Airborne Particulate Matter and Meteorological Interactions during the Haze Period in Malaysia

Carolyn Payus, Noraini Abdullah, and Norela Sulaiman

Abstract—**Haze has become a major concern as it has highly significant impacts over Malaysia by several occurrences of haze episodes throughout the country. During the haze periods, airborne particulate matter (PM_{10}) was found as the major pollutant while the other air quality parameters remained within the permissible healthy standards. Haze arise by fires from land clearing in Indonesia that builds up during the dry season affecting tourism, transportation, biodiversity, and contributing to health problems across the region. The variations of the PM_{10} concentrations are due to various atmospheric processes of emissions, dilutions and accumulations that are affected by meteorological conditions. In this study, an analysis of haze status will be performed using PM_{10} values from two commercial urban and industrial areas, which involved Kajang and Shah Alam, and one station that was located outside the city, which is in Kota Bahru, Kelantan, that was selected as a rural station for comparison. The aim of this study is to determine the correlation of PM_{10} concentrations with the meteorological factors (namely on temperature, wind speed and ultraviolet intensity) at different monitoring stations (at different type of land use). Twelve (12) multiple regression models with interactions for each station were developed from data sets of 90; the best model was used to forecast the upcoming haze weather.**

Index Terms—**Haze, airborne particulate matter (PM_{10}), multiple regression models with interactions, meteorological factors.**

I. INTRODUCTION

In April 2009, open burning of land and forest in Kalimantan and Sumatra, in Indonesia caused a great haze phenomenon which spread over the larger parts of South East Asia. Malaysia was affected really badly and the haze hits its peak on 24 April, 2009 when the Air Pollution Index has reached levels higher than 300. During that time, a state of emergency was announced. Given the hazardous air quality, schools were closed to keep the children from exposed with the dangerous air pollutants especially from the outdoors. It is reported from previous study that physical and mental health problems are normally the result of excessive exposure to the haze [1]. As in [2], [3] have showed how the impact of haze from forest fires has affected the human lung and respiratory system in Indonesia and Japan, especially to the children. Research also indicates that air pollution has negative effects on human emotions and behaviors [4], [5]. From these previous researches, it seems to indicate that the haze can caused greatly on physical and mental health problems, as well as cancer sickness [6], and pre-term delivery [7].

According to the Malaysia Department of Environment [8], haze is define as the weather phenomenon that leads to an atmospheric visibility of less than 10km due to the amount of suspended solid or liquid particles, smoke and vapor in the atmosphere. In Malaysia, it has experienced several haze periods since early 1980s in which the airborne particulate matter (PM_{10}) was found to be the major pollutants, while other parameters remained within the permissible limit [9]-[11]. Haze formation is strongly influenced by meteorological conditions [12]-[14]. Meteorological factors have a complex interaction on the various processes such as emission, transport and chemical transformation, as well as wet and dry depositions [15], [16]. The spatial and temporal behaviors of wind fields are characterized by the high coarseness of the surface and differences in thermal conditions [17], [18]. To get a better overview of the haze pollution in Southeast Asia, particularly in Malaysia, this study investigate the importance of meteorology factors in determining the haze pollution, which in this case using the PM_{10} concentrations as the factor. The PM_{10} was chosen in this study because it has been identified as an important atmospheric pollutant in major cities in Malaysia, and also due to the fact that during the haze phenomena, haze contributes a highly amount of PM_{10} in the atmosphere. The study focuses on the impact of meteorological parameters, namely temperature, ultraviolet intensity and the wind speed, on PM_{10} variability at the urban and rural area during the haze period in Malaysia.

II. MATERIALS AND METHODS

A. Study Area

There are three air monitoring stations used in this study; which are the Kajang (S1), Shah Alam (S2) and for comparison Kota Bahru - Kelantan (S3) was selected, and all stations are on Peninsular Malaysia (West Malaysia). The Kajang (S1) and Shah Alam (S2) are located in the Klang Valley area, on the west coast of Peninsular Malaysia. These stations experience weather with consistent temperatures throughout the year with an average high temperature of 33ºC and an average low temperature of 27ºC. The cities are 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 two stations are expected to be highly polluted due to industrialization; rapid development and economic growth, accompanied by a

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drastic population expansion. The data from these two stations were compared with the data recorded at Kota Bahru-Kelantan (S3), as a baseline station.

B. Data Collection

The air quality data for this study were obtained from the Air Quality Division of the Department of Environment, from the Malaysian Ministry of Natural Resource and the Environment. The air pollutant parameter used in this study was the airborne particulate matter (PM_{10}). PM_{10} was chosen in this study, due to the fact that during the haze phenomena, haze contributes a highly amount of PM_{10} in the atmosphere. It was also found as the major pollutant, while the other air quality parameters remained within the permissible healthy standards. The meteorological parameters involved in this study were ambient temperature, ultraviolet intensity and wind speed. The data were collected over a period of 1 year through a continuous air quality monitoring during the haze phenomena. In this analysis, the hourly concentrations for meteorological conditions and PM_{10} were used. Due to the haze peak and the Air Pollution Index has reached levels higher than 300, air quality and meteorological data for year 2009 was used for the study.

C. Statistical Analyses

Multiple regression (MR) models with interactions: Multiple Regression analysis, a form of general linear modeling [19] is a statistical technique that can be used to analyze the relationship between a single dependent (criterion) variable, *Y* and several independent (predictor) variables, *x*'s. A random response *Y* relating to a set of independent variables x_1, x_2,..., x_k based on the multiple regression model is as shown in equation (1) below [20]:

$$Y = \gamma + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \qquad (1)$$

where; γ ,β_1,...,β_k are unknown parameters and ε is an error term factor.

The description of these variables involved can be seen in Table I.

TABLE I: DESCRIPTION OF VARIABLES INVOLVED IN THE MODEL BUILDING

Variable	Description
Y	PM_{10}
X_1	Temperature
X_2	UV
X_3	Wind Speed

The objective of regression analysis is to predict a single Dependent Variable (DV) from the knowledge of one or more Independent Variables (IV_S). Interaction effects represent the combined effects of variables on the criterion or dependent measure. When an interaction effect is present, the impact of one variable depends on the level of the other variable. Part of the power of Multiple Regression (MR) is the ability to estimate and test interaction effects when the predictor variables are either categorical or continuous. As in [21] had mention, the idea that multiple effects should be studied in research rather than the isolated effects of single variables is one of the important contributions in Multiple Regression (MR).

Procedures in Getting the Best Model: According to model building by [22], twelve possible models can be obtained from three independent variables as stated before. The summary of all possible models is shown in Table II. The table shows seven individual models are without interactions while the four models are up to first order and one with a second order interaction.

TABLE II: SUMMARY OF ALL POSSIBLE MODELS

Number of Variables	Individual	Interactions		
		First Order	Second Order	Total
1	3			3
2	3	3		6
3	1	1	1	3
Total	7	4	1	12

III. RESULTS AND DISCUSSIONS

Modelling results: The Multiple Regression (MR) models are developed based on the model building phases using the datasets for each station. The selected models obtained by the multicollinearity and coefficient tests. The existence of multicollinearity can be identified if correlation coefficients ≥0.95 (|r|≥0.95). Pearson correlation analysis verifies that there is an existence of multicollinearity between the independent variables in the parent model M11, as shown in Table III.

TABLE III: MODEL M11 WITH MULTICOLLINEARITY EFFECTS

	Y	*X1*	*X2*	*X3*	*X12*	*X13*	*X23*
Y	1						
X1	0.176634	1					
X2	-0.18366	0.551325	1				
X3	-0.12407	0.472772	0.58147	1			
X12	-0.15807	0.613068	0.996184	0.59445	1		
X13	-0.07321	0.614645	0.62509	0.984976	0.649663	1	
X23	-0.22407	0.574743	0.941743	0.796531	0.945838	0.82404	1

Table IV shows that, after two process of removal for the least effect on the dependent variable, now there are no more multicollinearity variables in the model M11.2, where the correlation coefficients are all ≤ 0.95.

TABLE IV: MODEL M11.2 WITH NO MORE MULTICOLLINEARITY SOURCE VARIABLES

	Y	*X1*	*X12*	*X13*	*X23*
Y	1				
X1	0.176634	1			
X12	-0.15807	0.613068	1		
X13	-0.07321	0.614645	0.649663	1	
X23	-0.22407	0.574743	0.945838	0.82404	1

Model M11.2 then becomes M11.2.1 after the removal of the insignificant variable of X1. Model M11.2.1 hence signified M11 as the parent model, two multicollinearity source variables being removed and one insignificant variable eliminated.

TABLE V: COEFFICIENT TEST ON MODEL M11.2.1

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-18.0713	13.86192	-1.30366	0.195828
X12	0.01916	0.004096	4.677528	1.07E-05
X13	0.95547	0.198368	4.816641	6.21E-06
X23	-0.19387	0.035836	-5.40998	5.59E-07

Next, all the twelve possible models have to undergo the model-building phases in [22]. Table VI shows the corresponding selection criteria values for each of the seven selected models obtained from station Kajang (S1) after the multicollinearity and coefficient tests. It can be seen that model M11.2.1 has the majority of the least values of the eight selection criteria (8SC).

TABLE VI: THE CORRESPONDING SELECTION CRITERIA VALUES FOR EACH SELECTED MODELS FOR STATION KAJANG

MODEL	K+1	N	SSE	AIC	FPE	GCV	HQ	RICE	SCHWARZ	SGMASQ	SHIBATA
M4.0.0	3	90	11012.23	130.7934	130.7966	130.9421	135.263	131.098	132.028	126.5774	130.5153
M5.0.0	3	90	11758.79	139.6603	139.6638	139.8191	144.433	139.9856	140.3699	135.1585	139.3634
M8.1.0	3	90	11009.76	130.7641	130.7673	130.9127	135.2327	131.0686	132.0004	126.549	130.4861
M9.1.0	3	90	11789.47	140.0247	140.0281	140.1839	144.8098	140.3508	140.7127	135.5111	139.727
M10.0.0	3	90	11120.54	132.0798	132.0831	132.23	136.5934	132.3874	133.2384	127.8224	131.799
M11.2.1	4	90	**9351.375**	**113.563**	**113.5697**	**113.7944**	**118.7667**	**114.0412**	**113.4618**	**108.7369**	**113.1401**
M12.3.0	5	90	9776.357	121.3918	121.4057	121.7816	128.3842	122.2045	118.2137	115.016	120.6958
MIN VALUE			9351.375	113.563	113.5697	113.7944	118.7667	114.0412	113.4618	108.7369	113.1401

The best model M11.2.1 is then validated based on the residual analysis using the randomness and normality tests. Fig. 1 and Fig. 2 show the scatter plot of the randomness test and normality plot of the normality test of the best model M11.2.1. It can be seen that the plots have met the assumptions of the regression analysis. All the regression models for all the stations are developed by executing the model building phases.

Table VII below shows the comparison of the regression models obtained from the stations in Kajang (S1), Shah Alam (S2) and Kota Bharu (S3). There are seven selected models from stations Kajang (S1) and Shah Alam (S2) while only one selected model remained for Kota Bharu (S3). The best model with least SSE for station Kajang (S1) is M11.2.1; for station Shah Alam (S2) is M5.0.0; and for station Kota Bharu (S3) is M2.0.0.

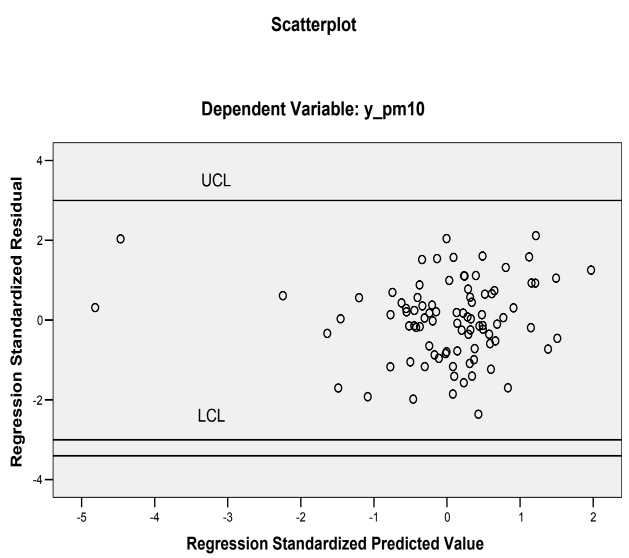

Fig. 1. Randomness test

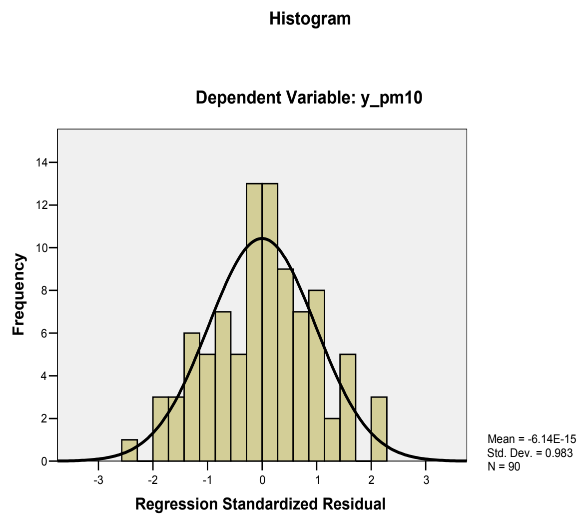

Fig. 2. Normality test

From Table V, the best regression model M11.2.1 is given by the equation (2):

$$\hat{Y} = -18.0713 + 0.01916X12 + 0.955547X13 - 0.19387X23 \tag{2}$$

The interaction variables (X12 and X13) have direct positive relationships while X23 has direct negative relationship with Y. Substituting back the defined variables into equation (2), the model then becomes:

$$\begin{aligned} PM10 &= -18.0713 + 0.01916(Temp)(UV) \\ &+0.955547(Temp)(Wind) - 0.19387(UV)(Wind) \end{aligned} \tag{3}$$

Table VIII shows the comparisons of best models from stations Kajang (S1), Shah Alam (S2) and Kota Bharu (S3) respectively. It can be seen from Table VIII that the best regression model with the least SSE is model M11.2.1 from Station Kajang (S1).

TABLE VII: COMPARISONS OF SELECTED MODELS ACCORDING TO STATIONS

	SELECTED MODEL								
	Stations:	Kajang (S1)		Shah Alam (S2)			Kota Bharu (S3)		
N	Model	K+1	SSE	Model	K+1	SSE	Model	K+1	SSE
90	M4.0.0	3	11012.23	M1.0.0	2	15288.87	M2.0.0	2	**13776.5**
90	M5.0.0	3	11758.79	M4.0.1	3	14746.45			
90	M8.1.0	3	11009.76	M5.0.0	3	**13186.66**			
90	M9.1.0	3	11789.47	M6.0.1	3	15011.47			
90	M10.0.0	3	11120.54	M8.1.1	3	14777.79			
90	M11.2.1	4	**9351.375**	M9.1.0	3	13258.4			
90	M12.3.0	5	9776.357	M10.0.2	2	15030.17			

TABLE VIII: COMPARISONS OF REGRESSION MODELS ACCORDING TO STATIONS BASED ON THE 8SC

Station	MODEL	K+1	N	SSE	**AIC**	**FPE**	**GCV**	**HQ**	**RICE**	**SCHWARZ**	**SGMASQ**	**SHIBATA**
Shah Alam	M5.0.0	3	90	13186.66	156.619	156.623	156.797	161.9715	156.98	156.319	151.571	156.286
Kajang	M11.2.1	4	90	9351.375	113.56	113.569	113.794	118.7667	114.041	113.462	108.737	113.140
Kota Bharu	M2.0.0	2	90	13776.5	160.029	160.03	160.109	163.6542	160.192	162.906	156.551	159.875
	MIN VALUE			9351.375	113.56	113.569	113.794	118.7667	114.041	113.462	108.737	113.140

This paper is the first that we are aware of to document the meteorological interactions (Temperature and UV; Temperature and Windspeed; UV and windspeed), interact each other to predict the PM_{10} concentrations. Certain combinations of Temperature and UV; Temperature and Windspeed; UV and Windspeed, might produce unique effect beyond exposure to one of these meteorological factors alone. From the model M11.2.1 obtained, shows that high Temperature with high UV, associated with high Temperature with stronger Wind will result to PM_{10} concentrations increase. On the other hand, decreased of PM_{10} concentrations are associated with high UV with strong Wind. Overall, it can be concluded that PM_{10} has a reverse relationship with wind speed and ultraviolet radiation, but a positive relationship with the ambient temperature. High temperature in the tropical climate usually increases the quantity of biomass burning and the evaporation of materials, for example soil dust, from the surface earth [23], [24]. In contrast to temperature, wind speed showed a negative influence on the concentration of PM_{10}, which means that the concentration of PM_{10} tends to be higher in low wind speed areas [25]. Reference [26] stated that tall building in effect and hilly regions prevent wind speeds from being sufficiently strong to be able to transport the pollution away and will affect 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 [27]. The study also demonstrated that UV has a negative correlation with PM_{10}. Large particles such as dust and haze are objects that are good absorbers of UV and UV emitters [28]. The UV absorption could be affected by the presence of PM_{10} in the air; which will lower UV intensity caused of higher presence of the PM_{10} and higher absorbance by the airborne particulates [29].

IV. CONCLUSION

The best model M11.2.1 can be used to forecast the upcoming haze weather; which is given by:

$$PM10 = -18.0713 + 0.01916(Temp)(UV)$$

$$+0.955547(Temp)(Wind) - 0.19387(UV)(Wind)$$

Hence, it can be concluded that the temperature plays the important factor for increasing the PM_{10} concentrations in the atmosphere; however the wind speed and UV can be the limiting factors for PM_{10} concentrations.

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