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Relationships between Air Pollutants and Meteorological Factors during Southwest and Northeast Monsoon at Urban Areas in Peninsular Malaysia

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Abstract. People who currently live in urban areas are subjected to significantly higher levels of exposure to air pollution. Pollutant concentrations in the air change according to the weather, the locations of the many sources of pollution, and the topography of the area. This study examines the link between meteorological parameters (ambient temperature, relative humidity, and wind speed) and daily air pollutant concentrations in four monitoring stations at Peninsular Malaysian cities (Seberang Perai, Pasir Gudang, Batu Muda, and Kemaman) during southwest and northeast monsoon. Pearson Correlation Analysis analyzed air quality data over two years (January 2016 - January 2018). The study found that PM_{10} concentrations were highest at all monitoring locations. At all monitoring locations, climatic parameters correlated with NO_2, PM_{10}, and CO. Air pollution and meteorological conditions correlate weakly to moderately during the southwest monsoon. The investigation found that weather conditions affect O_3 most during the dry season. CO and climatic parameters correlated weakly at all four monitoring stations during the northeast monsoon. PM_{10} correlated positively with ambient temperature and negatively with relative humidity and wind speed at all four stations. The northeast monsoon correlation values were weak to moderate. This study will help officials identify optimal air pollution controls for metropolitan areas during monsoon seasons in line with SDG-11, which promotes sustainable cities and communities.

1. Introduction

In the 21st century, air pollution poses a significant risk to the health and well-being of human beings [1]. The negative effects that air pollution has on human health are the primary focus of study that is conducted on the subject of air pollution. The release of complex gases and particulates from various sources such as transportation, energy consumption, industrial processes, and population density in urban areas poses significant risks to public health, agriculture, and climate. Moreover, air pollution has become a global issue that negatively affects the environment and human welfare [2]. Air pollution is a problem in emerging nations like China and India, putting a strain not only on their citizens' health but also on their economies and the billions of people who live in areas where the air quality does not reach the safety limits established by the World Health Organization [3].

Manufacturing activities are the primary source of major pollutants. Air pollution originates from various sources such as power stations, construction sites, quarries, and waste incinerators, and open burning [4]. In urban areas of developing countries, automobiles are the primary cause of mobile air pollution [5]. The severe impacts of air pollution on human health and welfare are of great concern to scientists and economists. Research has shown that the combination of poor air quality and high temperatures may cause adverse health effects, particularly in urban populations. 6.5 million deaths globally are attributed to dirty air, affecting 92% of the world's population [6].

Because of its proximity to the equator, Malaysia has a hot and humid climate, and as a result, the country is subject to two different types of monsoons [7]. Climate elements such as temperature, relative humidity, and wind speed, in addition to the monsoon seasons, have a considerable impact on the amount of air pollution that is present in Malaysia [8]. The southwest monsoon and the northeast monsoon are the two types of monsoons seasons that Malaysia experiences. The southwest monsoon is normal between the months of June and September, and the northeast monsoon is typical between the months of November and March. In addition, Malaysia is subject to transitional wind times known as inter-monsoons, which take place between the months of April and May and October and November respectively [7]. Due to the significant impact of air pollutants on human health in Malaysia, the purpose of this study is to determine whether or not there is a correlation between temperature, wind speed, relative humidity, and five important air pollutants. These pollutants include NO_2, PM_{10}, O_3, and SO_2 respectively. The purpose of this study is to figure out which pollutant in Peninsular Malaysia is most impacted by the different weather conditions that occur during the southwest and northeast monsoons. Malaysia has 52 Continuous Air Quality Monitoring Stations (CAQMS) that are monitored by the Department of Environment Malaysia. The Peninsular Malaysia urban monitoring stations are chosen based on the monitoring station categories specified by the Department of Environment Malaysia. The fact that four monitoring stations are situated in a residential area while also being surrounded by industrialized areas classifies these stations as urban monitoring stations.

2. Methods

2.1. Study Areas and parameters

This study's primary objective is to investigate the influence that temperature, wind speed, and relative humidity have on the levels of air pollutants (NO_2, PM_{10}, O_3, SO_2, and CO) in four urban areas located on the peninsula of Peninsular Malaysia. These urban areas are Seberang Perai, Pasir Gudang, Batu Muda, and Kemaman respectively.Table 1 contains a listing of all the variables that were considered.

Table 1. List of parameters

Air pollutants	Unit	Meteorological	Unit
NO_2	ppm	Temperature	°C
PM_{10}	$\mu g/m^3$	Wind speed	m/s
O_3	ppm	Relative humidity	%
SO_2	ppm		
CO	ppm		

The Continuous Air Quality Monitoring (CAQM) station in Pulau Pinang is located in Sekolah Kebangsaan Seberang Jaya 2 (100.4039472°, 5.3981700°), Perai, Pulau Pinang, which has undergone rapid development and urbanization. The monitoring station in Pasir Gudang, Johor, is located in a residential area near main roads and industrialized areas. The CAQM for urban areas in Wilayah

Persekutuan Kuala Lumpur is located in Sekolah Kebangsaan Batu Muda (101.6822278 º, 3.2124389 º), which is in the Klang Valley, Malaysia's largest economic region with high levels of industrialization and urbanization. Lastly, the urban area monitoring station in Terengganu is Sekolah Menengah Kebangsaan Bukit Kuang (103.4257780º, 4.2621210º), Terengganu, which is known for its high population growth, industrialization, and pollution levels in Malaysia. Table 2 and Figure 1 depict the geographic locations of the research areas and the CAQM station, respectively.

Table 2. Location of study áreas

Station	State	Location	CAQM category
Seberang Perai (S1)	Pulau Pinang	Sekolah Kebangsaan Seberang Jaya 2	Urban
Pasir Gudang (S2)	Johor	Sekolah Menengah Kebangsaan Pasir Gudang 2	Urban
Batu Muda (S3)	Wilayah Persekutuan Kuala Lumpur	Sekolah Kebangsaan Batu Muda	Urban
Kemaman (S4)	Terengganu	Sekolah Menengah Kebangsaan Bukit Kuang	Urban

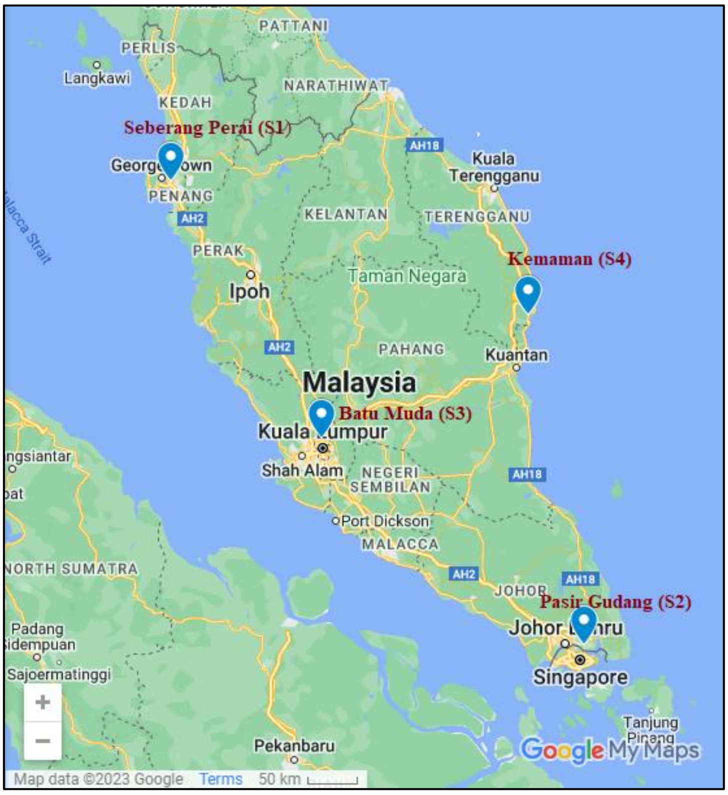

Figure 1. The Continuous Air Quality Monitoring (CAQM) station

2.2. Pearson Correlation Analysis
In order to establish a relationship between two variables that are continuous, the Pearson Correlation (*r*) is commonly employed [3]. The Pearson correlation is represented by '*r*' and its a formula in general, Eq (1), is defined as follows:

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sqrt{\sum X^2 - \frac{(\sum X)^2}{N}})\,(\sqrt{\sum Y^2 - \frac{(\sum Y)^2}{N}})}} \quad (1)$$

The formula for the Pearson correlation coefficient (*r*) includes N, which represents the sample size, and X and Y, which respectively refer to the independent and dependent variables. The value of '*r*' can range from -1 to +1, with -1 indicating a perfect negative relationship among the variables, 0 indicating that there is no linear relationship, and +1 indicating that there is a perfect positive correlation between the variables.

3. Results and Discussion

3.1. Descriptive of temperature, wind speed, and relative humidity
The characteristics of the data sets such as the mínimum (min.), máximum (max.) and mean is presented in Table 3 for temperature, wind speed and relative humidity in Seberang Perai (S1), Pasir Gudang (S2), Batu Muda (S3) and Kemaman (S4) from January 2016 to January 2018.

Table 3. Descriptive of temperature, wind speed, and relative humidity

Statistics	2016				2017				2018			
	Temperature (°C)											
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Valid	366	366	366	366	286	286	286	286	31	31	31	31
Missing	-	-	-	-	79	79	79	79	-	-	-	-
Min.	23	25	22	**21**	24	25	24	24	24	24	23	23
Max.	32	32	32	**34**	30	31	31	29	28	29	29	27
Mean	29	29	28	28	28	28	28	27	26	27	27	25
	Wind speed (m/s)											
Valid	366	366	366	366	286	286	286	286	31	31	31	31
Missing	-	-	-	-	79	79	79	79	-	-	-	-
Min.	1.6	0.4	0.8	1	0.7	0.5	**0.3**	0.8	0.7	0.5	0.4	0.8
Max.	**10**	5	6	6	3	2	2	4	2	2	1	3
Mean	4	2	2	3	2	1	1	2	1	1	0.7	2
	Relative humidity (%)											
Valid	366	366	366	366	286	286	286	286	31	31	31	31
Missing	-	-	-	-	79	79	79	79	-	-	-	-
Min.	47	60	44	**31**	49	61	53	69	71	74	70	84
Max.	88	88	96	**99**	95	93	**99**	97	93	92	93	97
Mean	67	74	76	81	75	78	79	84	83	83	82	90

Malaysia's climate is distinguished by constant temperature, high humidity, and abundant rainfall. The wind is normally light [7]. The mean ambient temperature for all monitoring stations ranges between 25°C to 29°C. The mínimum and maximum ambient temperature recorded is 21°C and 34°C in 2016 at Kemaman. In addition, when compared to the other stations, Kemaman had the lowest relative humidity (31%), as well as the highest (90%). The minimum wind speed was recorded at Batu Muda (0.3 m/s),

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while the maximum wind speed was recorded at Seberang Perai at 10 m/s. The average wind speed for all locations ranges from 1 m/s to 4 m/s. Pollutant dispersion rates are determined by wind intensity, the nature of turbulent fields, and wind shears based on land/sea surface features [9]. The highest levels of contaminants are typically found during still weather conditions with low wind velocity, while increasing wind velocities have a substantial affect on air quality. It was discovered that high wind speed has a significant impact on lowering air pollutants because it reduces the likelihood of pollutants to concentrate and disperse in the air [10].

3.2. *Descriptive of five major air pollutants (NO_2, PM_{10}, O_3, SO_2, and CO)*

Table 4 shows the descriptive of air pollutants such as NO_2, PM_{10}, O_3, SO_2, and CO. The concentrations of NO_2 (0.049 ppm) and PM_{10} (147 µg/m^3) in Pasir Gudang are the highest observed among the other sites. However, the mean PM_{10} concentration in Seberang Perai was greater, at 53 µg/m^3. Seberang Perai has the greatest maximum O_3 concentration (0.06 ppm), with mean O_3 values ranging from 0.01 ppm to 0.02 ppm for all locations. In 2016, high levels of SO_2 and CO were also detected at the Pasir Gudang monitoring station. In the Bayesian Model Averaging prediction model, Ramli et al. [11] discovered that NO_2 and PM_{10} were the most prevalent pollution at Pasir Gudang. Within a radius of two to three kilometres, both residential and business areas can be found in close proximity to the Pasir Gudang monitoring station. Primary industries in this region include a power plant owned by Tenaga Nasional Berhad, palm oil storage and distribution, petrochemical and fertiliser manufacture, electroplating, and logistics and transportation [12].

Table 4. Descriptive of NO_2, PM_{10}, O_3, SO_2, and CO

Statistics	2016				2017				2018			
	NO_2 (ppm)											
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Valid	366	366	366	366	286	286	286	286	31	31	31	31
Missing	-	-	-	-	79	79	79	79	-	-	-	-
Min.	0.004	0.001	0.004	0.001	0.003	0.002	0.002	0.001	0.005	0.005	0.005	0.002
Max.	0.030	**0.049**	0.034	0.007	0.022	0.027	0.041	0.007	0.014	0.016	0.026	0.003
Mean	0.012	0.011	0.019	0.003	0.010	0.012	0.019	0.003	0.010	0.009	0.018	0.002
	PM_{10} (µg/m^3)											
Valid	365	366	366	364	286	286	286	286	31	31	31	31
Missing	1	-	-	2	79	79	79	79	-	-	-	-
Min.	8	3	3	11	4	2	9	7	**14**	7	10	8
Max.	118	**147**	140	100	86	58	75	86	35	28	27	36
Mean	**53**	47	41	48	36	33	31	32	23	17	18	19
	O_3 (ppm)											
Valid	366	366	366	366	286	286	286	286	31	31	31	31
Missing	-	-	-	-	79	79	79	79	-	-	-	-
Min.	0.002	0.003	0.006	0.007	0.003	**0.001**	**0.001**	0.007	0.010	0.003	**0.001**	0.009
Max.	0.035	0.036	0.044	0.048	**0.060**	0.038	0.040	0.039	0.035	0.020	0.026	0.033
Mean	0.014	0.010	0.020	0.019	0.019	0.016	0.019	0.017	0.020	0.013	0.014	0.018
	SO_2 (ppm)											
Valid	366	366	366	366	286	286	286	286	31	31	31	31
Missing	-	-	-	-	79	79	79	79	-	-	-	-
Min.	**0.001**	**0.001**	0.004	**0.001**	0.0002	0.0003	0.0004	0.0003	**0.001**	**0.001**	**0.001**	0.002
Max.	0.006	**0.014**	0.008	0.003	0.009	0.011	0.007	0.005	0.002	0.001	0.001	0.001
Mean	0.002	0.004	0.003	0.002	0.001	0.003	0.003	0.001	0.001	0.001	0.001	0.000
	CO (ppm)											
Valid	366	366	366	366	286	286	286	286	31	31	31	31

Statistics	2016				2017				2018			
	NO_2 (ppm)											
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Missing	-	-	-	-	79	79	79	79	-	-	-	-
Min.	0.11	**0.02**	0.32	0.09	0.24	0.32	0.40	0.12	0.68	0.46	0.79	0.20
Max.	1.37	1.38	**1.50**	1.14	1.42	1.25	1.45	0.87	1.14	1.00	1.41	0.52
Mean	0.65	0.59	0.83	0.45	0.78	0.74	0.93	0.42	0.87	0.61	1.05	0.39

3.3. Southwest Monsoon Pearson Correlation

In Peninsular Malaysia, the southwest monsoon begins in the month of June, lasts for nearly four months, and typically comes to a close in the month of September. During this time of the year, the region is recognised for having temperatures which are not high but also generally consistent. In addition, the southwest monsoon is a consistent occurrence that occurs every year. The association between meteorological conditions and air pollutants in Peninsular Malaysia's four urban monitoring stations during the southwest monsoon is depicted in Table 5.

Table 5. Pearson correlation analysis during the southwest monsoon

Station	Variable	Temp.	RH	WS	SO_2	NO_2	O_3	CO	PM_{10}
Seberang Perai	Temp.	1							
	RH	-0.922**	1						
	WS	0.481**	-0.623*	1					
	SO_2	-0.337*	0.215*	-0.156	1				
	NO_2	0.375**	-0.233	-0.191*	0.251**	1			
	O_3	0.528**	-0.371**	0.153*	0.341**	-0.211*	1		
	CO	0.211*	0.347**	0.258*	-0.157	0.379**	-0.217*	1	
	PM_{10}	0.412**	-0.503**	-0.171*	0.305**	0.213*	0.415**	0.213*	1
Pasir Gudang	Temp.	1							
	RH	-0.625**	1						
	WS	-0.275**	-0.279*	1					
	SO_2	-0.283**	0.015	-0.273*	1				
	NO_2	-0.012	0.411**	-0.388**	0.068	1			
	O_3	0.289**	-0.241*	0.118*	-0.311**	-0.323**	1		
	CO	0.423**	-0.327**	-0.215*	0.143	0.129*	-0.118*	1	
	PM_{10}	0.228*	0.116	-0.068	0.414**	0.352**	0.153*	0.217*	1
Batu Muda	Temp.	1							
	RH	-0.322*	1						
	WS	0.215*	-0.159*	1					
	SO_2	0.196*	-0.291**	0.153*	1				
	NO_2	0.259**	-0.185	0.271**	0.417**	1			
	O_3	0.518**	-0.249*	0.261*	0.019	-0.219*	1		
	CO	-0.313**	-0.355**	0.401**	0.349**	0.597**	-0.222*	1	
	PM_{10}	0.159*	-0.189	0.211*	0.191*	0.361**	0.210*	0.519**	1
Kemaman	Temp.	1							
	RH	-0.323**	1						
	WS	0.294*	-0.350*	1					
	SO_2	-0.496**	0.211*	0.201*	1				
	NO_2	0.116	0.315**	0.115	0.296**	1			
	O_3	0.317**	-0.357**	0.135*	0.191*	-0.381**	1		

Station	Variable	Temp.	RH	WS	SO_2	NO_2	O_3	CO	PM_{10}
	CO	0.275**	0.175	-0.271*	-0.377**	0.123*	-0.279**	1	
	PM_{10}	0.192*	0.262*	0.086	0.401**	0.320**	0.331**	0.103	1

The strongest positive significant correlation was found between O_3 and the ambient temperature at Seberang Perai and Batu Muda during the southwest monsoon period, with values of (r = 0.528) and (r = 0.518) respectively. This correlation was observed during the period when the southwest monsoon was in effect. It is possible for large amounts of O_3 concentrations to be caused by photochemical reactions if gaseous contaminants, including O_3 precursors, are transported from one region to another while temperatures are high. At Pasir Gudang, a significant positive association (r = 0.423) was found to exist between the temperature of the surrounding air and CO levels. This is due to the fact that carbon monoxide is engaged in chemical processes that take place in the atmosphere and have the potential to produce ozone as well as increase the temperatures in the surrounding areas. At Kemaman, the correlation between NO_2 and relative humidity with a value of (r = 0.315) was found to be the most significant and positive of any other correlation. With a value of (r = -0.171), the PM_{10} and wind speed correlation at all Seberang Perai sites was observed to have the weakest significant negative correlation. The weakest relationship was found between CO and wind speed at Pasir Gudang and Kemaman, where the values were (r = -0.215) and (r = -0.271), respectively. The lowest negative significant correlation was found between O_3 and relative humidity at Batu Muda, where the value was (r = -0.249). This is because high relative humidity or rainfall causes a drop in atmospheric temperature, which then depletes O_3 production as the generation of ozone requires heat.

3.4. Northeast Monsoon Pearson Correlation

The northeast monsoon period in Peninsular Malaysia, which normally runs from November to March, is characterised by a variation in the average number of monthly rainstorms that take place across the country's various areas. Table 6 displays the relationships between climatic variables and air pollutants at four urban monitoring stations in Peninsular Malaysia during the northeast monsoon.

Table 6. Pearson correlation analysis during the northeast monsoon

Station	Variable	Temp	RH	WS	SO_2	NO_2	O_3	CO	PM_{10}
Seberang Perai	Temp	1							
	RH	-0.615**	1						
	WS	-0.213*	0.297**	1					
	SO_2	0.279*	-0.311**	0.253**	1				
	NO_2	-0.277*	0.249*	0.413**	0.311**	1			
	O_3	0.233**	-0.451**	-0.318**	-0.165*	-0.214*	1		
	CO	0.215*	0.103	0.061	-0.129*	0.182*	-0.237**	1	
	PM_{10}	0.439**	-0.502**	-0.129*	0.086	0.077	0.449**	0.206*	1
Pasir Gudang	Temp	1							
	RH	-0.416**	1						
	WS	0.318**	-0.263*	1					
	SO_2	0.352**	-0.266*	0.017	1				
	NO_2	0.185*	0.160*	-0.135*	0.519**	1			
	O_3	0.165*	-0.473**	-0.262*	-0.182*	-0.255**	1		
	CO	-0.185*	0.105	-0.037	0.355**	0.321**	-0.429**	1	
	PM_{10}	0.293**	-0.350**	-0.218*	0.398**	0.212*	0.159*	0.279**	1

Station	Variable	Temp	RH	WS	SO_2	NO_2	O_3	CO	PM_{10}
Batu Muda	Temp	1							
	RH	-0.514**	1						
	WS	-0.213**	-0.171*	1					
	SO_2	0.262**	-0.334**	0.258**	1				
	NO_2	-0.261**	0.312**	-0.186*	0.328**	1			
	O_3	0.499**	-0.461**	-0.262**	-0.109*	0.185*	1		
	CO	-0.119	0.174	0.115	0.269**	0.418**	-0.303**	1	
	PM_{10}	0.192*	-0.267**	-0.337**	0.157*	0.004	0.241*	0.293**	1
Kemaman	Temp	1							
	RH	-0.478**	1						
	WS	0.252*	0.307**	1					
	SO_2	-0.397**	-0.273**	-0.185*	1				
	NO_2	0.291**	0.174*	0.107	-0.016	1			
	O_3	0.361**	-0.396**	-0.131	0.207*	-0.116	1		
	CO	-0.109*	-0.125	-0.263**	0.350**	0.131	0.471**	1	
	PM_{10}	0.130*	-0.350**	-0.293*	0.201*	-0.226*	0.515**	0.219*	1

The south coast, the east coast, the west coast, and the highland regions all have varied patterns for the diurnal fluctuation in the frequency of rain.Due to chemical processes in the atmosphere brought on by high temperatures, the largest positive significant association between PM_{10} and ambient temperature was seen in Seberang Perai ($r = 0.439$). The link between SO_2 and ambient temperature in Pasir Gudang was found to be positive ($r = 0.352$). The strongest positive connection between O_3 and ambient temperature was found at Batu Muda and Kemaman, with values of ($r = 0.499$) and ($r = 0.361$), respectively.The SO_2 and relative humidity relationship at Seberang Perai had the lowest significant negative correlation ($r = -0.311$). At Pasir Gudang and Batu Muda stations, respectively, the lowest correlations between NO_2 and wind speed were found ($r = -0.135$ and ($r = -0.186$)). Similar patterns were seen between CO and ambient temperature in Kemaman ($r = -0.109$) due to reduced atmospheric temperature affecting the chemical conversion of CO to CO_2 for photosynthesis, resulting in higher levels of carbon monoxide.

4. Conclusion

During the dry season, Kemaman showed the weakest correlation between meteorological factors and air pollutants, where NO_2 did not show any significant association with the surrounding temperature or wind speed, CO did not show any correlation with the relative humidity, and PM_{10} did not show any correlation with the wind speed. Despite this, O_3 consistently demonstrated substantial connections with a variety of meteorological parameters across all four monitoring stations. In contrast, there was not a significant link between CO and PM_{10} with wind speed at Seberang Perai, Pasir Gudang, or Batu Muda during the Northeast monsoon. In addition, the investigation found that of the five air pollutants that were present throughout this season, CO had the lowest association with the climatic parameters that were present. On the other hand, the most significant factors that affected PM_{10} were the ambient temperature, the relative humidity, and the wind speed.

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