside ash, dust storm etc. whereas anthropogenic source including biomass burning, industrial and motor vehicle emission (Tarmizi, Siti & Alias, 2020). Particulate matter with the aerodynamic size of < 10 micrometer (PM_{10}) and < 2.5 micrometers ($PM_{2.5}$) was usually classified particulate matter found in haze event. Studies show that $PM_{2.5}$ dangerous than PM_{10} as it was more likely affects the heath of the public. Chooi et al., (2016) reported that Singapore started to include $PM_{2.5}$ in their air quality measurement instead of PM_{10} only in 2014. The reason was because of the health effect of $PM_{2.5}$ is more adverse than PM_{10} and temporal exposure to the high concentration of $PM_{2.5}$ increases the risk of myocardial infarction after a few hours in a high risk population as finer particles ($PM_{2.5}$).

The physical property of PM_{10} different from $PM_{2.5}$. According Yang et al., (2018) PM_{10} tend to sediment rapidly while $PM_{2.5}$ was able to float and travel for long distance compared with PM_{10} due to their physical sizes. The PM_{10} known as coarse particle and commonly found in smoke, dust, bacteria. These particles was able to penetrate into nose, throat and eyes. However, $PM_{2.5}$ categorized as fines particle which was found in vehicle exhaust, combustion activities and industrial emission. These particles dangerous compared with PM_{10} as it is able to penetrate into deep into human lungs and bloodstream (Khan et al., 2016).

2.7 Extreme Meteorology

As Malaysia strategically closed located on equatorial line which cause the tropical weather whole years. However, Malaysian experience extreme weather during monsoon season changes. As mention by Ho and Tang (2019) that the extreme weather events in Malaysia include days with high temperatures, heavy rainfall, a dry spell, thunderstorms, and strong winds. According to the Malaysia Meteorological Department (2017), there have two monsoon season in Malaysia which south-west monsoon (June - September) and northeast monsoon (November – March). Malaysia also experience transitional wind periods know as inter-monsoon from April May and October to November.

In accordance to Asmat et al., (2018) research high PM_{10} concentration (80.71 $\mu g/m^3$) were measured during southwest monsoon followed by both inter-monsoon (66.78 $\mu g/m^3$) and (77.6 $\mu g/m^3$) and lowest measurement during northeast monsoon (33.78 $\mu g/m^3$). This shows that during northeast season consume high rainfall cause the decrease of PM_{10} concentration. In meanwhile, southwest season together with El- Nino monsoon cause summer monsoon which elevated the PM_{10} concentration as low rainfall occurred and less humidity. This supported by Hashim et al., (2018) studies found that the Southwest Monsoon combine with El-Nino monsoon was the ideal moment for transboundary air pollution to occur because the southwesterly wind transports pollution from neighbouring countries to Malaysia. In Meanwhile, northeast monsoon always brought heavy rainfall. These agreed by Tella, Balogun and Faye (2021) studies stated that during northeast monsoon degrade the PM_{10} concentration due to overflowing rainfall.

Therefore, the meteorology variable like temperature, relative humidity and wind speed was crucial parameters which influence the particulate matter (PM_{10} and $PM_{2.5}$) concentration.

2.8 Relation of extreme PM Concentration with Co-Pollutant & Weather Parameter

Numerous studies have enlightened that particulate matter has a strong correlation of co-pollutant as the mainly due to particulate matter may be constituted of mixtures of precursors element and / or it may also reacts with other element and chemical compound in the atmosphere as in secondary particulates. The extreme particulate event which consisted of numerous of the particulate matter which is airborne particle as it has small and various shape where easily influence by trace gas and meteorology parameters. Asmat et al., (2018) report that Malaysia has tropical and seasonal weather throughout the year as the air quality not only depends on emission source but weather elements such as temperature, humidity and wind play a significant role.

Weather is an important factor in the distribution of ambient air pollution. It is proven by Chooi et al., (2016) reported that air pollution was largely influenced by meteorological factors such as temperature, humidity and wind. Air pollutants such as PM, CO, NO_2, SO_2 and O_3 are small particles and very sensitive toward the surrounding condition. Rahman et al., (2015) was reported that the co-pollutant (CO, NO_2, SO_2 and O_3) showed a positive correlation with wind velocity, temperature but a negative correlation with humidity.

Particulate matter (PM_{10} and $PM_{2.5}$) have been the most common pollutants found in extreme particulate events, which originate from both natural and anthropogenic sources. (Alifa et al., 2020). However, the complication of particulate matter and chemicals from the emission of vehicle and industrial led to toxic air quality. Ming et al., 2018 report during the non-haze seasons, the concentration of SO_2, NO_2, and CO are related to vehicle exhaust emission whilst O_3 is influenced by its precursors and intensity of sunlight particularly during midday.

Seasonal monsoon plays a significant role as responsible control the concentration and dispersion of air pollutant. There are two major monsoons in Malaysia and two intermonsoons in between. The wet monsoon, also known as the Northeast monsoon blows from November to March, followed by the April inter-monsoon, where the northeasterly winds change to southwesterly winds. The dry monsoon, otherwise the Southwest monsoon starts from May and ends in September and replaced by the October inter-monsoon (Lee, Ibrahim, Yong, Ismail & Albani, 2015). The concentration of PM_{10} in industrial and residential areas is higher during the normal period as well as during the haze which can be influenced by the monsoon season (Sun et al., 2018). The highest PM_{10} is expected to reach the peak during the Southwest Monsoon because it is a dry season (Md Yusof, Ramli, Yahaya, Sansuddin, Ghazali & Al Madhoun, 2015).

This explained that the extreme particle matter highly influence with meteorological parameter as risen temperature together with less wind speed and relative humidity cause the significant increase of PM_{10} & $PM_{2.5}$ concentration as corresponding with Yang et al., (2018); Ceylan et al., (2018) studies.

2.9 Studies Related on Prediction Model of extreme PM Concentration

By awaring the seriousness of haze impact on human health and the ecosystem scientists have conducting numerous studies to enlighten the correlation of particulate matter with meteorology variables by developing a statistical models to forecast the air quality in relation to co-pollutant and meteorology parameters.

The quantile regression (QR) model used in prediction of extreme particulate matter and meteorological variable were rarely used by Malaysia researcher. The most recent research done by Ng et al., (2017) on using quantile regression (QR) analysis on PM_{10} concentration with predictor variables in Petaling Jaya station in year 2014. In the end of research he concluded that using QR model worked more efficient compare using Multiple Linear Regression (MLR) in completing predictor variables effects on PM_{10} at different distribution as MLR model did not show the significant level of predictor variables impact on PM_{10} concentration but QR model shows the significant impact of variables. However, this research DOEs not focus extremes particulate event and $PM_{2.5}$ concentration was not used for analysis impact on weather parameter.

Furthermore, Hashim et al., (2018) conducted the research to analyze the performance of PM_{10} concentration during haze phenomena in their case study areas Klang, Muar, Seremban in 4 years period (2004-2009). This study have developed Multiple Linear Regression (MLR) model and a hybrid model which was a combination of Principle Component Analysis (PCA) with the MLR model. From the result of analysis found that PCA - MLR model performs 60 % more efficiently than MLR model alone due to the less calculated error and better fitted model between the predicted and observed.

Research conducted by Mohd Kalkausat et al., (2019) applied Artificial Neural Network (ANN) and Multiple Linear Regression (MLR) coupled with a sensitivity analysis to recognize the pollutant relationship status over particulate matter (PM_{10}) in the eastern region Kelantan, Terengganu and Pahang. From the findings, ANN performs better in full and selected model as both model shows significant results during hazy and non-hazy periods. This was because MLR mostly focused on API pollutants as an additional contributor, while ANN model proved fully utilized during haze event as shown better performance measurement compares with MLR model.

In the earlier research study conduct by Wong et al., (2018) to estimate the trend of PM_{10} concentration at three urban and industrial areas in Peninsular Malaysia at Shah Alam, Kuala Terengganu and Melaka from 2008 to 2012. The descriptive statistics were used to characterize of PM_{10} concentration and Pearson Correlation and Principal Component Analysis (PCA) were used to identify the relationship between PM_{10} concentration and other contaminants as well as meteorological variables. The research concluded that the Artificial Neural Network (ANN) model was best model to forecast the PM_{10} concentration compared with Multiple Linear Regression (MLR) and two hybrid model for instances PCA - MLR and PCA - ANN model for the next three consecutive days. Nevertheless, this research never focused on extreme particulate events; the research merely concentrated on the PM_{10} concentration at urban-industrial region.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Hourly data for 4 years periods (2015 – 2018) from two air quality monitoring stations at Klang Valley which is Petaling Jaya and Shah Alam was obtained from the Department of Environment (DOE) Malaysia. The air pollutant parameters included for in this study were particulate matter (PM_{10} and $PM_{2.5}$) and the weather parameters such as temperature, relative humidity and wind speed were used.

The characteristic of the temporal analysis of particulate matter was analyzed and presented as descriptive statistics table, box plot and time series graph diagrams. The correlation of extreme particulate matter and extreme weather variable was evaluated using Pearson Correlation.

Next, regression model like Multiple Linear Regression (MLR) and Quantile Regression (QR) model ware developed for forecasting the extreme correlation of particulate matter in the study areas. The model was validated using of performance measurement such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Index of Agreement (IA) and Coefficient of Determination (R^2). Figure 3.1 shows the research flowchart of study.

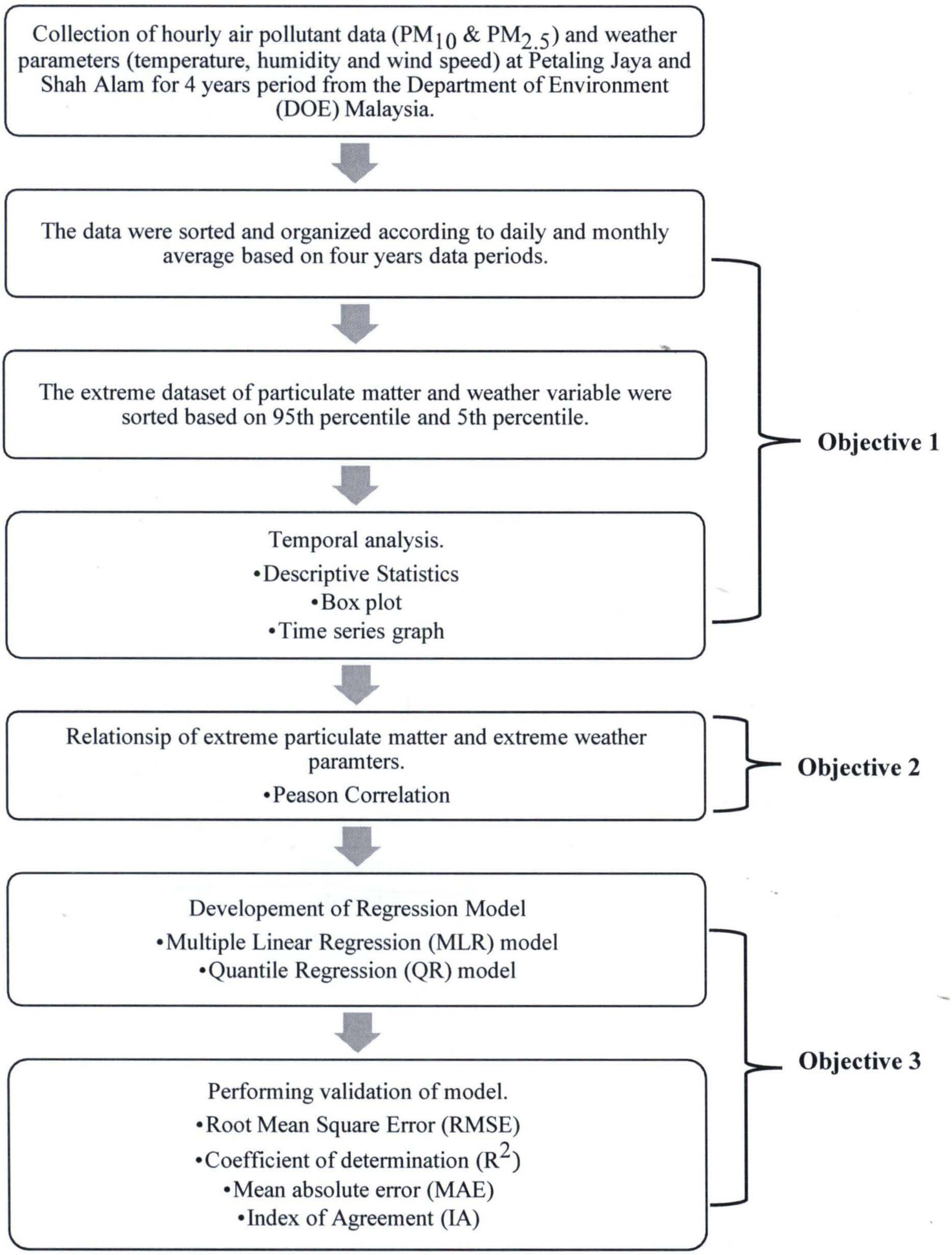


Figure 3.1: Flowchart of the research study

3.2 Air Pollutant Datasets

The data measurements in two industrial-urban station i.e. Petaling Jaya and Shah Alam were gathered from the Department of Environmental Malaysia. The air pollutant datasets include of particulate matter (PM_{10} and $PM_{2.5}$), and weather variables were temperature, relative humidity and wind speed. The hourly datasets were collected for 4 years periods from 2015 – 2018. Furthermore, the extreme dataset was sorted 95^{th} percentile as high values and 5^{th} percentile as small value. The dataset used 95^{th} percentile was particulate matter (PM_{10} and $PM_{2.5}$), and temperature, while relative humidity and wind speed sorted according to 5^{th} percentile. This is because the higher the temperature, the higher distribution of particulate matter; low wind speed and humidity indicates there low rainfall and air pollutant in atmosphere not wash out and less dispersal. The Table 3.1 below shown the symbol and unit of measurement for each of the data used in this studies.

Table 3.1: Summary of parameters included in the research

Categories of variables	Parameters	Symbols	Units
Air pollutant	Particulate matter < 10 µm	PM_{10}	µg/m³
	Particulate matter < 2.5 µm	$PM_{2.5}$	µg/m³
Meteorology variables	Temperature	T	°C
	Humidity	H	%
	Wind speed	WS	m/s

3.3 Study Area

The selected area of air monitoring station for this research is Petaling Jaya and Shah Alam were located at Klang Valley, Selangor. The Klang Valley is comprises of Kuala Lumpur and its suburbs and adjoining cities and towns in the state of Selangor. It is geographically delineated by Titiwangsa Mountains to the north and east and Straits of Malacca to the west with 7.56 million populations in Klang Valley (in 2018) (Asmat et al., 2018).

The air quality in Klang Valley normally poor due to the rapid urbanization and increase of emission in industrial and use of moto vehicle. Mohtar et al., (2018) describe the Klang Valley as heartland of Malaysia's industrial and commerce, and encompassed Kuala Lumpur, its suburban area, and adjoining cities and towns as reason cause poor air quality. The study areas contains two types of backgrounds as Petaling Jaya has industrial background whereas Shah Alam has urban background as shows in Figure 3.2 and Figure 3.3 and the geographical coordinates of both air monitoring station shows in Table 3.2 Petaling Jaya with 543,415 population and consists of handful of residential development, industrial lots such as Shell and Nestle factory, shopping mall and educational buildings like 25 colleges and University together with 58 primary and 28 secondary schools. Shah Alam with 617,149 population which occupies 55.2 km^2 of residential areas and commercial centre disseminated around 56 section. Shah Alam is city and the state capital of Selangor and neighbour with Petaling Jaya and Klang district. Also, Shah Alam surround with main and busy highways like Federal Highways and Shah Alam Expressway. By providing two different background of air quality station able to show the concentration of particulate matter and effect of meteorology variable with the dispersion of particulate matter in study areas

For this study, the 24-hour and 1-hour averaging time of particulate matter (PM_{10} & $PM_{2.5}$) ($\mu g/m^3$) were sourced from the automatic air quality monitoring stations of the Department of Environment (DOE). The record were collected on behalf of the Department of Environmental, Malaysia through a continuous monitoring stations by Alam Sekitar Sdn. Bhd. (ASMA) were placed in the west cost of Peninsular Malaysia.

Table 3.2: Location of air monitoring stations in Klang Valley (DOE, 2018)

Station	District	Coordinates		Background
		Longitudes	Latitudes	
Sek Rendah Sri Petaling, Petaling Jaya	Petaling Jaya	3°06.612'N	101°42.274'E	Industrial
Sek Keb TTDI Jaya	Shah Alam	3°06.636'N	101°33.673'E	Urban

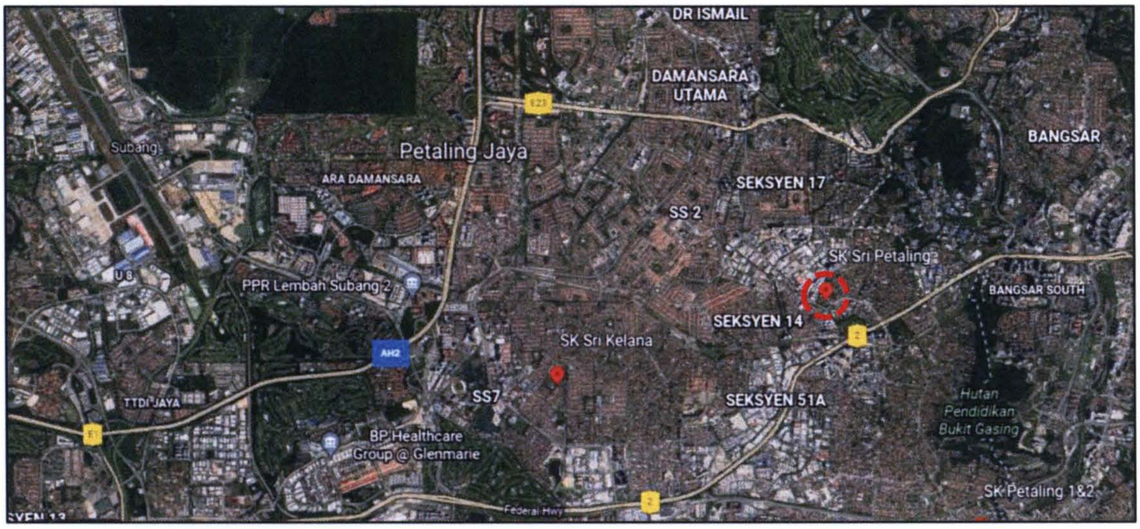


Figure 3.2: Study area of Petaling Jaya (Google Earth, 2021)

Figure 3.3: Study area of Shah Alam (Google Earth, 2021)

3.4 Treatment of missing data

The hourly data of air pollutant obtained from DOE from 2015 – 2018 for Petaling Jaya and Shah Alam stations contains missing values. In order to solve inadequate data problem the nearest neighbour method was implemented. The nearest neighbour technique were used to treat the missing data in dataset and it was introduced by Chapra & Canale (1998). The nearest neighbour method widely used because it is convenient to use and has high accuracy for instance fill the missing data based on mean evaluation of previous data. The equation 3.1 was show the equation of nearest neighbour method (Yazdanpanah, Karimi & Hejazizadeh, 2009):

$$y = y_1 \text{ if } x \leq x_1 + [\,(x_2 - x_1)/2]$$
$$y = y_2 \text{ if } x \geq x_1 + [\,(x_2 - x_1)/2] \qquad (3.1)$$

Where y serve as interpolate, x is time point of interpolate, y_1 and x_1 are the coordinates of the starting point of the gap and y_2 and x_2 are the end point of the gaps.

3.5 Descriptive Statistics

The measurement of preliminary data was given importance as it was help to determine the characteristic of the studied data. Descriptive statistics is the common analysis used to compare data variables. Besides, descriptive statistics is able to show the dispersion, distribution that can reduces the error in the results. This is corresponding with Huebner, Vach and Le Cessie (2016) that use of descriptive statistics to reduce the possibility of presenting misleading results, by using a systematic approach to report the most appropriate descriptive statistics. The most common test used in describing the dataset are measure of central tendency and measure of dispersion. Measures of central tendency includes of mean, median and mode. Whereas, measures of dispersion consists of variance and standard deviation. Table 3.3 used as summarize the formula and description of descriptive statistics.

Table 3.3: The summarization formula and description of descriptive statistics

Type	Analysis	Formula	Description
Measure of central tendency	Mean	$\bar{x} = \frac{\sum_{i=1}^{i=n} xi}{n}$ (3.2)	Mean is average as the divide the sum of date with total number of observations (n).
	Median	$\tilde{x} = \frac{n+1}{2}$ (3.3)	Median is the centre value of set data of observation.
	Mode	-	Mode is the high frequent number that appear in the data sets.
Measure of dispersion	Variance	$S^2 = \frac{\Sigma(x-\bar{x})^2}{n-1}$ (3.4)	The sum of the squared deviations from the mean.
	Standard deviation	$S= \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$ (3.5)	SD is defined as the square root of the sum of the squared variance divided by the number of observational data.

3.6 Time series plot

Time series plot was used to determine the daily mean average for PM_{10} and $PM_{2.5}$ concentration at Petaling Jaya and Shah Alam in 2015 to 2018. The y-axis of time series graph represent the PM_{10} and $PM_{2.5}$ concentration. While, the y- axis represent the days.

3.7 Boxplot

Boxplot is a method for graphically interpret groups of numerical data through their quartiles. The boxplot were used in this research to evaluate the trend of meteorological variables. The boxplot contains interquartile range (IQR) that serves out as a measurement of mutability about the median. The whisker symbolize the maximum and minimum value that represents large and small value of datasets. The outlier shown the excesses value of datasets.

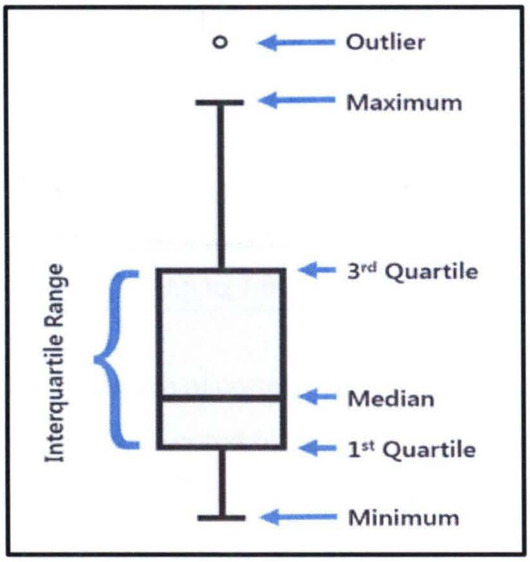


Figure 3.4: Boxplot example (Rigoni, 2014)

3.8 Pearson Correlation Analysis

Pearson Correlation is a measurement of strength of a linear association between two variables. The Pearson Correlation also known as Pearson correlation coefficient, was denoted by r. The Pearson Correlation analysis were used in this study to evaluate the relationship between extreme particulate matter and meteorology variables involved the temperature, relative humidity and wind speed. The range between - 1 and 1 which indicated negative correlation, positive correlation and no correlation, respectively. Positive correlation where the outcome of r value score high of the extreme particulate matter concentration correlate with high score of meteorology parameters. Negative correlation where the r value score lower extreme particulate matter concentration correlate with high score of meteorology parameters. Meanwhile, no correlation where there is no linearly correlation between extreme particulate matter and meteorology parameters. Gogtay and Thatte (2017) have introduced the guideline for the interpretation of correlation coefficient that is shown in Table 3.4.

Table 3.4: The guideline of interpretation of correlation coefficient

Strength of Association	Coefficient, r	
	Positive	Negative
Weak	0.1 to 0.3	- 0.1 to - 0.3
Moderate	0.3 to 0.5	- 0.3 to - 0.5
Strong	0.5 to 1.0	- 0.5 to - 1.0

Based on Table 3.4 the degree of correlation can be determined as high correlation when the coefficient of correlation scored higher than 0.5; if the correlation coefficient was smaller than 0.3 then it was known as low correlation; the correlation coefficient in between 0.3 to 0.5, was classified as moderately correlated.

3.9 Regression Model Development

In this research study multiple linear regression and quantile regression model were used to model the extreme particulate matter of PM_{10} concentration and extreme weather variable in 2015 at Petaling Jaya and Shah Alam.

3.9.1 Multiple Linear Regression (MLR)

Multiple Linear Regression one of the air pollutants modelling practices that have been used by many researcher to determine the relationship between a dependent variable and numerous independent variables. Early studies, Abdullah, Kamarudin, Zakaria & Md Shakaff (2017) and Fong, Abdullah & Ismail (2018) used MLR model to predict air pollution in Malaysia. The extreme particulate matter and weather parameters in 2015 was used in this studies due to extreme particulate event which causes by wildfire in Indonesia. The general equation of MLR model can be written as equation 3.6 (Ul-Saufie, Yahaya, Ramli & Hamid, 2012).

$$y = A + Bx_1 + Cx_2 + Dx_3 + Ex_4 \quad (3.6)$$

Where,

y = Next 24hours of PM_{10} concentration ($\mu g/m^3$)

x_1= PM_{10} concentration

x_2= Temperature (°C)

x_3= Relative Humidity (%)

x_4= Wind Speed (m/s)

3.9.2 Quantile Regression (QR)

Quantile regression is a type of regression analysis used in statistical hypothesis testing. Although the least squares method estimates the conditional mean of the response variable across predictor variable values, quantile regression estimates the likelihood median (or other quantiles) of the response variable. The quantile regression model widely used in forecasting the concentration of particulate matter. Quantile regression introduced by Koenker and Hallock (2001) and the equation 3.8 was formulated by Baur, Saisana & Schulze (2004) and Sousa, Pires, Martins & Alvim (2009) as the solution to minimize the problem. Given a random variable y with right continuous distribution, F_y = Pr (Y≤ y). The quantile regression Q (τ) with τ ϵ (0,1) is defined as following (Ul-Saufie et al., 2012):

$$Q(\tau) = \inf\{y: F(y) \geq \tau\} \tag{3.7}$$

The quantile was formulated by (Baur et al., 2004) & (Sousa et al., 2009):

$$\widehat{Q_y}(\tau) = \arg\min_{a} \{\textstyle\sum_{i:y_i \geq a} \tau|y_i - a| + \sum_{i:y_i<a}(1 - \tau\,|y_i - a|\} = \arg\min_{a} \sum_i \rho_\tau(y_i - a) \tag{3.8}$$

From equation 3.8, the quantile regression coefficient are obtained by solving with respect to β (τ):

$$\hat{\beta}(\tau) = \underset{\beta(\tau)\in\mathbb{R}^k}{argmin} \{\textstyle\sum_{i:y_i \geq \acute{x}\beta(\tau)} \tau|y_i - x_i\beta(\tau)| + \sum_{i:y_i<\acute{x}\beta(\tau)}(1 - \tau)|x_i\beta(\tau)|\} \tag{3.9}$$

In this study, the percentile used to model PM_{10} concentration and weather parameter were 0.2, 0.4, 0.6 and 0.8. The dataset of 2015 were used in this research as higher PM_{10} concentration was recorded in 2015 because of extreme particulate event that occurred due to peatland clearing activities which cause wildfire at Sumatra and Kalimantan, Indonesia (Awang, Ramli, Shith, Zainordin & Manogaram (2018); Abdullah et al., (2018)) .

3.10 Performance Indicator

The performance of indicator used to test the validation of model. The Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Index of Agreement (IA) and coefficient of Determination (R^2) were used in this research to test the validation of quantile regression model. The observed and predicted data were compared to select the best model for predicting extreme particulate matter. The error measurement of MAE and RMSE the closer the value to 0, the better the model, while for accuracy measurement IA and R^2 the closer the value to 1, the better the model.

Table 3.5: Summarize of performance indicator measurement formula

Indicator	Formula	
Mean Absolute Error (MAE)	$\text{MAE} = \frac{\sum_{i=1}^{N} \lvert P_i - O_i \rvert}{N}$	(3.10)
Root Mean Square Error (RMSE)	$\text{RMSE} = \frac{1}{N} \sum_{i=1}^{N} [P_i - O_i]^2$	(3.11)
Index of Agreement (IA)	$\text{IA} = 1 - \left[\frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} (\lvert P_i - \bar{O} \rvert + \lvert O_i - \bar{O} \rvert)^2} \right]$	(3.12)
Coefficient of Determination (R^2)	$R^2 = \left[\frac{1}{N} \frac{\sum_{i=1}^{N} [(P_i - \bar{P})(O_i - \bar{O})]}{\sigma_P \sigma_O} \right]^2$	(3.13)

Where,

N = Sum of annual measurement at particular site

P_i = Predicted values

O_i = Observed values

$\bar{P}$ = Mean of predicted values

$\bar{O}$ = Means of observed values

σ_P = Standard deviation of predicted values

σ_O = Standard deviation of observed values

CHAPTER 4

RESULTS AND DISCUSSION

The trend analysis of extreme particulate matter and weather parameters were evaluated. The descriptive statistics were used to determine the characteristic of concentration of particulate matter, trace gas concentration and meteorological variables included temperature, relative humidity and wind speed. The boxplot and time series graph were used to interpret the analysis of characteristic of PM concentration and weather variables.

4.1 Descriptive Statistics

The descriptive statistics of hourly PM_{10} and $PM_{2.5}$ concentration at Petaling Jaya and Shah Alam from year 2015 to 2018 is shown in Table 4.1 and Table 4.2.

Based on Table 4.1 the mean values of particulate matter for all years were higher than the median value respectively. This indicates that the data was skewed to the right and there were extreme event happened (Sun et al., 2018). The highest mean value of PM_{10} concentration were at Petaling Jaya and Shah Alam in 2015 was 59.82 $\mu g/m^3$ and 66.22 $\mu g/m^3$ respectively. The mean value of PM_{10} concentration gradually decrease in Petaling Jaya and Shah Alam the following years and the lowest mean value was recorded in 2018 which was 34.58 $\mu g/m^3$ and 34.45 $\mu g/m^3$ respectively.

Table 4.1: Descriptive statistics table of PM_{10} concentration at studies area

Station	PM	PM_{10}			
Petaling Jaya	Years	2015	2016	2017	2018
	Mean ($\mu g/m^3$)	59.82	42.35	33.96	34.58
	Median ($\mu g/m^3$)	49.0	40.0	32.86	32.54
	Standard Deviation ($\mu g/m^3$)	44.04	16.02	13.05	14.13
	Variance ($\mu g/m^3$)	1939.54	256.77	170.36	199.54
	Maximum ($\mu g/m^3$)	390	142	115	131
	Minimum ($\mu g/m^3$)	0	0	0	3
Shah Alam	Mean ($\mu g/m^3$)	66.22	50.27	35.20	34.45
	Median ($\mu g/m^3$)	52.0	47.0	34.13	32.18
	Standard Deviation ($\mu g/m^3$)	49.51	20.52	14.80	15.61
	Variance ($\mu g/m^3$)	2451.11	421.13	219.05	243.56
	Maximum ($\mu g/m^3$)	426	160	137	168
	Minimum ($\mu g/m^3$)	17	15	1	1

The standard deviation of PM_{10} concentration was recorded highest in 2015 with the highest value was observed in Shah Alam 49.51 $\mu g/m^3$. Follow by in year 2016, 2017 and 2018 Shah Alam recorded higher standard deviation of 20.52 $\mu g/m^3$, 14.80 $\mu g/m^3$, and 15.61 $\mu g/m^3$ respectively while, Petaling Jaya recorded 16.02 $\mu g/m^3$, 13.05 $\mu g/m^3$, and 14.13 $\mu g/m^3$.

The maximum value of PM_{10} concentration at Shah Alam was recorded higher compared with Petaling Jaya from 2015 to 2018. However, Shah Alam recorded highest reading which was 426 $\mu g/m^3$ respectively in 2015. The zero minimum value of PM_{10} concentration recorded in Petaling Jaya continuously in excepted in 2018.

Table 4.2: Descriptive statistics table of $PM_{2.5}$ concentration at studies area

Stations	Petaling Jaya	Shah Alam
Years	2018	
Mean ($\mu g/m^3$)	24.55	25.15
Median ($\mu g/m^3$)	22.83	23.55
Mode ($\mu g/m^3$)	11.76	17.27
Standard Deviation ($\mu g/m^3$)	11.19	12.47
Variance ($\mu g/m^3$)	125.16	155.53
Maximum ($\mu g/m^3$)	112.73	153.80
Minimum ($\mu g/m^3$)	0.38	0.09

Based on Table 4.2 the mean value for $PM_{2.5}$ concentration at Petaling Jaya and Shah Alam was recorded lower than PM_{10} concentration that was 24.55 $\mu g/m^3$ and 25.15 $\mu g/m^3$ respectively in 2018. The standard deviation of $PM_{2.5}$ concentration in Shah Alam recorded 12.47 $\mu g/m^3$ while, Petaling Jaya recorded 11.19 $\mu g/m^3$.

The standard deviation PM_{10} and $PM_{2.5}$ concentration for Shah Alam was calculated high compared with Petaling Jaya. The high value of standard deviation indicates that the datasets were high in variability or that the range between maximum and minimum data were big. The maximum value of $PM_{2.5}$ concentration higher in Shah Alam which was 153.53 $\mu g/m^3$ and the minimum value 0.09 $\mu g/m^3$ was lower in Shah Alam compared to Petaling Jaya.

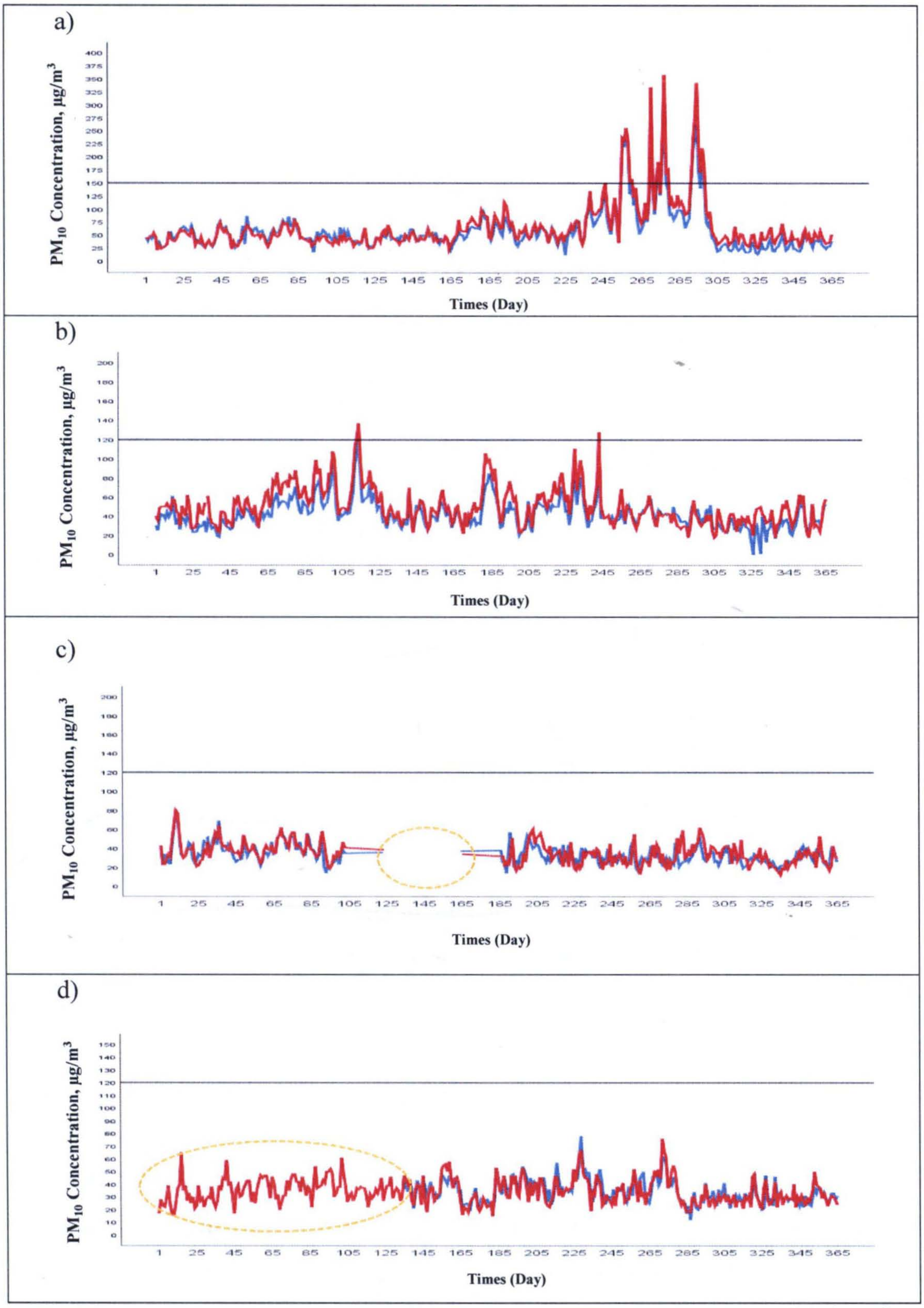
In the nutshell, in 2015 the mean and maximum reading in Petaling Jaya and Shah Alam result shown significantly higher than other years due to wildfire in Kalimantan and Sumatra, Indonesia cause extreme particulate event in study areas and degradation of air quality in Malaysia until API reading shows hazardous level (Stockwell, Veres, Williams & Yokelson, 2015).

4.2 Daily Average of Particulate Matter (PM_{10} & $PM_{2.5}$) Concentration

Figure 4.1 embodied the time series plot for daily average of PM_{10} concentration at Petaling Jaya and Shah Alam from 2015 to 2018 respectively. The black solid line indicate the Malaysia Ambient Air Quality Standard (MAAQS) for 24 hour average time which was 150 $\mu g/m^3$ (IT-1) and 120 $\mu g/m^3$ (IT-2).

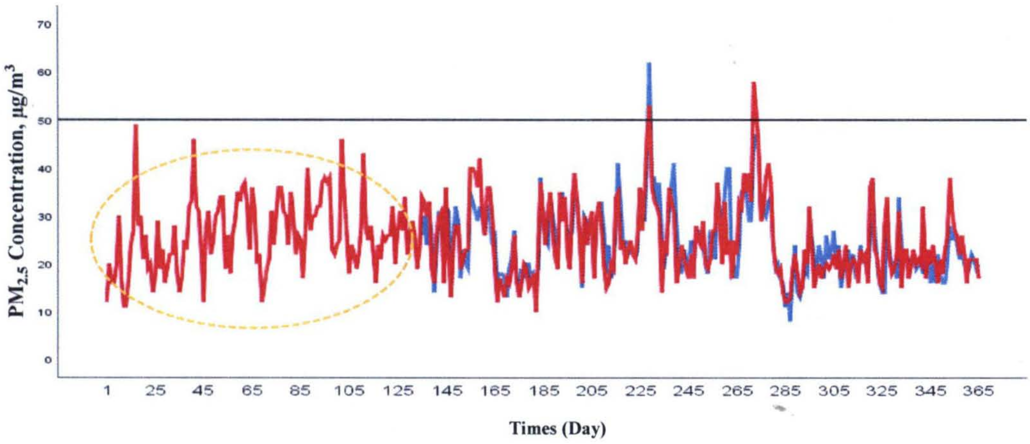
Based on the Figure 4.1(a), it was concluded that in 2015 at Petaling Jaya and Shah Alam experience hazardous level of air quality degradation condition as the highest reading of PM_{10} concentration in day 261 till 301 was logged 331 $\mu g/m^3$ and 358 $\mu g/m^3$ respectively. This shows the extreme dangerous particulate event happened due 2015 wildfire in Indonesia as the reading exceeded the MAAQS (IT-1) and USEPA limits for 24 hour average which was 150 $\mu g/m^3$. This is consistent with the research by Mead et al., (2018) that stated during Kalimantan and Sumatra, Indonesia wildfire in 2015 have accelerated trans-boundary high particulate event that cause unhealthy air quality conditions in Malaysia.

In 2016, both Petaling Jaya and Shah Alam experience unhealthy extreme particulate event as the average PM_{10} concentration reading was recorded 138 $\mu g/m^3$ and 144 $\mu g/m^3$ in early of year in mid-March. This extreme particulate event happened due to irresponsible farmer in West Coast Division, Sabah was set fire on forest for agricultural activities. This confirm by Sabah fire Department (SFD) the forest fire have burned Trusmadi and Binsuluk Forest Reserves (John, 2016). On day 246 the PM_{10} concentration recorded 130 $\mu g/m^3$ and 138 $\mu g/m^3$ in both study areas. These air quality reading have exceeding the MAAQS (IT-2) and WHO limit which was 120 $\mu g/m^3$and 50 $\mu g/m^3$. This unhealthy air quality condition cause by peatland fire activity in Sumatra and Kalimantan, Indonesia. Malaysia Air Pollution Index (API) have reached unhealthy air condition due to slash and burn activities by some farmers and companies in order to clearing plantation (BBC, 2016).


a)
PM10 Concentration, µg/m3
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400
1 25 45 65 85 105 125 145 165 185 205 225 245 265 285 305 325 345 365
Times (Day)
b)
PM10 Concentration, µg/m3
0 20 40 60 80 100 120 140 160 180 200
1 25 45 65 85 105 125 145 165 185 205 225 245 265 285 305 325 345 365
Times (Day)
c)
PM10 Concentration, µg/m3
0 20 40 60 80 100 120 140 160 180 200
1 25 45 65 85 105 125 145 165 185 205 225 245 265 285 305 325 345 365
Times (Day)
d)
PM10 Concentration, µg/m3
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
1 25 45 65 85 105 125 145 165 185 205 225 245 265 285 305 325 345 365
Times (Day)

Continued

e)



Black solid line: MAAQS limit
Orange doted circles: Missing data

Petaling Jaya (PJ)
Shah Alam (SA)

Figure 4.1: Time series plot for PM_{10} & $PM_{2.5}$ concentration at PJ and SA. (a) Daily average of PM_{10} Concentration at PJ and SA (2015), (b) Daily average of PM_{10} Concentration at PJ and SA (2016), (c) Daily average of PM_{10} Concentration at PJ and SA (2017), (d) Daily average of PM_{10} Concentration at PJ and SA (2018) and (e) Daily average of $PM_{2.5}$ Concentration at Petaling Jaya and Shah Alam (2018). Continued

Figure 4.1 (c) and (d) show that at Petaling Jaya and Shah Alam have no extreme particulate matter event that exceeding the MAAQS limits and there have some missing data at Petaling Jaya in 2017 and 2018 that have circulated in orange doted lines. Based on Figure 4.1(e) the average $PM_{2.5}$ concentration in Petaling Jaya on 226 days shown sharp rise as the reading logged 62 $\mu g/m^3$ and Shah Alam recorded 58 $\mu g/m^3$. These point out that the $PM_{2.5}$ concentration in Petaling Jaya and Shah Alam have exceeded the MAAQS (IT-2), WHO and USEPA limits which was 50 $\mu g/m^3$, 35 $\mu g/m^3$ and 15 $\mu g/m^3$. The risen of $PM_{2.5}$ concentration due to industrial and motor vehicles emission as both study areas are located in the centre of city with surrounding heavy traffic roads and industrial emissions. This is corresponding with Fujii, Mahmud, Tohno, Okuda and Mizohata (2016) research that the increase of $PM_{2.5}$ concentration was contributed to biomass burning, industrial and motor vehicle emission. Besides, higher concentration of $PM_{2.5}$ was also influenced by the major activities conducted in the study areas as Petaling Jaya and Shah Alam station which have industrial-urban background.

4.3 Variability of monthly Particulate Matter (PM_{10} & $PM_{2.5}$) Concentration

The monthly concentration level of particle matter at Petaling Jaya and Shah Alam from 2015 to 2018 are shown in the Figure 4.2 to Figure 4.4.

Based on the Figure 4.2 and Figure 4.3, the PM_{10} concentration risen sharply in 2015. The highest reading was recorded in September at Petaling Jaya which is 151.88 $\mu g/m^3$ and Shah Alam was 117.17 $\mu g/m^3$ this was followed by the concentration recorded in October which was at Petaling Jaya the PM_{10} concentration was recorded 98 $\mu g/m^3$ and Shah Alam recorded 124 $\mu g/m^3$. In 2016, there have slight increase of PM_{10} concentration at Shah Alam in March – April and August compare to Petaling Jaya in April. The result shown exceeding the MAAQS (IT-1 and IT-2) which was 50 $\mu g/m^3$ and 45 $\mu g/m^3$.

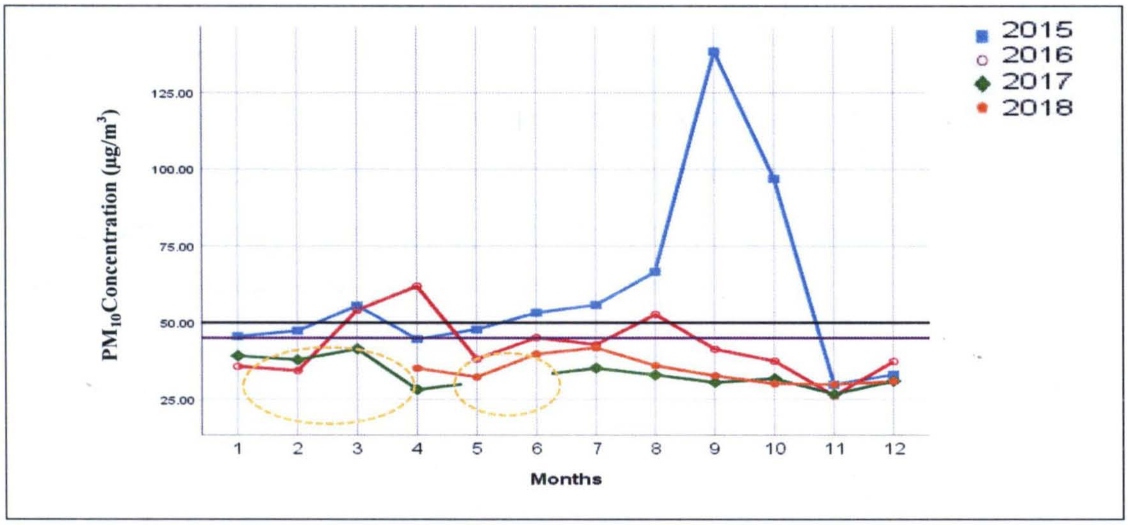


Figure 4.2: The PM_{10} concentration at Petaling Jaya in 2015-2018

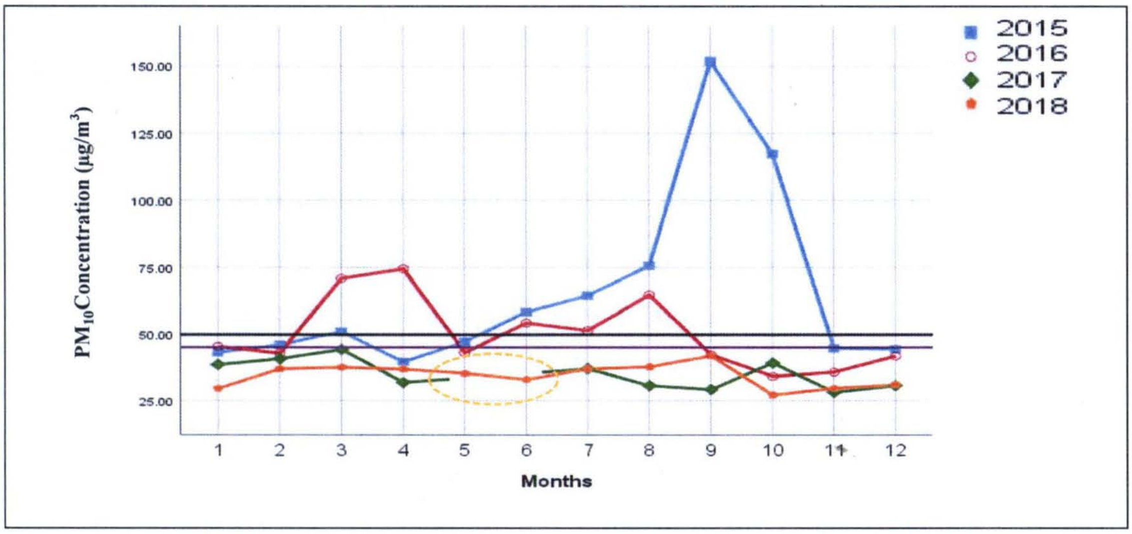


Figure 4.3: The PM$_{10}$ concentration at Shah Alam in 2015-2018

This indicates that extreme particulate event occur in 2015 due to peatland fire in Kalimantan and Sumatra, Indonesia as the haze phenomena become worsen when Southwest monsoon and El-Nino monsoon occurred same time (Khan et al., 2020). The risen of PM$_{10}$ concentration in 2016 shows the forest burning activities in West Coastal Division, Sabah (NST, 2016) and emission of industrial together with traffic from both studies area influence the PM$_{10}$ concentration. The concentration of PM$_{10}$ in industrial and residential areas is higher during the normal period as well as during haze which can influenced by the monsoon season (Sun et al., 2018).

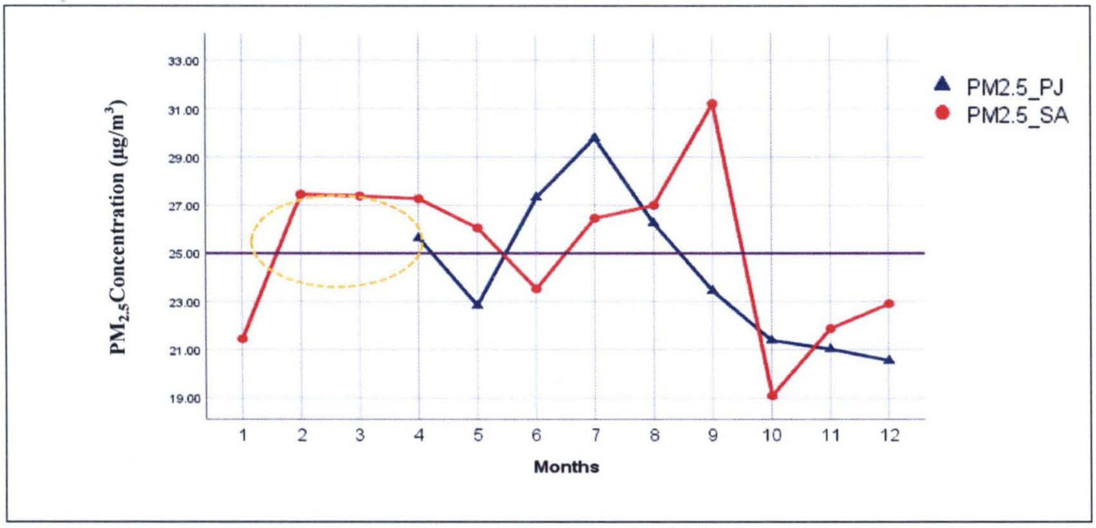


Figure 4.4: The PM$_{2.5}$ concentration at Petaling Jaya and Shah Alam in 2018

From Figure 4.4 the $PM_{2.5}$ concentration peaks recorded at Shah Alam which in February and September of 2018 ware 27.47 $\mu g/m^3$ and 31.22 $\mu g/m^3$ respectively. While, one peak reading in June which is 29.79 $\mu g/m^3$ Petaling Jaya in 2018. The 1 year mean average $PM_{2.5}$ concentration exceed IT-2 (2018) MAAQS standard limit which is 25 $\mu g/m^3$. The PM_{10} and $PM_{2.5}$ concentration in May and October in 2018 at Petaling Jaya and Shah Alam, respectively has logged lowest reading.

Rahman et al., (2015) and Lee et al., (2015) discovered that the main sources of $PM_{2.5}$ originated from that soil dust and vehicle emission. This shows that Petaling Jaya located in industrial area and Shah Alam nearby residential area cause the high $PM_{2.5}$ concentration and the influence of NE and SE monsoon cause distribution $PM_{2.5}$ mass concentration. Also, the heavy down pour recorded in May and October which cause decrease of PM_{10} and $PM_{2.5}$ concentration in Petaling Jaya and Shah Alam (Muhammad, Abdullah & Julien, 2020).

There have been some missing data in PM_{10} and $PM_{2.5}$ concentration and had labeled with orange dotted line. This missing cause by technical error like incomplete data, missing file and so on as in Dahari, Latif, Muda and Hussein (2020) revealed that the PM_{10} data were missing due to technical error like default data record. However, the missing data not severely influenced the research.

In conclusion, the concentration of particulate matter are significantly influenced by the seasonal monsoon as the concentration of particulate natter decrease from SE through the NE as the Southeast monsoon cause the dry season compare to Northeast monsoon.

4.4 Distribution of weather parameters

Figure 4.5 signify the boxplot of weather parameters for Petaling Jaya and Shah Alam from 2015 to 2018.

The ambient temperature for Petaling Jaya and Shah Alam shows almost constant range reading 20 °C – 40 °C. The distribution of temperature at Petaling Jaya and Shah Alam skewed to the right. The relative humidity in Petaling Jaya was higher than in Shah Alam. The boxplot of relative humidity in Petaling Jaya skewed to the right while the boxplot in Shah Alam skewed to left. The relative humidity at Shah Alam in 2016 and 2017 was recorded less variation. Based on observation of Figure (c), Shah Alam experience high velocity of wind speed compare with Petaling Jaya in 2016 and 2017 as the boxplot wind speed at Shah Alam skewed to right. The less wind speed was recorded in Petaling Jaya and Shah in 2018.

The high temperature affect due to Southeast monsoon together with El-Nina Monsoon which cause dry and draught season in Southeast Asian. The Southeast monsoon was dry monsoon cause increase of temperature and particle matter (Khan et al., 2020; Khan et al., 2016). Furthermore, Petaling Jaya receive high rainfall than Shah Alam which was lead to received higher humidity values as heavy down pour washes out air pollutant in atmosphere. Petaling Jaya wettest city as its recorded low average of temperature (27 °C) and relative humidity (72.42 %) (Asmat et al., 2018). The higher wind speed influence the dispersion of air pollutant. The study undertaken by Rahman et al., (2015) discussed that topography nearby coastal region tend to experiences high wind speed. As Shah Alam nearby Klang river which experience high wind speed compared with Petaling Jaya which surrounded by tall building affect the wind speed and air pollutant.

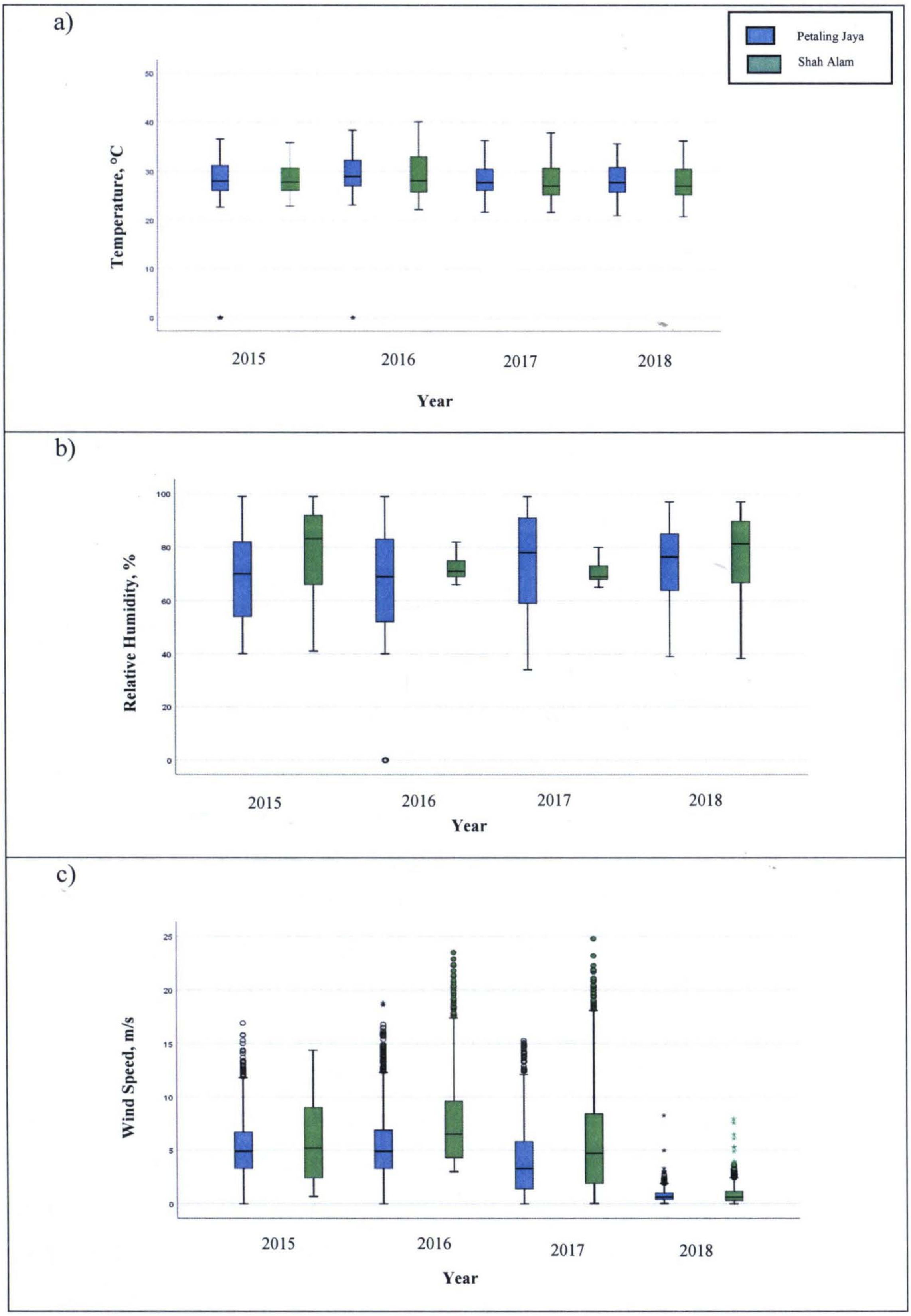


Figure 4.5: Boxplot for weather parameters in PJ and SA from 2015 to 2018. (a) Temperature, (b) Relative humidity and (c) Wind Speed.

4.5 Correlation of extreme particulate matter (PM_{10} & $PM_{2.5}$) and weather parameters

The Table 4.3 shows the Pearson correlation coefficient of extreme particulate matter (PM_{10} & $PM_{2.5}$) concentration and weather parameters including temperature, relative humidity and wind speed.

Table 4.3: Correlation of extreme particulate matter and weather parameters

Station	Variables	PM_{10}	$PM_{2.5}$	Temperature	Humidity	Wind Speed
Petaling Jaya	PM_{10}	1				
	$PM_{2.5}$	0.832**	1			
	Temperature	- 0.018	- 0.041	1		
	Humidity	- 0.948**	- 0.842**	0.040	1	
	Wind Speed	0.082**	0.065**	- 0.046	- 0.103**	1
Shah Alam	PM_{10}	1				
	$PM_{2.5}$	0.969**	1			
	Temperature	- 0.116**	- 0.121**	1		
	Humidity	- 0.980**	- 0.967**	0.133**	1	
	Wind Speed	0.135**	0.119**	0.007	- 0.129**	1
** Correlation is significant at the 0.01 level (2-tailed)						

Based on the observation in Table 4.3, strong correlation were observed between PM_{10} and $PM_{2.5}$ in Petaling Jaya and Shah Alam with r value 0.832 and 0.969. This positive correlation indicated that both particulate matter variable move same direction. The strong negatively correlation of relative humidity with particulate matter were shown in table with r value range of - 0.8 to - 0.9 in Petaling Jaya and Shah Alam. This indicated that both relative humidity and particulate variables move inverse direction like increase of particulate matter concentration, decreased the relative humidity level. The weak positive correlation between wind speed and particulate matter were observed in Shah Alam and Petaling Jaya logged r value range to 0.1 to 0.08. The temperature in Petaling Jaya shown no significant correlation between Particulate matter, while in Shah Alam the temperature recorded weak negative correlation between particulate matter with r value - 0.116 and - 0.121.

The strong positive correlation between PM_{10} and $PM_{2.5}$ indicate the particulate matter pollution dominated at urban and industrial. Corresponding with Xuehua et al., (2016) PM pollution dominate at urban region because of high population lead to anthropogenic activities in China. This situation is similar to Klang Valley as it is the most populated areas in Malaysia.

The PM_{10} and $PM_{2.5}$ shows negative association with relative humidity. Munir et al., (2017) reported similar correlation between particulate matter and relative humidity in Makkah Saudi Arabia from 2014 to 2015. This indicated heavy rain diluted the decrease the dispersion of particulate matter concentration and also lower relative humidity will increase the hygroscopic growth effect, more spaces in atmosphere that can be filled up by particulates. Thus, low relative humidity higher particulate matter. Corresponding with Zalakeviciute, López & Rybarczyk (2018) studies found that the elevation of relative humidity influences during day time depending on temperature and clouds formations in South America. The higher the wind speed, the lower the distribution of particle into the atmosphere. The air monitoring studies in Portland shown that higher wind speed correspond with lower PM_{10} concentration (Cichowicz, Wielgosinski & Fetter, 2020; Alifa et al., 2020).

The weak negative association of temperature and particulate matter corresponding with Liu, Zhou and Lu (2020) studies shown that the negative correlation between particle matter (PM_{10} and $PM_{2.5}$) concentration and humidity in China. The similar with weather condition in Malaysia received generous amount of rainfall through out whole year even though during summer season.

Thus, the correlation analysis at Petaling Jaya and Shah Alam had proven that particulate matter concentration was closely related to the meteorology condition with the strongest correlation were observed with relative humidity.

4.6 Multiple Linear Regression (MLR) model

Multiple Linear Regression model were developed based on air pollutant data in 2015. The Multiple Linear Regression model used to forecast the next 24 hours or one day ahead of PM_{10} concentration namely, PM_{10+24}. The model investigated with air pollutant such as PM_{10} and weather variables like temperature, relative humidity and wind speed were of year 2015 used as predicted variable from the dataset obtain from Department of Environmental.

The Multiple Linear Regression equation were obtained from 80 % of data were used to test the MLR model by using SPSS software. Table 4.4 shows the summary of equation of MLR model for Petaling Jaya and Shah Alam in year 2015. From the model equation shows high positive correlation with PM_{10} concentration at Petaling Jaya followed by at Shah Alam. The high negative correlation with meteorological variable in Petaling Jaya. While in Shah Alam the meteorological variable like relative humidity and wind speed shows negative correlation where the temperature shows positive correlation.

Table 4.4: MLR model equation at Petaling Jaya and Shah Alam in 2015

Location	Model equation
Petaling Jaya	$PM_{10+24} = 95.465 + 0.754PM_{10} - 1.506T - 0.463H - 1.039WS$
Shah Alam	$PM_{10+24} = 20.975 + 0.568PM_{10} + 0.107T - 0.041H - 0.269WS$

4.7 Quantile Regression (QR) model

The Quantile regression model at Petaling Jaya and Shah Alam in 2015 were shown in Table 4.5. The quantile that used in this research were 0.2, 0.4, 0.6 and 0.8 to provide efficiency information about PM_{10} and weather variable such as ambient temperature (T), relative humidity (H) and wind speed (WS). PM_{10+24} act as observed value that provide the reading for next 24 hours PM_{10} concentration. The quantile regression equation found when 80 % of extreme PM_{10} concentration and weather variable used to train the data and remain 20 % of data used for model validation measurement.

Table 4.5: Coefficient of Quantile Regression for next 24 hours

Location	Quantile	Model equation
Petaling Jaya	0.2	$PM_{10+24} = 68.011 + 0.535PM_{10} - 0.980T - 0.343H - 0.761WS$
	0.4	$PM_{10+24} = 68.865 + 0.688PM_{10} - 1.026T - 0.341H - 0.789WS$
	0.6	$PM_{10+24} = 70.971 + 0.837PM_{10} - 1.114T - 0.358H - 0.671WS$
	0.8	$PM_{10+24} = 54.791 + 1.035PM_{10} - 0.760T - 0.278H - 0.682WS$
Shah Alam	0.2	$PM_{10+24} = 14.790 + 0.528PM_{10} + 0.088T - 0.041H - 0.296WS$
	0.4	$PM_{10+24} = 19.558 + 0.551PM_{10} + 0.046T - 0.031H - 0.271WS$
	0.6	$PM_{10+24} = 27.283 + 0.595PM_{10} + 0.175T - 0.025H - 0.106WS$
	0.8	$PM_{10+24} = 23.244 + 0.\ 615PM_{10} + 0.201T - 0.030H - 0.029WS$

Table 4.5 shows the coefficient of air pollutant and weather variable increase as the number of percentile increases. For instants the coefficient of PM_{10} increases as the number of percentile increase at Petaling Jaya and Shah Alam. Moreover, Petaling Jaya

had negative correlation with ambient temperature. While, at Shah Alam had negative correlation with ambient temperature.

4.8 Performances of the Prediction Model

Table 4.6 shows the validation of multiple linear regression and quantile regression model using different performance indicator measurement i.e. Mean Absolute Error (MAE), Root Mean Square Root Error (RMSE), Coefficient of Determination (R^2) and Index of Agreement (IA).

Table 4.6: Validation of MLR and QR model with different performance indicator

Station	Model	Quantile	MAE	RMSE	R^2	IA
Petaling Jaya	MLR	-	15.3844	28.0103	0.5995	0.8596
	QR	0.2	18.5979	33.3431	0.5997	0.7600
		0.4	15.2773	28.8781	0.5997	0.8404
		0.6	**15.1344**	**28.3137**	**0.5996**	**0.8688**
		0.8	20.3320	33.4356	0.5986	0.8550
Shah Alam	MLR	-	8.3354	10.5934	0.3362	0.6931
	QR	0.2	11.0246	14.0365	0.3353	0.6107
		0.4	8.5585	11.1915	0.3356	0.6728
		0.6	**8.2247**	**10.6826**	**0.3548**	**0.7018**
		0.8	11.1491	13.4378	0.3348	0.6483

Based on the Table 4.6, overall, percentile regression modeling with quantile 0.6 predicted better PM_{10} concentration compared to MLR. The prediction of PM_{10} concentration at 0.6 quantile achieved best fit value followed by MLR, 0.4, 0.8 and 0.2.

The quantile 0.6 predicted best performance as the result shown in table 4.7 in Petaling Jaya the logged lowest reading of MAE (15.1344) and RMSE (28.3137) while higher accruement measurement like R^2(0.5996) and IA (0.8688). In meanwhile at Shah Alam the result shown higher accurate measurement as R^2 (0.3548) and IA (0.7018) and lower error measurement as MAE (8.2247) and RMSE (10.6826) was recorded in quantile 0.6.

In Petaling Jaya, QR with percentile of 0.6 given better prediction compared to the MLR. QR resulted in less error measurement compared to MLR with of MAE

(15.1344) and RMSE (28.3137). While, accuracy measurement of R^2 (0.5996) and IA (0.8688). QR with percentile of 0.4 predicted as well compared to percentile of 0.8 as the result of error measurement of MAE (15.2773) and RMSE (28.8781) whereas, high accuracy measurement of R^2 (0.5997) and IA (0.8404). Followed by the QR with 0.2 percentile resulted inferior compared with percentile of 0.8 as the error measurement of MAE (18.5979) and RMSE (33.3431) whereas, the accuracy measurement of R^2 (0.5997) and IA (0.7600).

In meanwhile at Shah Alam QR with percentile of 0.6 given better prediction compared to MLR. QR shown low error measurement of MAE (8.2247) and RMSE (10.6826). While, accuracy measurement of R^2 (0.3548) and IA (0.7018). QR with percentile of 0.4 forecasted well compared with percentile with 0.8 as the error measurement of MAE logged 8.5585 and RMSE logged 11.1915 whereas accuracy measurement of R^2 reported 0.3356 and IA reported 0.6728. Followed by the QR with 0.2 percentile resulted inferior compared with 0.8 percentile as the error measurement of MAE (11.0246) and RMSE (14.0365) while accuracy measurement of R^2 (0.3353) and IA (0.6107).

The Figure 4.6 and Figure 4.7 showed the scatter plot of observed PM_{10} concentration vs predicted PM_{10} concentration in Petaling Jaya and Shah Alam. According to the figure, the line fitted in Petaling Jaya compared to Shah Alam. This indicated that QR (0.6) fits better with dataset in Petaling Jaya compared to Shah Alam. This is because PM_{10} concentration was observed higher in Petaling Jaya compared to Shah Alam.

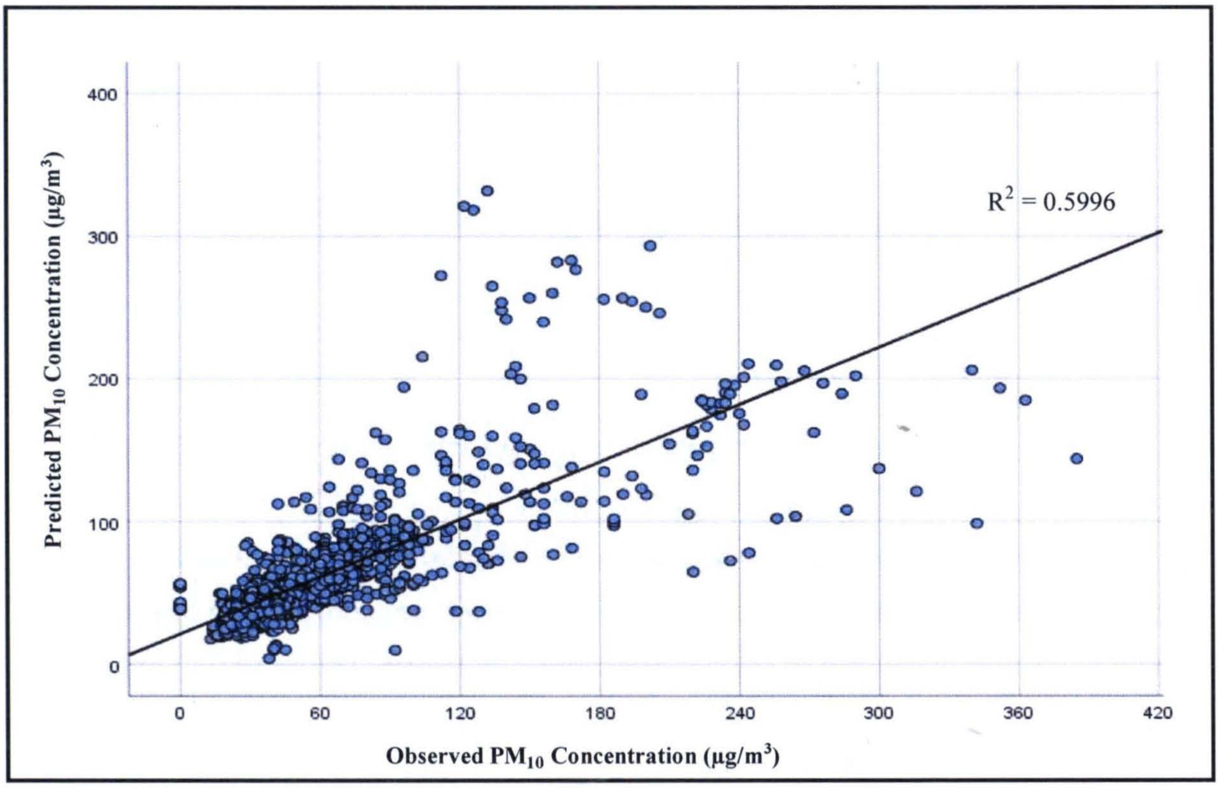


Figure 4.6: Scatter plot of PM_{10} concentration at Petaling Jaya

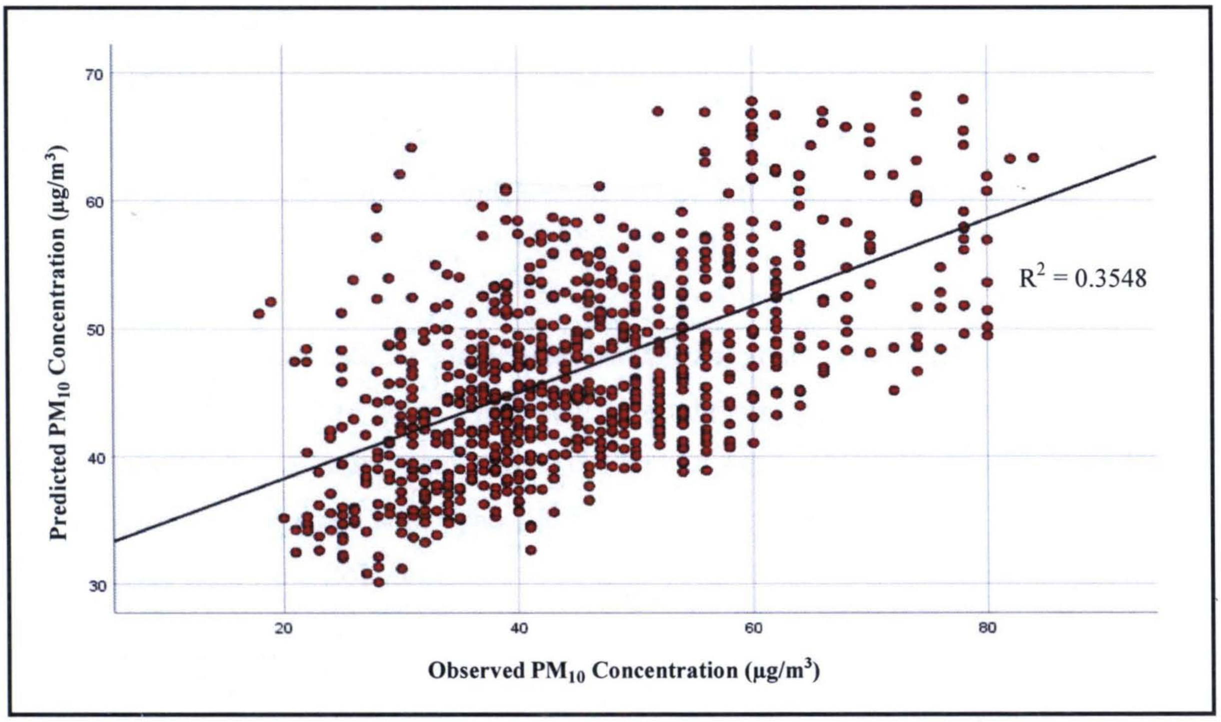


Figure 4.7: Scatter plot of PM_{10} concentration at Shah Alam

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 The temporal characteristic of particulate matter and meteorology variables

The hourly dataset of particulate matter and weather variable obtained from DOE from two air monitoring station namely, Petaling Jaya and Shah Alam station for 4 year period (2015 – 2018). A total of 4 parameter consists of particulate matter and weather parameter i.e. temperature, relative humidity and wind speed.

Based on the examination on temporal analysis the first objective was achieved. The characteristics of particulate matter analysis and served in descriptive table for hourly; daily and monthly average time series graphs. The result shows that the PM_{10} concentration of daily average exceeding the API reading into hazardous limit in 2015 compared with following years. PM_{10} concentration reached peak reading in September 2015 during Southwest monsoon due to peatland cleaning activity in Sumatra and Kalimantan, Indonesia.

The trend weather variable was evaluated at study areas Petaling Jaya and Shah Alam for 2015 to 2018 years. The result shown the less variable of ambient temperature in both Petaling Jaya and Shah Alam. The highest relative humidity reading recorded in Petaling Jaya compare with Shah Alam. The wind speed trend shown that Shah Alam received high wind flow compared to Petaling Jaya.

5.2 The extreme trend of particulate matter concentration with weather variables

The correlation of extreme particulate matter and extreme weather variable was evaluated by using Pearson Correlation Analysis. The extreme datasets of particulate matter and weather variable from Petaling Jaya and Shah Alam was sorted according to 95^{th} and 5^{th} percentile. This enable the evaluation of extreme particulate matter and extreme weather parameters by using correlation coefficient analysis.

The result shown that the strongest association between PM_{10} and $PM_{2.5}$ in Petaling Jaya and Shah Alam. This indicated the $PM_{2.5}$ concentration need to control in order to sustain health air quality. The stronger negative association between particulate matter and humidity was recorded in Petaling Jaya and Shah Alam. This established that the concentration of air pollutant decease when increase of precipitation that dilute the PM concentration at atmosphere. The weak positive association between particulate matter and wind speed at Petaling Jaya and Shah Alam with r value range to 0.1 to 0.08. This shows that high wind speed able transport PM_{10} concentration and dilute particulate concentration in atmosphere. The correlation of temperature and PM_{10} in Petaling Jaya shown not significant relation. However, at Shah Alam the temperature was result weak negative correlation.

5.3 Model Development and Performance Comparison

The regression model like multiple linear regression (MLR) and quantile regression (QR) model was developed to analysis extreme particulate event in 2015 at Petaling Jaya and Shah Alam. The MLR and QR model were validated by using performance indicator i.e. MAE, RMSE, R^2 and IA. Based on result, quantile regression model at 0.6 quantile provide better prediction compared to MLR followed by on quantile 0.4, 0.8 and 0.2. The indicated that PM_{10} concentration performed well together with weather variable in quantile 0.6. Moreover, Petaling Jaya predicted better compared to Shah Alam as the resulted shown higher PM_{10} concentration in Petaling Jaya compared to Shah Alam. The analysis of regression model shows QR model most suitable for predicting PM_{10} concentration during extreme particulate event in Malaysia. The model suitable for prediction for next 24 hours of PM_{10} concentration as it is produce warning sign that able protect public health crisis during extreme particulate event.

5.4 Recommendations for Future Study

The extreme particulate matter forecasting model like Quantile Regression (QR) model necessary to investigate influences of extreme weather parameter and extreme particulate matter level in this studies. The analysis of extreme particulate event in Petaling Jaya and Shah Alam at 2015 has shown that QR model produce best fit performances in predicting PM_{10} concentration. For further scientific research in order to improve the efficiency for future analysis use more extreme dataset of air pollutant and increase the quantile level into 0.1 - 0.9. Therefore, the quantile model work more efficiency and able gain more datasets of PM_{10} concentration during extreme particulate matter events. The author need expand the study areas, so that able evaluated the impact of PM_{10} during extreme particulate event by collection of more dataset.

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