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Research paper

Evaluating the Influence of Meteorological Parameters on Ozone Concentration Levels

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Abstract

Over the years, anthropogenic activities have led to the increase in air pollution concentration levels in the atmosphere, this persistent increase in pollution levels can be influenced by meteorological parameters. These parameters assist in the formation and transportation of air pollutants in the atmosphere. Hence, this study aims at evaluating the association between meteorological parameters and air pollutants. The analysis was carried out using Ozone (O_3), Particulate matter (PM_{10}), Nitrogen dioxide (NO_2), temperature, humidity, wind speed, and wind direction data from 2006 to 2010, from two industrial air quality monitoring stations. Stepwise regression (SR) analysis was used to assess the influence of meteorological parameters in accounting for the variability of O_3 concentration levels. The SR analysis showed that meteorological parameters accounted for more than 50 % of O_3 variability. It can be concluded that different relationship between meteorological parameters and O_3 can exist in different locations in the same region.

Keywords: *Air pollution; Ozone; Particulate matter; Multiple linear regression; Stepwise regression.*

1. Introduction

The presence of air pollutants particularly Ozone (O_3) due to anthropogenic activities tend to increase the pollution in the atmosphere [1]. Industrial activities and mobile emission are the main sources of air pollutants [1]. These activities assist in the release of O_3 precursor pollutants. The formation of O_3 is achieved through the chemical reaction of precursor pollutants particularly, Oxides of Nitrogen (NO_x), Carbon Monoxide (CO) and Volatile Organic Compounds (VOC's) with the aid of suitable atmospheric conditions. This in turn increases O_3 concentration in the atmosphere [2]. Also, the formation and transportation of air pollutants can be influenced by meteorological parameters [3].

O_3 has resulted in tremendous health effects to the exposed citizens, especially the young and the elderly [4, 5]. Furthermore, the severity of these effects can be peculiar in different regions, these can be attributed to seasonal variation, geographical location and topographic conditions [6].

Various statistical methods have been used in evaluating O_3 concentration levels in different parts of the world [7, 8]. The distinction in seasonal variations of regions makes the influence of meteorological parameters of each region distinct. As such the absolute understanding of the peculiar pollution pattern should be assessed. Hence, the aim of this paper is to assess the relationship and evaluate the influence of four meteorological parameters namely; temperature, humidity, wind speed and wind direction with O_3 using stepwise regression (SR). In addition, Nitrogen dioxide (NO_2) was also included in the analysis.

2. Methodology

2.1 Study Area

Selangor: State of Selangor in Malaysia is growing rapidly due to urbanization and industrialization. Having a population of 5.4 million people, covering an area of 8,104 sq km. This area is constantly exposed to air pollution problems [1, 9]. The industrial air quality monitoring station in the Klang valley area is located in Petaling Jaya. This sampling station is the nearest station to the Kuala Lumpur city center and it is surrounded by industries, residential areas, commercial areas and congested roads.
Terengganu: The state of Terengganu is located in the North-eastern Peninsular, adjoined in the east by the southern China Sea. Covering an area of 13,035 sq.km, with a total populace of about a million people [10]. The industrial air quality monitoring station is in Kemaman. The area has ample industries, substantial traffic activities and residential areas [11].

2.2 Monitoring Records

For this study, hourly average O_3, PM_{10}, NO_2, temperature, humidity, wind speed and wind direction data from 2006 to 2010 was used. The data was acquired from the Department of Environment (DoE) Malaysia.

2.3 Methods

2.3.1 Stepwise Regression

It is a step by step approach where insignificant variables are removed from the regression analysis, allowing only important variables to be present in the models [12]. SR analysis is used to evaluate the order of importance of variables and subsequently select a useful subset [13, 14]. SR equation is as shown in equation 1.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_3 X_3 + \varepsilon i \quad (1)$$

Where; Y is the dependent variable, β_0 is the constant, β_1, β_2,….β_p are the regression coefficients of the independent variables X_1, X_2,…X_p (predictors) and ε is the residual error (the difference between observations and predicted values).

2.3.2 Performance Indicators

The performance of the model was assessed using the coefficient of determination (R^2).

Table 1: Performance Indicators

Performance Measure	Equation
Coefficient of Determination (R^2)	$R^2=\left[\frac{\sum_{i=1}^{n}(O_i-\bar{O})^2.(P_i-\bar{P})}{n.\sigma_O.\sigma_P}\right]^2$
Root Mean Square Error (RMSE)	$RMSE=\sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{n}}$
Mean Absolute Error (MAE)	$MAE=\frac{\sum_{i=1}^{n}\lvert P_i-O_i\rvert}{n}$
Normalized Absolute Error (NAE)	$NAE=\frac{\sum_{i=1}^{n}\lvert P_i-O_i\rvert}{\sum_{i=1}^{n}O_i}$

Additionally, the performance indicators are Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Normalized Absolute Error (NAE) were used to evaluate the error levels of the SR models as shown in Table 1.

3. Result and discussion

3.1 Descriptive statistics

Descriptive statistics of the data used for this study is shown in Table 2, the analysis included mean, median, maximum, standard deviation, skewness and kurtosis of all data used. The descriptive statistics showed that O_3 was below the Malaysian ambient air quality guideline (MAAQG) levels of 0.20 ppm hourly average in Petaling Jaya but slightly higher in Kemaman. While, NO_2 was slightly above the hourly average level of 0.32 ppm in Petaling Jaya but lower in Kemaman. Additionally, high hourly PM_{10} levels were recorded in both areas having maximum levels of 402 and 264 µg/m^3.

Stepwise Regression of O_3

The SR analysis involves hourly average O_3, NO_2, temperature (T), humidity (H), wind speed (WS), and wind direction (WD). Based on Petaling Jaya analysis, the SR for O_3 shows that T accounts for 53 % of O_3 variability as shown in Table 3. The addition of WS, H, and WD accounted for 54 % of O_3 variability, establishing that these meteorological factors can account for 54 % variability of O_3. Temperature assist in the chemical formation of ozone establishing a positive dependence [1].

Meanwhile, NO_2 was insignificant in the analysis therefore it was not involved in the O_3 model. This stipulates that NO_2 has less significance in the formation of O_3 and there is a possibility of other precursor pollutants aiding in the formation of O_3 in the area, while meteorologial parameters were more significant [15]. Subsequently, in the SR analysis of Kemaman, the model showed that WS accounts for 52 % of O_3 variability. The addition of H, WS, and WD accounted for 60 % O_3 variability. The addition of PM_{10} and NO_2 to the meteorological parameters accounted for 63 % O_3 variability.

Table 2: Descriptive statistics of hourly average levels for Petaling Jaya

Petaling Jaya			
Variables	Mean	St Dev	Median
O_3	0.014	0.02	0.01
PM	46.14	23.03	43.00
NO_2	0.52	3.66	0.029
Temp	27.92	4.11	27.00
Humidity	73.20	15.64	77.000
Wind speed	3.77	2.22	3.4
Wind direction	146.56	101.11	128.00
Petaling Jaya			
Variables	Max	Skewness	Kurtosis
O_3	0.13	1.76	3.33
PM	402.00	1.99	10.86
NO_2	0.12	7.57	56.61
Temp	39.40	0.51	-0.71
Humidity	94.00	-1.86	5.90
Wind speed	16.90	0.90	0.64
Wind direction	360.00	0.58	-0.79

Table 3: Descriptive statistics of hourly average levels for Kemaman

Kemaman			
Variables	Mean	St Dev	Median
O_3	0.02	0.015	0.02
PM	35.59	18.855	32.00
NO_2	0.003	0.0026	0.002
Temp	26.97	4.90	25.20
Humidity	78.50	11.77	79.00
Wind speed	4.60	2.84	3.90
Wind direction	198.67	120.04	211.00
Kemaman			
Variables	Max	Skewness	Kurtosis
O_3	0.09	0.77	0.14
PM	264	2.48	13.33
NO_2	0.03	2.16	7.69
Temp	39.40	0.74	-0.72
Humidity	100.00	-0.29	0.09
Wind speed	18.60	1.12	0.95
Wind direction	360.00	-0.23	-1.45

Table 4: Stepwise Regression of hourly O_3

No.	Models	R^2(%)
	Petaling Jaya	
1	O_3= -0.0719+0.0031T	52.52
2	O_3= -0.0671+0.0028T+0.0011WS	53.76
3	O_3= -0.0504+0.0025T+0.0010WS-0.0001H	54.33
4	O_3= -0.0505+0.0025T+0.0010WS-0.0001H-0.000005WD	54.39
5	O_3= -0.0504+0.0025T+0.0010WS-0.0001H-0.000001WD-0.00001PM	54.39
6	O_3= -0.0501+0.0025T-0.0001H+0.0010WS-0.000001WD	53.89
	Kemaman	
1	O_3= 0.0033+0.0361WS	53.60
2	O_3= -0.0153+0.0026WS+0.0009T	58.77
3	O_3= -0.0191+0.0026WS+0.00009PM	60.74
4	O_3= -0.0195+0.0026WS+0.0008T +0.00007PM+0.6160NO_2	61.84
5	O_3= -0.0145+0.0026WS+0.0008T + 0.00007PM+0.5470NO_2-0.00001WD	62.57
6	O_3= -0.0044+0.00251WS+0.0007T +0.00008PM+0.558NO_2-0.00001WD - 0.00011H	63.05
7	O_3= -0.0032+0.0007T -	60.20

	0.00007H+0.0025WS-0.000012WD	

Table 5: Performance Indicator result

Study Area	Pollutant	RMSE	MAE	NAE
Petaling Jaya	O_3	0.02	0.03	0.54
Kemaman		0.01	0.01	0.20

The performance indicators result for O_3 as shown in Table 4 established that the RMSE, MAE, and NAE results of Kemaman was slightly better, having low error levels than the Petaling Jaya SR model.

4. Conclusion

Overall, O_3 had a substantial relationship with humidity, temperature, wind speed and direction. In Petaling Jaya and Kemaman, temperature and wind speed accounted for >53% O_3 variability. This analysis would help atmospheric analyst and statisticians in assessing the peculiarity in air pollution assessment.

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