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SOURCES APPORTIONMENT OF FINE AND COARSE AEROSOL IN BANGI, SELANGOR USING POSITIVE MATRIX FACTORIZATION

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ABSTRACT

Samples of fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$) fraction of airborne particulate were collected on weekly basis during the period from May 2012 to July 2014 at Bangi, Selangor. The samples were collected using a Gent Stacked Filter Sampler in two fractions of < 2.5 µm and 2.5 - 10 µm sizes. This research paper aims at establishing the concentration level of $PM_{2.5}$, $PM_{10-2.5}$ and PM_{10} at Bangi area and investigates their possible sources and contribution to the ambient aerosol of the area. The samples were analyzed for their elemental composition and black carbon content by Particle Induced X-ray Emission (PIXE) and Smoke Stain Reflectometer, respectively. The average for $PM_{2.5}$, $PM_{10-2.5}$ and PM_{10} ranged from1.8 µg/m^3 to 78.0 µg/m^3, 9.6 µg/m^3 to 76.8 µg/m^3 and 12 µg/m^3 to 134 µg/m^3, respectively. Positive Matrix Factorization (PMF) technique was also applied to fine and coarse data set in order to identify the possible sources of particulate matter (PM) and their contribution to the ambient particulate matter concentrations in the area. The best solution was found to be five factors for both elemental compositions of fine and coarse PM, respectively. The PMF results show that motor vehicles and secondary sulphate contribute about 40.3% and 33.0% of the fine mass respectively followed by soil, sea salt and smoke/biomass burning with the average contribution of 10.5%, 10.3% and 6.4%, respectively. In case of coarse particles the PMF results show that a large fraction of about more than 50% of the coarse mass comes from motor vehicle. Soil dust including road dust and soil construction contribute about 32.5% of the coarse mass whilst the smoke/biomass burning factor contributes about 6.7% of the coarse mass

Keywords: Airborne particulate, Bangi, elemental composition, Positive Matrix Factorization

INTRODUCTION

Bangi is a small town situated on the south of the district of Hulu Langat in Selangor, Malaysia. It is a suburban area located in Klang Valley (southeastern), about 10 kms from the city of Kajang and 10 kms from Putrajaya, the Malaysia’s federal administrative capital. There is a main road with shops houses on both side of the road. The town is linked to KTM commuter train services via the Bangi Komuter station and is surrounded by small Malays villages, within 3 kilometers distance, namely, Kampung Bangi, Kampung Bahagia, Kampung Batu Lima and Kampung Rinching. Twenty years ago the town was also surrounded by many palm oil estates and rubber estates but it is now suffered with the development threatened to turn it all to concrete. Many palm oil estates had been converted into townships, learning institution, research centre and residential area. Within a 3 kilometers distance, there are residential areas namely Seri Putra Bangi, Bukit Mahkota Bangi, Bangi Avenue, Taman Impian and many more. About 7 kms north there is a larger township namely Bandar Baru Bangi, named after the town (Bangi). It has a population about 1,500,000 and located between Kajang and Putrajaya about 25 kms away from the capital city, Kuala Lumpur. The town was developed in stages beginning in 1974 and provides commercial, industrial, business, training, recreation and higher learning institutions (Najihah and Rozilah, 2012). Basically, development of the area around Bangi (especially 10 to 20 kms radius) such as road upgrading, construction of buildings, opening of new residential area and shopping centre take place continuously since 20 years ago. In 2011 for example the Mass Rapid Transit (MRT) project with a span of 51 km from Sungai Buloh to Kajang city centre was launched and was formally opened on 17 July 2017 (http://www.mymrt.com.my/en/sbk/the-mrt-sungai-buloh-kajang-line). In 2012 new residential area namely Southville City located only few km from the town has been developed (https://www.propwall.my/insight/3269/southville_city) and still under construction.

Dust and particulate matter (PM) emissions can come from a number of sources during construction activities, as well as from off-site vehicles associated with the construction works and on-site machinery (off-road emissions), including both static and non-road mobile machinery. Fine particles (particulate matter smaller than 2.5 µm in diameter) can travel further than coarser dust (particulate matter between 2.5 µm and 10 µm in diameter) and can therefore affect the health of people living and working in the surrounding area of the site. The measurements of chemical composition have been reported for different city of Malaysia (Azman et al., 2015; Norhayati et al., 2008; Rahman et al., 2011). However, most of the studies were focused on PM_{10} - particles up to ten micrometres in size. Fewer studies of this kind have considered fine particles of less than 2.5 µm ($PM_{2.5}$) or particles between 2.5 µm and 10 µm ($PM_{10-2.5}$). This paper reports about monitoring activities conducted in the year 2012 to 2014 of the continuous study on air paticulate pollution in Bangi area. The main objective of the study is to presents the first comprehensive investigation of particulate matter with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$) and between 2.5-10 µm ($PM_{10-2.5}$) compositions and sources in the area. With the growth of the area over the last twenty years, the study enhances an understanding of chemical properties of atmospheric pollution in the area and apportions the chemical constituents of particulate matter (PM) to their emitting sources. This work is an ongoing project undertaken by the Malaysian Nuclear Agency on air particulate pollution in collaboration with International Atomic Energy Agency (IAEA) through Regional Cooperative Agreement (RCA) program. The project involves sampling of air dust, measurement of mass, black carbon (BC) and elemental concentrations. The concept of receptor model was used in this study whereby the concentrations of elements at the sampling site were used to identify the fingerprints of major pollution sources and to estimate the contribution of major pollution sources to the area.

MATERIALS AND METHODS

Sampling

The Bangi monitoring site (Figure 1) is located at Malaysian Nuclear Agency Complex, Bangi (2°54'24.56"N, 101°46'1.34"E) which is 35 kms south of Kuala Lumpur. The complex is just a few hundred meters to the road side and the north - south highway. Air particulate samples were collected from May 2012 to July 2014 using Gent Stack sampler (Hopke, 1997) provided by IAEA. The sampler was placed on a rooftop of a two storey building at approximately 10 meters height. The sampler was programmed to run automatically to collect two 24 hours duration sample (< 2.5 µm and 2.5 -10 µm aerodynamic diameter particles) twice a week from 12 noon to 12 noon. A total of 217 pair of samples were collected and analyzed covering the period of May 2012 to July 2014. Statistics of samples collected yearly starting from 2012 to 2014 were 61, 118 and 38 pairs.

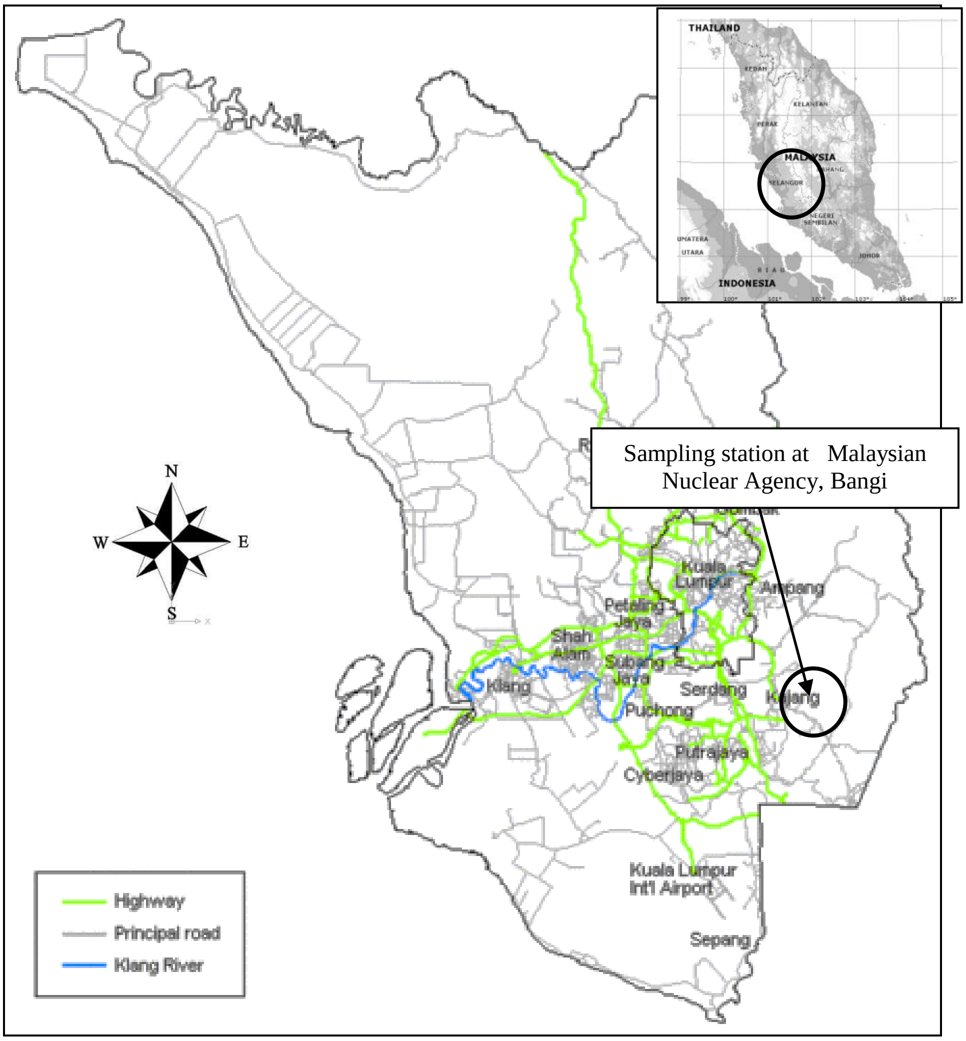

Figure 1: Location of sampling station at Malaysian Nuclear Agency, Bangi

Mass and Black Carbon Measurement

The total mass of each sample was determined by weighing the filter using a microbalance (METTLER Model MT5) equipped with a Po-212 (alpha emitter) electrostatic charge eliminator (STATICMASTER) to eliminate the static charge accumulated on the filters before each weighing. Black carbon (BC) measurements for both fine and coarse fraction were performed using an EEL Smoke Stain Reflectometer and the black carbon concentration was determined according to the method for 47 mm polycarbonate filter (Cohen et al., 2000).

Elemental Analysis

Concentration of the elements for each sample was analyzed by Particle Induced X-ray Emission (PIXE) (Cohen, 1998; Koltay, 1994) at Geological and Nuclear Science Limited, GNS Science, New Zealand under RRU services. Elemental analysis of samples was also performed by Neutron Activation Analysis (NAA) (EPA, 1999) at the Analytical Chemistry Laboratory of Malaysian Nuclear Agency. The concentration of the following twenty elements were measured and analyzed for each sample i.e Al, As, Br, Ca, Cl, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S, Si, Ti, V and Zn.

Data Analysis by Positive Matrix Factorization (PMF)

A factor analysis method, Positive Matrix Factorization (PMF), utilizes error estimates of the data to provide optimum data scaling (Paatero and Tapper, 1993). The method is based on solving the factor analysis problem by least squares approach using a data point weighting method which decomposes a matrix of data of dimension *n* rows and *m* columns into two matrix, *G(nxp)* and *F(pxm)*, where *n* is the number of samples while *m* is the number of species. The model can be written as:

$$X = GF + E \qquad (1)$$

Briefly, a data matrix *X* of *i* by *j* dimensions, in which *i* is the number of samples and *j* is the chemical species, which can be written as:

$$x_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij} \qquad (2)$$

Where *p* is the number of factor, *f* is species profile, *g* is amount of mass and e_{ij} is the residual for each sample. The task of PMF is to minimize the object function (*Q*), based upon the uncertainties:

$$Q = \sum\sum(e_{ij/s_{ij}})2 \qquad (3)$$

where s_{ij} is the uncertainties in x_{ij}. The results are constrained so that all species profiles (matrix F) are non-negative and each sample has a non-negative source contribution (matrix G). Solution of equation (3) and the model are described in detail elsewhere by Paatero and Tapper (1994) and Paatero (1997).

The advantage of PMF is the ability of the model to handle the incomplete data such as missing data, below detection limit data and negative value data. In this study, data below the detection limit (MDL) were substituted by half of the detection limit values and the uncertainty was set $\frac{5}{6}$ times the detection limit value (Polissar et al., 1998). The data obtained was then investigated for the probable sources of aerosol in the area by applying the receptor modeling PMF (PMF2 DOS) (Hopke, 1991) to the data set to confirm the possible sources of air pollution that contribute to the area.

RESULTS AND DISCUSSION

Fine and Coarse Mass Concentration

The daily concentration and the monthly average level of fine ($PM_{2.5}$) and course ($PM_{10-2.5}$) for the Bangi area is shown in Figure 2 and Figure 3, respectively. Relatively lower concentrations were observed in November to January periods or during the northeast monsoon and higher concentrations were observed during the dry season between May to September or during the southwest monsoon. There is no Malaysian guideline or standard for the fine or coarse fractions, but the USEPA National Ambient Air Quality Standard (NAAQS) for fine particle annual averages of 12 µg/m^3 with a maximum of 35 µg/m^3 averaged over 24 hour period was adopted for reference. The daily $PM_{2.5}$ and $PM_{10-2.5}$ level recorded between May 2012 to July 2014 were in the range of 1.8 - 78.0 µg/m^3 and 9.6 - 75.8 µg/m^3, respectively. The 24 hour average of $PM_{2.5}$ (29.4 µg/m^3) was found to be slightly lower than the 24 hours maximum NAAQS standard of 35 µg/m^3 (Figure 2). However the annual average (31.0 µg/m^3) was found to be higher and more than doubled the annual NAAQS standard of 12 µg/m^3 as shown in Figure 3. This could be due to several short spell of haze resulted from trans-boundary air pollution in Klang Valley which occurred during the dry season period of June to August 2012 and June 2013. (MEQR, 2012; MEQR, 2013). The haze episode was also reported on 14 Mac 2014 as the Air Pollution Index (API) level rose to the hazardous level and during the southwest monsoon between the month of June to October 2014 due to land and forest fires in Sumatra and Kalimantan, Indonesia (MEQR, 2014).

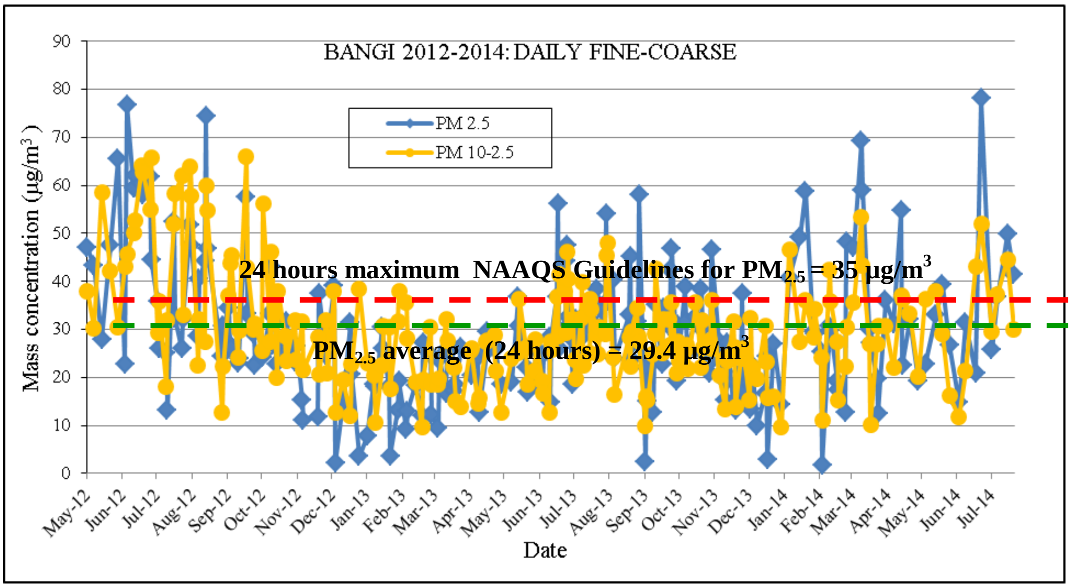

Figure 2: Daily concentration of $PM_{2.5}$ and $PM_{10-2.5}$ at Bangi

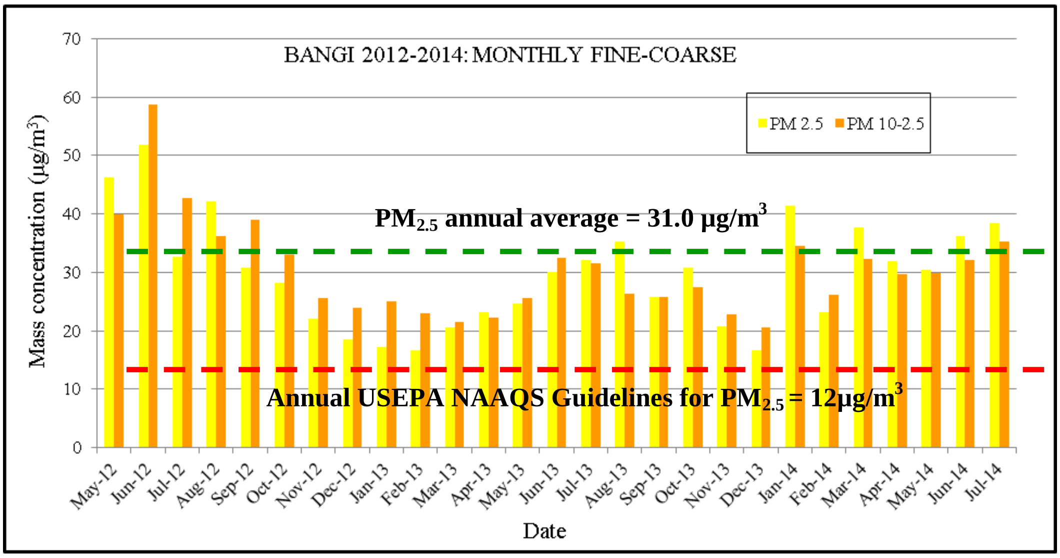

Figure 3: Monthly concentration of $PM_{2.5}$ and $PM_{10-2.5}$ at Bangi

PM_{10} Mass Concentration

The Department of Environment (DOE) monitors the country's ambient air quality through 52 continuous monitoring stations. Air particulate matter of less than 10 microns in size (PM_{10}) is one of the air pollutants measured using High Volume Sampler. According to DOE, PM_{10} was the predominant pollutant in the dry season during the south-westerly monsoon. The current Malaysian Ambient Air Quality Guidelines (MAAQ) goals are 50 µg/m^3 annual averages with a maximum of 150 µg/m^3 for 24 hours. In this study the Gent Sampler used to collect the samples was a stacked filter system with two size fraction, fine and coarse. The addition of the fine fraction (2.5 µm) to the coarse fraction (2.5-10 µm) gives an estimate of the PM_{10} mass fraction. The daily concentration of PM_{10} in the study period was in the range 12 -134 µg/m^3 with an annual average of 61.3 µg/m^3. Relatively lower concentrations were observed in November to January periods or during the northeast monsoon and higher concentrations were observed during the dry season between May to September (Figure 4). During the study period the annual average (61.3 µg/m^3) of PM_{10} was found to be exceeded the annual MAAQ Guidelines of 50 µg/m^3. This is also could be due to the serious haze recorded in Klang Valley in 2012, 2013 and 2014 as mentioned earlier in previous section. In 2012, the concentration of PM_{10} in Bangi was recorded to reach 123 µg/m^3, 124 µg/m^3 and 134 µg/m^3 on 06/06/2012, 19/06/2012 and 14/08/2012 respectively whilst in 2013 and 2014 the highest concentration was found on 26/06/13 (93.8 µg/m^3), 10/03/14 (123µg/m^3) and 23/06/14 (130 µg/m^3) respectively. All measurements were found to be higher as compared to the 24 hour average of 59.3 µg/m^3 but still below the 24 hours maximum MAAQ Guideline value of 150 µg/m^3 as shown in Figure 4.

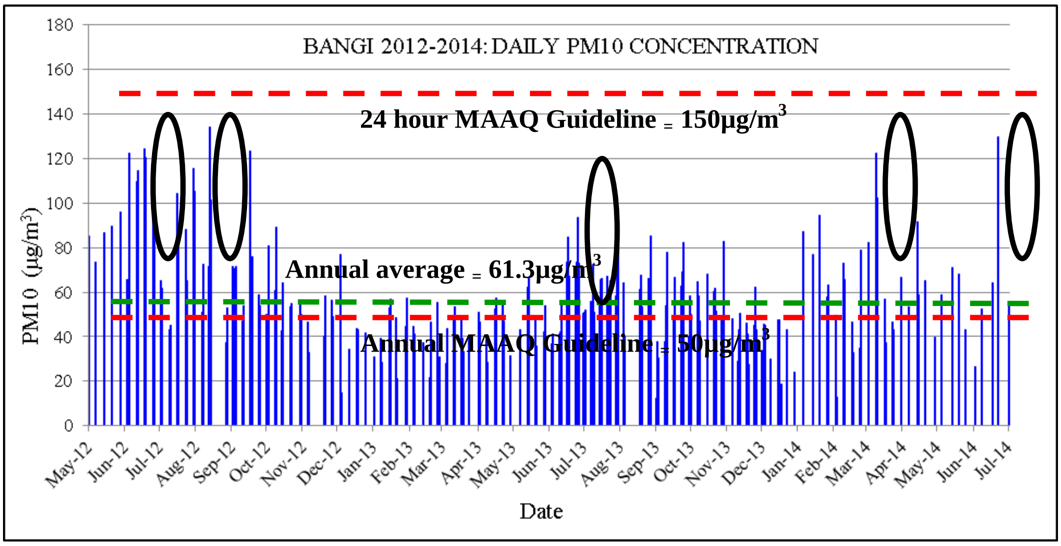

Figure 4: Daily concentration of PM_{10} 2012 -2014

PMF Analysis Result of Fine Fraction

The PMF solution for the elemental composition of fine aerosol in Bangi area was found to be a five factor solution. The identified source profiles are presented in Figure 5.

- Factor 1 represents biomass burning/smoke and contributed about 6.2% of the fine mass concentration The factor has a characteristic of high black carbon (BC), S, K, Ca and Zn. Approximately 60% of the total measured K mass concentrations was in this source fingerprint. Fine K is an accepted key element for smoke from biomass burning which is released especially under high temperatures in fires mostly as potassium chloride and potassium sulfate (Baxla et al., 2009; Begum et al., 2004; Khalil and Rasmussen, 2003).

- Factor 2 is attributed to soil dust that contains characteristic elements of Al, Si, K, Ca and Fe. (Watson and Chow, 2001). Approximately 80% of the total measured Si was in this source. This fingerprint contributed about 10.5% of the fine mass. The presence of other elements such as Mn and Fe indicated the influence of road dust to the factor during transport. Fe could be produced from tires bearing wear; car break lining or car break dust (Adachi and Tainosho, 2003) whereas Mn may have produced from brake dust (Sternbeck et al., 2002)
- Factor 3 has high loading of BC, Si, S, Cl, K and Fe represents a source from motor vehicles. It was found to be the main source of pollutant in Bangi area that contributed about 40.3% of the fine mass. Population is one of the dominant factors for increased motorization in any country. As mentioned earlier, Bangi and its surround growth continuously with road upgrading, new residential as well as its population. As the population rises, demand for transportation also rises proportionately (Azeez, 2009). Moreover the location of the sampling site is close to the main road that link the town of Bangi to the Kajang city and only few hundreds meter to the north-south highway
- Factor 4 represents secondary sulphate due to the dominance of sulphur in the profile (Kim et al., 2004). The factor contributed about 33.0% of the mass fine concentration with traces of Na, Mg, Si, K and Zn. The presence of potassium loading in the factor could be connected with the possible contribution of local wood smoke and possibly from other combustion related sources
- Factor 5 has high loading of Na, Mg, Si and Cl. It was labelled as sea salt which contributes about 10.3% of fine mass. The presence of BC, S, K and other traces element in the factor suggests the mixing of particles such as road dust or from other possible local sources such as smoke from motor vehicles or coal combustion during transport.

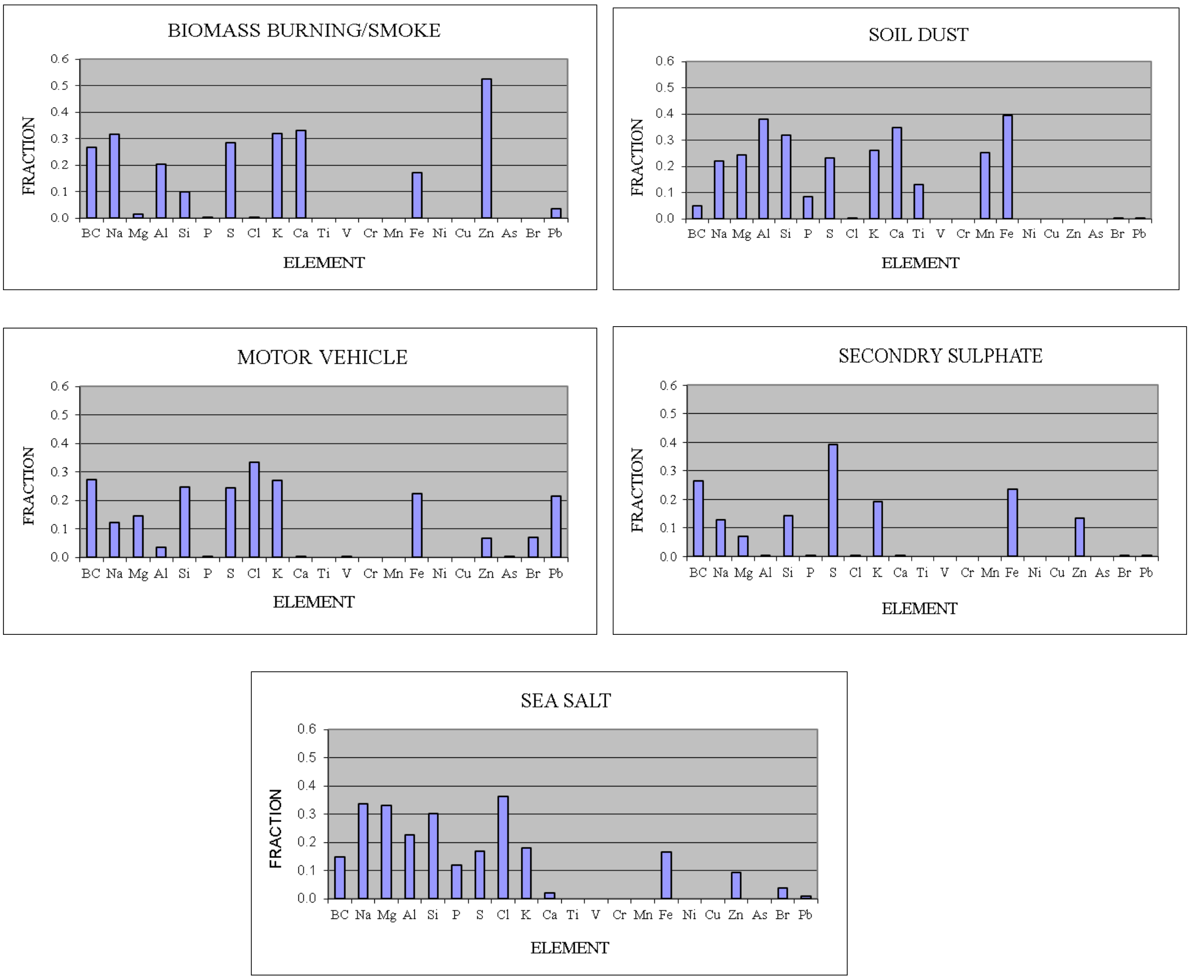

Figure 5: Source apportionment for the $PM_{2.5}$ mass measured at Bangi, 2012-2014

PMF Analysis Result of Coarse Fraction

The PMF solution for the elemental composition of coarse aerosols (Figure 6) in Bangi was also found to be a five factor solution. The same three sources were identified for the coarse fraction as for the fine fraction results i.e. soil dust (10.4%), biomass burning/smoke (6.7%) and motor vehicle (57.3%). Another two factors are soil construction and road dust:

- Soil construction (Factor 1) contributed about 14.5% of the coarse mass. This source seems to be mix source fingerprint dominated by Si, P, Ca, Mg, BC, Ni and Ti with traces of Na, Al, Cl, K, V and Fe   Al, Si, Fe and Ca are associated with the cement industry as well as fly ash from coal fired plant.
- Road dust (Factor 2) contributed about 7.9% of the coarse mass. This fingerprint most likely represents soil and motor vehicle emissions and dominated by Ti, K, Ni, Ca, Cl, P, Na and BC with traces of Mg, Al, Si, Fe, Mn and V.   Al, Ca, Fe, Mg and Na could also be produced from tires bearing wear; car break lining or car break dust whereas Ca could also came from construction activities and construction materials (Rahman et al., 2013)

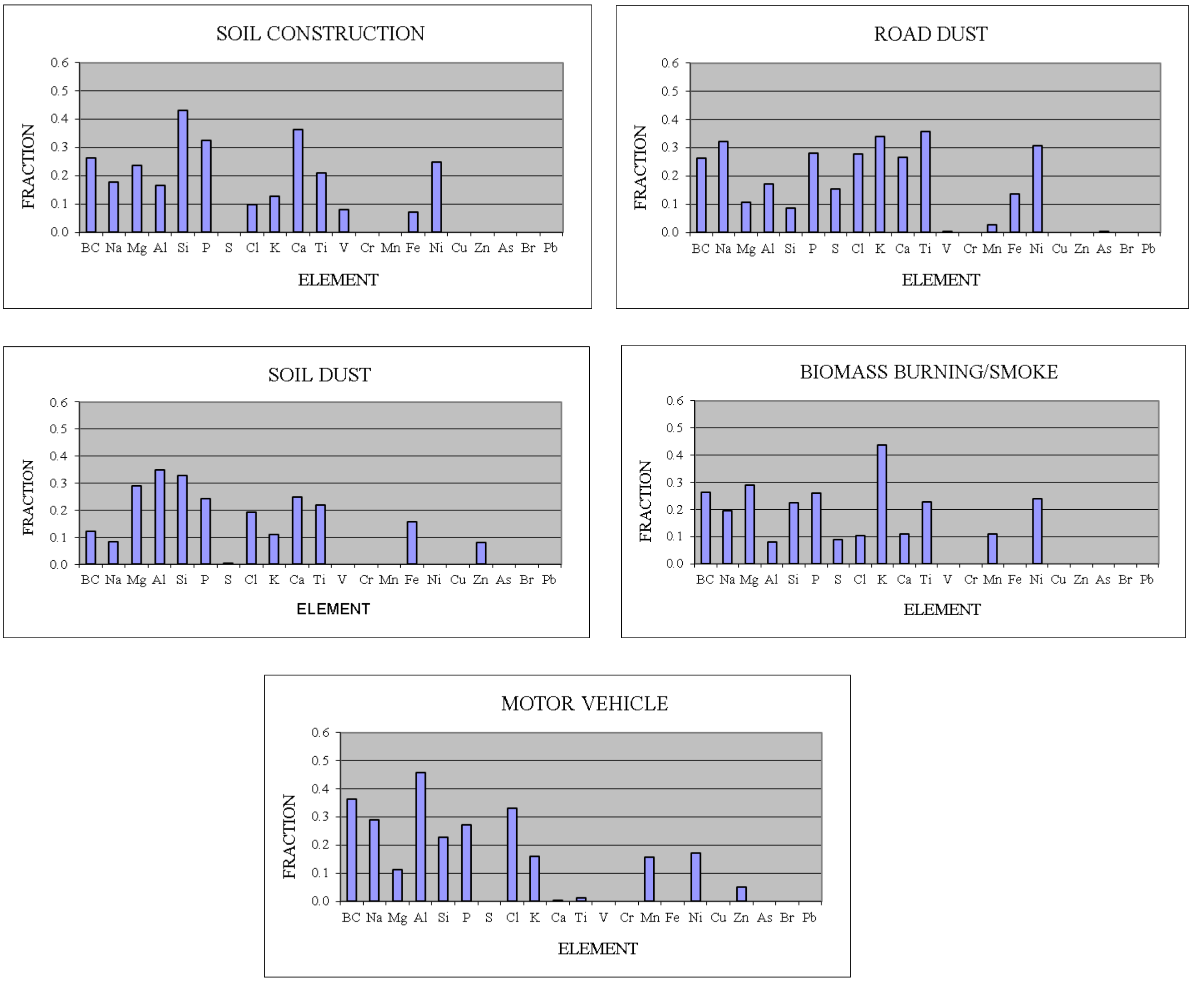

Figure 6: Source apportionment for the PM $_{10\text{-}2.5}$ mass measured at Bangi, 2012-2014

CONCLUSION

This study provides for the first time total mass as well as chemical composition of fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$) particles at Bangi, Selangor. PM_{10} mass concentration was estimated by the sum of fine fraction and the coarse fraction. The annual average of $PM_{2.5}$ concentration (31.0 µg/m^3) for the study period was found to be higher than the USEPA National Air Quality Guidelines of 12 µg/m^3. Even the PM_{10} concentration which is mostly influenced by the $PM_{2.5}$ concentration was also found at the higher end of the MAAQ Guidelines of 50.0 µg/m^3. Thus, slight increase of the air pollutants during dry spell due to open burning or forest fire may cause occurrence of haze episode. The application of the PMF model (PMF2 DOS) to both $PM_{2.5}$ and $PM_{10-2.5}$ speciation data resolved seven possible sources that contributed to the ambient air particulate matter concentration in Bangi area. The sources identified as motor vehicles, biomass burning/smoke, secondary sulfate, sea spray, soil dust, soil construction and road dust. The PMF results showed that motor vehicles were the main source for both fine and coarse particles of Bangi with an average contribution of 48.8% followed by the source from secondary sulfate (33.0%), soil construction (14.5%), soil dust (10.5%), sea salt (10.3%), road dust (7.9%) and biomass burning (6.4%).

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