Journal of Engineering and Applied Sciences 11 (12): 2588-2593, 2016
ISSN: 1816-949X

Particulate Matter Status and its Relationship with Meteorological Factors in the East Coast of Peninsular Malaysia

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Abstract: This study aims to determine the trend and status of Particulate Matter (PM_{10}) concentrations in the three major cities (i.e., Kota Bahru, Kuala Terengganu and Kuantan) in East Coast of Peninsular Malaysia and its relationship with meteorological factors. PM_{10} concentration and meteorological data from 2006-2012 for the three study areas were obtained from Department of Environment of Malaysia. The highest daily average PM_{10} concentration was recorded in Kuala Terengganu with the value of 50.3 μg m^{-3}. All the three stations have statistically different PM_{10} concentration due to each having different percentage of urbanized areas. Positive correlation was observed for PM_{10} concentration and temperature in all the three study areas. For back-trajectory analysis, the air masses were noted to travel through the South China Sea from China and Philippines before arriving at the stations during North East Monsoon whereas during South West Monsoon, the air masses generally originates from Indonesia, passing thru the Straits of Malacca. In conclusion, it is apparent that rate of urbanization is directly proportional to atmospheric PM_{10} concentration in these three cities.

Key words: Particulate, matter, temperature, meteorological factor, cities, stations

INTRODUCTION

Particulate Matter (PM) is the most dominant pollutant that contribute to the unhealthy days in the Air Pollution Index (API) measurements in Malaysia. In the East Coast of Peninsular Malaysia (Pahang, Terengganu, Kelantan and East Johor), the air quality remained between good to moderate most of the time with the exception of a few unhealthy days during the dry period of June to September (2014). Unhealthy days recorded at those areas were due to PM_{10} pollutant during local haze episode. The API system closely follows the Pollutant Standard Index (PSI) of the United States Environmental Protection Agency (USEPA) and is mainly based on five major pollutants (PM_{10}, SO_2, NO_2, CO and O_3) in the ambient air. Hourly values for PM_{10} and SO_2 are averaged over a 24 h running period with an 8 h period for CO while O_3 and NO_2 are read hourly before an hourly index is calculated with the use of sub-index functions for each pollutant. Then, the highest index value recorded is then taken as the API for the hour:

$$\text{API} = \text{Max } \{\text{sub-indices of all 5 air pollutants}\} \quad (1)$$

PM can be formed from primary sources such as soot and dust from combustions and secondary sources such as nitrates and sulphates that form during atmospheric chemical reactions (Cox *et al*., 2013) urbanization process has resulted in deterioration of ground level air quality and studies have proven that vehicular emission is one of the major sources of PM (Gupta and Kumar, 2006). The trend of the annual average levels of PM_{10} concentration in the ambient air between 1999 and 2012 based on land-use categories shows that urban area have the highest level of PM_{10} in the 11 out of the 14 year period (2014). The major sources of PM_{10} emission are: motor vehicles (76%), power plants (15%), industries (4%) and others (5%). High levels of PM are consistently associated with adverse health effects such as worsening of asthma, lungs inflammation and increased mortality as well as hospital admissions (Pascal *et al*., 2014). Deposition of PM on the surface of vegetation instigated radiative heating, reduction of photosynthesis rate and alters cycles of decomposition which in turn, effecting animal communities (Grantz *et al*., 2003). Monitoring is one way to protect and assess air quality and important due to significantly increase in air pollutants emissions. Air monitoring provides the status of the air quality for a given source of pollution at a given time. The air monitoring involves measurement and the measurement may be accurate but it is costly and time-dependent. In Malaysia, the monitoring was done under the responsibility of DOE.

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Terengganu, Pahang and Kelantan are the three states located at the East Coast of Peninsular Malaysia facing the South China Sea (Najid *et al*., 2009). As it is near the coastal region, there will be particles come from the sea. Inorganic sea salt and organic matter combined together to form sea-spray aerosol. It is composed of sodium chloride (NaCl) with traces of Magnesium (Mg) and sulphate (SO_4^{2-}). The giant sea spray particles come from the sea which the particle diameter is influenced by wind speed (Leeuw, 1986). Sea spray from the ocean is considered for contributing the PM_{10} concentrations in the air (2008-2009). This study aim to determine the trend of PM_{10} concentration in the three major cities in the East Coast of Peninsular Malaysia plus the correlation between the PM_{10} concentrations and the meteorological factors in the three study areas. Furthermore, backward trajectories will also be executed to trace the former path of the air parcel before arriving at the study areas.

MATERIALS AND METHODS

Sampling locations: One air quality monitoring station in the urban area of each state, i.e., Kelantan, Terengganu and Pahang in the East Coast of Peninsular Malaysia were selected for this study. The station for Kelantan is located in Maktab Sultan Ismail, Kota Bahru (S1-06°6.383" N; 102°12.822" E); for Terengganu is SK Chabang Tiga, Kuala Terengganu (S2-05°18.487" N; 103°07.226" E) and for Pahang is SK Indera Mahkota, Kuantan (S3-0349.138" N; 103 17.817" E). Department of Environment Malaysia has classified S1 and S2 as urban area whilst S3 as sub-urban area, respectively.

Data collections: All the monitoring stations were installed, operated and maintained by Alam Sekitar Malaysia Sdn. Bhd. (ASMA) under concession by the Department of Environment Malaysia (Afroz *et al*., 2003). The data used was daily average temperature, daily average relative humidity, daily average wind speed and daily average PM_{10} concentration for the duration of 6 year from January 2006 to December 2012, excluding year 2008 for all three stations as the data for year 2008 was not available.

Data analysis: The PM_{10} concentration and meteorological data for the respective stations were sorted for the period of 2006-2012. In this study, for which at least one value is missing from at least one parameter, that incomplete data rows were removed. The missing values from the study period were omitted in the statistical computations since the missing values is <10% of the total data for each year. It was specified that the minimum data capture criterion in the data sets must be 90% completeness (maximum 10% of missing data) within 1 year of data for all years in study period to enable comprehensive data analysis and interpretation (Voukantsis *et al*., 2011). The monthly trends of the assembled data were depicted in graphs whilst analysis of variance were used to determine the normal distribution as well as the significant difference between the data sets. Pearson correlation was performed to define the relationship between the PM_{10} concentration with the meteorological factors such as relative humidity, wind speed and ambient temperature.

Trajectory analysis: The backward trajectories were calculated using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) Model. This model is introduced by the National Oceanographic and Atmospheric Administration (NOAA) through the website http://www.arl.noaa.gov/ready.html. The backward trajectories tracks the parcel of air reverse in time in hourly sequence for a specified period to determine the path where the air parcel passed by. The trajectories for the four stations were developed for 72 h and the model calculation were set at the height of 100 m above ground level on 1st of January and 1st of August of year 2006 and 2012 signifying North East Monsoon and South West Monsoon, respectively.

RESULTS AND DISCUSSION

Variations of PM_{10} concentration and meteorological data: Daily average PM_{10} concentration and meteorological data at the three stations were tabulated in Table 1. The daily averaged concentration for PM_{10} for S1-S3 are 41.3 $\mu g\ cm^{-3}$ (21.5-60.2 $\mu g\ m^{-3}$), 50.3 $\mu g\ m^{-3}$ (31.4-64.5 $\mu g\ m^{-3}$) and 36.4 $\mu g\ m^{-3}$ (21.5-60.9 $\mu g\ m^{-3}$), respectively. The daily average PM_{10} concentration for the three stations were within the range of the suggested concentration recommended by the Malaysian government which is 150 $\mu g\ m^{-3}$ for the duration of 24 h. The daily averaged ambient temperature are 26.9°C (24.5-29.3°C) for S1, 27.3°C (25.2-29.5°C) for S2 and 26.9°C (24.7-28.8°C) for S3. The P-value obtained from the ANOVA is <0.05 which indicates that the daily average PM_{10} concentration and daily average temperature is statistically different between the three stations as shown in Table 2. The S2 recorded the highest value for the daily average PM_{10} concentration and the daily average temperature daily maximum temperature

Table 1: Summary of PM_{10} concentration and meteorological data at different stations

Parameters	Stati-on	dura-tion	Mean	Median	SD	Max.	Min.
PM10[b]	S1		41.3	41.9	6.6	60.2	21.5
	S2		50.5	49.9	7.9	64.5	31.4
	S3		36.4	35.8	7.4	21.5	0.9
WS[c]	S1		5.2	5.1	1.0	8.7	3.5
	S2		5.5	5.3	1.0	8.1	1.8
	S3	Jan 2006-	6.6	6.6	0.7	7.9	4.8
RH[d]	S1	Dec 2012a	79.7	80.1	3.5	87.9	73.6
	S2		81.6	81.0	3.4	92.0	74.8
	S3		85.4	82.9	5.1	97.7	78.4
T[e]	S1		26.9	26.9	1.0	29.3	24.5
	S2		27.3	27.4	1.0	29.5	25.2
	S3		26.9	27.1	0.9	28.8	24.7

[a]Duration of data used for analysis, excluding year 2008; [b]Daily averaged concentration of particulate matter <10 microns (μg m^{-3}); [c]Daily averaged windspeed (km h^{-1}); [d]Daily averaged relative humidity (percentage); [e]Daily averaged ambient temperature (°C)

Table 2: Analysis of variance of PM_{10} concentration and meteorological data at different stations

Para-meter	Compa-rison	Sum of squares	df*	Mean square	F-values	p-values
PM10	Between groups	7125.542	2	3562.771	65.819	0.000
	Within groups	11529.679	213	54.130		
	Total	18655.221	215			
WS	Between groups	74.391	2	37.195	42.767	0.000
	Within groups	176.552	203	0.870		
	Total	250.943	205			
RH	Between groups	1183.148	2	591.574	34.742	0.000
	Within groups	3575.822	210	17.028		
	Total	4758.970	212			
T	Between groups	6.366	2	3.183	3.475	0.033
	Within groups	195.128	213	0.916		
	Total	201.494	215			

due to the fact that Terengganu is the most urbanized state among the three study area. According to the Department of Statistics (2005), by year 2010, the Terengganu state have achieve the percentage of urbanization of 59.1% which ranked the 8th most urbanized state throughout Malaysia, excluding Federal Territories. The lowest urbanization percentage were recorded for Kelantan state whereas for Kelantan and Pahang is 53.77 and 57.52% (Department of Statistics, 2005). Deforestation reduces land cover and result in higher ground surface temperature due to irradiative heating of the earth surface like a black body (Leeuw, 1986). Reduction of land cover and land use change causes substantial reductions in precipitation and surface temperature increment (Duangdai and Likasiri, 2015). The daily average wind-speed for S1-S3 are 5.2 km h^{-1} (3.5-8.7 km h^{-1}), 5.5 km h^{-1} (1.8-8.1 kmh^{-1}) and 6.6 km h^{-1} (4.8-7.9 km h^{-1}). The daily averaged relative humidity for S1, S2 and S3 are 79.7% (73.6-87.9%), 81.6% (74.8-92.0%) and 85.4% (78.4-97.7%). The values for both daily averaged wind-speed and daily averaged relative humidity for the three stations were found to differ significantly

Table 3: Correlation (r-value) between PM_{10} concentration and meteorological factors at different stations

Station	Factors	PM10[a]	Ws[b]	Rh[c]	T[d]
S1	PM10	1			
	WS	0.07996	1		
	RH	-0.4145	0.07869	1	
	Temp	0.04097	-0.08901	-0.50330	1
S2	PM10	1			
	WS	0.22066	1		
	RH	-0.39492	-0.02910	1	
	Temp	0.22395	-0.38791	-0.38780	1
S3	PM10	1			
	WS	0.16292	1		
	RH	-0.11343	0.116414	1	
	Temp	0.30965	-0.08141	-0.47472	1

[a]Daily averaged concentration of particulate matter <10 microns (μg m^{-3}); [b]Daily averaged windspeed (km h^{-});[1] Daily averaged relative humidity (percentage); [d]Daily averaged ambient temperature (°C)

($p<0.05$) and for both parameters the highest values occurs in S3 with the daily averaged wind-speed of 6.6 km h^{-1} and daily averaged relative humidity of 85.4%.

Monthly trend for PM_{10}: The monthly trend for PM_{10} in the three stations is depicted in Fig. 1. In months June and November, the concentration of PM_{10} will rise with some minor fluctuations whereas in month July and October, the concentration will start to decrease. There is two distinct monsoon and two inter-monsoon seasons. The South West Monsoon (SWM) winds blow from May to September and the North East Monsoon (NEM) winds blow from November to March. The SWM is the dry monsoon and usually linked with the trans-boundary haze caused by the biomass burning in the neighboring country.

Thus, the PM_{10} concentration will be higher in these period. The NEM is the wet monsoon, accompanied by heavy precipitation. The aerosols concentrations can decrease by 55-70% during the monsoon period where heavy rainfall were observed (Hyvarinen *et al*., 2011).

Correlation between PM_{10} with meteorological factors: The correlation between the daily average PM_{10} concentration and meteorological factors at all three stations are presented in Table 3. Daily average PM_{10} concentration shows positive correlation with temperature and wind-speed in all three stations. The correlation coefficient for PM_{10} and temperature for S1-S3 are 0.0409, 0.2239 and 0.3096 whereas for daily average PM_{10} and daily average wind-speed are 0.0799, 0.2206 and 0.1629 for S1-S3, respectively. High temperature in the tropical climate country often induces open fires and during hot dry weather, minor air turbulence can stir up road dust and soil particles and suspend them in air (Azmi *et al*., 2010). The strongest correlation coefficient were recorded for the relationship between relative humidity and temperature which is -0.5033 for S1. The relative humidity of the ambient atmosphere depends strongly on

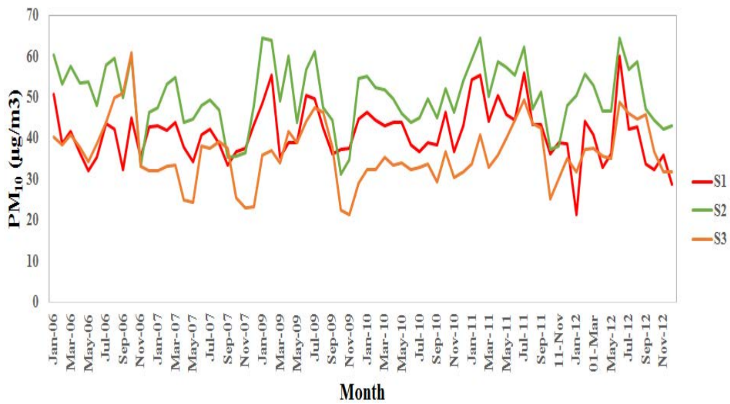

Fig. 1: Monthly trends for PM_{10} concentration at different stations

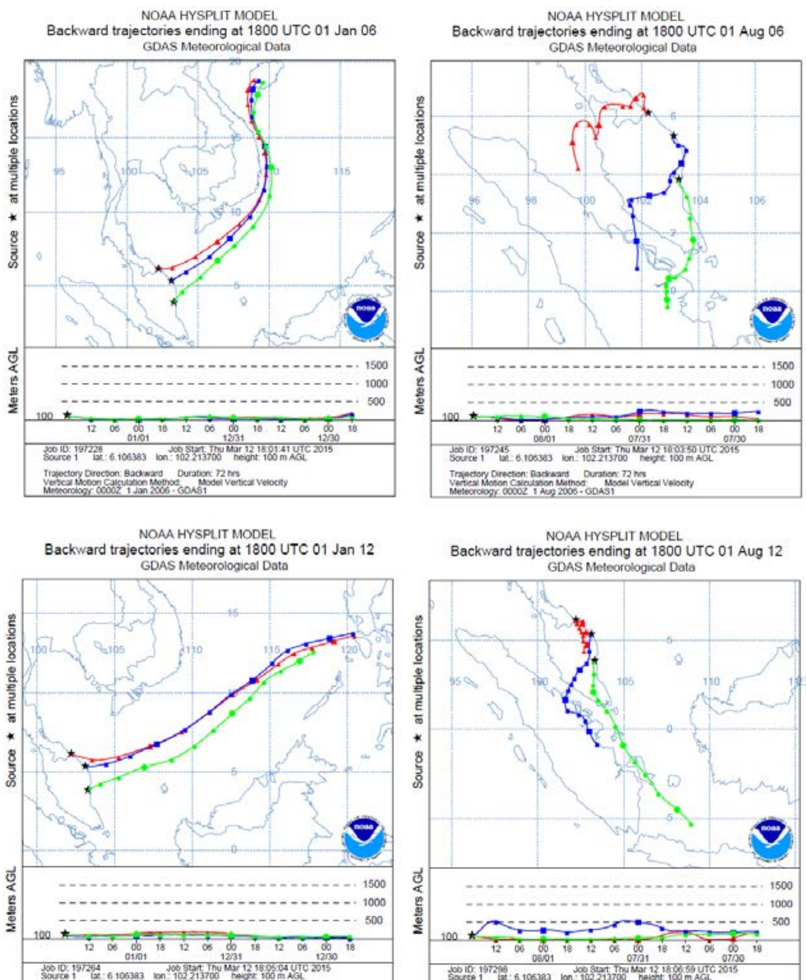

Fig. 2: Back trajectory analysis using HYSPLIT Model for North-East Monsoon (NEM) and Southwest Monsoon (SWM) for Year 2006 and 2012

the temperature as well as the amount of moisture available. High temperature increase the evaporation rate and in return, reduces the relative humidity if the amount of moisture in remains the same (Lawrence, 2005).

Back-trajectory analysis: The Back trajectory analysis of the NEM and SWM for year 2006 and 2012 by utilizing the HYSPLIT model were shown in Fig. 2. In both monsoons, the air masses can arrive at the study area within 72 h. During the NEM of year 2006, the air mass passes along the Eastern coast of Vietnam and arrive at all stations from Hainan, China whereas in year 2012, the direction of the wind changes and brought air masses from Philippines to the stations by passing through South China Sea. Sea-spray aerosols is one of the major sources for ionic species associated with PM in East coast of Peninsular Malaysia (Tahir *et al*., 2013). In the SWM of both year 2006 and 2012, air masses were brought over from Sumatera, Indonesia in southern direction. The concentration of PM are usually high during SWM due to the haze episodes as a result of forest fires from Sumatera, Indonesia. The trajectory model of S1 in year 2012 shows that the air masses linger around the North-eastern part of Peninsular Malaysia, particularly Kelantan. This is due to the unique geographical features of the Kelantan state where it is surrounded by highlands and deep valleys, thus, trapping the air parcel.

CONCLUSION

The results from this study shows that averaged concentration of PM_{10} at all three stations are below the concentrations recommended by the Malaysia Government. The PM_{10} concentration varies significantly among the three stations. The highest daily average and PM_{10} concentration and daily average temperature were recorded at S2 with the value of 50.3 $\mu g\ m^{-3}$ and 27.3°C due to the fact that Terengganu have the highest percentage of urbanization compared to the other two states. For wind-speed and relative humidity, the highest value were recorded at S3. The monthly trend of the daily average PM_{10} concentration shows that the peak usually occurs during the dry monsoon (SWM) which is in month June. The daily average PM_{10} concentration shows positive correlation with temperature and wind-speed in all three stations. The air masses were noted to travel through the South China Sea from China (2006) and Philippines (2012) before arriving the stations during NEM whereas during SWM, the air masses usually originates from the Indonesia, passing the Straits of Malacca. Based on the findings of this study, it is noticeable that urbanization process is directly proportional to atmospheric PM_{10} concentration. Therefore, future development especially in Kuala Terengganu must be subjected to proper planning and assessment before project implementation.

NOMENCLATURE

PM	=	Particulate Matter ($\mu g\ m^{-3}$)
SWM	=	Southwest Monsoon
API	=	Air Pollution Index
NEM	=	Northeast Monsoon
PSI	=	Pollutant Standard Index
RH	=	Relative Humidity (%)
ASTHMA	=	Alam Sekitar Malaysia
T	=	Temperature (°C)
HYSPLIT	=	Hybrid Single Particle Lagrangian Integrated Trajectory
WS	=	Wind Speed (km h^{-1})

ACKNOWLEDGEMENTS

This study was funded by Fundamental Research Grant Scheme FRGS/2/2013/STWN01/UMT/02/1 (VOT 59312) and Universiti Malaysia Terengganu Scholarship Scheme (BUMT). The authors also would like to thank the Air Quality Division, Malaysian Department of Environment (DOE) for the air quality data. We gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and/or READY website (http://www.arl.noaa.gov/ready.html) and NASA's Earth Observing System Data and Information System (EOSDIS) on the Fire Information for Resource Management System (FIRMS) (https://firms.modaps.eosdis.nasa.gov) used in this publication.

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