An assessment of influence of meteorological factors on PM_{10} and NO_2 at selected stations in Malaysia

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ABSTRACT

This study aims to determine the influence of meteorological parameters (ambient temperature, relative humidity and wind speed) based on a daily average computation of air pollutants PM_{10} and NO_2 at three selected stations in Malaysia, namely Shah Alam and Johor Bahru on the Peninsular Malaysia, and Kuching on the island of Borneo. A three-year (2007-2009) database was statistically analysed using the Pearson Correlation and Multiple Linear Regression methods. The results obtained through these analyses show that at all the three stations, NO_2 has a reverse relationship with wind speed, while PM_{10} has a negative relationship with relative humidity and wind speed, but a positive relationship with ambient temperature. The statistical model of NO_2 and PM_{10} including meteorological parameters highlights that among the three stations, Shah Alam Station which is located near to Kuala Lumpur city centre, is most influenced by meteorological parameters. The coefficients of determination, R^2 for Shah Alam station model on NO_2 and PM_{10} are 0.301 and 0.293 respectively. The results from this study could provide some useful input for Malaysian air quality management with respect to an ongoing plan to deal with increasing trend of PM_{10} and NO_2 in the ambient air.

INTRODUCTION

In recent years, the deterioration of air quality in urban areas has been caused by continuous industrial and commercial development, population growth and an increase in energy consumption [1,2]. Among different environmental pollution problems, air pollution is reported to cause the greatest damage to health and loss of welfare as a result of environmental issues in Asian countries [3]. The concentration of air pollutants varies depending on meteorological factors, the source of pollutants and the local topography. However, of these three factors, the one which most strongly influences variations in the ambient concentration of air pollutants is that of meteorological factors [4]. Meteorological factors experience complex interactions between various processes such as emissions, transport and chemical transformation, as well as wet and dry depositions [5,6]. In addition, the spatial and temporal behaviour of wind fields are characterized by the high coarseness of the surface and differences in thermal conditions [7,8]. These in turn have a further effect on the dispersion of pollutants [9]. A study by Bhaskar and Mehta [10] states that meteorology plays a crucial

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role in ambient distributions of air pollution. The emission of the air pollutants from the ground surface into the air, as well as their residence in the atmosphere and the formation of secondary pollutants is influenced not only by the rate of emission of the pollutants but also by wind speed, turbulence level, air temperature and precipitation. Previous studies by Espinosa et al. [11] and Karar et al. [12] state that there is a strong seasonality in meteorological variables that modulate air quality level.

Malaysia is a country with a tropical climate which experiences uniform temperatures and continuous high relative humidity. According to the Malaysian Meteorological Department [13], changes in wind flow patterns and rainfall distinguish the seasons in this country. The wind throughout the country is generally light and variable as the country is located near the equator. However, uniform periodic changes in wind flow patterns determine the country's four seasons: the Northeast Monsoon (November to March), a transitional period (April to May), the Southwest Monsoon (June to September) and a second transitional period (October to November). Additionally, the Peninsular Malaysia is characterized by quite high but uniform temperatures (between 23 and 31 °C), along with high relative humidity and high rainfall (± 2500 mm annually) [13]. The movement of air pollutants usually follows the pattern of wind direction base on the northeast monsoon and southwest monsoon. The southwest monsoon usually brings the high amount of particulate matter to Malaysia due to biomass burning in Sumatera and Kalimantan, Indonesia. During the northeast monsoon there are also indicators of the influence of biomass burning particularly in Peninsular Malaysia from Indochina region [14].

In Malaysia, there are three major sources of air pollution. These are motor vehicles, industry and domestic fossil fuel burning, and open burning [15]. The main pollutants recorded at the Malaysian air quality monitoring stations are given as particulate matter (PM_{10}), NO_2, SO_2, CO and O_3 [16]. Several recent studies e.g., Azmi et al. [17] and Latif et al. [18] show that the concentrations of NOx and PM_{10} are showing an increasing trend due to the complete combustion of motor vehicles and biomass burning from inter-boundary sources. The oxides of nitrogen (NOx) is the generic term for a group of highly reactive gases such as NO and NO_2 as well as other gases which contain nitrogen and oxygen in varying quantities. Many of the oxides of nitrogen are colourless and odourless. However, NO_2, one of common pollutant along with particles in the air, can often be seen as a reddish-brown layer over many urban areas. The NO_2 concentration is particularly high in urban and industrial areas predominantly as a result of fuel being burned at high temperatures in the combustion process. The NO_2 emission load comprises 28% from motor vehicles, 69% from power stations and industry, with the remaining 3% originating from other sources [19]. PM_{10} has been identified as an important atmospheric pollutant in major cities in Southeast Asia, including Malaysia, and it is a decisive factor in the computation of the Malaysia Air Pollution Index [17,20,21]. Breathing in gaseous pollutants such as NO_2 and suspended particulate e.g., PM_{10} are known to have detrimental effects on human health [22]. Inhalation of NO_2 can irritate the upper respiratory tract and lungs even at low concentrations and will cause cardiovascular diseases [23,24]. Moreover, a single breath or two of a very high concentration can cause severe toxicity. As such, breathing in PM_{10} triggers off increases in the number of respiratory hospital admissions and the mortality rate [24,25]. It is useful to mention that NOx are the important precursors that enhance the formation of secondary PM_{10} by chemical reaction in the atmosphere.

Multivariate statistical approaches such as Multiple Linear Regressions (MLR) are used to predict the relationship between input variables (predictors) and output variables (predictants) without detailing the causes of these relationships [26,27]. The application of the MLR technique allows the formulation of explicit equations that are simple and can be used to improve understanding [28]. The MLR technique has been used in previous studies [1,15,29-32] to investigate the relationship between the concentration of air pollutants and meteorological parameters.

To get a better overview of air pollution in Southeast Asia, particularly in Malaysia, this study focuses on the investigation of any correlation between air pollutants (NOx and PM_{10}) and meteorological parameters namely temperature, relative humidity and wind speed. PM_{10} and NO_2 were chosen in this study because PM_{10} has been identified as an important atmospheric pollutant in major cities in Malaysia due to the factor of haze and biomass burning which usually contribute to the high amount of PM_{10}. At the same time, the development of motorways with complete combustions motor vehicles will emit high amount of NOx. The two pollutants are main contribution to the secondary air pollutants and the composition of particulate matter in the ambient air.

MATERIALS AND METHODS

1. Sampling Location

The continuous air quality monitoring in Malaysia has been started in 1996 with privatisation of air quality monitoring station by Department of Environment to a private company, Alam Sekitar Sdn. Bhd. Starting from several air sampling stations, the additional air quality monitoring stations have been developed in stages. For the time being, there are 51 continuous air quality monitoring stations in Malaysia.

There are three air monitoring stations used in this study to represent Malaysia. The Shah Alam (S2) and Johor Bahru (S3) stations are on Peninsular Malaysia (West Malaysia), while Kuching (S1) station is on East Malaysia (Borneo Island). The S2 station is in the capital city of Selangor and located in the Klang Valley area, on the west coast of Peninsular Malaysia, close to the Straits of Malacca. This station experiences weather with consistent temperatures throughout the year with an average high temperature of 32 °C and an average low temperature of 28 °C. The city is warmest in the month of March, and experiences heavy rains and showers during the month of November as the northeast monsoon moves in from October to March.

The S3 station is located in the south of the Peninsular Malaysia, just north of Singapore. It is separated from the Republic of Singapore by the Straits of Johor on the south. It is also surrounded by the South China Sea and the Straits of Malacca. The weather at this station is influenced by the monsoon rain from November until February blowing in from the South China Sea. The average annual rainfall is 1778 mm with average temperatures ranging between 26 and 28 °C with relative humidity between 82 and 86%.

The S1 station is bordered by the South China Sea along its northwest coast, while Java Sea is on the south and to the east is Kalimantan, Indonesia. Kuching experiences the wettest period during the North-East monsoon months of November to February and the dry season begins in June and lasts till August. The temperature in Kuching ranges from 19 to 36 °C.

Table 1. Air quality monitoring stations at the study areas

Station ID	Station location	Coordinates	
		Latitude	Longitude
S1	Kuching Sarawak	1.5622°	110.3888°
S2	Shah Alam, Selangor	3.0773°	101.5112°
S3	Johor Bahru	1.4969°	103.727°

The three stations are expected to be highly polluted due to industrialization, rapid development and rapid economic growth accompanied by population growth. The locations and coordinates of the selected continuous air quality monitoring stations in Malaysia are shown in Table 1 and Fig. 1.

2. Air Quality Data

The air quality data for this study were obtained from the Air Quality Division of the Department of Environment and the Malaysian Ministry of Natural Resources and the Environment. The air pollutants parameters used in this study are NO_2 and PM_{10}. The meteorological parameters taken into account are ambient temperature, relative humidity and wind speed. The data were collected over a period of 3 yr through a monitoring programme. In this analysis, the daily average concentration was used. Due the time and cost constraints as well as the limitation in resources computational, only data from 2007 and 2009 were used for the study.

3. Data Analyses

3.1. MLR

MLR is a statistical technique that allows us to predict the percentage or degree of association between the independent variable and the dependent variable [33,34]. The general MLR model has k independent variables and there are n observations. Thus the regression model can be written as in Eq. 1 [35]:

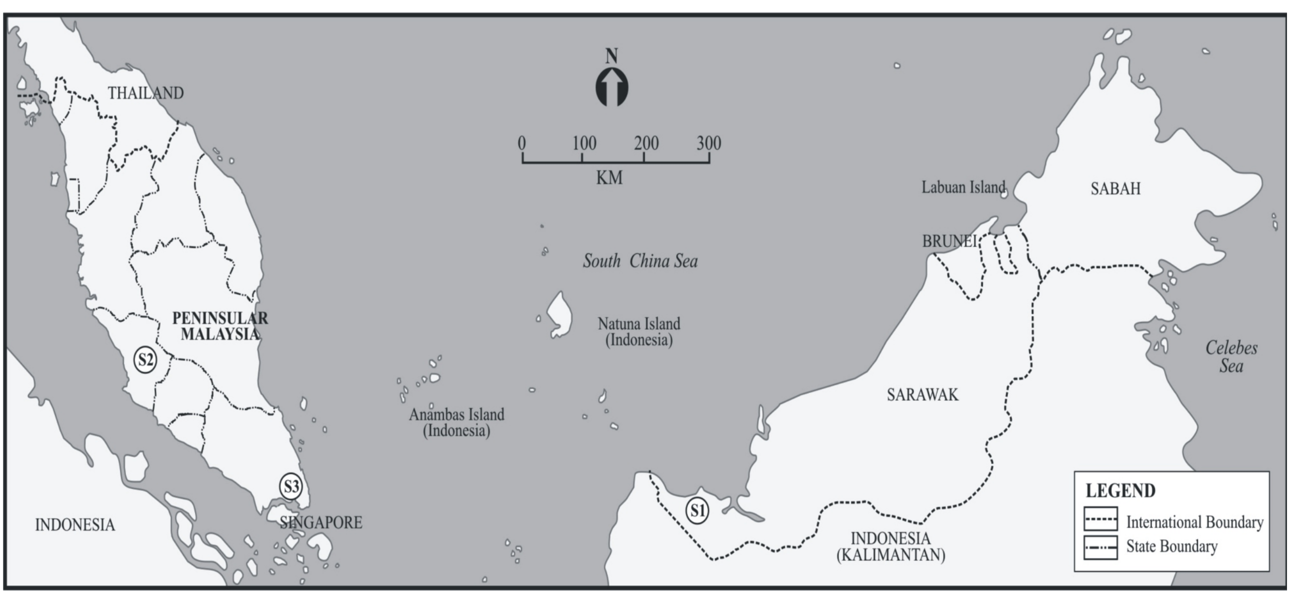

Fig. 1. Location of the three selected continuous air quality monitoring stations in Malaysia.

$$Y_i = \beta_0 + \beta_1 x_{1i} + ... + \beta_k x_{ki} + \varepsilon_i \text{ with } i = 1, ..., N \quad (1)$$

where β_1 are the regression coefficients, x_1 are independent variables and ε is error associated with the regression.

The root mean square error (RMSE) and the coefficient of determination (R^2) are the important values. The value R^2 is usually used as the measure of the reliability or fit of a linear model. This is also termed as the regression coefficient of determination. The R^2 is the proportion of the total variability in the dependent variable that is accounted for by the regression equation model [36,37]. The range of the R^2 value is within 0 to 1. A value of $R^2 = 1$ indicates that the regression equation fits all the values of the dependent and independent variables in the sample data. However, if $R^2 = 0$, it indicates that the regression equation explains none of the variability. The higher the value of R^2, the more significant the regression equation is [36]. However, R^2 tends to somewhat overestimate the success of the model when applied to the real world, so an adjusted R^2 value is calculated which takes into account the number of variables in the model and the number of observations (participants) the model is based on. This adjusted R^2 value gives the most useful measure of the success of the model. The RMSE is calculated for all possible subset models. The model with the smallest RMSE is taken as the best linear model.

3.2. Pearson Correlation Analysis

Correlation analysis is often used in conjunction with regression analysis because correlation analysis is used to measure the strength of association between two variables. In the present study, the Pearson Correlation (r) is used to find a correlation between at least two continuous variables. The Pearson value or Pearson correlations is denoted as r. Other factors, such as group size, will determine if the correlation is significant. The general formula of the r is shown in Eq. 2 [38].

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N}}\right)\left(\sqrt{(\sum Y^2 - \frac{(\sum XY)^2}{N}}\right)}} \quad (2)$$

where N is the sample size, X the value of the independent variable, and Y the value of the dependent variable.

The r value can fall between -1 and +1. A value of $r = -1$ demonstrates that there is a perfect negative relationship between the two variables. If $r = 0$, it shows a lack of correlation and a value of $r = +1$ equates to a perfect positive correlation [38].

Here in this study, PM_{10} and NO_2 together with meteorological parameters database were analyzed by using the XLSTAT 2012 add-in software.

RESULTS AND DISCUSSION

1. Daily Average Distribution of PM_{10} and NO_2 within the Study Areas

Descriptive analysis results of NO_2 and PM_{10} for the three selected air monitoring stations (S1, S2 and S3) are listed in Table 2. The statistics include minimum, maximum, mean and standard deviation.

The overall daily concentration of NO_2 in the three stations shows that the mean values varied from 0.007 to 0.02 ppm (Table 2). This value is below the standard value for 1-h average concentration of NO_2 (0.17 ppm). The mean concentrations values for PM_{10} were ranging between 38 and 50 μg m^{-3} which are lower than the standard value given by Recommended Malaysian Air Quality Guidelines (RMAQG) for the 24-h average concentration (150 μg m^{-3}).

2. Relationship between NO_2 and PM_{10} Concentration and Meteorological Parameters

Table 2. Overall descriptive analysis of NO_2 and PM_{10} at three monitoring stations in Malaysia 2007 to 2009

Variables	Statistics	Stations			Avg Time	RMAQG
		S1	S2	S3		
NO_2 (ppm)	Min	0.002	0.002	0.002	1-h	0.17
	Max	0.015	0.076	0.045		
	Mean	0.007	0.020	0.014		
	SD	0.002	0.015	0.008		
PM_{10} (μg m^{-3})	Min	10	15	13	24-h	150
	Max	173	130	108		
	Mean	38	50	46		
	SD	18	17	15		

RMAQG = Recommended Malaysian Air Quality Guidelines
Note: The values of NO_2 are based on the monthly average of hourly concentration and the values of PM_{10} are based on the daily average concentration.

Table 3. Correlations (r) between NO_2, PM_{10} and meteorological parameters within three stations

		Correlation matrix (Pearson)				
Stations	Variables	PM_{10}	NO_2	Temp	Relative humidity	Wind speed
Kuching	PM_{10}	1				
(S1)	NO_2	0.278*	1			
	Temp	0.297*	0.018	1		
	Relative humidity	-0.328*	-0.006	-0.882*	1	
	Wind speed	-0.004	-0.159*	0.130*	-0.260*	1
Shah Alam	PM_{10}	1				
(S2)	NO_2	0.496*	1			
	Temp	0.293*	-0.054	1		
	Relative humidity	-0.350*	0.100*	-0.775*	1	
	Wind speed	-0.305*	-0.537*	0.235*	-0.273*	1
Johor Bahru	PM_{10}	1				
(S3)	NO_2	0.397*	1			
	Temp	0.185*	0.224*	1		
	Relative humidity	-0.299*	0.037	-0.745*	1	
	Wind speed	-0.109*	-0.243*	0.408*	-0.518*	1

*Correlation is significant at both 0.05 level ($p < 0.05$) and 0.01 ($p < 0.01$)

The relationship between NO_2, PM_{10} and meteorological parameters (ambient temperature, wind speed and relative humidity) was investigated by Pearson Correlation analysis. The correlations (r) between daily average NO_2, PM_{10} concentrations and daily average meteorological parameters are shown in Table 3.

Table 3 shows that the parameters recorded at S3 station were found to correlate with each other apart from the correlation between relative humidity and NO_2. The highest positive significant correlation was between wind speed and ambient temperature (r = 0.408). The lowest negative significant correlation was between relative humidity and ambient temperature (r = -0.745). The S2 station showed that all parameters correlated with each other except ambient temperature and NO_2. The highest positive significant correlation was between NO_2 and PM_{10} (r = 0.496). The lowest negative significant correlation was between relative humidity and ambient temperature (r = -0.775). Nevertheless, S1 station showed that there is no significant correlation between ambient temperature and NO_2, relative humidity and NO_2 and wind speed and PM_{10}. At Kuching station, the highest positive significant correlation was recorded between temperature and PM_{10} (r = 0.297) and the lowest negative significant correlation was between relative humidity and ambient temperature (r = -0.882). The correlation patterns at S3 and S2 stations were predominantly identical. Both stations recorded one correlation which was insignificant. Thus only the relationship between PM_{10} and meteorological parameters (Fig. 2(i), a-c) and the relationship between NO_2 and meteorological parameters (Fig. 2(ii), d-f) for S2 station are plotted. S3 and S2 stations are both located in industrial zones which are near urban areas (Kuala Lumpur and Singapore, respectively) and they are also exposed to high emissions from motor vehicles. Geographically, Kuching is located in Sarawak, Borneo, on the South China Sea. Of the three stations, S1 station showed the strongest negative correlation between relative humidity and ambient temperature (r = -0.882). An increase in the relative humidity value normally decreases the value of temperature due to the weather and location of the station. According to the Malaysian Meteorological Department [13], Kuching (Borneo) is the wettest place in Malaysia with an average rainfall of 4128 mm and 247 d of rain a year. The rainfall in effect, reduces the temperature. Another reason why this station was found to be slightly cooler when compared to those in the Peninsular Malaysia was ocean cooling. The relationship between PM_{10} and meteorological parameters in Kuching station are graphed in Figs. 3(i), a-c and the relationship between NO_2 and meteorological parameters are plotted in Figs. 3(ii), d-f. The NO_2 and PM_{10} concentrations decreased with increasing wind speed as seen in Figs. 2(i), c; 2(ii), f; 3(i), c; and 3(ii), f. This situation shows that when wind speed is high, pollutants are diluted by dispersion [2]. The findings of other researchers relating to correlations between air pollutants (NO_2 and PM_{10}) and meteorological variables are shown in Table 4. As seen in Table 4, the correlations (r) between NO_2 and PM_{10} and meteorological variables differ among the researchers. This is due to differences in terms of location and topography of the studied areas [1]. In addition, dissimilarities in climatic conditions and main economic activities also influence the concentration of the air pollutants studied.

Table 4. Correlations (r) values of NO_2, PM_{10} and meteorological parameters at several stations in this study and other studies

Air pollutants	Locations/Stations	Temperature	Relative humidity	Wind Speed	References
NO_2	S1	0.018	-0.006	-0.159	This study
NO_2	S2	-0.054	0.100	-0.537	This study
NO_2	S3	0.224	0.037	-0.243	This study
PM_{10}	S1	0.297	-0.328	-0.004	This study
PM_{10}	S2	0.293	-0.350	-0.305	This study
PM_{10}	S3	0.185	-0.299	-0.109	This study
NO_2	Pantnagar, India	-0.383	-0.459	0.470	[1]
PM_{10}	*Ahmedabad, India (2005)	0.160	-0.890	-0.370	[10]
PM_{10}	*Ahmedabad, India (2006)	0.240	-0.860	0.470	[10]
PM_{10}	*Ahmedabad, India (2007)	-0.130	-0.520	0.600	[10]
PM_{10}	*Ahmedabad, India (2008)	-0.340	-0.440	-0.170	[10]
PM_{10}	Klang Valley, Malaysia	0.650	-0.407	0.322	[17]

*The correlation (r) values are based on years

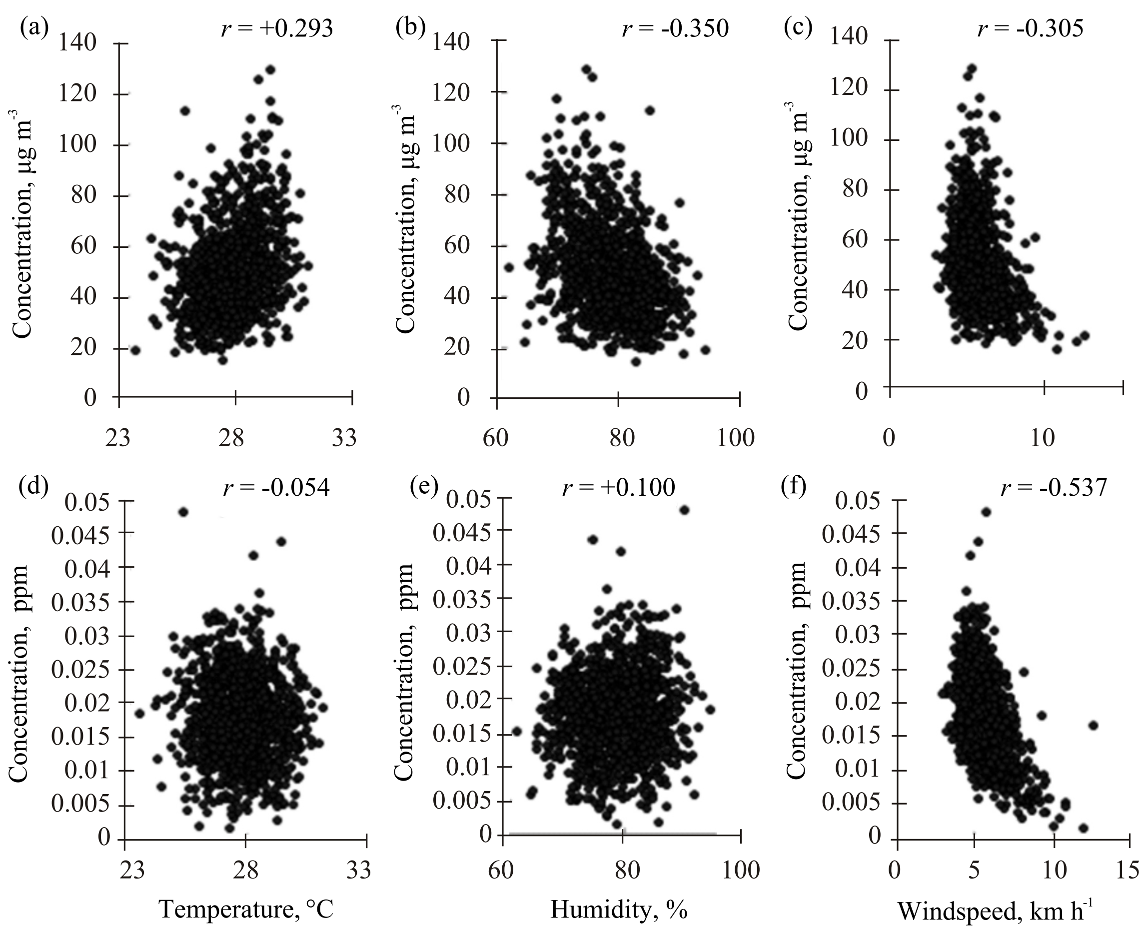

Fig. 2. Parameter concentration versus (a,d) Temperature; (b,e) Humidity; and (c,f) Wind speed for Shah Alam Station. (i) PM_{10}; (ii) NO_2.

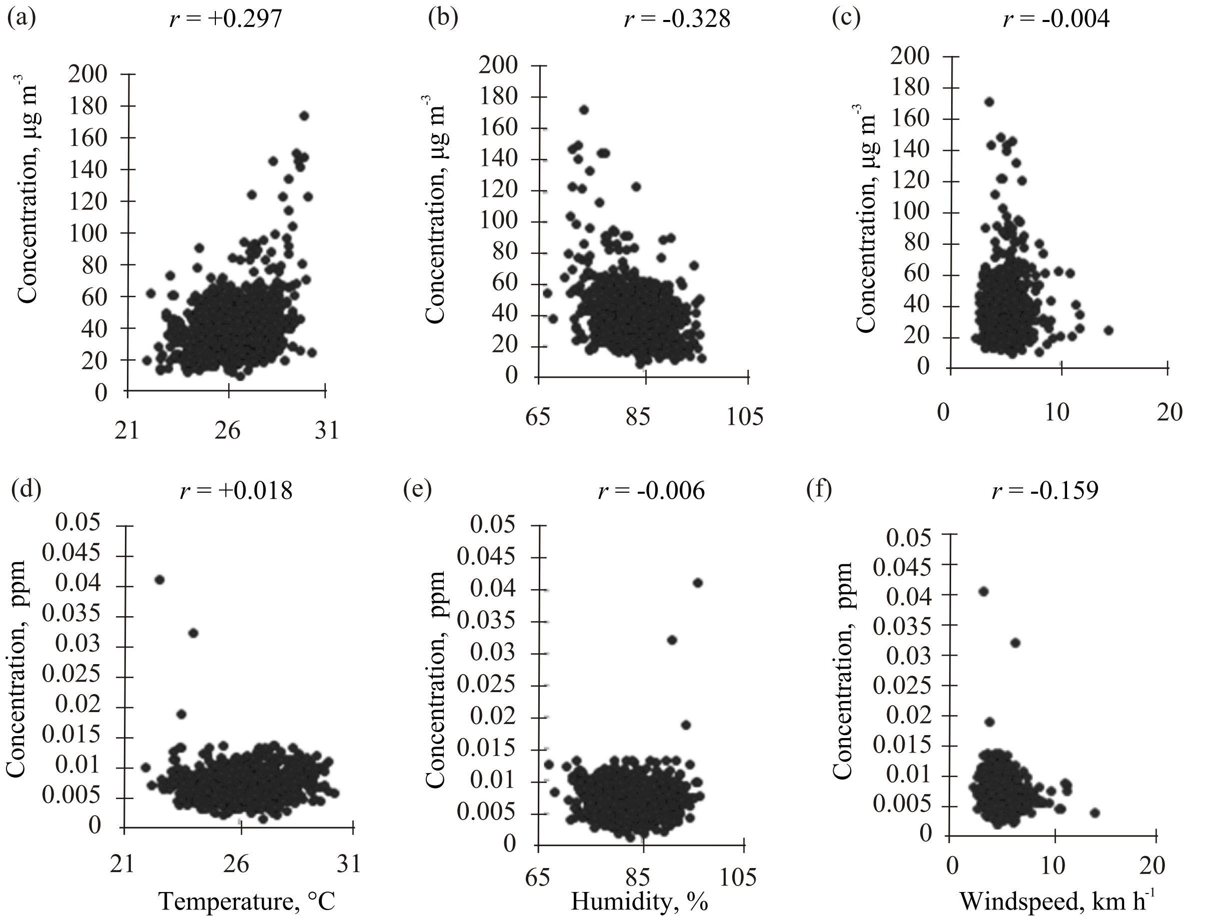

Fig. 3. Parameter concentration versus (a,d) Temperature; (b,e) Humidity; and (c,f) Wind speed for Kuching Station. (i) PM_{10}; (ii) NO_2.

3. Regression Analysis

The MLR of the daily average of PM_{10} and NO_2 concentrations at all the sites with different meteorological factors was conducted in order to establish their relationship. In this study, the dependent variables are PM_{10} and NO_2 and the independent variables are the ambient temperature, wind speed and relative humidity. The proposed regression equation between PM_{10} and all the meteorological variables for each station is expressed in Eqs. 3(i) to 3(iii). Meanwhile, the proposed equation between NO_2 and all the meteorological variables for each station is shown in Eqs. 4(i) to 4(iii). The value of RMSE and value of R^2 for the regression equation between PM_{10} as well as NO_2 with meteorological variables for each station are also shown in Eqs. 3(i)-3(iii) and 4(i)-4(iii), respectively.

S2 Station:

$$PM_{10} = 1.523(T) - 1.160(H) - 6.385(WS) + 135.471 \quad 3(i)$$
($R^2 = 0.293$, adjusted $R^2 = 0.291$, RMSE = 14.593)

S3 Station:

$$PM_{10} = -0.933(T) - 1.430(H) - 5.476(WS) + 207.991 \quad 3(ii)$$
($R^2 = 0.182$, adjusted $R^2 = 0.180$, RMSE = 12.947)

S1 Station:

$$PM_{10} = -0.104(T) - 1.329(H) - 1.441(WS) + 159.277 \quad 3(iii)$$
($R^2 = 0.114$, adjusted $R^2 = 0.111$, RMSE = 16.453)

S2 Station:

$$NO_2 = 4.882 \times 10^{-4}(T) + 2.420 \times 10^{-5}(H) - 2.998 \times 10^{-3}(WS) + 1.951 \times 10^{-2} \quad 4(i)$$
($R^2 = 0.301$, adjusted $R^2 = 0.299$, RMSE = 0.005)

S3 Station:

$$NO_2 = 2.413 \times 10^{-3}(T) + 3.214 \times 10^{-4}(H) - 1.697 \times 10^{-3}(WS) - 7.280 \times 10^{-2} \quad 4(ii)$$
($R^2 = 0.242$, adjusted $R^2 = 0.240$, RMSE = 0.004)

S1 Station:

$$NO_2 = -6.856 \times 10^{-5}(T) - 4.093 \times 10^{-5}(H) - 3.879 \times 10^{-4}(WS) + 0.014 \quad 4(iii)$$

($R^2 = 0.028$, adjusted $R^2 = 0.025$, RMSE = 0.002)

Based on Eqs. 3(i) to 3(iii), the influence of meteorological factors on the concentration of PM_{10} was found to be the highest at S2 station 0.293 (29%), followed by S3 and S1 stations at 0.182 (18%) and 0.114 (11%) respectively. Average temperature showed a positive influence on the concentration of PM_{10} in contrast to that of relative humidity and wind speed. A high temperature in the tropics usually increases the quantity of biomass burning and the evaporation of materials, for example soil dust, from the earth's surface [17]. Meanwhile, all meteorological parameters indicated a negative influence on the concentration of PM_{10} at both S3 and S1 stations. The contribution of meteorological parameter (relative humidity) in this study showed a negative relationship to the concentration of PM_{10} at the three stations. This condition results because high relative humidity is usually related to rainfall. Rainfall washes out the atmospheric pollutants in the ambient air [10,21]. A study done by Jaenicke [39] states that wet deposition by precipitation or wet removal is one of the main mechanisms for removal of aerosols from the atmosphere. In contrast to PM_{10}, there was a strong influence of meteorological factors on the concentration of NO_2 at all three stations. These results are expressed in the regression Eqs. 4(i) to 4(iii). As with the result for PM_{10} the contributions of the meteorological parameters to the concentration of NO_2 was found to be the highest at S2 (0.301/30%), followed by S3 (0.242/24%) and S1 stations (0.028/3%). In the proposed Eqs. 4(i) and 4(ii), average temperature and relative humidity showed a positive influence on the concentration of NO_2 compared with wind speed. Meanwhile, the meteorological factors named as temperature, relative humidity and wind speed showed a negative influence on NO_2 at Kuching station (Eq. 4(iii)). Nevertheless, wind speed showed a negative influence on the concentration of PM_{10} and NO_2 at all three stations. Donnelly et al. [40] states that wind speed has been well-established as being inversely related to NO_2 concentration, which means that the concentration of NO_2 tends to be higher in low wind speed areas. Another study undertaken by Celik and Kadi [41] states that tall buildings in effect, prevent wind speeds from being sufficiently strong to be able to transport the pollution away. In this study, the topography for the three stations is characterized by coastal plains with hilly regions as well as those surrounded by tall buildings which will affect the speed of the wind and the concentration of the air pollutants. Moreover, temperatures affect pollutant concentrations by causing variations in wind circulation and simultaneously dilute the concentration of air pollutants [1]. The Eqs. 3(i)-3(iii) and 4(i)-4(iii) show the minimum value of RMSE and maximum value of R^2 for the regression equations.

Graph plotting between the actual NO_2 and PM_{10} values compared with the predicted values is shown in Fig. 4. Graphs for S2 station are shown in Figs. 4a-4b, while Figs. 4c-4d and Figs. 4e-4f are graphs for S3 and S1 stations, respectively. The upper and lower 95% mean of the confidence interval regression lines are also drawn. This plot was used to measure the accuracy of the regression model. As seen in Figs. 4a-4f, most points fall in the range of a 95% confidence interval and generally the predicted values are able to reflect well the actual values.

CONCLUSIONS

The present study shows that the daily average concentrations of PM_{10} and NO_2 recorded at S2, S3 and S1 stations are under the permissible value suggested by RMAQG. The Pearson Correlation analysis indicates significant correlations between air pollutants (PM_{10} and NO_2) and meteorological factors (ambient temperature, relative humidity and wind speed) at the studied locations. The analysis shows that wind speed has a negative correlation to the concentration of NO_2. The results also show that temperature has a positive correlation to the concentration of PM_{10} but a negative correlation to relative humidity for all three stations. These suggest that the wind direction and speed are good indicator for the distribution of both air pollutants. The temperature usually increases evaporation processes and the high relative humidity will lead to the amount of water vapour and rain that will downwash the amount of pollutants.

The MLR analysis indicates that the influence of meteorological factors on the variability of PM_{10} and NO_2 was found to be the highest at S2, followed by S3 and S1 stations. The highest level of PM_{10} was recorded at S1 station. Evidently, this relates to the transboundary pollutants one of which is PM_{10}. Most often PM_{10} is associated with biomass burning in South Sumatera and the Kalimantan forest located close to Kuching. The amount of NO_2 mostly related to high and complete combustion from motor vehicles due to the development of motorways especially in the area near to the city centre such as Shah Alam. Since the air pollutants levels are mostly significantly related to meteorological factors, the results from this study could provide some useful input for Malaysian air quality management with respect to an ongoing plan to deal with air quality issues.

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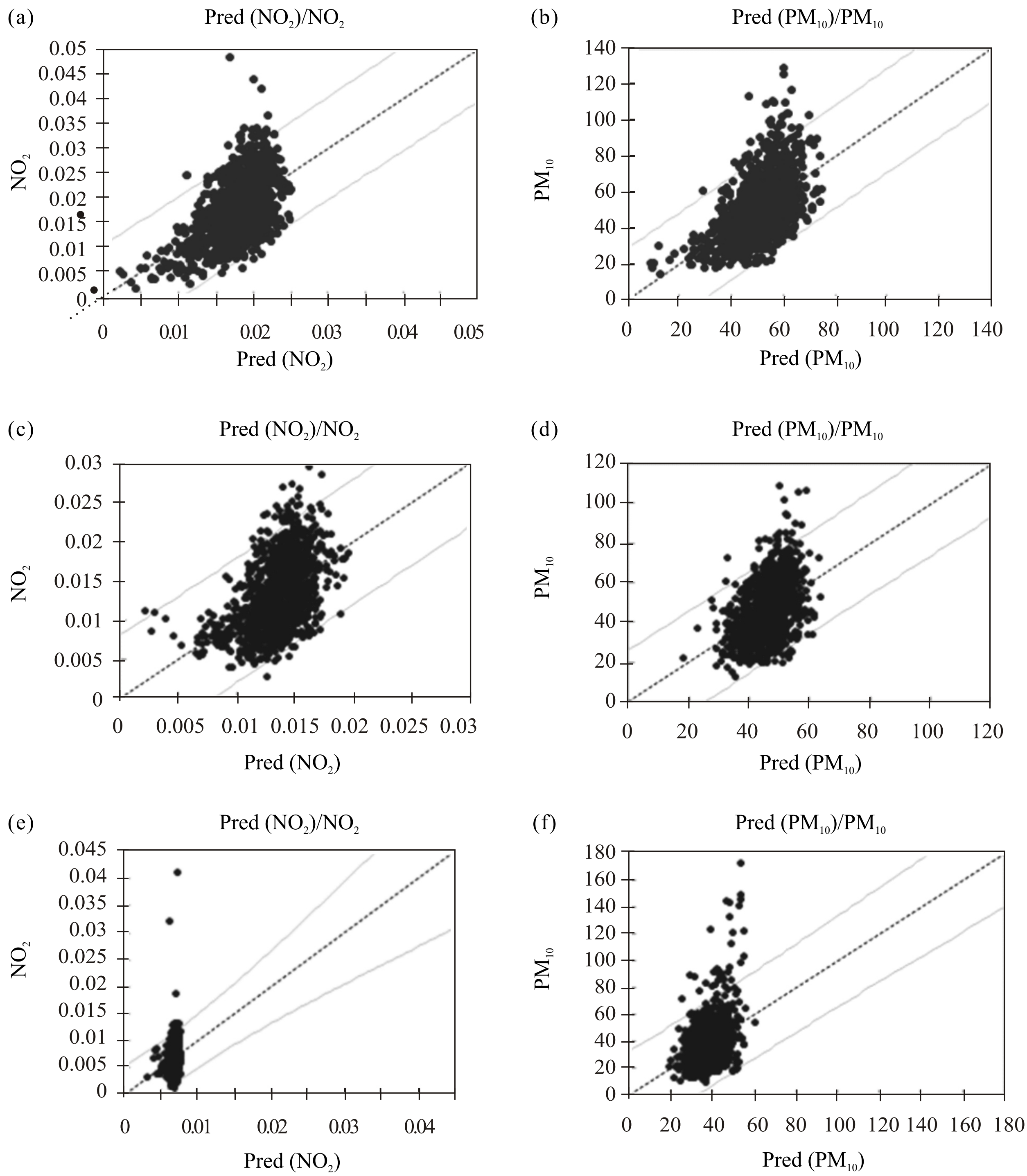

Fig. 4. Graph plotting between actual values and predicted values of NO_2 and PM_{10} for three study stations: Shah Alam: (a)-(b), Johor Bahru: (c)-(d), Kuching: (e)-(f).

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