Variation of Air Pollutant (Particulate Matter - PM_{10}) in Peninsular Malaysia

Study in the southwest coast of peninsular Malaysia

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Particulate matter (PM_{10}) received great attention due to its potential to cause adverse health effects. In this study, the variation of the long-term PM_{10} concentration from monitoring records in the southwest coast of peninsular Malaysia was analysed. Higher concentration of PM_{10} was detected in the southwest coast of peninsular Malaysia during the southwest monsoon. This is due to the low level winds that blow southerly or southwesterly during the summer period of peninsular Malaysia that associated with the long-range transportation of aerosol particles to Asian countries. The diurnal trend shows two peaks that can be observed in the morning at 9.00 a.m. and during evening starting at 10.00 p.m. The connection between PM_{10} concentration and meteorological factors such as ambient temperature, UVB, wind speed and humidity were also studied. The results show positive correlation of PM_{10} concentration with ambient temperature and negative correlation with humidity for most of the study areas.

Keywords: PM_{10}; peninsular Malaysia; meteorological factor; correlation coefficient

PM_{10} or particulate matter with aerodynamic diameter of less than 10 m has been classified as the most significant pollutant in Southeast Asia including peninsular Malaysia [1]. PM_{10} can be characterized by origin, e.g. anthropogenic or geogenic, primary or secondary particles; by source e.g. combustion products and traffic, or by physic-chemical properties such as solubility [2]. There are three main contributors of PM_{10} in Malaysia i.e. vehicular emissions, power stations and industrial sectors. Seventy six percent (4585 tonnes) of PM_{10} emission in Malaysia originated from motor vehicles whereas power plant emission impacted fifteen percent (15 tonnes) and only four percent (4 tonnes) caused by industrial sector [3]. The amount of PM_{10} in 2012 reduced to 22.7% if compared to 2011 that recorded 26 720 tonne in total.

As the most prevalent pollutant in Malaysia, PM_{10} concentration was frequently recorded exceeded the safe value of Recommended Malaysia Ambient Air Quality Guideline (RMAAQG), especially during the dry season [4-6]. High PM_{10} concentrations were detected during dry season or also known as summer monsoon (June to September) due to the vast quantities of smoke releases by biomass burning from regional sources. However, these study only focused on particulate pollution in Klang Valley, as it is reported as the most affected area [4, 5]. Hence, in this research, the coastal line of southwest of peninsular Malaysia is considered since the locations of these areas are closer to Sumatera.

Long-term studies on temporal distribution of the main pollutants such as PM_{10} and ozone are rare [6, 7]. Thus, the concentrations of PM_{10} in the southwest coast of peninsular Malaysia from 2000 to 2009 were operated in this research. The long-term chronological data of PM_{10} concentration were covered so that the results of this study can provide information for the studied area. The trend of PM_{10} were studied and analyze according to the site and correlated with the meteorological factors such as temperature, humidity, wind and solar radiation [6, 8-13].

Experimental part

Figure 1 shows the location of study area. Four stations were selected to represent the southwest coast of peninsular Malaysia i.e. SWC1, SWC2, SWC3 and SWC4. Two of the stations (SWC 1 and SWC2) monitor urban areas; one monitors a suburban area (SWC3); and one an industrial area (SW4). Weather plays a very important role in the formation, presence and behaviour of PM_{10}. Thus, in this study, the connection between PM_{10} concentrations and four weather parameters such as ambient temperature, humidity, wind speed and solar radiation were carried out. Hourly monitoring observations of 2009 for the four weather parameters were used to accomplish this connection.

Instruments and methodology

The hourly PM_{10} concentration was obtained from Air Quality Division, Department of Environment Malaysia (DoE) through continuous air quality monitoring (CAQM) station. In addition, meteorological parameters namely ambient temperature, UVB, humidity and wind speed were also used to study the relationship between PM_{10} concentration and meteorological factors. Generally, hourly

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Fig. 1. Location of study area

PM_{10} concentration was assembled from 2000 to 2009 whereas for meteorological parameters, hourly observations collected were for 2009. The Pearson correlation was conducted to determine the correlation between PM_{10} and meteorological factors [6]. The HYSPLIT 4.9 Model developed by the National Oceanic and Atmospheric Administration (NOAA) Air Resource Laboratory (ARL) was used for trajectory analysis [14]. The backward trajectory was used to study the effects of long range of transportation during two monsoons to the study areas. The meteorological input for the trajectory analysis was the National Weather Service's National Centers for Environmental Prediction (NCEP) GDAS (Global Data Assimilation System) dataset. All time given or discussed in this paper is the local time (Malaysian Standard Time, MST), which is 8h ahead of Universal Coordinated Time (UCT).

Results and discussions

Variations of PM_{10} observation

The statistics of PM_{10} concentrations in 4 stations located in southwest coast of peninsular Malaysia from 2000 to 2009 are represented in table 1. The mean concentration of PM_{10} recorded in SWC3 is higher compared to other stations. There are 7 out of 10 years; the concentrations exceeded the RMAAQG for PM_{10} that is 50 μg/m^3. Nevertheless, SWC4 station is an industrial area, the mean values of PM_{10} concentrations most of the times are below the recommended values of RMAAQG. However, the higher mean values were recorded in 2005, 2006 and 2009 for all stations due to moderate haze caused by the trans-boundary sources of biomass burning around Southeast Asia (DoE 2005- 2009). Observations of PM_{10} in SWC3 station shows higher variability due to higher standard deviations values ranging from 22.0 μg/m^3 to 36.0 μg/m^3 compared to other stations. The maximum value was recorded in SWC4 station (2009) that is 780 g/m^3 whereas the minimum values recorded are 5 μg/m^3.

Seasonal variation

The monthly trend of mean PM_{10} concentration in the southwest coast and the east figure 4 respectively. In the southwest coast area, there are noticeable seasonal variations in PM_{10} concentrations with very high concentrations recorded from June to September. Days when PM_{10} exceeded the RMAAQG value of 50μg/m^3 are infrequent, however, during the summer monsoon (June to September), PM_{10} reading for all stations exceeded 50 μg/m^3 [1]. Apparently, higher concentration can be observed starting June and reached the peak in August. The southwest monsoon occurs from June to September each year and usually associated with haze pollution in the peninsular Malaysia due to biomass burning from Sumatra, Indonesia [15]. PM_{10} observations exhibit minimum concentration during the month of November to December where the southwest coast of peninsular Malaysia experienced the maximum rainfall during this period (Malaysian Meteorological Department; www.met.gov.my).

The effect of higher PM_{10} concentration recorded in the southwest coast of peninsular Malaysia during southwest monsoon (June to September) and northeast monsoon (November to Mac) can be visualized by trajectory analysis. Figure 2 illustrate the 120 h backward trajectory for 3 February 2009 (during the northeast monsoon) and 15 July 2009 (during the southwest monsoon) ending at 0000UTC (08:00MST). The explanation of the trajectory analysis will be associated with the monthly mean values of PM_{10} concentrations for stations in southwest coast and east coast of peninsular Malaysia (table 2). All stations show high value of PM_{10} concentration during southwest monsoon or summer monsoon and lower concentration of PM_{10} were observed during the northeast monsoon or often called the rainy season (table 2). The highest concentration was recorded in SWC3 i.e. 63μg/m^3 during the southwest monsoon and the lowest was observed in SWC2 (33 μg/m^3) during the northeast monsoon. The variation of PM_{10} concentration is associated with the distribution of rainfall with negative correlation [16-18]. Juneng et al. (2009) characterized the southwest coast of peninsular Malaysia with PM_{10} concentration detected highest during the summer monsoon i.e. when the winds are southerly or southwesterly, and minimum concentration was recorded during the rainy season (northeast monsoon).

Peninsular Malaysia experiences were performed in the dry season during the summer monsoon where low level winds were mainly southerly or southwesterly. Thus, the forest fire incidence during these period will caused the long-range transportation of particulate across Malacca Strait to the southwest of peninsular Malaysia [19]. Figure 2 (B) shows the backward trajectories of the stations in the southwest coast. The coastal area was affected with the transboundary haze pollution directed from Sumatra; hence, high concentration of PM_{10} was observed during this particular time (table 3). However, no significant effect of northeasterly wind on PM_{10} concentration was observed in the southwest area of peninsular Malaysia since the monthly mean of PM_{10} concentration show no significant rise that range from 42 μg/m^3 to 47μg/m^3 (table 3).

Diurnal variations

The diurnal trend of PM_{10} concentration in the southwest region of peninsular Malaysia is presented in figure 3. The variations of PM_{10} observation demonstrated a peak in the morning and maximum peak at night. Sunrise in peninsular Malaysia started at 7.00 a.m. and sunset around 7.30 p.m. PM_{10} concentrations started to rise in the morning at 7.00 a.m. and reach a peak at 9.00 a.m. before slowly decrease. The morning peak is due to vehicular emissions as most of people are leaving for work and school. SWC4, an industrial area demonstrates highest concentrations of PM_{10} during

YEAR	STATION	PARAMETER					
		Available data	Mean	Standard deviation	Mode	Maximum	Minimum
2000	SWC1	7121	48.0	30.4	37	427	5
2001		8423	41.3	24.0	23	374	5
2002		8548	45.3	24.8	29	266	5
2003		8596	43.7	23.2	40	328	5
2004		8609	47.6	26.1	30	361	5
2005		8564	**49.1**	36.7	41	528	5
2006		8446	**48.8**	35.1	29	531	5
2007		8422	37.9	19.5	29	241	5
2008		8503	39.1	19.6	34	343	5
2009		8533	**42.8**	23.5	34	433	5
2000	SWC2	7731	39.4	23.2	31	387	5
2001		8442	36.9	20.8	25	233	5
2002		8608	42.4	24.4	32	311	5
2003		8639	38.4	22.9	26	382	5
2004		8584	39.2	26.5	31	519	5
2005		7389	**57.2**	30.1	39	362	8
2006		8364	**50.2**	34.2	41	500	5
2007		8340	36.2	21.2	30	397	5
2008		8506	36.7	19.8	32	310	5
2009		8582	**45.4**	33.1	32	640	5
2000	SWC3	8482	54.0	**32.9**	35	391	5
2001		7908	49.4	27.4	34	351	6
2002		8649	**62.6**	**35.5**	39	563	8
2003		8205	51.5	26.8	47	300	5
2004		8440	50.0	**35.0**	34	546	5
2005		8672	**53.7**	**34.5**	43	503	5
2006		8674	**53.8**	**36.4**	35	447	6
2007		8584	42.2	22.3	28	242	5
2008		8485	47.6	21.8	34	290	5
2009		8499	**53.0**	**34.0**	36	576	6
2000	SWC4	8529	51.9	19.2	44	229	6
2001		8576	49.6	18.5	47	211	6
2002		8416	47.0	26.9	52	398	5
2003		8548	48.9	26.9	42	421	5
2004		8536	46.9	23.0	39	269	5
2005		8547	**46.8**	23.9	38	258	5
2006		8333	**49.0**	29.0	32	358	5
2007		7624	44.8	24.3	33	378	5
2008		8527	53.3	36.2	46	620	5
2009		8633	**58.3**	33.7	49	**780**	7

Table 1
STATISTICS OF PM_{10} CONCENTRATIONS FOR STATIONS LOCATED IN THE SOUTHWEST COAST OF PENINSULAR MALAYSIA FROM 2000-2009

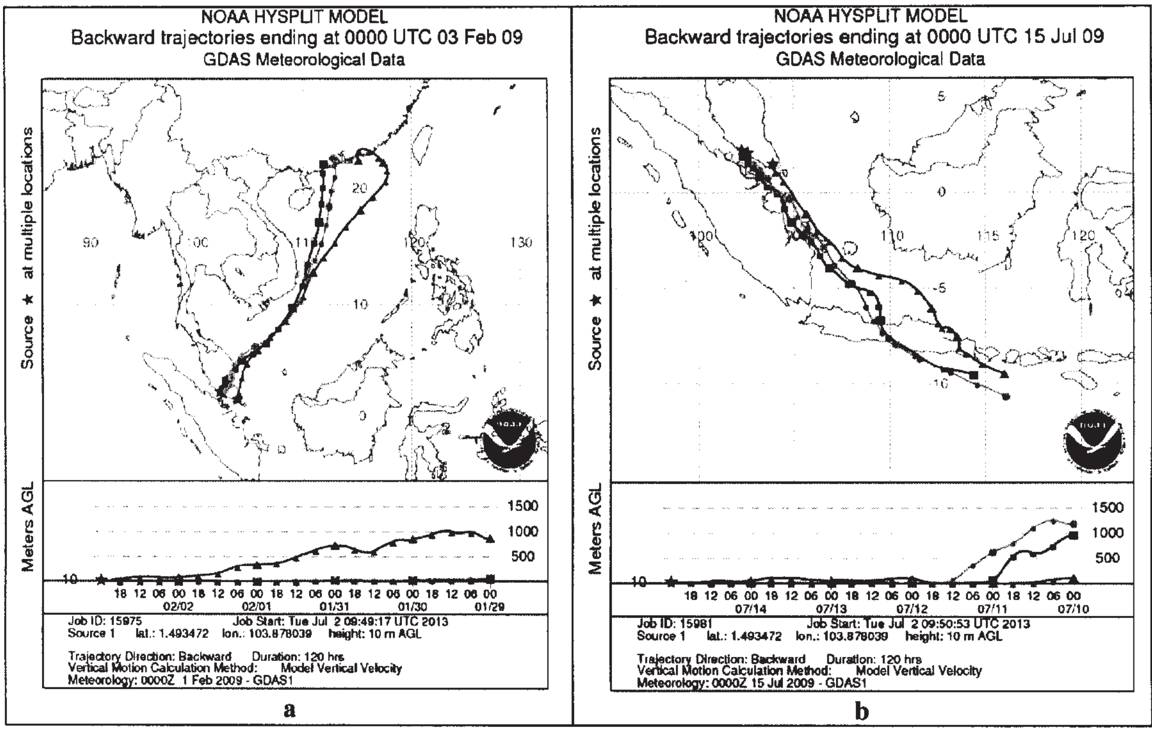

Fig. 2. The 120 h backward trajectory for 3 February 2009 and 15 July 2009 ending at 0000UTC (08:00MST) for stations located in the southwest coast (a and b) of peninsular Malaysia respectively

the morning peak. This phenomenon is contemplated with the location of this station that is situated near by few residential areas. Hence, during these particular times, the number of motor vehicles increased as people are performing their morning routine. The evening peak starts at 6.00 p.m. and reach the maximum peak at 11.00 p.m. This occurrence is in line with the people returning back from work. SWC3 shows higher peak compared to other areas. The late evening peak is attributed with the meteorological conditions that are mainly atmospheric

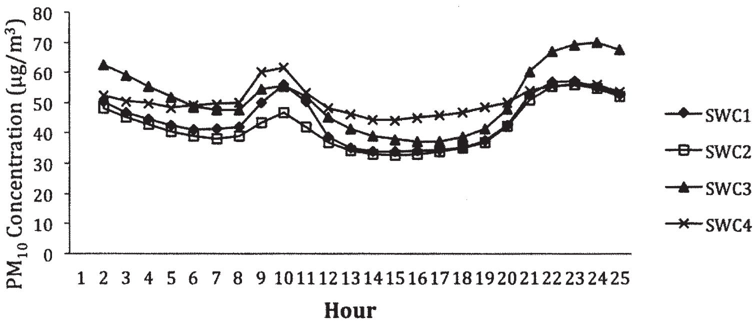

Fig. 3. Hourly mean of PM_{10} concentrations in the southwest coast of peninsular Malaysia

Table 2
MONTHLY MEAN OF PM_{10} CONCENTRATION RECORDED FROM 2000 TO 2009

MONTH	STATION Southwest coast of peninsular Malaysia			
	SWC1	SWC2	SWC3	SWC4
January	34	36	36	40
February	42	42	47	43
March	43	41	51	45
April	40	39	49	47
May	48	44	57	54
June	49	46	61	55
July	50	46	61	60
August	56	51	**63**	57
September	48	46	61	56
October	49	46	55	56
November	36	**33**	39	44
December	35	34	40	37

Table 3
STATISTICS OF METEOROLOGICAL PARAMETERS IN PENINSULAR MALAYSIA

PARAMETER		Available data	Mean	Standard deviation	Mode	Maximum	Minimum
Temperature (°C)	SWC1	8031	27.0	3.0	24.5	35.4	20.7
	SWC2	8762	28.1	2.6	25.8	35.1	23.0
	SCW3	8723	27.5	3.0	24.5	35.4	22.0
	SCW4	8765	26.8	2.5	24.5	34.3	21.3
UVB (J/m²/h)	SWC1	N/A	N/A	N/A	N/A	N/A	N/A
	SWC2	N/A	N/A	N/A	N/A	N/A	N/A
	SCW3	N/A	N/A	N/A	N/A	N/A	N/A
	SCW4	8112	182.3	293.0	1	1490.0	0.0
Humidity (%)	SWC1	8763	76.2	14.7	92.0	100.0	32.0
	SWC2	8775	74.3	11.0	84.0	93.0	32.0
	SWC3	8723	77.2	12.9	91.0	95.0	33.0
	SWC4	8765	81.6	11.3	93.0	96.0	43.0
Wind speed (km/h)	SWC1	8738	4.9	2.9	2.3	18.9	0.9
	SWC2	7352	6.3	3.4	3.5	26.9	1.0
	SWC3	8716	5.3	3.0	1.0	17.7	0.9
	SWC4	8734	5.9	3.2	2.9	19.2	0.9

Table 4
CORRELATION MATRIX BETWEEN PM_{10} AND METEOROLOGICAL PARAMETERS

STATIONS	PARAMETERS	PM_{10}	Temperature	UVB	Humidity	Wind Spe
SWC1	PM_{10}	1				
	Temperature	0.241^{**}	1			
	UVB	N/A	N/A	1		
	Humidity	-0.118^{*}	-0.795^{**}	N/A	1	
	Wind Speed	0.082	0.516^{**}	N/A	-0.639^{**}	1
SWC2	PM_{10}	1				
	Temperature	0.373^{**}	1			
	UVB	N/A	N/A	1		
	Humidity	-0.406^{**}	-0.508^{**}	N/A	1	
	Wind Speed	0.71	0.120^{*}	N/A	-0.296^{**}	1
SWC3	PM_{10}	1				
	Temperature	0.363^{**}	1			
	UVB	N/A	N/A	1		
	Humidity	-0.222^{**}	-0.603^{**}	N/A	1	
	Wind Speed	0.46	0.176^{**}	N/A	0.093	1
SWC4	PM_{10}	1				
	Temperature	0.421^{**}	1			
	UVB	-0.226^{**}	-0.820^{**}	1		
	Humidity	-0.177^{**}	0.229^{**}	-0.500^{**}	1	
	Wind Speed	-0.177^{**}	0.229^{**}	-0.500^{**}	1.000^{**}	1

stability and wind speed [20, 21]. The minimum concentrations of PM_{10} can be observed in the afternoon from 2.00 p.m. to 4.00 p.m. due to less outdoor activities, thus lesser vehicle emissions was produced compared to morning and evening.

Meteorological effects

The meteorological parameters data recorded at each station in the southwest coast of peninsular Malaysia is summarized in table 3. The averaged temperature recorded in all stations varies from 24.5 to 25.8°C while humidity range from 74% to 88%. The wind speed was recorded higher from usual (3 km/h to 5km/h) that varies from 4.9 km/h to 6.3 km/h [6]. Since, most of the stations are located near to the sea, higher wind speed values were observed. Sequentially, the relationship between PM_{10} concentration and meteorological parameters is obtained via Pearson correlation matrix that is presented in table 6. Almost all stations show positive correlation coefficient (*r*) between PM_{10} concentration and ambient temperature that ranging from 0.241 to 0.421. A negative correlation also can be observed between PM_{10} concentration and humidity for all stations. The highest correlation coefficient was observed in SW2 (r = -0.406) whereas the smallest value was demonstrated in SWC1 (r = -0.118). High humidity is usually associated with the rain occasions, thus reduces the particles due to wash-out processes of atmospheric aerosols in the atmosphere [6]. While for wind speed and UVB, minor influence was observed in the study area.

Conclusions

The long-term trend of PM_{10} concentration from 2000 to 2009 in the southwest coast of peninsular Malaysia was studied. Four stations in the southwest coast of Malay peninsular that represent urban, suburban and industrial were analyzed. Generally, PM_{10} concentration in the southwest area of peninsular Malaysia exhibits higher concentration than the east coast. However, Kuala Terengganu (EC3) that is categorized as urban area in the east coast of peninsular Malaysia demonstrates high PM_{10} concentration that exceeded the RMAAQG value for PM_{10} that is 50 g/m^3 most of the time. Rapid development and urbanization were detected as the main cause of this occurrence. The seasonal variation for the southwest region of peninsular Malaysia is observed during the southwest monsoon (June to September), where high PM_{10} event can be detected. This is due to the low level winds that blow southerly or southwesterly during the summer period of peninsular Malaysia, where usually during this particular time, biomass burning in Sumatra will cause long range transportation of aerosol particles to Asian countries. The diurnal trend shows two peaks i.e. at 9.00 a.m. and during evening at 10.00 p.m. This is due to people leaving and returning from work and school.

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