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# Preliminary study of the sources of ambient air pollution in Serpong, Indonesia

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## ABSTRACT

There has been increasing interest regarding air pollution in the Serpong area of Indonesia, a region near Jakarta, especially with respect to high concentrations of Pb detected in early 2001. Several studies have been conducted, but the appropriate action needed to control this pollution has not been identified because of inadequate identification of the particulate matter sources. In this study, source investigation was performed using the chemical characteristics of ambient airborne particulate matter samples from several locations in Serpong and its surroundings. Sampling of airborne particulate matter was conducted using a Gent stacked filter unit sampler in Serpong between August and November 2008. Black carbon (BC) was determined by reflectance and elemental analysis were performed using particle induced X–ray emission (PIXE). Al, As, Ba, Br, Ca, Cl, Co, Cr, Cu, Fe, Hg, I, K, Mg, Mn, Na, Ni, P, Pb, S, Sc, Si, Se, Sr, Ti, V and Zn were determined. The results showed that the higher Pb concentrations in both fine and coarse particulate matter were observed in the industrial area compared to adjacent residential areas. The Pb percentages in the collected $PM_{2.5}$ mass in the residential and industrial areas were 3.1% and 4.3%, respectively, while for $PM_{2.5–10}$, Pb represented 1.9% and 6.0% of the PM mass, respectively. The fine fraction data from two residential areas (Setu and EMC) were analyzed using EPA PMF (version 3) for source apportionment. The source apportionment identified 5 factors, i.e., lead industry and road dust (12%), diesel vehicles (30%), oil and power plant (26%), road dust (17%) and biomass burning mixed with road dust (15%).

***Keywords:***
*Pb pollution*
*Serpong*
*PMF*
*Source apportionment*
*PIXE*

***Article History:***
*Received: 14 June 2010*
*Revised: 04 October 2010*
*Accepted: 19 October 2010*

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**doi:** 10.5094/APR.2011.024

## 1. Introduction

Air pollution has become an important problem that requires serious attention because of its impact on human health and environmental quality. A large number of epidemiological studies have shown that air pollution causes adverse human health effects (Dockery et al., 1993; Katsouyanni, 2005). In Indonesia, interest in air pollution in the Serpong area has increased especially following the detection of elevated lead concentrations in early 2001. A prior study conducted by the Environmental Management Center (EMC), an institution under the Ministry of the Environment (MoE) in 2001–2004 using high volume sampling (HVS) showed that lead concentrations in the residential area of Serpong ranged from 0.5–6.0 μg/m$^3$ with an average of 2.51 μg/m$^3$. Such values exceeded the national ambient air quality standard since Government Regulation no. 41/1999 states that 24–hour average lead concentration should be less than 2 μg/m$^3$ (Ministry of Environment, 2006). The most recent Pb monitoring using HVS have been done from January to February 2006. Multiple monitoring locations were established in the Serpong region. The results showed that the highest concentrations of lead were 7.2 μg/m$^3$ at one site and 4.0 μg/m$^3$ at another site (Ministry of Environment, 2006). These results showed that lead monitored in Serpong area was still very high.

Several activities were initiated by MoE to build a team involving all of the institutions in Serpong area such as National Nuclear Energy Agency of Indonesia (BATAN), Environmental Management Center (EMC), Science and Technology Indonesia, several industries, other local stakeholders and the Serpong Environmental Protection Agency (EPA). This team was built to study and investigate the sources of Pb and improve the emission inventory in Serpong. In 2008, a cooperative activity between BATAN Bandung and EMC was initiated, and the field work was conducted between August and November 2008 at six locations. These locations included two sites in the industrial area and four sites in residential areas [Setu, EMC, Bumi Serpong Damai (BSD), and BATAN Indah].

The main objective of this study was to investigate the possible sources of particulate air pollution, especially Pb in the Serpong area through the application of receptor models. The work focused on particulate matter (PM) with aerodynamic diameter of less than 2.5 μm (fine particulate matter or $PM_{2.5}$). Coarse particulate matter ($PM_{2.5–10}$) was also studied and the $PM_{10}$ concentrations were calculated by summing the $PM_{2.5}$ and $PM_{2.5–10}$ values. Identification and apportionment of the pollutants to their sources is an important step in air quality management. In order to identify sources, multivariate receptor modeling can be applied to observed PM composition data. Receptor modeling uses the measured pollutant concentrations at a sampling site (Hopke, 1991). Multivariate approaches are based on the assumption that the time dependence of chemical species at the receptor site will be the same for species from the same sources. Chemical species

are measured in a number of samples gathered at a receptor site over time. Species of similar variability are grouped together in a minimum number of factors that explain the variability of the data set (Chueinta et al., 2000). Among the multivariate receptor modeling used for aerosol source identification, positive matrix factorization (PMF) is a technique developed by Paatero and Tapper (1993) to provide a flexible modeling approach that can effectively use the information content in the data (Paatero and Tapper, 1993; Paatero and Tapper, 1994; Paatero, 1997). The applications of PMF have been successful in many atmospheric studies (e.g. Chueinta et al., 2000; Begum et al., 2004; Begum et al., 2005; Santoso et al., 2008).

## 2. Experimental

### 2.1. Sampling

Samples were collected using a Gent stacked filter unit sampler capable for collecting particulate matter in the $PM_{2.5–10}$ and $PM_{2.5}$ size fractions (Hopke et al., 1997). The coarse fraction samples were collected on an 8.0 μm pore nuclepore filters, whereas the $PM_{2.5}$ samples were collected on 0.4 μm pore nuclepore filters. Sampling was performed at a flow rate of 15–18 L/min for 24 hours with a frequency of three to four times per week over 2 to 3 week periods. The total of 68 pairs of $PM_{2.5}$ and $PM_{2.5–10}$ samples were collected.

### 2.2. Sampling site

Sampling was conducted in Serpong and its surrounding areas. Serpong is a district of South Tangerang, an independent city of Banten Province in Indonesia, and categorized as an industrial city with a population of more than 14 thousand inhabitants in an area of approximately 24 $km^2$. Six sampling sites were established in Serpong and its surrounding area as shown in Figure 1. Two sites were in the Serpong industrial area (Industry 1/I1 and Industry 2/I2), while the other four sites were established in the residential areas at Setu (residential 1/R1), EMC (residential 2/R2: 6.35 S and 106.67 E), BSD (residential 3/R3) and BATAN Indah (Residential 4/R4). Sites I1 and I2 were located about 20 and 17 km respectively, from EMC facility in the northwesterly direction. R1 and R4 are located about 500 meters and 3 km to the north of EMC, respectively, while R3 is located about 9 km to the northwest of EMC.

### 2.3. Sample characterization

The masses of both the coarse and fine fractions were determined by weighing the filters before and after exposure, then they divided by the volume of air passing through the filter to obtain the concentration of $PM_{2.5}$ and $PM_{10–2.5}$ (μg/$m^3$), respectively. The $PM_{10}$ concentrations were obtained by summing these two values. The black carbon (BC) concentrations of the samples were determined by reflectance measurement using a smoke stain reflectometer (Diffusion Systems Ltd. Model 43D). Secondary standards of known black carbon concentrations are used to calibrate the reflectometer. The filter samples were analyzed for their elemental composition using proton induced X–ray emission (PIXE) at the Institute of Geological and Nuclear Sciences (GNS), New Zealand. The X–ray spectrum obtained from PIXE measurements were analyzed using the computer code GUPIX developed by Guelph University (Maxwell et al., 1995). Al, As, Ba, Br, Ca, Cl, Co, Cr, Cu, Fe, Hg, I, K, Mg, Mn, Na, Ni, P, Pb, S, Sc, Si, Se, Sr, Ti, V and Zn were detected. Calibration of the PIXE system was performed by irradiating suitable Micromatter thin target standards (Cohen et al., 2004; Begum et al., 2004).

### 2.4. Data analysis

EPA Positive Matrix Factorization (PMF) Version 3.0 (US EPA, 2010) is one of the receptor models that have been developed by the United States Environmental Protection Agency Office of Research and Development. PMF is a multivariate factor analysis tool that resolves a matrix of speciated sample data into two matrices, source contributions and source profiles that then need to be interpreted by the analyst as to what source types are represented using measured source profile information, wind direction analysis, and emission inventories. The method is reviewed briefly here and described in greater detail elsewhere (Paatero and Tapper, 1994; Paatero, 1997).

A chemically speciated data set can be viewed as a data matrix X of *n* by *m* dimensions, in which *n* number of samples and *m* chemical species were measured. The goal of multivariate receptor modeling, for example with PMF, is to identify a number of factors *p*, the species profile *f* of each source, and the amount of mass *g* contributed by each factor to each individual sample (Equation 1):

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

where $e_{ij}$ is the residual for each sample/species.

Results are constrained so that samples cannot have negative source contributions. PMF allows each data point to be individually weighed. This feature allows the analyst to adjust the influence of each data point, depending on the confidence in the measurement. For example, data below detection can be retained for use in the model, with the associated uncertainty adjusted so these data points have less influence on the solution than measurements above the detection limit. The PMF solution minimizes the object function *Q* (Equation 2), based upon these uncertainties (*u*).

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[ \frac{x_{ij} - \sum_{k=1}^{p} g_{ik} f_{kj}}{u_{ij}} \right]^2 \quad (2)$$


***Figure 1.*** *Location of sampling sites (source: Google Maps).*

## 3. Results and Discussion

### 3.1. Particulate matter

PM mass, BC, and lead concentrations for each site are summarized in Table 1. Twenty four hour $PM_{2.5}$ levels at the industrial sites ranged from 15 to 42 μg/m$^3$, while at the residential sites, values ranged from 9 to 36 μg/m$^3$. $PM_{2.5}$ concentration for the six locations over 2 to 3 weeks sampling periods are shown in Figure 2. The mean $PM_{2.5}$ concentrations for sites I1, I2, R1, R2, R3 and R4 are 23.0, 26.1, 21.0, 20.2, 19.2 and 18.5 μg/m$^3$, respectively. The mean $PM_{10}$ concentrations for these sites are 72.3, 62.6, 47.7, 39.9, 47.2 and 40.9 μg/m$^3$, respectively. Assuming that these 2 to 3 weeks of sampling can represent the annual mean of $PM_{2.5}$ levels, all of the $PM_{2.5}$ concentration at these sampling sites would exceed the Indonesian national ambient air quality standard of an annual mean $PM_{2.5}$ value of 15 μg/m$^3$ (PP no. 41/1999). The $PM_{2.5}$ values measured at the residential sites in Serpong were higher than the values reported for Bandung (Santoso et al., 2008) where the mean values of $PM_{2.5}$ from 2002 to 2004 were 14.0 ± 6.9 μg/m$^3$ for Bandung and 11.9 ± 6.6 μg/m$^3$ for Lembang. However, none of the sampling sites exceeded the twenty four hour Indonesian NAAQS for $PM_{2.5}$ and $PM_{10}$ (65 and 150 μg/m$^3$, respectively). There were one and two samples from sites R2 and I2, respectively that exceeded the twenty four hour US standard (35 μg/m$^3$). While for the $PM_{10}$ concentrations at the residential sites in Serpong are similar to the concentrations reported for other cities such as Semarang and Surabaya where the annual mean values for $PM_{10}$ in 2001–2004 and 2001–2005 for these locations ranged from 50 to 60 μg/m$^3$ (National Development Planning Agency, 2006a; 2006b).

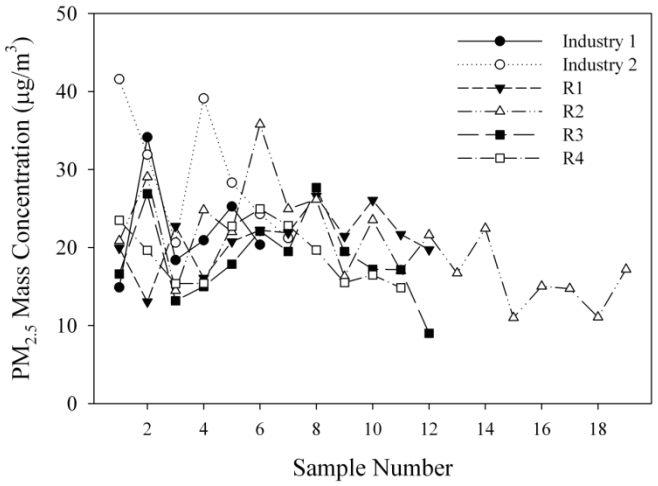


***Figure 2.*** *$PM_{2.5}$ concentrations at the six sampling sites in Serpong area and surroundings in August – November, 2008.*

Previous measurements of $PM_{2.5}$ concentrations at the EMC/R2 site were made by Cohen in 1996 (Cohen et al, 1997). Over a similar period of August to October (dry season), the $PM_{2.5}$ monthly averages ranged from 42 to 45 μg/m$^3$. The mass contributions of biomass burning (smoke) and motor vehicles to $PM_{2.5}$ represented more than 75% of the measured mass (Cohen et al., 1997). Compared to the result in 1996, the $PM_{2.5}$ in the 2008 study period at the EMC site decreased to approximately forty percent (18.5 μg/m$^3$) of the 1996 values. This reduction may be the result of decreased smoke from open burning and reductions in motor vehicle emissions especially the emissions from "dirty" vehicles such as two stroke engines and poorly tuned diesel engines. In that period, smoke from burning in open landfills and of agricultural litter and stubble burning were the major sources and occurred intensively, compared to 2008 when local agricultural activities were reduced since the landfill was converted into residential and commercial uses.

### 3.2. Black carbon

The average concentrations of BC at I1, I2, R1, R2, R3 and R4 are 4.4, 4.5, 3.2, 2.6, 2.4 and 2.6 μg/m$^3$ respectively. The average ratio of BC to $PM_{2.5}$ concentration at these sampling sites ranged from 13 – 25%. Figure 3 shows that generally, the concentration of BC at the six sampling sites are in the same range, except for industry 2 where a high concentration of BC was detected on one sampling day. The BC concentrations at the industrial sites were higher than in the residential area because of the industrial activities including heavy diesel truck traffic. A container truck industry is located near a major highway and the prevailing wind direction was from the northwest. However, the concentrations were similar to the annual BC levels reported in the urban area of Bandung and of suburban Lembang between 2002 and 2004 (4.2 ± 1.8 μg/m$^3$ and 3.0 ± 1.0 μg/m$^3$, respectively) (Santoso et al., 2008).

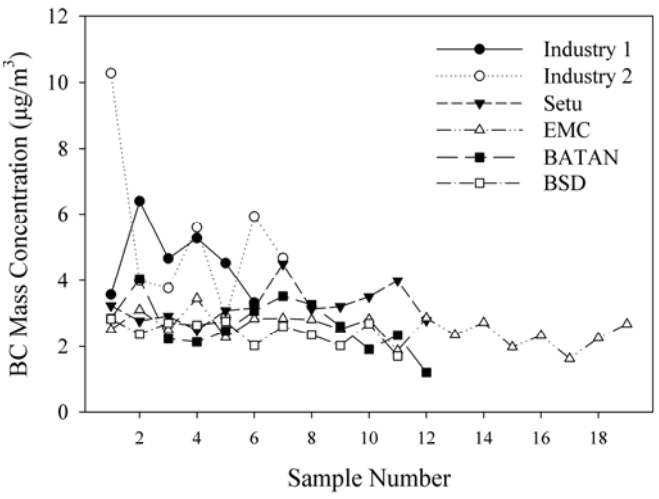


***Figure 3.*** *Black carbon concentration at the six sampling sites.*

***Table 1.*** *The sampling data, mean mass, BC and Pb concentrations (μg/m$^3$)*

| Sampling sites | Number of Samples | $PM_{2.5}$ (μg/m$^3$) | | $PM_{10}$ (μg/m$^3$)[a] | | Black carbon | | Mean % Pb in $PM_{2.5}$ | Mean % Pb in $PM_{2.5-10}$ | Mean % Pb in $PM_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Range | Mean | Range | Mean | Range | Mean | | | |
| Industry 1 (I1) | 6 | 15–34 | 23.0 | 29–77 | 72.3 | 3.3–6.4 | 4.4 | 0.63 ± 0.07 | 1.60 ± 0.12 | 2.22 ± 0.21 |
| Industry 2 (I2) | 8 | 21–42 | 26.1 | 23–51 | 62.6 | 2.9–10 | 4.5 | 0.17 ± 0.05 | 0.35 ± 0.06 | 0.51 ± 0.11 |
| Residential 1, Setu (R1) | 12 | 13–27 | 21.0 | 18–41 | 47.7 | 2.8–4.5 | 3.2 | 0.13 ± 0.04 | 0.18 ± 0.04 | 0.31 ± 0.08 |
| Residential 2, EMC (R2) | 19 | 11–36 | 20.2 | 13–30 | 39.9 | 1.6–3.5 | 2.6 | 0.10 ± 0.03 | 0.12 ± 0.03 | 0.22 ± 0.06 |
| Residential 3, BSD (R3) | 11 | 9–27 | 19.2 | 10–32 | 47.2 | 1.9–4.0 | 2.4 | 0.10 ± 0.03 | 0.21 ± 0.04 | 0.31 ± 0.07 |
| Residential 4, BATAN Indah (R4) | 12 | 15–24 | 18.5 | 13–44 | 40.9 | 1.7–2.8 | 2.6 | 0.10 ± 0.03 | 0.21 ± 0.04 | 0.31 ± 0.07 |

[a] *$PM_{10}$ is the sum of the measured $PM_{2.5}$ and $PM_{2.5-10}$*

### 3.3. Lead

Average lead, BC and mass concentrations are summarized in Table 1, while the concentrations of the other measured elements are summarized in Table 2. Figures 4 and 5 show the Pb results for $PM_{2.5}$ and $PM_{2.5–10}$, respectively. The average concentration of lead in $PM_{2.5}$ for the I1, I2, R1, R2, R3 and R4 sites are 0.63, 0.17, 0.13, 0.10, 0.10, and 0.10 μg/m$^3$, respectively. The average lead concentrations in $PM_{2.5–10}$ are 1.60, 0.35, 0.18, 0.12, 0.21 and 0.21 μg/m$^3$, respectively. Lead concentrations were higher in the coarse fraction than in fine particles by approximately a factor of two. The ranges of Pb percentages in $PM_{2.5}$ at I1, I2, R1, R2, R3 and R4 sites were 0.63–4.25, 0.18–1.61, 0.04–3.13, 0.05–1.56, 0.03–2.15 and 0.03–2.14%, respectively, while for $PM_{2.5–10}$, they were 0.56–6.00, 0.30–2.95, 0.12–1.32, 0.15–1.76, 0.08–1.77 and 0.09–1.89%, respectively. Lead in coarse particles can arise from road dust that have been re–suspended by the motion of tires over the road surface (Hopke et al., 2008) and from lead reprocessing facilities (Glover et al., 1991). Historically, much of the lead in the fine fraction has typically come from the emissions of vehicles burning fuel containing tetraethyl lead (Hopke et al., 2008). However, Indonesia has eliminated leaded gasoline in July 2006 and in Jakarta, leaded gasoline was eliminated in early 2001. The high lead concentrations could be from other lead sources such as the battery recycling plant that could play a continuing role in elevated lead concentrations, similar to the situation that was reported in Bangladesh (Begum et al., 2004). It can be seen that lead in $PM_{2.5}$ and $PM_{2.5–10}$ in the industrial areas were much higher, 3.4 to 7 times, than the concentrations in the residential region. The highest lead in $PM_{2.5}$ and $PM_{10}$ (1.07 and 4.73 μg/m$^3$, respectively) were detected at the industry 1 site that has a lead recycling and bar production facility.

Browne et al. (1999) reported lead concentrations in total suspended particulate matter collected over 1 to 2 weeks period in Semarang between August 1996 and November 1997. The mean lead levels in the highway zone were 0.35 μg/m$^3$, in the residential zone were 0.95 μg/m$^3$, in the commercial zone were 0.99 μg/m$^3$ and in the industrial zone were 8.41 μg/m$^3$ with a maximum of 16.5 μg/m$^3$. Concentrations at most residential and highway zone sample sites were below the 24–hour Indonesian air lead standard of 2 μg/m$^3$ (Browne et al., 1999). Lead concentrations in total suspended particulate matter at the residential sites in Serpong from 2001 to 2004 as reported by Environmental Management Center (EMC) ranged from 0.5 to 6 μg/m$^3$ with an average of 2.51 μg/m$^3$. These values were higher than in Semarang and violated the annual lead of NAAQS standard of 1 μg/m$^3$. Some samples were also in violation of the 24–hour Indonesian standard of 2 μg/m$^3$.

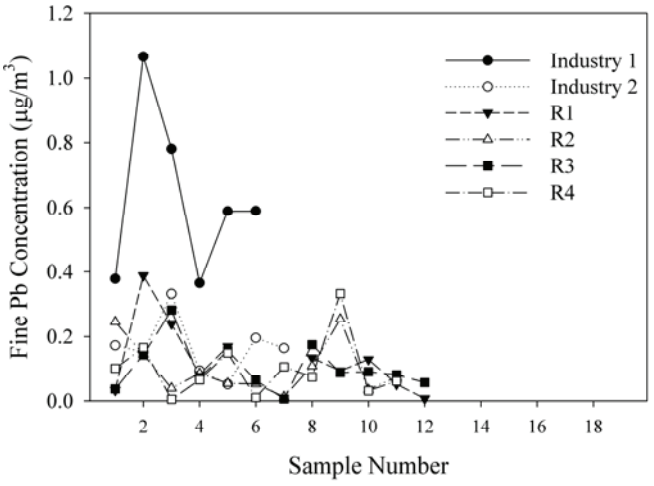


***Figure 4.*** *Pb concentrations in fine particulate matter at the six sampling sites.*

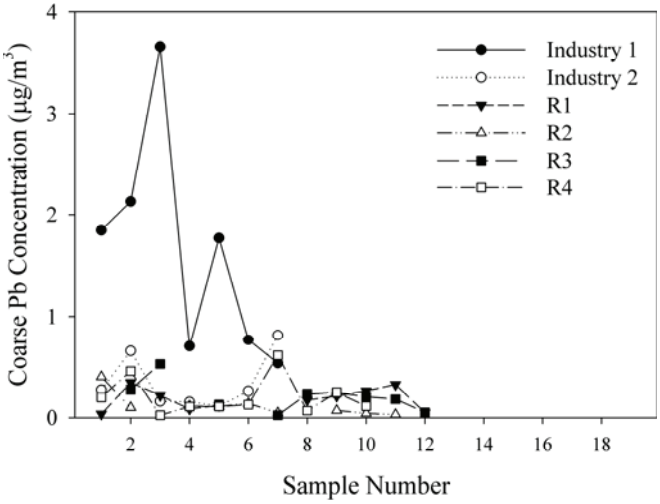


***Figure 5.*** *Pb concentrations in coarse particulate matter at the six sampling sites.*

Cohen et al. (1997) reported that from August to October 1996 (dry season) at the EMC site, the monthly average lead concentrations were 0.49 to 0.93 μg/m$^3$, while the highest concentration was 2.4 μg/m$^3$ representing 7.5% of the fine PM mass. The lead sources were dominated by motor vehicles (32%) and lead processing (1%) (Cohen et al., 1997). The lead concentrations in the 2008 study period at the EMC site had decreased to approximately one–ninth (0.10 μg/m$^3$) compared to 1996. Since the lead emissions from leaded fuel burning was eliminated in 2001 for the Jakarta area and its surroundings, the significant changes of lead concentrations in this area can be attributed to the elimination of this source. Although lead emissions from vehicles had been minimized, the Serpong area still experienced high lead levels that could no longer be associated with motor vehicle emissions. Therefore, another source of lead such as lead processing appears to be increasing while the vehicle emissions decreased. The source contribution of lead in fine particulate matter could be identified using PMF receptor modeling.

### 3.4. Source apportionment

In this source identification study, the fine particulate data for sites R1 and R2 were used as the input to PMF since these two sites are about 500 m apart and lie in the same region. Determining the number of factors is one of the major difficulties in factor analysis. In this study, the number of resolved source profiles was 5 where a good fit of the predicted concentrations to the measured values was obtained. This number of factors adequately fit the data with the most physically meaningful results. Also, since rotational ambiguity exits in the PMF solutions, PMF was run several times with different *Fpeak* value to determine the range within which objective function of *Q* value described in Equation 2 remains essentially constant (Kim et al., 2004). The optimal solution should lie in this *Fpeak* range. After reviewing the solutions, an *Fpeak* of zero was chosen as providing the most interpretable solution.

The source apportionment results using EPA PMF Version 3.0 (US EPA, 2010) for the residential data set of fine samples are shown in Figure 6. The PMF results resolved five sources for this fraction. The first factor shows a high value of lead. The lead in this factor dominates more than 80% of lead in the samples. It should be noted that S also appears along with Al, Ca, Fe, and Si suggesting contaminated road dust. This factor likely represents a lead industrial complex that recycles lead–acid batteries and produces lead ingots. The profile is mixed with road dust and represented 12% of fine fraction mass. These industrial facilities involved in lead reprocessing are to the northwest of sampling sites.

***Table 2.*** *The range of elemental concentrations at the six sampling sites (ng/m$^3$)*

| Element | Industry 1/I1 | | Industry 2/I2 | | Setu/R1 | |
|---|---|---|---|---|---|---|
| | $PM_{2.5}$ | $PM_{2.5-10}$ | $PM_{2.5}$ | $PM_{2.5-10}$ | $PM_{2.5}$ | $PM_{2.5-10}$ |
| Al | 176–504 | 603–1 268 | 127–712 | 465–1 240 | 91–337 | 610–1 346 |
| As | 31–48 | 20–90 | 9–39 | 17–29 | 7–23 | 13–15 |
| Br | 8–17 | 19–29 | 8–13 | 8–12 | 9–13 | 7–8 |
| Ca | 185–591 | 660–1 835 | 81–606 | 287–1 147 | 39–192 | 325–1 001 |
| Cl | 100–297 | 639–1 756 | 29–272 | 268–927 | 27–51 | 122–675 |
| Cr | 1–12 | 5–26 | 1–13 | 6–10 | 1–4 | 4–10 |
| Cu | 2–12 | 4–29 | 2–27 | 6–12 | 3–9 | 3–13 |
| Fe | 155–528 | 588–1 240 | 92–509 | 282–880 | 65–203 | 381–858 |
| K | 168–356 | 137–416 | 160–473 | 63–340 | 145–275 | 172–262 |
| Mg | 51–112 | 128–262 | 40–204 | 144–392 | 41–85 | 145–220 |
| Mn | 6–22 | 22–38 | 3–19 | 12–26 | 2–11 | 12–28 |
| Na | 90–320 | 323–1 264 | 63–422 | 68–1 425 | 43–219 | 215–558 |
| Ni | 2–8 | 5–8 | 3–5 | – | 1–5 | 3.6–4.1 |
| P | 46–91 | 94–179 | 28–130 | 52–162 | 24–59 | 94–136 |
| Pb | 365–1 067 | 535–3 658 | 51–332 | 113–814 | 7–388 | 36–344 |
| S | 777–1 893 | 453–1 639 | 838–2 763 | 268–927 | 681–1 409 | 456–746 |
| Si | 382–1 084 | 1 263–2 879 | 257–723 | 899–2 590 | 171–543 | 1 082–2 523 |
| Ti | 9–35 | 44–95 | 4–55 | 24–81 | 4–16 | 34–81 |
| V | 3–6 | 3–15 | 3–12 | 4–12 | 2–9 | 3–5 |
| Zn | 44–129 | 84–151 | 20–386 | 22–540 | 24–57 | 36–101 |
| **Element** | **EMC/R2** | | **BSD/R3** | | **BATAN Indah/R4** | |
| | $PM_{2.5}$ | $PM_{2.5–10}$ | $PM_{2.5}$ | $PM_{2.5–10}$ | $PM_{2.5}$ | $PM_{2.5–10}$ |
| Al | 93–195 | 121–1 008 | 62–190 | 166–1 117 | 76–151 | 446–1 640 |
| As | 13–17 | 13–43 | 7–33 | 13–34 | 15–17 | 22–59 |
| Br | 8–11 | 7–8 | 6–12 | 11–20 | 14–15 | 9–16 |
| Ca | 39–96 | 387–849 | 21–117 | 137–1 023 | 31–65 | 312–795 |
| Cl | 28–44 | 112–931 | 19–41 | 125–647 | 25–37 | 157–1 116 |
| Cr | 2–4 | 3–9 | 0.3–2 | 3–7 | 2–4 | 2–6 |
| Cu | 1–6 | 3–11 | 2–7 | 3–16 | 2–7 | 4–14 |
| Fe | 59–120 | 347–668 | 33–131 | 101–818 | 49–93 | 276–1 110 |
| K | 139–263 | 97–233 | 122–270 | 46–258 | 123–230 | 130–257 |
| Mg | 37–71 | 41–248 | 35–75 | 55–238 | 35–62 | 119–284 |
| Mn | 1–8 | 8–24 | 2–9 | 5–26 | 1–7 | 9–25 |
| Na | 71–222 | 311–786 | 34–178 | 42–676 | 67–163 | 319–1 043 |
| Ni | 2–5 | 3.9–4.3 | 1.7–1.8 | 2.1–4.9 | 2–3 | 3.9–4.6 |
| P | 24–44 | 73–120 | 5–51 | 32–146 | 14–38 | 91–151 |
| Pb | 12–254 | 30–401 | 6–282 | 25–527 | 5–332 | 23–613 |
| S | 892–1 533 | 146–697 | 687–1 362 | 113–674 | 776–1 721 | 311–847 |
| Si | 183–357 | 1 126–1 972 | 108–352 | 326–2 238 | 150–269 | 898–2 803 |
| Ti | 1–12 | 30–61 | 2–10 | 11–70 | 1–10 | 25–98 |
| V | 2–7 | 3–5 | 2–7 | 3–10 | 3–5 | 2–10 |
| Zn | 18–106 | 17–150 | 12–76 | 14–39 | 21–152 | 21–260 |

The formation of lead sulfate in old batteries could be the source of the observed sulfur in the profile.

The second factor characterized by high values of Zn and S. This combination of elements suggests the contribution from two–stroke vehicles (Chueinta et al., 2000; Begum et al., 2004) and diesel vehicles. Sulfur comes from diesel vehicle emissions since Indonesia still has a high sulfur content in diesel fuel (~ 5 000 ppm) (Santoso et al., 2008). At this sampling site, off–road diesel vehicles are used in sand exploitation activities. Lead also appears in this factor suggesting contamination by fugitive emissions from lead processing facilities (Begum et al., 2005). This factor represents about the 30% of fine mass fraction.

High values of S appeared in factor three which probably arises from multiple fueled power plants that burn coal and residual oil. There are two power plants within 50 km of the sampling site. These power plants use multiple fuels to reduce the operational costs. They use coal as their main fuel. However, residual oil is burned as well. These emissions represent 26% of fine fraction. The Indonesian government's energy policy is to use 1 000 MW coal power plants for base loading in Java to provide the needed electricity. To meet the electrical power demand, the government is promoting the construction of coal power plants in Java, where now in West Java, there are 3–4 more coal power plants under construction that will be ready to operate in 2010.

The fourth factor was identified to be road dust containing crustal elements Al, Ca, Fe, Si and Ti (Cohen et al., 2010). This factor represents 17% of fine fraction mass. The road dust includes crustal metal from construction sites as well as paved and unpaved roads (Hien et al., 2001). The fifth factor characterized by high values of K and BC. It is assigned as the emissions from biomass burning that produce high concentrations of carbonaceous particles (Santoso et al., 2008). Burning wood, paper, cardboard and biomaterial including vegetation produce significant emissions in this area since open burning is a common habit. The study by Cohen et al. (1997) found that burning was a major source representing 44% of fine fraction mass in 1996. There appears to be decreased biomass burning emissions although this factor still represents 15% of the fine fraction mass. The crustal elements representing road dust appear in both the first and fifth factors suggest that road dust mixed into these other sources is not well separated, possibly because of the limited sized data sets.

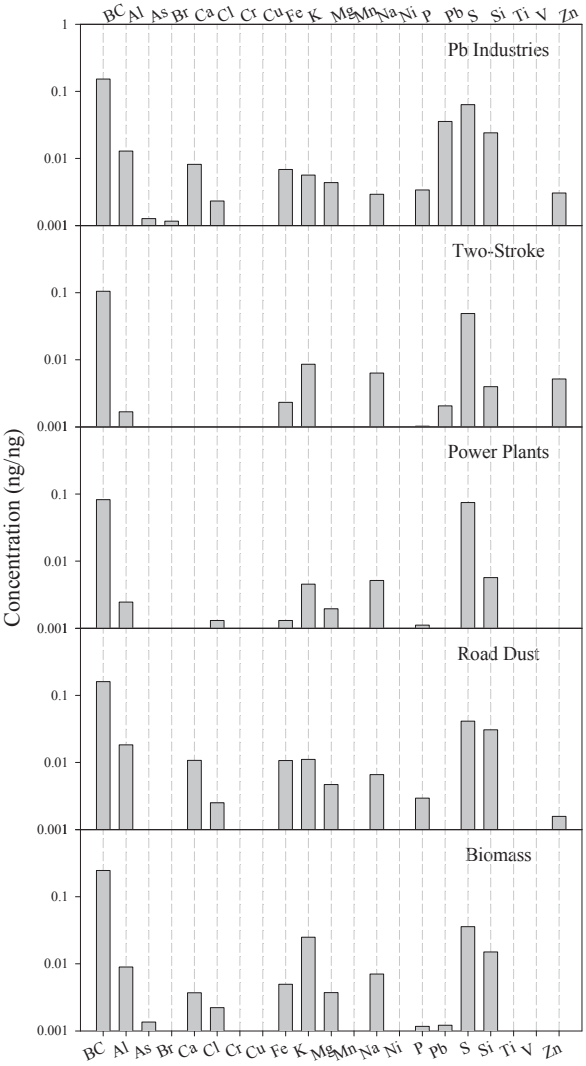


***Figure 6**. Source profiles derived from PM2.5 data in Serpong.*

## Conclusions

Airborne particulate matter samples were collected using a Gent stacked filter unit in Serpong, Indonesia in August to November 2008 to examine and investigate the possible sources of air pollution. The highest percentage of Pb compared to $PM_{2.5}$ concentration in residential and industrial areas were 3.13% and 4.25%, while for $PM_{2.5–10}$ were 1.89% and 6.00%, respectively. Positive matrix factorization had been applied to determine source apportionment of fine particulate matter in the residential area. The results show that 5 sources were identified, i.e., lead industry mixed with road dust (12%), diesel vehicles (30%), oil and coal fired power plant (26%), road dust (17%) and biomass burning mixed with road dust (15%). The high concentrations of lead in this area appear to be primarily associated with a lead battery recycling and bar production facility.

## Acknowledgement

The authors acknowledge the Environmental Management Center – Minister of Environmental of Indonesia and Directorate General of Higher Education for the financial support and cooperation throughout this work. The authors also gratefully acknowledge Dr. David D. Cohen (ANSTO) for expert assistance and all staff of the Radiometry Analytical group for their technical assistance.

## References

BAPPENAS, National Development Planning Agency. 2006a. Surabaya Local Strategy and Action Plan for Urban Air Quality Improvement.

BAPPENAS, National Development Planning Agency. 2006b. Semarang Local Strategy and Action Plan for Urban Air Quality Improvement.

Begum, B.A., Biswas, S.K., Kim, E., Hopke, P.K., Khaliquzzaman, M., 2005. Investigation of sources of atmospheric aerosol at a hot spot area in Dhaka, Bangladesh. *Journal of the Air and Waste Management Association* 55, 227–240.

Begum, B.A., Kim, Eugene., Biswas, S.K., Hopke, P.K., 2004. Investigation of sources of atmospheric aerosol at urban and semi–urban areas in Bangladesh. *Atmospheric Environment* 38, 3025–3038.

Browne, D.R., Husni, A., Risk, M.J., 1999. Airborne lead and particulate levels in Semarang, Indonesia and potential health impact. *Science of the Total Environment* 227, 145–154.

Chueinta, W., Hopke,P.K., Paatero, P., 2000. Investigation of sources of atmospheric aerosol at urban and suburban residential areas in Thailand by positive matrix factorization. *Atmospheric Environment* 34, 3319–3329.

Cohen, D.D., Crawford, J., Stelcer, E., Thu Bac, V., 2010. Characterisation and source apportionment of fine particulate sources at Hanoi from 2001 to 2008. *Atmospheric Environment* 44, 320–328.

Cohen, D.D., Gorton, D., Stelcer, E., Hawas, O., 2004. Accelerator based studies of atmospheric pollution processes. *Radiation Physics and Chemistry* 71, 759–767.

Cohen, D.D., Gras, J., Garton, D., Firestone, T., Johnson, G., Bailey, G., Ayers, G., 1997. Study of Fine Atmospheric Particles and Gases in the Jakarta Region. Final Report, Project Report No.3 December 1997.

Dockery, D.W., Pope, C.A., Xu, X., Spengler, J.D., Ware, J.H, Fay, M.E., Ferris, B.G., Speizer, F.E., 1993. An association between air pollution and mortality in six US cities. *New England Journal of Medicine* 329, 1753–1759.

Glover, D.M., Hopke, P.K., Vermette, S.J., Landsberger, S., D'Auben, D.R., 1991. Source apportionment with site specific source profiles. *Journal of the Air and Waste Management Association* 41, 294–305.

Hien, P.D., Binh, N.T., Truong, Y., Ngo, N.T., Sieu, L.N., 2001. Comparative receptor modeling study of TSP, $PM_{2.5}$ and $PM_{2–10}$ in Ho Chi Minh City. *Atmospheric Environment* 35, 2669–2678.

Hopke, P.K., Cohen, D.D., Begum, B.A., Biswas, S.K., Ni, B.F., Pandit, G.G., Santoso, M., Chung, Y.S., Davy, P., Markwitz, A., Waheed, S., Siddique, N., Santos, F.L., Pabroa, P.C.B., Seneviratne,.M.C.S., Wimolwattanapun, W., Bunprapob, S., Vuong, T.B., Hien, P.D., Markowicz, A., 2008. Urban air quality in the Asian region. *Science of the Total Environment* 404, 103–112.

Hopke, P.K., Xie, Y., Raunemaa, T., Bieglski, S., Landsberger, S., Maenhaut, W., Artoxo, P., Cohen, D.D., 1997. Characterization of gent stacked filter unit $PM_{10}$ sampler. *Aerosol Science and Technology* 27, 726–735.

Hopke, P.K., 1991. *Receptor Modeling for Air Quality Management*. Elsevier, Amsterdam.

Katsouyanni, K., 2005. Long term effect of air pollution in Europe. *Occupational and Environmental Medicine* 62, 432–433.

Kim, E., Hopke, P.K., Edgerton, E.S., 2004. Improving source identification of Atlanta aerosol using temperature resolved carbon fractions in positive matrix factorization. *Atmospheric Environment* 38, 3349–62.

Maxwell, J.A., Teesdale, W.J., Campbell, J.L., 1995. The Guelph PIXE software package II. *Nuclear Instruments and Methods in Physics Research B: Beam interactions with materials and atoms* 95, 407–421.

Ministry of Environment, 2006. State of Environment Report in Indonesia 2005. Available from http://www.menlh.go.id/slhi/14-%20Bab%202_28_37.pdf.

Norris, G., Vedantham, R., Wade, K., Brown, S., Prouty, J., Foley, C., Martin, L., 2008. EPA Positive Matrix Factorization (PMF) 3.0 Fundamentals & User Guide, U.S. Environmental Protection Agency, Office of Research and Development, Washington, EPA600/R-08/108. Available from http://www.epa.gov/heasd/products/pmf/pmf.html.

Paatero, P., 1997. Least squares formulation of robust non–negative factor analysis. *Chemometrics and Intelligent Laboratory Systems* 37, 23–35.

Paatero, P., Tapper, U., 1994. Positive matrix factorization: a non–negative factor model with optimal utilization of error estimates of data values. *Environmetrics* 5, 111–126.

Paatero, P., Tapper, U., 1993. Analysis of different modes of factor analysis as least squares fit problems. *Chemometrics and Intelligent Laboratory Systems* 18, 183–194.

PP no.41/1999, Government Regulation on National Air Ambient Quality Standard – Indonesia, Available from http://puu-pi.menlh.go.id/pdf/ind/IND-PUU-3-1999-PP-41-1999.pdf.

Santoso, M., Hopke, P.K., Hidayat, A., Dwiana, D.L., 2008. Sources identification of the atmospheric aerosol at urban and suburban sites in Indonesia by Positive Matrix Factorization. *Science of the Total Environment* 397, 229–238.

U.S. Environmental Protection Agency (USEPA), 2010. EPA Positive Matrix Factorization (PMF) 3.0 Model, http://www.epa.gov/heasd/products/pmf/pmf.html.