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Review

Chemical composition of the haze in Malaysia 2005

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HIGHLIGHTS

- The high concentrations of PM_{10} due to the intrusion of particles arising from forest fire in Sumatra.
- Positive relationship between PM_{10} concentration and wind speed.
- The high concentrations of NO_3^- and SO_4^{2-} associated with acidic pH.
- The highest concentration of Fe due to land clearing activities and exposed soil.

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ABSTRACT

A study of the chemical composition of the haze was conducted in two areas: Klang Valley and Malacca in Peninsular Malaysia, from July to September of 2005. The data is based on the reports of the air quality monitoring for particulate matter (PM_{10}), pH of rainwater, anions (NO_3^-, SO_4^{2-}, Cl^-), cations (NH_4^+, Na^{2+}, Ca^{2+}, K^+, Mg^{2+}), heavy metals (Fe, Zn, Pb, Mn, Cu, Ni) and a meteorology parameter, the wind speed. The monthly concentrations of PM_{10} for the Klang Valley ranged from 35.90 to 104.46 $\mu g\ m^{-3}$ whilst in Malacca the concentration ranged from 35.80 to 54.30 $\mu g\ m^{-3}$ which was over the permitted level of 50 $\mu g\ m^{-3}$ for the time period of a month as stipulated by the Department of Environment Malaysia (DOE). The pH of rainwater collected in the Klang Valley ranged from 4.26 ± 0.12 to 5.45 ± 0.58, while in Malacca the pH varied from 4.35 ± 0.20 to 5.43 ± 0.12. The mean concentrations for NO_3^-, SO_4^{2-}, Cl^-, NH_4^+, Ca^{2+}, Na^{2+}, K^+, Mg^{2+} for three months in the Klang Valley were 46.40 ± 11.16 $\mu eq\ L^{-1}$, 34.84 ± 9.82 $\mu eq\ L^{-1}$, 12.34 ± 4.13 $\mu eq\ L^{-1}$, 29.28 ± 11.02 $\mu eq\ L^{-1}$, 8.92 ± 0.88 $\mu eq\ L^{-1}$, 8.18 ± 1.00 $\mu eq\ L^{-1}$, 2.08 ± 0.34 $\mu eq\ L^{-1}$, 1.38 ± 0.24 $\mu eq\ L^{-1}$, respectively, whilst in Malacca, the mean concentrations were 24.46 ± 6.99 $\mu eq\ L^{-1}$, 28.4 ± 7.24 $\mu eq\ L^{-1}$, 27.32 ± 7.36 $\mu eq\ L^{-1}$, 30.92 ± 1.26 $\mu eq\ L^{-1}$, 4.10 ± 2.56 $\mu eq\ L^{-1}$, 21.44 ± 7.54 $\mu eq\ L^{-1}$, 3.18 ± 1.82 $\mu eq\ L^{-1}$ and 1.54 ± 1.66 $\mu eq\ L^{-1}$, respectively. These values were lower than the non haze period (January to March and April to June) except for the Cl^- ion which recorded the highest anion in Malacca. However, the mean values were similar for the period from October to December. The mean concentrations of metals showed that Cu > Ni, whilst in Malacca, in descending order, were Fe > Zn > Cu > Mn > Pb > Ni.

1. Introduction

Uncontrolled forest fires originating from the Indonesian province of Sumatra during the burning season in 2005 produced a regional haze episode that affected the ASEAN countries, especially Malaysia. Previous haze events have occurred in 1983, 1990, 1991, 1994, 1997, 1998 and 2005 and their causes and effects have been widely reported (Keywood et al., 2003). Haze is defined as the presence of fine particles (0.1–1.0 μm in diameter) in the air that dispersed at high concentrations, which are barely visible to the naked eye (Soleiman et al., 2003). Particulate matter of size less than 10 μm (PM_{10}) can affect meteorological processes and be involved in chemical reactions in the atmosphere producing secondary pollutants (Roosli et al., 2001). They can be fine either as droplets of liquids in fogs and mists or as solid particles like soot or those suspended in smoke (Mahajan, 2003).

According to Abdul Rahman (2002) anthropogenic activities such as forest fires, open burning and agricultural land clearings have been identified as among the main causative factors for the worsening of air quality and visibility. About 80% of the haze problems in equatorial Southeast Asia are caused by burning of peat soils (ADB, 1999). According to Applegate et al. (2002), the

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agricultural burning activities by farmers disposed unwanted products such as straw, husks and fires after harvesting.

Agricultural practices such as open biomass burning had led to the occurrences of haze events (Mahmud, 2010, 2012). In Indonesia, about 60% of the particulates and carbon dioxide in smoke and haze came from peat fires and 20% from forest conversion burning (ADB, 1999). PM_{10} in the smoke from forest fires is produced by combustion source, which is more harmful than PM_{10} from crustal or other non-combustion sources. It is possible to produce toxic particles in the atmosphere (Vedal and Dutton, 2006). In Southeast Asia, rapid economic development has deteriorated the air quality due to the high emissions of pollutants in nearby urban cities and industrialized areas (Hu et al., 2003). In urban areas, particles collected during the haze conditions are generally derived both from anthropogenic sources such as biomass combustion, motor vehicle and industrial emissions, which could also affect the human health (Soleiman et al., 2003; Abdul Rahman, 2002; Norela et al., 2008).

The objectives of this study are two fold: to study the components of haze that include the PM_{10}, anions (NO_3^-, SO_4^{2-}, Cl^-), cations (NH_4^+, Na^{2+}, Ca^{2+}, K^+, Mg^{2+}) and heavy metals in wet fallout (Fe, Zn, Pb, Mn, Cu, Ni) and their relationships to the climatological conditions.

2. Materials and methods

The chemical composition of air pollutants data was obtained from the Malaysian Meteorological Department in Petaling Jaya and Malacca (MMD, 2012). The parameters analyzed were the anions (NO_3^-, SO_4^{2-}, Cl^-), cations (NH_4^+, Na^{2+}, Ca^{2+}, K^+, Mg^{2+}) and heavy metals (Fe, Zn, Pb, Mn, Cu) in wet fallout. Rainwater was collected using the Wet-Only Rainwater Sampler (Ecotech Model 200). This instrument consists of a tipping bucket precipitation gauge, collection funnel, sample bottle unit and a solar panel as power unit. When the sensor detects precipitation, the lid covering the collection funnel opens and initiates sampling of rainwater. The collected rainwater is stored in bottles inside the instrument over a seven-day period. The samples are sent to the Department of Chemistry for chemical analysis. Anions (NO_3^-, SO_4^{2-}, Cl^-) and cations (NH_4^+, Na^{2+}, Ca^{2+}, K^+, Mg^{2+}) were determined using ion chromatography (IC, Dionex DX600) with method detection limits of 0.002 mg L^{-1} for NO_3^-, 0.004 mg L^{-1} for SO_4^{2-}, 0.006 mg L^{-1} for Cl^-, 0.003 mg L^{-1} for NH_4^+, 0.010 mg L^{-1} for Na^{2+}, 0.020 mg L^{-1} for Ca^{2+}, 0.003 mg L^{-1} for K^+ and 0.010 mg L^{-1} for Mg^{2+}, while heavy metals (Fe, Zn, Pb, Mn, Cu, Ni) were determined using an inductively coupled plasma-mass spectrometer (ICP-MS, Perkin Elmer ELAN 6000) with method detection limits of 0.070 mg L^{-1} for Fe, 0.020 mg L^{-1} for Zn, 0.005 mg L^{-1} for Pb, 0.010 mg L^{-1} for Mg, 0.020 mg L^{-1} for Mn, 0.020 mg L^{-1} for Cu, 0.009 mg L^{-1} for Cd and 0.030 mg L^{-1} for Ni.

3. Results and discussion

3.1. Particulate matter (PM_{10})

The spatial distribution of the Malaysian Air Pollution Index (MAPI) over Peninsular Malaysia shows that the state of Selangor was affected by high MAPI's value 500 on 11 August 2005 (Fig. 1). The monthly variations of particulate matter of size 10 μm (PM_{10}) are shown in Fig. 2. The overall PM_{10} concentrations in the Klang Valley ranged from 35.90 μg m^{-3} to 104.46 μg m^{-3}, while the Malaysian Air Pollution Index (MAPI) ranged from 23.39 to 69.64. The PM_{10} concentrations in Malacca were lower and ranged from 35.80 μg m^{-3} to 54.30 μg m^{-3}, with the MAPI ranging from 23.87 to 36.20 μg m^{-3}. The PM_{10} concentrations in the Klang Valley and Malacca showed an abrupt increase in August. The PM_{10} values in the Klang Valley were over the permissible limit stipulated by the Clean Air Act Amendment 1978 of the Environmental Quality Act (EQA) 1974 of the Department of Environment, Malaysia, which is 50 μg m^{-3} is for a period of one month. The reason for the high concentrations of PM_{10} was likely due to the intrusion of particles arising from forest fires in Sumatra brought over by the prevailing southwesterly monsoon (Mahmud, 2010). Ensembles of backward air mass trajectories have identified the sources of particulate matter to originate from several provinces in Sumatra, particularly from Riau (Mahmud, 2009).

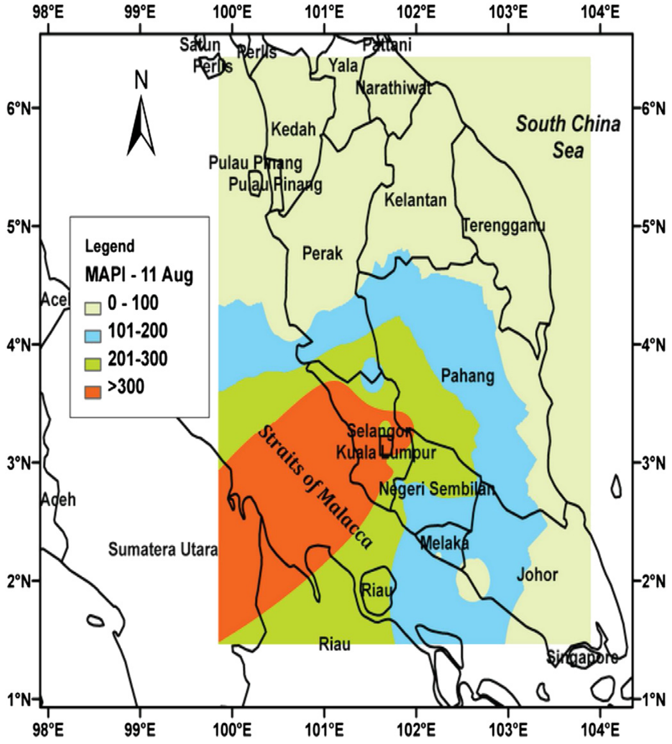

Fig. 1. The spatial distribution of Malaysian (API) over Peninsular Malaysia on 11 August 2005.

3.2. Relationship between PM_{10} concentrations and wind speed

Fig. 3 shows the regression plots between the concentrations of PM_{10} and wind speeds in the Klang Valley and Malacca. The PM_{10} concentrations were higher from July to September 2005 due to the dry southwest monsoon that transported the air pollutants from Sumatra. According to Tacconi et al. (2006) and MdYusoh et al. (2008), haze pollution occurred every year during the dry periods from February to March, and from August to October, and it has been recognized as a major problem since the last two decades. Low wind speeds in the Klang Valley occurred in May (0.3 ms^{-1}) and increased to 2.2 ms^{-1} in September, whilst Malacca recorded the same speed (1.6 ms^{-1}) from May to August. Regression analysis showed that the wind speed related weakly to the PM_{10} concentration during the haze episode in the Klang Valley ($R = 0.109$), and in Malacca ($R = 0.481$), respectively. However, MdYusoh et al. (2008) found that PM_{10} concentrations were affected by the weather parameters as well as haze event.

3.3. pH of rainwater

Acid rain refers to precipitation, mainly rain and dry deposition, which has a pH value of less than 5.6 (Agrawal, 2002). Generally,

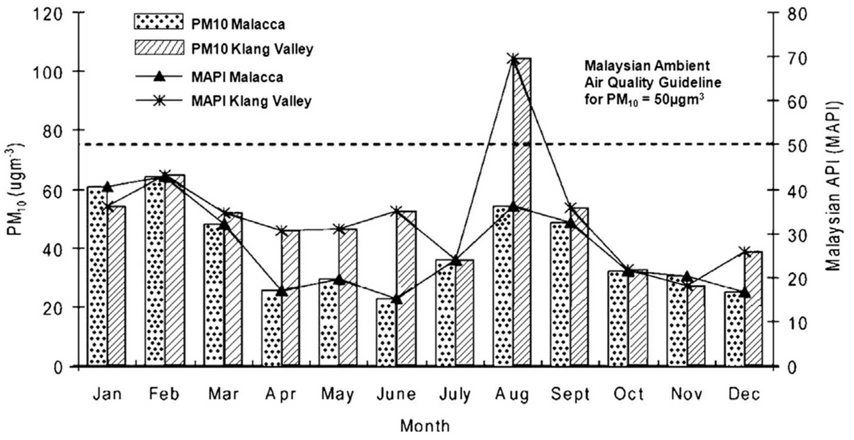

Fig. 2. PM_{10} concentration ($\mu g\ m^{-3}$) and MAPI level in Malacca and Klang Valley from January to December 2005.

acid precipitation ranges between pH 3.5 and 5.6. The pH of rainwater collected in the Klang Valley from January to December varied from 4.26 ± 0.12 to 5.45 ± 0.58, while in Malacca, the data showed pH variations from 4.35 ± 0.20 to 5.43 ± 0.12. These values were lower than the pH of normal rainwater in a clean atmosphere, which are generally around 5.6 due to the dissolution of CO_2 in the rain droplets. The exposure of rainwater to the haze in this study had caused chemical degradation and influenced the pH values (Tanner and Wong, 1997). The pH values in the Klang Valley increased from July (4.40 ± 0.12) to August (5.45 ± 0.58) due to the total monthly rain gauge rainfall received of 226 mm and 354 mm, in July and August, respectively. This is in contrast to the pH in Malacca, which decreased slightly from 4.75 ± 0.73 in July to 4.64 ± 0.06 in August (Fig. 4), when the total rain gauge rainfall was 235 mm and 143 mm in July and August, respectively. The different trend in pH values occurred due to the volume of rainwater at both stations. The pH value at the Klang Valley was less acidic, which was closer to the normal pH of rainwater (5.60) due to the less volume of rainwater in August. However, the acidic pH of rainwater was recorded at the value of 4.64 in Malacca. This could be due to the higher volume of rainwater during the haze period (August). This is in contrast to the study for an agricultural site in Chiang Mai, Thailand by Sillapapiromsuk and Chantara (2010), which indicated that 28% of the rainwater in 2008 was alkaline with pH of between 6.01 and 6.05.

3.4. *Statistical analysis for anions, cations and heavy metals*

The statistical correlations matrix test indiated the suitability of rainwater quality data for factor analysis and showed that the correlation matrix was an identity matrix which would indicate the relationship between the ions present in rainwater (Sillapapiromsuk and Chantara, 2010). The results of the Pearson Correlation test for anions, cations and heavy metals were calculated and listed in Table 3. The strong positive correlations between Cl^- and SO_4^{2-} ($R^2 = 0.806$, $p < 0.05$), and Na^+ and Cl^- ($R^2 = 0.913$, $p < 0.05$) suggested that these areas were influenced by marine and crustal sources such as soil particles, which were exposed to the atmosphere. NH_4^+ and NO_3^-($R^2 = 0.805$, $p < 0.05$) were strongly correlated, most likely due to biomass burning (Coelho et al., 2011), while K^+ and Ca^{2+}($R^2 = 0.841$, $p < 0.05$), were also strongly correlated, suggesting that the main sources were natural elements. Strong correlations between Mn and Mg ($R^2 = 0.950$, $p < 0.05$), Pb and Mg ($R^2 = 0.965$, $p < 0.05$), Zn and Mg ($R^2 = 0.966$, $p < 0.05$), Pb and Mn ($R^2 = 0.928$, $p < 0.05$), Zn and Mn ($R^2 = 0.978$, $p < 0.05$) and Zn and Pb ($R^2 = 0.974$, $p < 0.05$). Mg, Mn and Zn in the rainwater also suggested that the main sources could be natural elements. Heavy metals such as Pb usually occur in the atmosphere as a result of industrial activities and vehicle exhaust emissions (Momani et al., 2000). Thus, it can be deduced that these metals are most likely to have originated from the same sources, namely:

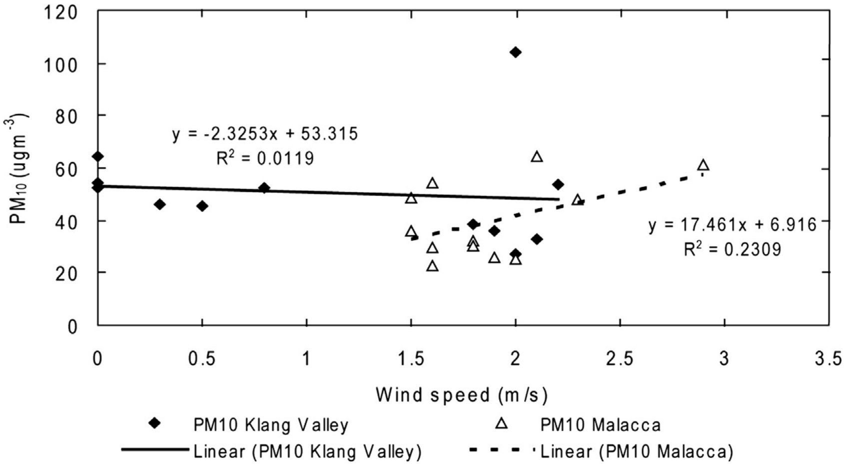

Fig. 3. Regression between the wind speed and PM_{10} concentrations at the Klang Valley and Malacca.

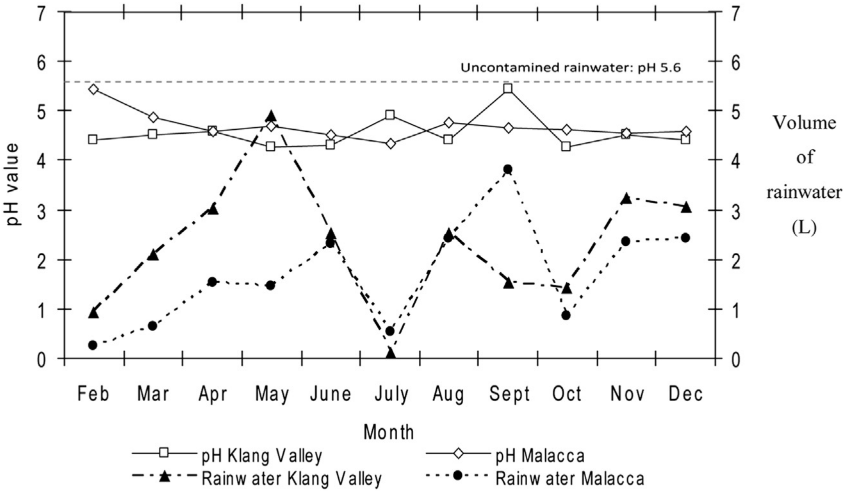

Fig. 4. The pH and volume of rainwater (L) between January and December 2005 in Klang Valley and Malacca.

natural elements. Based on the correlation matrix of elements in rainwater from the study area, it can be shown that the area was influenced by the antropogenic sources such as vehicle emissions and biomass burning.

3.5. *Wet depositions of ions*

Monthly deposition levels of major ions in the Klang Valley and Malacca in Table 1 indicate that the deposition in the Klang Valley was dominated by NO_3^- (273.40 μeq L^{-1}), followed by SO_4^{2-} (104.5 μeq L^{-1}), NH_4^+ (95.72 μeq L^{-1}), Cl^- (82.02 μeq L^{-1}), Ca^{2+} (26.74 μeq L^{-1}), Na^{2+} (24.44 μeq L^{-1}), K^+ (6.40 μeq L^{-1}) and Mg^{2+} (4.16 μeq L^{-1}), respectively. These four ions i.e., NO_3^-, SO_4^{2-}, NH_4^+ and Cl^- accounted for about 83.99% of the total three month ionic mass deposition. Coelho et al. (2011) found that NH_4^+, NO_3^- and H^+ accounted for 55% of the total ions from a sugar cane biomass burning in Brazil. Statistical analysis was performed to see whether there were any substantial variations between stations in terms of the concentrations of anions, cations and heavy metals. The *t*-test showed significant differences between the mean concentrations of trace elements, cations and anions in rainwater in Malacca and in the Kelang Valley at $p < 0.05$.

The monthly and total three-month deposition of major anions and cations in descending order in Malacca are: $NH_4^+ > SO_4^{2-} > Cl^- > NO_3^- > Na^{2+} > Ca^{2+} > K^+ > Mg^{2+}$ with values of 92.78 μeq L^{-1}, 85.32 μeq L^{-1}, 82.12 μeq L^{-1}, 73.34 μeq L^{-1}, 64.34 μeq L^{-1}, 12.32 μeq L^{-1}, 9.58 μeq L^{-1}, and 4.64 μeq L^{-1}, respectively. These four ions i.e., NH_4^+, SO_4^{2-}, Cl^- and NO_3^- accounted for about 78.59% of the total three-month ionic mass deposition. The mean values of anions and cations in the Klang Valley and Malacca were lower compared to the non haze period (January–March and April–June), except for the Cl^- ions, which recorded the highest anion value in Malacca. However, these values are almost similar with the mean value from October to December.

The dominant anion during the haze episode in the Klang Valley (from July to September) was NO_3^- (273.40 μeq L^{-1}), followed by SO_4^{2-} (104.50 μeq L^{-1}) and Cl^- (82.02 μeq L^{-1}), respectively, whilst in Malacca, the anion with highest value was SO_4^{2-} (85.32 μeq L^{-1}), followed by Cl^- (82.12 μeq L^{-1}) and NO_3^- (73.34 μeq L^{-1}), respectively. According to Chiras (2001), SO_4^{2-} and NO_3^- ions in the precipitation were presented mostly as neutralized forms, which were the main precursors of SO_2 and NO_2 acid deposition in the atmosphere. Sulphur and nitrogen oxides react in the air to form sulphuric acid and nitric acid, which fall to earth as acidic rain, snow, or dry precipitation. However, the smoke haze pollution worsened the situation. This is because the biomass burning from Sumatra has been identified as the main anthropogenic source for the NO_2 emissions to the air. There are no significant correlations ($p > 0.05$) between rainfall volume and the concentrations of SO_4^{2-} and NO_3^- in the rainwater samples from the Klang Valley and Malacca.

The highest concentration of cations in the Klang Valley during the haze period was for NH_4^+ (95.72 μeq L^{-1}), followed by Ca^{2+} (26.74 μeq L^{-1}), Na^{2+} (24.44 μeq L^{-1}), K^+ (6.40 μeq L^{-1}) and Mg^{2+} (4.16 μeq L^{-1}), whilst NH_4^+ recorded the highest value for cations in Malacca, at 92.78 μeq L^{-1}, followed by Na^{2+} (64.34 μeq L^{-1}), Ca^{2+} (12.32 μeq L^{-1}), K^+ (9.58 μeq L^{-1}) and Mg^{2+} (4.64 μeq L^{-1}), respectively. Similarly, Celis et al. (2003) concluded from their

Table 1
Monthly variations in rainfall (L) of major anions and cations (μeq L^{-1}) measured at the Klang Valley and Malacca.

Parameter	Rainfall (l)	SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	Ca^{2+}	Mg^{2+}	Na^{2+}	K^+
(a) Klang Valley									
July	2.53	33.14	77.4	26.04	35.08	7.02	0.98	5.84	1.66
Aug	1.54	18.10	68.2	19.76	45.7	9.24	1.26	8.86	2.74
Sept	1.43	53.26	127.8	36.22	14.94	10.48	1.92	9.74	2.00
Total	4.50	104.5	273.40	82.02	95.72	26.74	4.16	24.44	6.40
(b) Malacca									
July	2.40	18.58	12.92	20.18	7.24	1.76	0.4	10.14	1.04
Aug	3.80	24.26	23.58	17.52	42.66	2.92	0.96	18.72	1.86
Sept	0.87	42.48	36.84	44.42	42.88	7.64	3.28	35.48	6.68
Total	7.07	85.32	73.34	82.12	92.78	12.32	4.64	64.34	9.58

Table 2
Monthly variations in trace element measured at Klang Valley and Malacca, Malaysia.

Parameter	Fe	Zn	Cu	Pb	Mn	Ni
(a) Klang Valley						
July	2.14[a] 0.16[b]	0.12[a] 0.44[b]	0.01[a]	0.03[a] 0.00[b]	0.02[a] 0.02[b]	0.00[a]
Aug	1.77[a] 0.04[b]	0.13[a] 0.40[b]	0.02[a] 0.00[b]	0.02[a]	0.02[a] 0.02[b]	0.00[a]
Sept	1.99[a] 0.10[b]	0.11[a] 0.86[b]	0.01[a] 0.02[b]	0.00[a] 0.02[b]	0.03[a] 0.02[b]	0.00[a] 0.04[b]
Total	5.90[a] 0.30[b]	0.36[a] 1.70[b]	0.04[a] 0.02[b]	0.05[a] 0.02[b]	0.07[a] 0.06[b]	0.00[a] 0.04[b]
(b) Malacca						
July	1.21[a] 0.06[b]	0.17[a] 0.14[b]	0.01[a] 0.00[b]	0.01[a]	0.01[a] 0.00[b]	0.00[a]
Aug	0.74[a] 0.14[b]	0.03[a] 0.08[b]	0.01[a]	0.00[a]	0.01[a] 0.00[b]	0.00[a] 0.00[b]
Sept	1.59[a] 0.08[b]	0.04[a] 0.42[b]	0.01[a]	0.01[a]	0.00[a] 0.00[a]	0.00[a] 0.01[b]
Total	3.54[a] 0.28[b]	0.24[a] 0.64[b]	0.03[a] 0.00[b]	0.02[a]	0.02[a] 0.00[b]	0.00[a] 0.02[b]

[a] Dry fallout (mg m^{-2}).
[b] Wet fallout (μeq L^{-1}).

study that the high levels of NH_4^+ ions in the air were attributed to the application of pesticides and fertilizers in agricultural areas. Wind erosion can carry away K^+ and Na^{2+} from the exposed soil (John et al., 1981) similar to the land clearing activities by the farmers in Indonesia. The overall cations in the Klang Valley and Malacca have no correlations with the rainfall during the haze period.

In a study by Norela et al. (2009) for an industrial site in Nilai, Negeri Sembilan, which is located approximately 60 km from the Klang Valley, the cations detected, in descending order were K^+, Ca^{2+}, NH_4^+, Na^{2+} and Mg^{2+}. Sundarambal et al. (2010) found that the water soluble nutrients from aerosol particulates and rainwater were higher during the haze days than during the non-haze days during 2006 in Singapore. They found that the rainwater samples in May when there were biomass burnings in Kalimantan contained concentrations of Ca^{2+}, NH_4^+, Na^{2+}, Cl^- and Mg^{2+}. Another study by Alahmr et al. (2012) on the dust fall at the eastern part of the Klang Valley in Bangi and Kajang during 2010 found the dominant anions present were SO_4^{2-}, NO_3^-, Cl^- and F^-, while the cations present were Ca^{2+}, K^+, and Mg^{2+}. These studies showed slight variations in the dominant cations and anions in different areas, depending on the environmental surrounding conditions and the major events that influence the atmospheric composition of the areas investigated.

3.6. *Trace elements*

The hierarchical list of trace element concentrations at the Klang Valley is: Fe > Zn > Mn > Pb > Cu > Ni, whilst in Malacca, the decreasing order of concentrations is: Fe > Zn > Cu > Pb > Mn > Ni.

The iron concentrations in the dry fallouts were higher than the concentrations of other metals in both areas, which ranged from 1.77 mg m^{2-} to 2.14 mg m^{2-} in the Klang Valley, and from 0.74 mg m^{2-} to 1.59 mg m^{2-} in Malacca. Menwhile, Fe gave the second highest metal concentrations in the wet fallouts in the Klang Valley (0.04–0.16 μeq L^{-1}) and Malacca (0.06–0.14 μeq L^{-1} (Table 2). The highest concentration of Fe could be due to land clearing activities from Sumatra. According to John et al. (1981), when the earth's crust is exposed, wind erosion can carry the iron away from the exposed soil for thousands of kilometers. A significant correlation exists between the PM_{10} concentration and Fe ions in the Klang Valley ($R = 0.987$), while Fe ions were uncorrelated with the rainfall volume during the haze period in the Klang Valley ($R = 0.511$, $p > 0.05$) and Malacca ($R = 0.703$, $p > 0.05$).

The second highest concentration of heavy metals in the dry fallouts was for zinc (Zn) in both the Klang Valley (0.109–0.129 mg m^{2-}) and Malacca (0.029–0.168 mg m^{2-}). Meanwhile, this metal recorded the highest concentration in the wet fallouts in the Klang Valley, ranging from 0.20 to 0.43 μeq L^{-1} and in Malacca (0.04–0.21 μeq L^{-1}). The increased levels of zinc recorded in this study could have been released into the air as dust from the land clearing activities in Sumatra and might also be influenced by the large number of motorized vehicles in the Klang Valley in Peninsular Malaysia. A significant correlation exists between the PM_{10} concentration and Zn ions during the haze period in Malacca ($R = 0.972$). However, only a moderate correlation exists with rainfall volume and Zn ions in the Klang Valley ($R = 0.817$) and Malacca ($R = 0.945$). The other trace elements did not record significant correlations with the PM_{10} concentrations and rainfall volume in both areas. Chiriac et al. (2010) postulated that the heavy metals such as Cu and Ni were probably sourced from the spraying of pesticides in Romania. Norela et al. (2009) found that the haze contained the following descending metal concentrations of Pb > Fe > Cd > Co > Mn, in the industrial town of Nilai in Peninsular Malaysia during the 2005 haze episode.

Table 3
Correlation matrix of different parameters of anion, cation and heavy metals concentration in rainwater.

Correlation matrix[a]														
Parameters	SO_4^{2-}	NO_3^-	Cl^-	Na^{2+}	K^+	Ca^{2+}	NH_4^+	Mg^{2+}	Mg	Cu	Mn	Pb	Zn	Fe
SO_4^{2-}	1.000													
NO_3^-	0.663	1.000												
Cl^-	0.806[a]	0.546	1.000											
Na^{2+}	0.751	0.535	0.913[a]	1.000										
K^+	0.417	0.396	0.650	0.467	1.000									
Ca^{2+}	0.198	0.394	0.557	0.470	0.841[a]	1.000								
NH_4^+	0.511	0.805[a]	0.577	0.691	0.408	0.624	1.000							
Mg^{2+}	0.416	0.424	0.489	0.495	0.320	0.300	0.419	1.000						
Mg	−0.038	0.301	0.195	0.140	0.645	0.790	0.401	0.152	1.000					
Cu	−0.135	0.097	−0.050	−0.029	0.304	0.183	0.116	0.064	0.208	1.000				
Mn	−0.072	0.200	0.073	0.059	0.468	0.610	0.255	0.088	0.950[a]	0.072	1.000			
Pb	−0.111	0.239	0.124	0.053	0.567	0.790	0.362	0.098	0.965[a]	0.060	0.928[a]	1.000		
Zn	−0.124	0.152	0.084	0.020	0.521	0.696	0.248	0.068	0.966[a]	0.068	0.978[a]	0.974[a]	1.000	
Fe	0.382	0.112	0.303	0.400	−0.007	−0.186	−0.027	0.186	−0.130	0.154	−0.009	−0.186	−0.125	1.000

[a] Correlation is significant at the 0.05 level.

4. Conclusions

The haze period will be expected to occur in the future as it has occurred in the past in the Asean region. The impact will be localized or regional depending on the severity of the vegetation fires, especially in Sumatra and Kalimantan. In general, the chemical compositions of polluted air during the haze episode showed that the PM_{10} concentrations in the Klang Valley were higher than in Malacca. Meanwhile, the pH of the rainwater (7.0) was slightly less acidic in the Klang Valley compared to Malacca (pH 4.5) due to the lower amounts of rainfall in the latter. The concentrations of anions in the rainwater from the Klang Valley were higher (74.50%) than values recorded for Malacca. However, the concentrations of cations in the rainwater from the Klang Valley were lower (25.50%) compared to values from Malacca (43.27%). The Fe ions were the most dominant compared to the other metals in the dry fallouts (at concentrations of 91.10% in the Klang Valley and 91.95% in Malacca), whilst Zn recorded the highest concentrations of trace element in the wet fallouts from the Klang Valley (79.44%) and Malacca (68.09%).

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