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Characterization of Chemical Composition in Fine Particles ($PM_{2.5}$) from Industrial Site in Malaysia

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Abstract

This research aims to investigate variations of fine Particulate Matter ($PM_{2.5}$) and chemical composition in an industrialized area. Concentration levels of fine Particulate Matter ($PM_{2.5}$) were continuously monitored at three sampling site S1, S2 and S3. The variations of $PM_{2.5}$ concentration were analysed using descriptive statistics, time series plot, diurnal plot and correlation. Source apportionment and factor analysis were carried out using the chemical composition data from ICP-OES. Meteorological effects on $PM_{2.5}$ concentration were used to investigate the effects on $PM_{2.5}$ concentration. The results showed that, the average $PM_{2.5}$ concentration was 19.75 ± 12, 46.68 ± 27, and 20.55 ± 9 μg m^{-3} at sites in a S1, S2 and S3, respectively. The highest $PM_{2.5}$ concentration was recorded in S2 (115 μg m^{-3}). The $PM_{2.5}$ concentration in the diurnal plot exhibited an inversed unimodal pattern during morning (7:00 to 9:00) and evening (16:00 to 18:00). $PM_{2.5}$ concentration in S2 on weekends was 36% lower than that on weekdays. $PM_{2.5}$ was found to exhibit an inversed relation with wind speed and temperature. Although wind speed had a negative association with $PM_{2.5}$ in S1 and S2, a positive correlation was observed at S3. Source apportionment from factor analysis distinguished three groups of possible sources; crustal materials (Al, K, Sr, Ti and Na), vehicles emission (Cr, Fe, Mn, Zn and Ni) and industrial activities (Ca, Mg and Pb).

Keywords

source apportionment, tropical climate, meteorological parameter, temporal variations, trace elements, factor analysis

1. Introduction

Airborne Particulate Matter (PM) originates from a wide variety of natural and anthropogenic sources. Sources of PM can be generated by primary from sources such as automobile exhausts, industrial

combustion, biomass burning, volcanic eruptions, wind driven or traffic related suspension of road, soil and mineral dust, sea salt, biological materials, and mechanical processes and, secondarily, from gaseous pollutants (Tiwary & Colls, 2010). The variability of $PM_{2.5}$ concentration and composition are strongly influenced by seasonal meteorological factors, gaseous parameters, local activities (anthropogenic or natural emissions) and the location of the study area (Tai et al., 2010; Amil et al., 2016).

PM concentrations in Asian cities are increased due to the contribution of urbanization, industrialization, and vehicular usage as well as progressive expansion of suburbs into close proximity with industrial plants in certain areas (Chen et al., 2016; Khan et al., 2016). PM with an aerodynamic diameters less than 2.5 μm ($PM_{2.5}$) has been studied extensively as it is associated with air quality issues, particularly in industrial areas by Huang et al. (2013) in China and Shaltout et al. (2013) in Saudi Arabia including emission sources, physical characteristics, and chemical composition. Nilai, an industrialized area, have reported high readings of PM_{10} concentrations during normal periods and haze events by previous researcher (Sansuddin et al., 2011; Ul-Saufie et al., 2013; Mohamed Noor et al., 2011) as it is rapidly growing town surrounded by many industrial areas in the Seremban district. The particles released from industrial areas are suspected added to air pollution in Nilai and affected the residents exposed to such pollution. However, there were limited studies that focused to the spatial-temporal variations of $PM_{2.5}$ variation and chemical composition in Nilai.

Factor analysis is one of the receptor modeling that are chosen for an exploratory of possible sources of $PM_{2.5}$ in Nilai. This methods are well developed in source apportionment of air pollution as similar application of factor analysis by Khodeir et al. (2012) and Heal et al. (2012) for $PM_{2.5}$ and PM_{10} particles which resulted in five factors were identified: soil, heavy oil combustion, traffic, industry mix 1, and industry mix 2. In order to assess the contribution of traffic exposure to the $PM_{2.5}$ concentration, this study investigated the temporal variations of $PM_{2.5}$ concentrations and relationships between $PM_{2.5}$ and meteorological factors in an industrialized area. Monitoring have been performed at 3 industrial sites characterized by different exposure to the industrial source. The chemical composition of $PM_{2.5}$ was identified, and the possible sources of its associated elements were determined using Factor Analysis (FA).

2. Method

2.1 Sampling Site

This study has been conducted at the three sites in Nilai from December 29, 2014 to January 19, 2015. These three sites are sites S1, S2 and S3. The sampling sites within the industrialized areas were chosen for (1) their consistency with existing Continuous Air Quality Industrial Monitoring Station (CAQMS) done by Department of Environment (DOE), Malaysia and (2) their location in dominantly industrial settings to reflect the major $PM_{2.5}$ emission source as industrial activities. Table 1 shows a list of the monitoring sites used in this study and their pertinent geographic details. S1 is located in a residential

area within the vicinity of the town of Nilai; it is near a primary school (~500 m), and an industrial area (within 3 km radius). The S2 site is located near the KTM station northeast of the town of Nilai. It is close to main roads and influenced by emissions from the vehicles, industrial activities of a paint manufacturer in the northwest (~500 m), quarry activities in the northeast (1 km), and a concrete ready-mix facility in the east (~500 m). The S3 site is located in Bandar Baru Nilai, which is characterized by rapid developments in housing (~500 m), construction activities (~1 km), and urban centers (within 500 m). This three sites were surrounded by a few highway that links from Kajang to Seremban (LEKAS highway), Nilai to KLIA (ELITE highway) and PLUS Expressway (Figure 1).

Nilai has a typical tropical rainforest climate because it is located near the equator at an altitude of about 32 m above sea level. It experiences high temperatures between 22°C and 31°C and heavy precipitation throughout the year. This area received the mean annual rainfall about 222 cm.

Table 1. Specific Details of Monitoring Location

Site	Site Description	Latitude, N	Longitude, E
S1	Within 3 km radius from industrial area	2° 49’ 16.86	101° 48’ 47.41
S2	Within 1 km radius from industrial area	2° 49’ 47.89	101° 49’ 37.05
S3	Within 2 km radius from industrial area	2° 49’ 22.87	101° 47’ 24.35

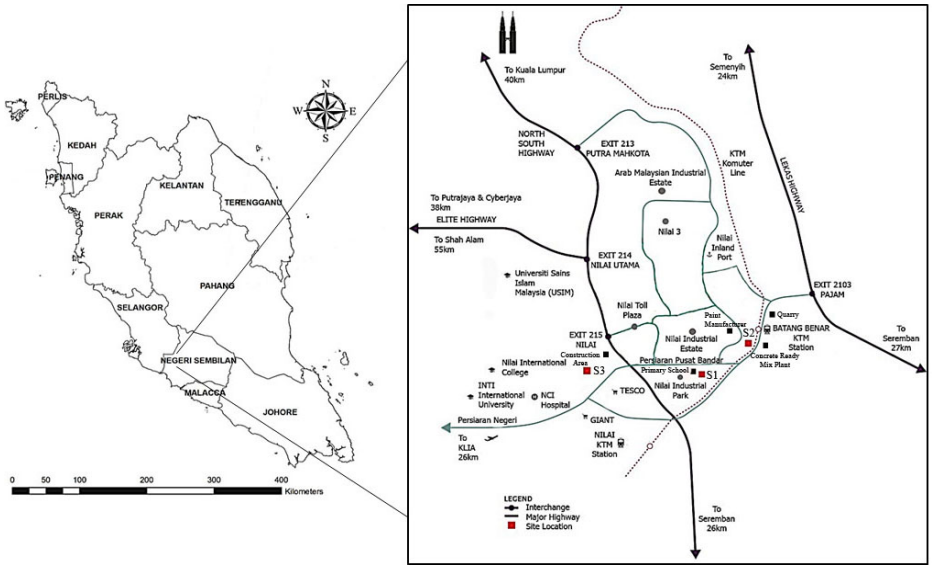


Figure 1. Sampling Sites at Nilai

2.2 Sampling of $PM_{2.5}$ Concentration

$PM_{2.5}$ concentration and meteorological parameters (relative humidity, temperature and wind speed) were measured continuously by using Met One Instrument (E-BAM), a portable real time sampler that meet the USEPA requirement of Federal Equivalence Method (FEM) for Class III $PM_{2.5}$ measurement (40 CFR Part 53) (Met One Instrument, 2008). This equipment was operated with the sampling flow rate (16.70 l m-1) through the glass fibre filter (#460130, Met One, Grant Pass, Oregon, USA). Measurements began at 7:00 and ended at 19:00 (GMT + 8 h) for seven days for each site. Data and tape advances was set for every 1 h intervals during the sampling period. Under normal operating conditions, $PM_{2.5}$ particle deposits on filter paper with diameter of 11mm and run continuously. Prior to weighing, the filters were stored under a constant temperature and relative humidity condition of 25 °C and 50%, respectively for 24 h as suggested by Watson et al. (2012).

2.3 Chemical Analysis of $PM_{2.5}$ Particles

Hot plate acid digestion was used for the extraction of chemical composition. The method of digestion was based on the compendium method IO 3.1 (Ventura et al., 2014; Gummeneni et al., 2011; Mateus et al., 2013). After a gravimetric analysis, a punch with 13 mm diameter on the sampled glass fiber filter was divided into two equal portions by using a sterile disposable scalpel (N0146687, size 10, Kiato, Hannover, Germany). The filter paper were treated with a mixture of 10 mL (HNO_3 and HCl, 3:1 (v/v) each) in a beaker before heating for 30 min at 85 ˚C on a hot plate. After digestion, the solutions were filtered through 0.22 μm pore size (Millipore), then diluted to 50 mL with deionized water. High Density Polyethylene (HDPE) bottles were used to store the solutions below 4 ˚C prior to analysis. Three types of blanks (reagent blank, field blank and laboratory blank) were also carried out with these extraction methods for quality control purposes.

Inductively coupled plasma–optical emission spectrometry (ICP–OES; Varian 715-ES) was employed for the chemical composition determination. The calibration of ICP-OES was carried out using NIST SRM 1648a urban particulate matter was used to verify the extraction procedure and results. Not less than 20 mg of NIST SRM 1648a was added to the sample beaker (Mateus et al., 2013). The SRM was then ready for extraction procedure similar to the sample digestion. The limits of detection and quantification were determined with the standard solution based on the standard deviation of the response and slope. The limits of detection ranged from 0.06 ppb to 9.49 ppb for most elements, except for Ca and Cr, which had limits of 26.74 ppb and 708.18 ppb respectively.

2.4 Variations of $PM_{2.5}$ Concentration

The data obtained from the three sites were analyzed with the Statistical Package for Social Sciences (SPSS; Windows version 22.0). Time series and diurnal plot were applied to investigate the hourly $PM_{2.5}$ concentrations in Nilai with data collected in 21 d (n=252). The hourly average was computed from 7:00 to 19:00 daily to record the diurnal plot.

2.5 Correlation between $PM_{2.5}$ and Meteorological Parameter

Pearson's correlation was utilized to analyze the significance of meteorological parameters in $PM_{2.5}$ concentration. When two variables have a linear relationship beyond what is expected by chance alone it is called correlation (Stockwell, 2008). The Pearson's correlation value is denoted as "r". It measures the degree of association between the two values of related variables given in the dataset, and its value ranges from +1 to −1. A value of +1 indicates that a perfect positive relationship exists between two variables. A value of 0 denotes the absence of correlation, and a value of −1 denotes a perfect negative correlation (Dominick et al., 2012). The general formula of r is shown in Eq. (1) (Elbayoumi et al., 2014):

$$r_{xy} = \frac{S_{xy}}{\sqrt{S_{xx} S_{yy}}} \quad (1)$$

$$S_{xy} = \sum(X_i - \overline{X})(Y_i - \overline{Y}),$$
$$S_{xx} = \sum(X_i - \overline{X})^2,$$
$$S_{yy} = \sum(Y_i - \overline{Y})^2,$$

where X_i and Y_i correspond to the values of variables X and Y, respectively, and $\overline{X}$ and $\overline{Y}$ are the mean values of X_i and Y_i, respectively.

2.6 Source Apportionment of $PM_{2.5}$ Chemical Composition

To identify and estimate the possible sources of $PM_{2.5}$, FA was applied to the hourly averaged of chemical composition that resulted from the ICP-OES analysis through varimax rotation and retention of factor components. After extraction, only factors with eigenvalues greater than one were considered to be the factor component based on Kaiser' s criterion in order to create the group (Khodeir et al., 2012; Martinez et al., 2012; Seinfeld & Pandis, 2006). FA analysis reduces the number of variables while holding the original information as much as possible. Therefore, variables with the same characteristics can be grouped into the same factors. FA proceed as follows (Seinfeld & Pandis, 2006):

(1) The correlation matrix for all the variables is computed.

(2) Factor extraction is applied.

(3) Factor rotation is applied between the original values and the extracted factors.

Maximum total variability of the dataset was explained in each data set, and this set is completely uncorrelated with the rest of the data. Thus, chemical elements with high loading in each factor are interpreted as fingerprints of the emission source that represent. Typically, only total variance higher than 60% can be considered as significant (Khodeir et al., 2012; Martinez et al., 2012).

3. Result

3.1 $PM_{2.5}$ Concentration and Meteorological Parameter

The 12 h concentrations of $PM_{2.5}$ at the three sites varied from 1.00 μg m^{-3} to 115 μg m^{-3}, as shown in Table 2. The highest $PM_{2.5}$ concentration was found at site S2 with an average of 46.68 μg m^{-3}, followed by S3 (20.55 μg m^{-3}) and S1 (19.75 μg m^{-3}). Relative humidity and wind speed ranged from

47.67 % to 69.39 % and 0.71 m s^{-1} to 1.80 m s^{-1}, respectively.

Table 2. $PM_{2.5}$ Concentration and Meteorological Parameter at Different Sites (n=252)

Parameter	Site	Mean	Median	S.D.	Min	Max.
$PM_{2.5}$ Concentration	S1	19.75	18.00	11.67	1.00	57.00
(μg m^{-3})	S2	46.68	38.50	27.65	6.00	115.00
	S3	20.55	20.00	9.66	2.00	45.00
Temperature	S1	28.61	28.70	3.03	24.40	34.90
(°C)	S2	28.85	28.65	3.44	20.10	34.60
	S3	31.63	32.40	3.32	25.80	36.20
Relative Humidity	S1	66.76	64.00	12.99	45.00	90.00
(%)	S2	69.39	68.50	14.09	27.00	90.00
	S3	47.67	45.00	11.37	33.00	69.00
Wind Speed	S1	0.71	0.80	0.32	0.30	1.90
(m/s)	S2	0.87	0.60	0.34	0.40	1.50
	S3	1.80	1.80	0.24	1.10	2.60

3.2 Hourly Variation in $PM_{2.5}$ Concentration

The hourly variation in the three sites obtained with E-BAM is presented in Figure 2. $PM_{2.5}$ concentration showed pattern variations from Days 1 to 7 (Monday to Sunday) during the monitoring of each site. The reference line shows the USEPA and WHO standards for 24 h averaged time of $PM_{2.5}$. The line was drawn in the plots to show the instances $PM_{2.5}$ concentration exceeded established standards during the monitoring. $PM_{2.5}$ concentration in S2 exceeded USEPA and WHO limits more frequently than those in S1 and S3.

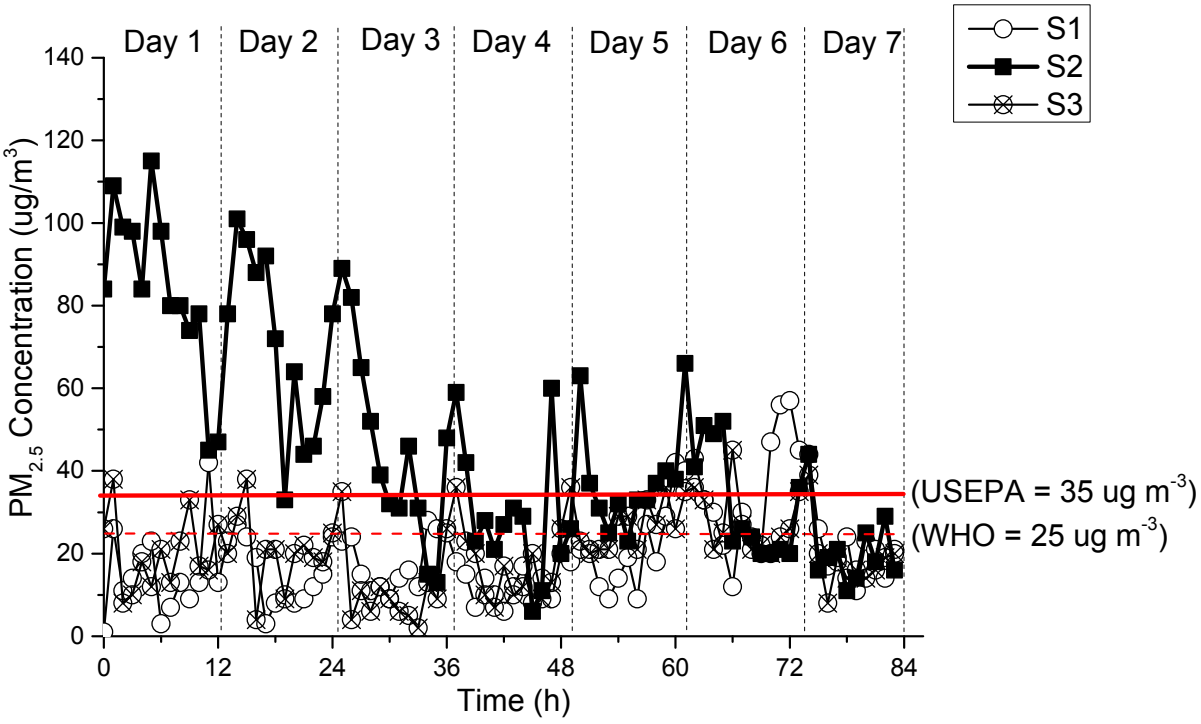


Figure 2. Hourly Variations of $PM_{2.5}$ Concentration Measured in Three Sites in Nilai

3.3 Diurnal Variations in $PM_{2.5}$ Concentration

Figure 3 shows the diurnal variations in $PM_{2.5}$ concentration in the three sites in Nilai. The $PM_{2.5}$ concentration in S1 and S3 exhibited an inverse unimodal pattern in 12 h. The $PM_{2.5}$ concentration in S2 increased in the morning (07:00 to 09:00), decreased in the afternoon (9:00 to 14:00) and increased again in the late evening (16:00 to 18:00).

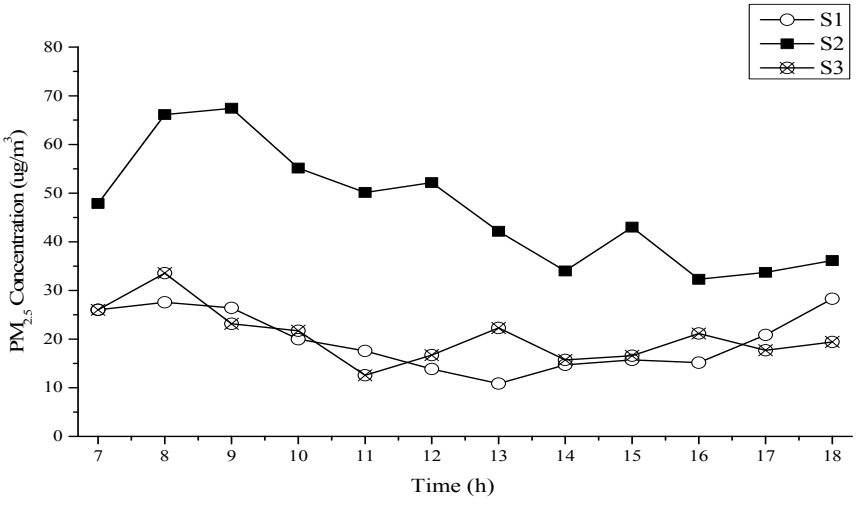
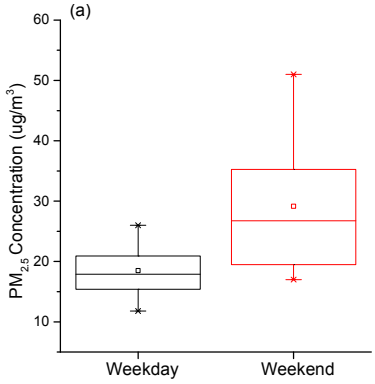
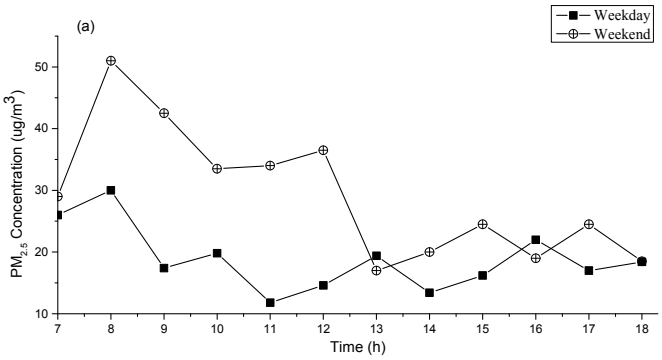


Figure 3. Diurnal Trends of $PM_{2.5}$ Concentrations at Three Sites

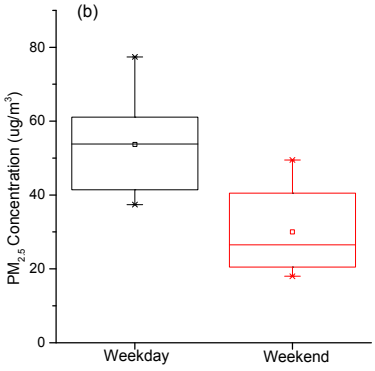
3.4 Effects of Weekday and Weekend Variations

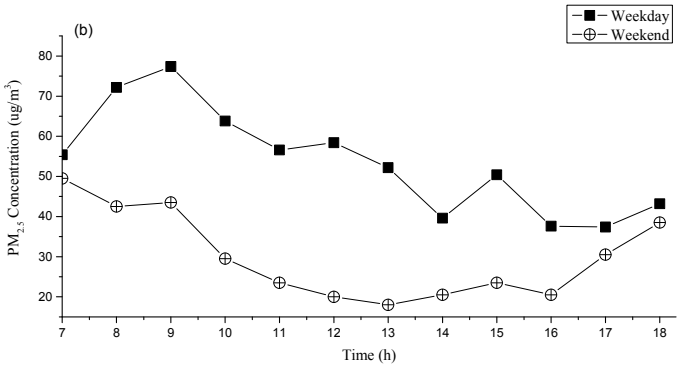
Figure 4 shows the patterns of hourly variations in $PM_{2.5}$ concentrations, i.e., the increment and decrement trends were different during the weekdays (Monday to Friday) and weekends (Saturday and Sunday). The average concentration of $PM_{2.5}$ in S2 was higher than those in S1 and S3 on weekdays and weekends because S2 is the closest to the industrial area. The concentrations ranged from 37.40 µg m^{-3} to 77.40 µg m^{-3} on weekdays and from 18.00 µg m^{-3} to 49.50 µg m^{-3} on weekends. Similar observation was found by Amil et al. (2016) where $PM_{2.5}$ concentration is lower during weekend (26.00 µg m^{-3}) compared to weekday (29.00 µg m^{-3}).



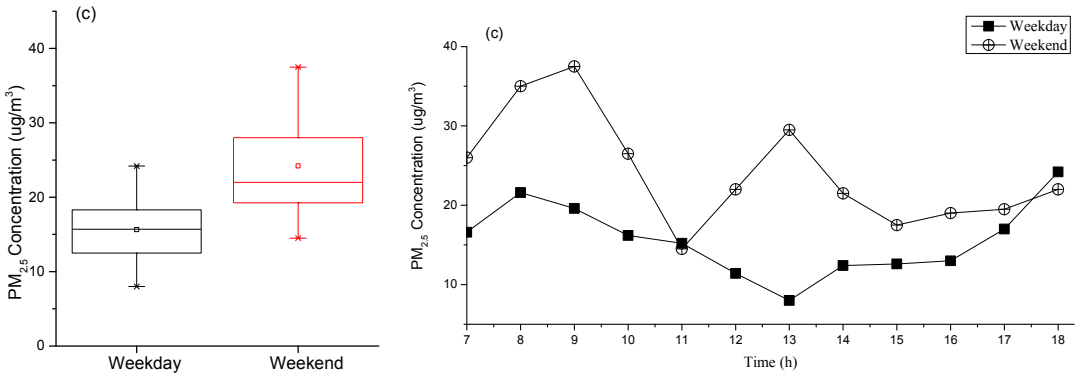


Sampling	Min.	1st Quartile, Q_1	Median	3rd Quartile, Q_3	Max.
Weekday	11.80	15.80	17.90	20.35	33.00
Weekend	17.00	19.75	26.75	34.62	51.00





Sampling	Min.	1st Quartile, Q_1	Median	3rd Quartile, Q_3	Max.
Weekday	37.40	42.30	53.80	59.75	77.40
Weekend	18.00	20.50	26.50	39.50	49.50



Sampling	Min.	1st Quartile, Q_1	Median	3rd Quartile, Q_3	Max.
Weekday	8.00	12.55	15.70	17.65	24.20
Weekend	14.50	19.37	22.00	27.25	37.50

Figure 4. Boxplot and Diurnal Trends of $PM_{2.5}$ Concentrations during Weekend and Weekday for (a) S1 (b) S2 (c) S3

3.5 Effects of Meteorological Parameters and $PM_{2.5}$ Concentration

Figure 5 shows the changes in $PM_{2.5}$ concentration and meteorological patterns in the different sites over time. Wind speed changes affect $PM_{2.5}$ concentration, and an increase in wind speed generally leads to a decrease in $PM_{2.5}$ concentration (Dawson et al., 2007). In S1 and S2, high $PM_{2.5}$ concentration was observed at a low wind speed. However, in S3, high $PM_{2.5}$ concentration was observed at high wind speed. The diurnal plot of temperature for all sites showed as air temperature increased, concentrations of $PM_{2.5}$ were significantly decreased at three sites. High temperature can be observed occurred at evening time (14:00 until 16:00), except for S2 (12:00). During this high temperature, $PM_{2.5}$ concentration was decreased. Wu et al. (2013) discussed that the low concentration of $PM_{2.5}$ during the maximum temperature happen because intense radiation heats city underlying surface. The lower atmosphere is not very stable and turbulent strengthens, which is advantageous to the diffusion of pollutants and the probability of atmospheric pollution decreased with the increase of air temperature can occurred. While Dawson et al. (2007) discussed that inversely proportional between $PM_{2.5}$ concentration and temperature was due to volatilization at high temperature. The diurnal plot of relative humidity for all sites showed, high relative humidity was recorded at the morning (7:00 until 8:00) for each site. The maximum relative humidity was occurred at S2, as there are a few of rain occurrences during the monitoring.

3.6 Correlation between $PM_{2.5}$ and Meteorological Parameter

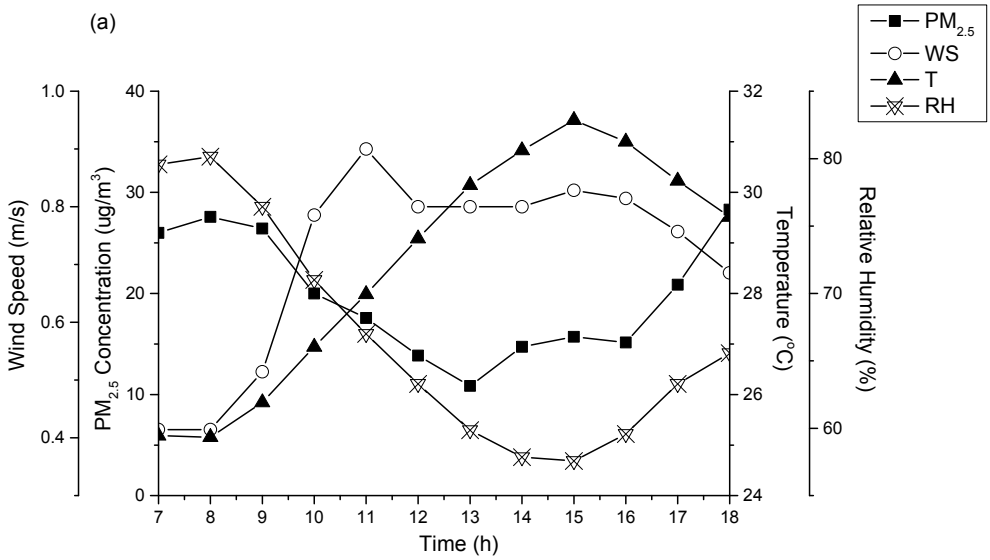
Table 3 shows the correlations between $PM_{2.5}$ and meteorological parameters (relative humidity, temperature, and wind speed) in all the sites. S1 and S2 presented a negative significant correlation ($p<0.05$) among $PM_{2.5}$, wind speed, and temperature compared with S3. Relative humidity was

positively correlated in S1 and S3 and weakly correlated in S3.

Table 3. Correlation (r Value) between Parameters at Nilai

Site	Parameter	$PM_{2.5}$	Wind Speed	Temperature	Relative Humidity
S1	$PM_{2.5}$	1			
	Wind Speed	-0.70*	1		
	Temperature	-0.45*	0.78*	1	
	Relative Humidity	0.75*	-0.85*	-0.97*	1
S2	$PM_{2.5}$	1			
	Wind Speed	-0.85*	1		
	Temperature	-0.53	0.57	1	
	Relative Humidity	0.45	-0.39	-0.90*	1
S3	$PM_{2.5}$	1			
	Wind Speed	0.15	1		
	Temperature	-0.61*	-0.72*	1	
	Relative Humidity	0.67*	0.68*	-0.99*	1

*Correlation is significant at the 0.05 level.



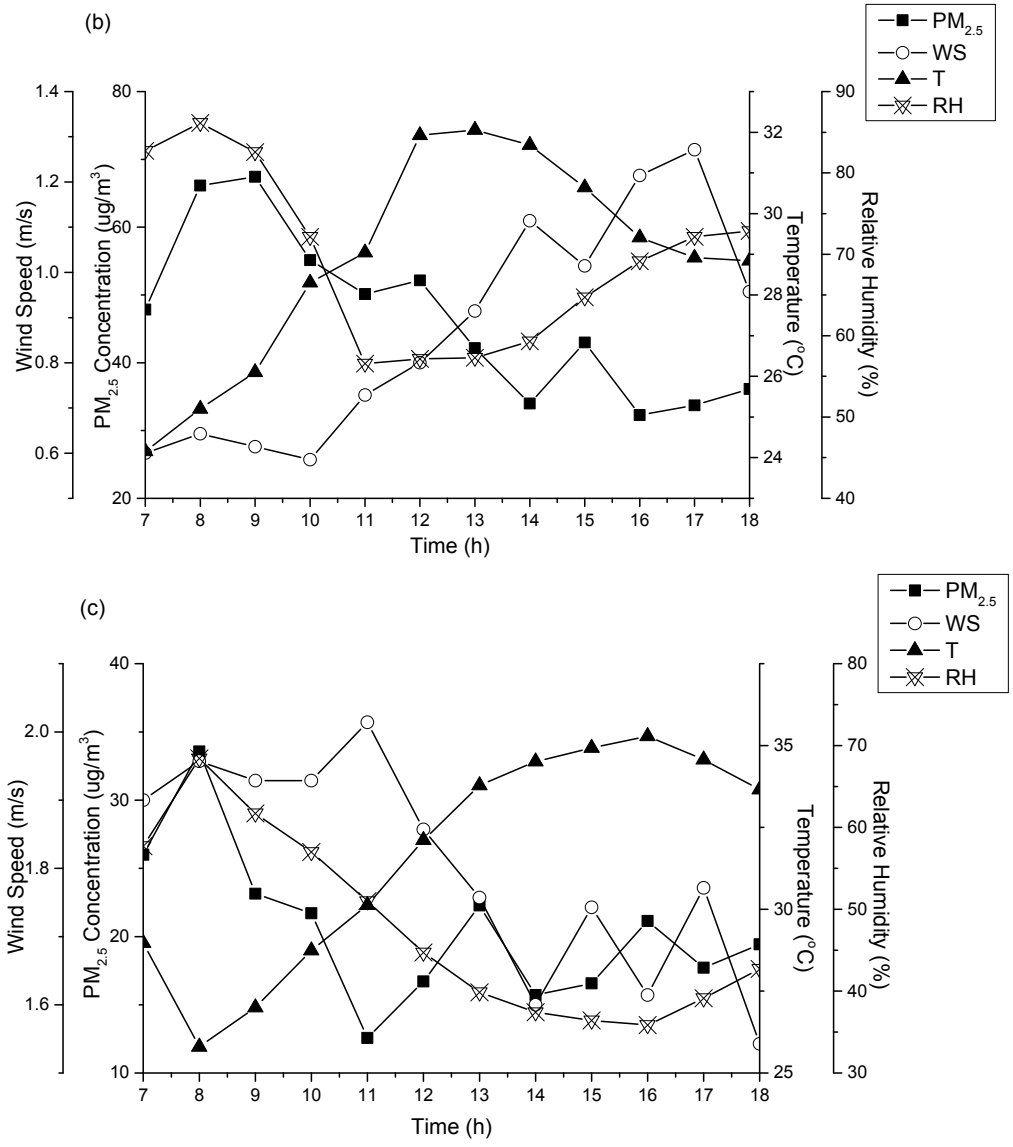


Figure 5. Diurnal Plot of $PM_{2.5}$ Concentration and Meteorological Parameters at (a) S1 (b) S2 (c) S3

3.7 Chemical Composition of $PM_{2.5}$ Particles

The average concentrations and standard deviation of the detected elements measured in industrial site are summarized in Table 4. Al, Ca and Fe were the major elements in the three sites. Al dominated in all the sites. Ca dominated in S1, and Fe dominated in S2 and S3. At S1, Al, Ca, Fe and K had the highest average concentrations of 3338 ng m^{-3}, 3155 ng m^{-3}, 1727 ng m^{-3} and 1063 ng m^{-3}, respectively. Figure 6 shows the distribution of chemical composition at all site.

Table 4. Concentrations of $PM_{2.5}$ and Trace Metals at S1, S2 and S3 sites (12 h Mean ± Standard Deviation)

Element	Unit	S1 (n=84)	S2 (n=84)	S3 (n=84)	Recovery (%)
Aluminium (Al)	ng m^{-3}	3338 ± 589	1951 ± 490	4945 ± 1375	95
Calcium (Ca)	ng m^{-3}	3155 ± 1024	1092 ± 327	1993 ± 603	102
Sodium (Na)	ng m^{-3}	2295 ± 0	451 ± 305	1459 ± 782	90
Ferum (Fe)	ng m^{-3}	1727 ± 132	1261 ± 338	4560 ± 614	101
Potassium (K)	ng m^{-3}	1063 ± 338	1012 ± 244	1466 ± 269	135
Zinc (Zn)	ng m^{-3}	374 ± 0	153 ± 87	592 ± 308	116
Magnesium (Mg)	ng m^{-3}	177 ± 175	151 ± 194	175 ± 97	102
Titanium (Ti)	ng m^{-3}	70 ± 17	65 ± 18	135 ± 59	94
Chromium (Cr)	ng m^{-3}	48 ± 4	100 ± 136	1909 ± 978	95
Lead (Pb)	ng m^{-3}	38 ± 0	132 ± 155	15 ± 0	94
Strontium (Sr)	ng m^{-3}	30 ± 4	20 ± 4	34 ± 12	92

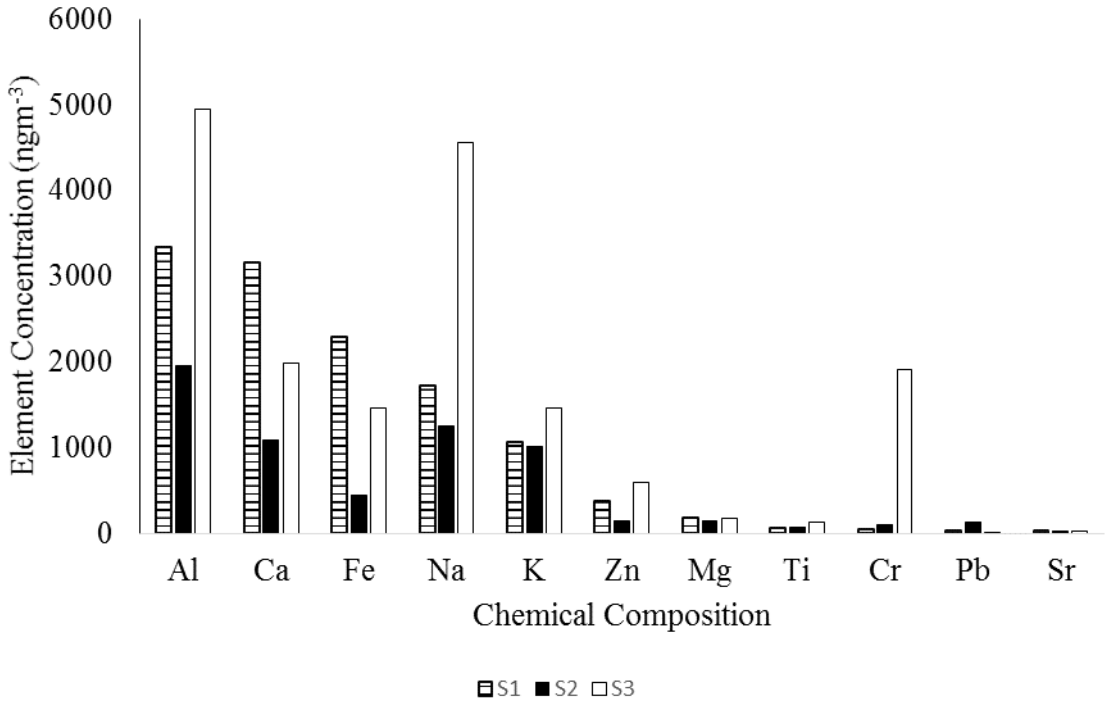


Figure 6. Average Elemental Concentrations Variations for Three Sites in Nilai

3.8 Factor Analysis (FA) of $PM_{2.5}$ Chemical Composition

FA was applied to the chemical composition and results of factor loading after varimax rotation for all sites are shown in Table 5. Three factors with various sources of $PM_{2.5}$ were obtained for all sites. For

S1, Factor 1 explained 40.60% of the total variance and was dominated by Al, K, Sr, Ti and Na indicating that the sources were crustal materials. Factor 2 explained 15.03% of the total variance, with high loadings of Cr, Fe, Mn, Zn and Ni indicating that the source was the industrial activities. Factor 3 was from vehicular sources dominated by Ca, Mg and Pb; it explained 11.63% of the total variance.

Table 5. Factor Loading for Chemical Composition of S1, S2 and S3 in Nilai

Elements	S1			S2			S3		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
	Crustal	Industrial	Vehicular	Crustal	Industrial	Vehicular	Crustal	Industrial	Vehicular
Al	0.85			0.94			0.79		
K	0.85			0.69			0.84		
Sr	0.88			0.96			0.90		
Ti	0.68			0.68			0.93		
Ca			0.60	0.68			0.94		
Fe		0.77						0.86	
Cr		0.84							
Mg			0.85						
Mn								0.84	
Na							0.87		
Pb						0.69			0.99
Zn					0.85				
Ni					0.82				
Eigenvalue	4.47	1.65	1.28	4.11	1.89	1.00	7.17	1.47	1.00
Variability (%)	40.60	15.03	11.63	34.23	15.75	8.23	59.75	12.25	8.33
Cumulative (%)	40.60	55.63	67.25	34.23	49.98	58.21	59.75	72.00	80.33

4. Discussion

The average $PM_{2.5}$ concentrations in S2 was higher than those obtained by Balasubramanian et al. (2003) in Singapore (27.2 μg m^{-3}), Mohd Tahir et al. (2013) in the East Coast of Malaysia (14.3 μg m^{-3}), and Ling et al. (2015) in Kuala Lumpur, Malaysia (30 μg m^{-3}). The mean temperature in all the sites ranged from 28.61 °C to 31.63 °C. Daily concentrations in S2 were higher than the $PM_{2.5}$ standards declared by USEPA and WHO, which are 55% and 75%, respectively. The highest $PM_{2.5}$ concentration in S2 was observed on Day 1 (12:00). The recorded concentration reached 115 μg m^{-3} because S2 is near a quarry. Similar findings have been presented in several studies (Shaltout et al., 2013; Karnae and John, 2011) which stated that this phenomenon is probably due to the site being adjacent to the industrial area that emits high levels of particles. S3, which presented the second highest level of $PM_{2.5}$

concentration, is located near a construction area (~1 km).

Meteorological conditions, particularly atmospheric stability and wind speed, might have caused the late evening peak from the diurnal variation (Afroz et al., 2003; Awang et al., 2000; Azmi et al., 2010). S2 clearly presented the highest concentration in Nilai and S1 and S3 differed slightly from each other. This phenomenon is directly correlated to the location of S2 which is near main roads, and people passing to and from work caused the uplifting of particles. The low values of $PM_{2.5}$ concentration at S1, S2 and S3 occurred at different time in the afternoon might be due to the minimal influence of anthropogenic activities on fine particulate levels during this time.

Lower $PM_{2.5}$ concentration during weekend was due to the day off of several employees in the industrial area, corporate offices, government offices, schools, and institutions as well as the minimal human-related activities during weekends (Owoade et al., 2013). Besides that, these two factors also reduce particulates emissions generated by tire wear and resuspension of street dust (Owoade et al., 2013; Almeida et al., 2005). In S1 and S3, the $PM_{2.5}$ concentrations on weekends were higher than those on weekdays, indicating that the emissions were not only derived from local sources, but some of them were transported from other sources around the sites. A number of industrial areas are located around S1 and S3. These areas are open for business on weekends, especially on Saturdays.

A few studies also reported that the increasing and decreasing of $PM_{2.5}$ concentration was influenced by meteorological conditions such as wind direction, wind speed, and precipitation (Liu & Cui, 2014). High $PM_{2.5}$ concentration was observed at low wind speed might be due to meteorological condition that is favourable for the dilution and dispersion of airborne particulate matter (Wu et al., 2013). A detailed analysis conducted by Wu et al. (2013) showed that high $PM_{2.5}$ exposure levels are always concurrent with low wind speed. These results stress the role of high wind speed in reducing $PM_{2.5}$ concentration level by improving the dispersive ability of the atmosphere (via mechanical and thermal turbulence). However, in S3, the high $PM_{2.5}$ levels may be caused by the reduced ventilation for transport emissions from distant sources at conditions of high wind speed conditions; the same results were obtained by Cheng and Li (2010). Norela et al. (2009) explained that wind and a busy main road could also be responsible for dispersing particles into the atmosphere in Nilai. These results are consistent with the observed wind speed, which is associated with high particulate matter concentrations and stagnation and therefore, low wind speed (Dawson et al., 2007). Rain generated play an important scavenging polluted air (Tai et al., 2010; Liu & Cui, 2014). When high relative humidity, $PM_{2.5}$ concentration increased. These result in line with the findings by previous studies (Tai et al., 2010; Barman et al., 2008). A high relative humidity can depress the absorption of gas phase organic species into particle surface and accelerate the removal of particle by dry deposition, this mechanism enhanced for hygroscopic particle (Shi et al., 2012).

Wind speed and air temperature are important determinants of $PM_{2.5}$ (Tai et al., 2010; Jung et al., 2002; Hien et al., 2002). As expected, these parameters were inversely related to particulate matter concentrations. Stable meteorological conditions will occurred when low wind speeds combined with

temperature inversions, which limited the dispersion of pollutants, cleared fine particulates, and induced high PM concentration (Hien et al., 2002). A high temperature in the tropics usually increases the amount of soil dust from the Earth's surface that coming from the biomass burning and the evaporation of materials (Azmi et al., 2010). High temperatures may lead to intense vertical dispersion of pollutants, which induce an inverse relation between temperature and PM, especially in fine particle categories ($PM_{2.5}$ and $PM_{1.0}$).

Al, Ca, Fe and K elements are indicators of crustal weathering and mineral dust (Ling et al., 2015; Srivastava et al., 2008; Cheng et al., 2015). Al at S3 had the highest concentration of 4945 ± 1375 ng m^{-3}, which was 2.5 times higher than that in S2 and 1.5 times higher than in S1. S3 is located in a construction area, the high concentration of Al and Ca most likely originated from resuspended road dust (Lin et al., 2005). The high concentration of Fe can be attributed to traffic emissions and soil dust (Ling et al., 2015). According to Caggiano et al. (2011), high concentrations of Fe, particularly in $PM_{2.5}$, are associated with exhaust emissions, especially from gasoline and diesel-fueled road vehicles. Several studies have also found that soil dust is a major source of Fe (Ling et al., 2015; Viana et al., 2008; Cheng et al., 2015).

Crustal materials in Factor 1 may comprise natural (resuspension of soil particles) and anthropogenic (road dust) sources. Given that the sampling site is located near a residential area, vehicular movement may generate suspensions of soil/road dust (Ny & Lee, 2011). Na is a component of marine sea salts. Therefore, this factor was identified as a mixture of crustal material and marine sources. Factor 2 indicates the sources were from industrial activities that can contain Cr, Fe, Zn and Ni (Srivastava et al., 2008; Cheng et al., 2015). Given that the sampling site is near the industrial area, prevailing winds could play a significant role in spreading the elements to the monitoring area. Fe can originate from the welding activities around the industrial area in the site, and Mn may exist in natural and anthropogenic sources. In Factor 3, Ca and Mg can be regarded as the mineral sources, and Pb in industrial area is emitted by different sources and each of these industries emits Pb with different chemical form (Chao et al., 2002; Marcazzan et al., 2001). The sources for the other sites were also classified in the same factor as S1.

5. Conclusion

The results showed that, the average $PM_{2.5}$ concentration was 19.75 ± 12, 46.68 ± 27, and 20.55 ± 9 μg m^{-3} at sites in a S1, S2 and S3. The high concentration of $PM_{2.5}$ recorded in S2 is influenced by the industrial activities around the area and heavy traffic, given that S2 is located near the main road. The diurnal patterns of $PM_{2.5}$ concentration in S1 and S3 exhibited an inverse unimodal pattern for 12 h of monitoring. The $PM_{2.5}$ concentration in S2 increased in the morning (07:00 to 09:00), decreased in the afternoon (9:00 to 14:00), and increased again in the late evening (16:00 to 18:00). The $PM_{2.5}$ concentration in S2 on weekends decreased by about 36%. Evident associations were also observed between fine particulate matter and meteorological factors and the highest correlation of 0.85 was

obtained between $PM_{2.5}$ concentration and wind speed in S2. All three stations were dominated by the same group of elements (i.e., Al, Ca and Fe). The results of FA indicated that the possible sources were from crustal materials, industrial and vehicular.

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