



Chiang Mai J. Sci. 2009; 36(2) : 123-135

www.science.cmu.ac.th/journal-science/josci.html

Invited Paper

Chemical Analysis of Airborne Particulates for Air Pollutants in Chiang Mai and Lamphun Provinces, Thailand

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ABSTRACT

Concentrations of airborne particulate matters with diameter less than 10 μm (PM_{10}) were measured for 24 hours every 3 days at four sampling stations located in Chiang Mai and Lamphun Provinces, Thailand. The sampling scheme was conducted during June 2005 to June 2006. The result revealed the same pattern for all stations, in which the PM_{10} concentration increased at the beginning of dry season (December) and reached its peak in March before decreasing by the end of April. The mean PM_{10} concentrations were in the range from $33.17 \pm 21.39 \mu\text{g}/\text{m}^3$ in rainy season to $73.64 \pm 25.34 \mu\text{g}/\text{m}^3$ in dry season. The analysis for air pollutants in particulate matters was carried out in order to determine polycyclic aromatic hydrocarbons (PAHs) by GC-MS, major dissolved ions by IC, some metals and elements by ICP-OES and total carbon by CHN/S/O analyzer. Mean concentration of total PAHs was in a range from 1.7 – 12.2 ng/m^3 . Ratio of non-carcinogenic and carcinogenic PAHs found was about 1:3 and 1:4 depending on sites. Major dissolved ions bound with PM_{10} were ammonium and sulfate ions. More than half of the water dissolved samples had the pH value less than 5.6. High concentrations of potassium, iron, calcium, silicon and aluminum were found in dry season, while low concentration of toxic metals such as arsenic, cadmium, mercury and lead was found only in some samples. Concentrations of most of carcinogenic PAHs, some metals, ions and total carbon were found to be positively correlated to PM_{10} concentrations. Seasonal variation of air pollutants based on PM_{10} composition was obviously observed. It was changed from higher amounts to lower amounts in the following order: dry season (December-March), transition periods (April-May and October-November) and wet season (June-September), which corresponded to the amounts of PM_{10} contaminated in the atmosphere. Spatial variation was not much observed except for one sampling site, where PAHs content was significantly higher than another sites. Apart from traffic congestion, this was probably due to specific local activities i.e. biomass burning.

Keywords: air pollution, PM_{10} , PAHs, traffic, biomass burning.

1. INTRODUCTION

Air pollution problem in urban areas have been known for quite a long time, since the world has rapidly developed. The population

has double increased and the number of people living in the cities has increased by more than a factor of four and the global energy

consumption by nearly a factor of five [1]. The air pollution is now mostly seen in developing countries with mega-cities. Atmospheric aerosol particles originate from a wide variety of natural and anthropogenic sources. Primary particles are directly emitted from sources such as biomass burning, incomplete combustion of fossil fuels and traffic-related suspension of road, soil, dust, sea salt and biological materials. Secondary particles are formed by gas-to-particle conversion in the atmosphere [2]. Concentration, composition and size distribution of atmospheric aerosol particles are temporally and spatially highly variable. The predominant particle components of air particulate matter (PM) are sulfate, nitrate, ammonium, sea salt, mineral dust, organic compounds and black or elemental carbon [2]. The effects of aerosols on the atmosphere, climate and public health are among the central topics in current environmental research. An airborne particulate matter contains several of inorganic and organic species, many of which can adversely affect human health [2,3]. Of these constituents, the classes of polycyclic aromatic hydrocarbons (PAHs) are widespread environmental pollutants which are formed during incomplete combustion process of organic material emitted from a large variety of industrial processes, motor vehicles, domestic waste burning and regenerated burning in agriculture [4]. Some of them are known to be carcinogen [5]. Therefore, the air polluted by airborne PAHs is of significant concern.

This study aims to determine PM_{10} component including PAHs, dissolved ions, metals and total carbon and to assess spatial and temporal variation of PM_{10} and its chemical composition in different areas of Chiang Mai and Lamphun Provinces, Thailand. The results are expected to be used for air pollution management in the northern part of Thailand, where air pollution

frequently occurs during dry season.

2. MATERIALS AND METHODS

2.1 PM_{10} Sampling

Three study sites were located in Chiang Mai Province: Yuparaj Witayalai School (YP), Municipality Hospital (HP), Saraphee District (SP) and one site was in Muang District, Lamphun Province (LP). Briefly, 24 hours PM_{10} samples were collected on quartz fiber filters every 3 days at each sampling site using a High Volume PM_{10} Air Sampler (Wedding & Associates Inc., USA) at the flow rate of 1,130 L/min. Sampling had been done for 1 year during June 2005 to June 2006 to cover 3 seasonal periods, which were wet season (Jun - Sep), dry season (Dec - Mar) and transitioned periods (Oct - Nov and Apr - May). PM_{10} samples were weighed using the five digits scale balance (Mettler Toledo (USA) AG285) covered by the temperature and humidity controlling cabinet (DE-300). More detail can be found in Pengchai, et al, 2008 [6].

2.2 Sample Preparation

The post-weighed quartz fiber paper (8×10 inch) of PM_{10} sample was equally divided into eight pieces (2.5×4 inch) by a stainless steel roller blade cutter. Two of eight pieces were grouped for analysis of PAHs, ions, metals and carbon. All samples except the samples for carbon analysis were cut into small pieces by a stainless scissor prior to analysis.

2.3 Sample Analysis

2.3.1 Analysis Method of 16 EPA-PAHs in PM_{10} Samples by GC-MS [7]

Samples was put into 60 ml amber-bottle wrapped with aluminium foil and mounted by paraffin film and extracted in 35 ml acetonitrile by ultrasonicator (I710DH, Elma, Germany) at 100% ultrasound power for

30 min under controlled temperature (approximately 20°C). The solution was filtered through a 0.45 µm nylon filter into a v-shape flask. The pellet was re-extracted in 30 ml acetonitrile by repeating the previous step and evaporated by low-pressure evaporator at 30°C until nearly dry. The solution was transferred into a 1 ml volumetric flask. After that a mixed solution of internal standards (D10-FLU, D10-PYR and D12-BaP) were added and adjusted to 1 ml by acetonitrile. The solution was then analyzed for 16 PAHs (naphthalene(NAP), acenaphthylene (ACY), acenaphthene (ACE), fluorene (FLU), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLA), pyrene (PYR), benz[a]anthracene (BaA), chrysene (CHR), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), indeno[1,2,3-cd]pyrene (IND), dibenz[a,h]anthracene (DBA) and benzo[g,h,i]perylene (BPER)) by GC-MS (Hewlett Packard, U.S.A., column HPTM-5MS packed with 5% Phenyl methyl polysiloxane, 30 m long, diameter 0.25 mm, 0.25 µm).

2.3.2 Ion Analysis Method of PM₁₀ Samples by Ion Chromatography

Dissolved ions including Na⁺, NH₄⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, NO₃⁻ and SO₄²⁻ were analyzed following a method developed from the Technical Document for Filter Pack Method in East Asia [8] using Ion Chromatography (IC) [9]. Samples were put into 100 ml beakers followed by 50 ml of deionized water. The beakers were then covered by paraffin film and ultrasonicated at 100% ultrasound power (T490DH, Elma, Germany) for 30 min. The solution was filtered through a cellulose acetate filter (pore size 45 µm, diameter 13 mm) into a plastic bottle for IC analysis (Dionex 300, USA and Metrohm, Switzerland). Analytical columns of Dionex 300 were IonPac[®]AS4A (4×250 mm) and IonPac[®]CS12 (12×250

mm) for anion and cation analysis, respectively, while those of Metrohm were Metrosep A Supp4 (4×250 mm) and Metrosep C2 (4×100 mm), respectively.

2.3.3 Elemental Analysis Method of PM₁₀ Sample by Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES)

Filter samples were extracted based on Compendium Method IO-3.1 [10] for 20 elements including Ca, Al, Si, Fe, Mg, K, Zn, Ti, P, Pb, Ba, Sr, Mn, Ni, Cu, V, Cr, Cd, Hg and As. They were analysed by Inductively Coupled Plasma – Optical Emission Spectroscopy (PerkinElmer[®] Optima 3000 operated with WinLab32™ software) based on Compendium Method IO-3.4 [11]. Samples were put into Erlenmayer flasks followed by 40 ml of mixed acid solution (5.55% HNO₃/16.75% HCl) and refluxed on hot plate for 3 hours. They were left until cool and transferred into 50 ml volumetric flasks. They were then filtered through a 0.45 µm syringe nylon filter into plastic bottles for further analysis.

2.3.4 Carbon Analysis Method of PM₁₀ Sample by CHN-S/O Elemental Analyzer

A tin capsule (1×1 cm) as a sample container was weighed by MX5 Automated-S Microbalance (Mettler Toledo). The quartz filter that collected the PM₁₀ was punched by a puncher with a diameter of 0.55 cm. The punched filter was put into a prepared capsule, wrapped and weighed. The sample was then analysed for total carbon (TC) by CHN-S/O Elemental Analyzer (PE 2400 series II CHNS/O analyzer, Perkin-Elmer Corporation) [12] using L-cystine and BS Slag 2 as standards and an unused quartz filter paper as a blank.

3. RESULTS AND DISCUSSION

3.1 PM₁₀ Concentrations

Seasonal and spatial variations of mean PM₁₀ concentrations and their standard deviation (SD) are illustrated in Table 1. It was found that concentration of PM₁₀ collected in dry season (Dec – Mar) was significantly higher than other seasons, while the lowest

concentration was found in rainy season (Jun – Sep). Average PM₁₀ concentration in each sampling site was very much similar. However, the mean concentration of the Sarapee (SP) site was higher than those of other sites. This is probably due to local activities i.e. traffic density and open burning.

Table 1. Mean concentrations ($\mu\text{g}/\text{m}^3$) \pm SD of PM₁₀ for 4 seasons and 4 sampling sites.

Season ^{*†}	PM ₁₀ concentration	Sampling site ^{*†}	PM ₁₀ concentration
Dec – Mar(n = 160)	73.64 \pm 25.34 ^{/7}	LP (n=127)	46.53 \pm 29.30 ^{/1}
Apr – May(n = 84)	40.44 \pm 25.33 ^{/2}	SP (n=127)	55.94 \pm 36.64 ^{/2}
Jun – Sep(n = 184)	33.17 \pm 21.39 ^{/1}	HP (n=127)	44.08 \pm 20.60 ^{/3}
Oct – Nov(n = 80)	47.19 \pm 12.36 ^{/2}	YP (n=127)	50.30 \pm 23.26 ^{/6}

* /n number of non detected or incomplete data

† Groups of number in *italic* and/or **bold** are not significant different ($p > 0.05$)

3.2 Analysis of 16 EPA-PAHs in PM₁₀ Samples by GC-MS

Average values of PM₁₀-bound PAHs (ng/m^3) in each season and sampling site are shown in Tables 2 and 3, respectively. It was found that the highest concentrations of an individual and total PAHs as well as carcinogenic PAHs were found in dry season and significantly higher than those in other seasons. In term of sampling site, high molecular weight and carcinogenic PAHs were significantly higher at the SP site than other sites.

Mean total PAHs concentrations detected in this study were almost the same as values found in community area of previous study [13] carried out in 2004 (Table 5). However, the concentrations found in this study were obviously lower than those found in Bangkok and Pathumthanee, even under the same category (roadside area) [14-17], but the values were similar to the rural [14] and general [16] areas as shown in Table 5. This is owing to transport pattern and traffic volume near the

sampling site.

Table 4 illustrates ratio of non-carcinogenic and carcinogenic PAHs found in PM₁₀ samples from each sampling site, which were approximately 1:4 (SP and LP) and 1:3 (HP and YP). The highest carcinogenic PAHs content was found at SP site and significantly higher than other sites (Table 4). The carcinogenic ratios of all sites found in this study were higher than that found in roadsides of inner part of Bangkok during November 02 to April 03 [15] (Table 5). This reveals that our study sites presented higher concentrations of carcinogenic PAHs but lower PM₁₀ contents in comparison to Bangkok area. This should be noticed and concerned for air quality management.

3.3 Ion Analysis of PM₁₀ Samples by Ion Chromatography

The extracted samples were divided into 2 parts for pH measurement and ion analysis. The pH distribution for all sampling stations was plotted as shown in Figure 1. More than 50% of the samples from all sampling sites

Table 2. Mean concentrations (ng/m³) ± SD of PM₁₀-bound PAHs in each season.

PAHs ^{*†}	Dec – Mar (n = 160)	Apr – May (n = 84)	Jun – Sep (n = 184)	Oct – Nov (n = 80)
Low M.W.				
NAP	0.03 ± 0.02 ^{/78}	0.03 ± 0.02 ^{/6}	0.02 ± 0.02 ^{/77}	0.03 ± 0.02 ^{/13}
ACY	0.05 ± 0.06 ^{/132}	0.02 ± 0.01 ^{/66}	0.03 ± 0.02 ^{/123}	0.02 ± 0.02 ^{/60}
ACE	0.03 ± 0.07 ^{/136}	-	0.02 ± 0.01 ^{/118}	0.01 ± 0.00 ^{/46}
FLU	<i>0.04 ± 0.04</i> ^{/77}	0.11 ± 0.25 ^{/64}	<i>0.03 ± 0.02</i> ^{/135}	<i>0.02 ± 0.02</i> ^{/50}
PHE	0.07 ± 0.08 ^{/2}	<i>0.04 ± 0.07</i> ^{/3}	<i>0.02 ± 0.02</i> ^{/28}	<i>0.03 ± 0.04</i> ^{/18}
ANT	0.06 ± 0.07 ^{/73}	0.04 ± 0.02 ^{/89}	<i>0.03 ± 0.02</i> ^{/93}	<i>0.03 ± 0.02</i> ^{/29}
Sum	0.15 ± 0.13 ^{/1}	0.10 ± 0.16 ^{/2}	0.07 ± 0.04 ^{/5}	0.08 ± 0.06 ^{/4}
High M.W.				
FLA	0.10 ± 0.06 ^{/2}	0.04 ± 0.02 ^{/3}	<i>0.03 ± 0.01</i> ^{/4}	0.05 ± 0.02 ^{/3}
PYR	0.11 ± 0.05 ^{/1}	<i>0.05 ± 0.02</i> ^{/3}	0.04 ± 0.02 ^{/4}	<i>0.05 ± 0.02</i> ^{/3}
BaA	0.37 ± 0.33 ^{/1}	<i>0.08 ± 0.06</i> ^{/4}	<i>0.09 ± 0.08</i> ^{/10}	<i>0.11 ± 0.07</i> ^{/2}
CHR	0.38 ± 0.29 ^{/1}	<i>0.09 ± 0.08</i> ^{/5}	<i>0.08 ± 0.05</i> ^{/7}	<i>0.09 ± 0.09</i> ^{/2}
BbF	1.42 ± 0.60 ^{/1}	0.52 ± 0.38 ^{/5}	<i>0.83 ± 0.69</i> ^{/1}	<i>0.74 ± 0.48</i> ^{/2}
BkF	0.93 ± 0.61 ^{/1}	<i>0.39 ± 0.37</i> ^{/15}	<i>0.41 ± 0.40</i> ^{/1}	<i>0.28 ± 0.16</i> ^{/2}
BaP	0.82 ± 0.51 ^{/1}	0.31 ± 0.27 ^{/2}	<i>0.59 ± 0.67</i> ^{/3}	<i>0.49 ± 0.30</i> ^{/2}
DBA	1.21 ± 0.64 ^{/1}	0.64 ± 0.52 ^{/2}	1.05 ± 0.90 ^{/1}	<i>0.90 ± 0.48</i> ^{/2}
IND	0.17 ± 0.10 ^{/5}	<i>0.11 ± 0.07</i> ^{/7}	<i>0.11 ± 0.08</i> ^{/2}	<i>0.11 ± 0.06</i> ^{/2}
BPER	1.07 ± 0.50 ^{/1}	0.62 ± 0.40 ^{/2}	<i>0.84 ± 0.59</i> ^{/1}	0.76 ± 0.32 ^{/2}
Sum	6.58 ± 3.20 ^{/1}	2.76 ± 2.05 ^{/2}	4.06 ± 2.96 ^{/1}	3.59 ± 1.69 ^{/2}
Carcinogenic[‡]	5.29 ± 2.72 ^{/1}	2.05 ± 1.65 ^{/2}	3.15 ± 2.42 ^{/1}	2.73 ± 1.41 ^{/2}
Non carcinogenic[‡]	0.36 ± 0.20 ^{/1}	0.20 ± 0.18 ^{/2}	0.13 ± 0.06 ^{/1}	0.18 ± 0.09 ^{/2}
Total	6.72 ± 3.20 ^{/1}	2.87 ± 2.08 ^{/2}	4.13 ± 2.97 ^{/1}	3.67 ± 1.71 ^{/2}

^{*/n} number of non detected or incomplete data

[†] Groups of number in *italic* and/or **bold** are not significant different ($p > 0.05$)

[‡] Carcinogenic PAHs are BaA, CHR, BbF, BkF, BaP, DBA and IND

Non-carcinogenic PAHs are NAP, ACY, ACE, FLU, PHE, ANT, FLA, PYR and BPER

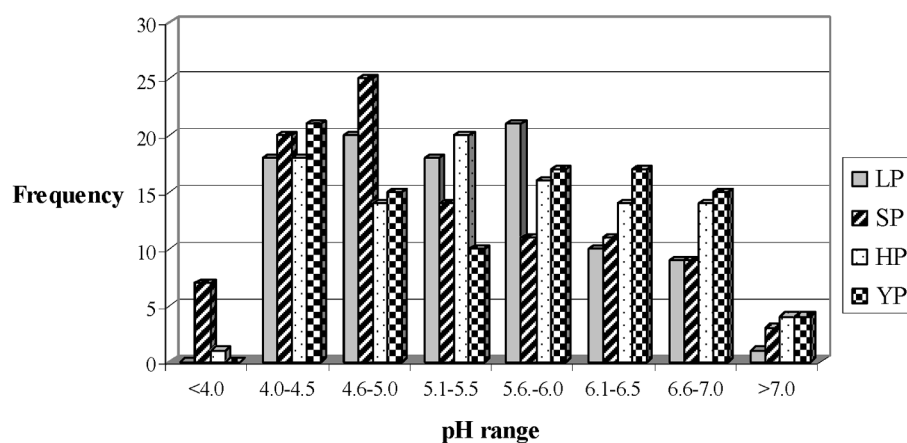
**Figure 1.** pH distribution of PM₁₀ extractions from four sampling stations.

Table 3. Mean concentrations (ng/m^3) \pm SD of PM_{10} -bound PAHs in each sampling site.

PAHs ^{*†}	Sampling site (n)			
	LP (n=127)	SP (n=127)	HP (n=127)	YP (n=127)
Low M.W.				
NAP	0.02 \pm 0.02 ^{/43}	0.02 \pm 0.02 ^{/45}	0.02 \pm 0.02 ^{/42}	0.03 \pm 0.02 ^{/44}
ACY	0.03 \pm 0.02 ^{/103}	0.03 \pm 0.03 ^{/101}	0.03 \pm 0.06 ^{/88}	0.03 \pm 0.01 ^{/89}
ACE	0.01 \pm 0.01 ^{/115}	0.02 \pm 0.05 ^{/94}	0.02 \pm 0.01 ^{/92}	0.02 \pm 0.03 ^{/83}
FLU	0.03 \pm 0.02 ^{/84}	0.04 \pm 0.05 ^{/88}	0.03 \pm 0.02 ^{/80}	0.06 \pm 0.16 ^{/74}
PHE	0.03 \pm 0.04 ^{/18}	<i>0.05 \pm 0.06</i> ^{/13}	<i>0.04 \pm 0.06</i> ^{/10}	<i>0.05 \pm 0.09</i> ^{/10}
ANT	0.03 \pm 0.02 ^{/69}	0.04 \pm 0.03 ^{/82}	0.03 \pm 0.03 ^{/60}	0.05 \pm 0.08 ^{/53}
Sum	<i>0.07 \pm 0.06</i> ^{/5}	<i>0.10 \pm 0.09</i> ^{/3}	<i>0.10 \pm 0.08</i> ^{/2}	0.14 \pm 0.17 ^{/2}
High M.W.				
FLA	0.05 \pm 0.04 ^{/5}	0.07 \pm 0.05 ^{/3}	0.06 \pm 0.05 ^{/2}	0.07 \pm 0.05 ^{/2}
PYR	0.05 \pm 0.04 ^{/4}	<i>0.07 \pm 0.05</i> ^{/4}	0.07 \pm 0.04 ^{/1}	<i>0.07 \pm 0.05</i> ^{/2}
BaA	<i>0.19 \pm 0.23</i> ^{/9}	0.27 \pm 0.37 ^{/3}	<i>0.13 \pm 0.11</i> ^{/2}	<i>0.14 \pm 0.09</i> ^{/3}
CHR	0.19 \pm 0.24 ^{/8}	0.26 \pm 0.32 ^{/3}	<i>0.14 \pm 0.14</i> ^{/1}	<i>0.14 \pm 0.12</i> ^{/3}
BbF	<i>0.92 \pm 0.57</i> ^{/2}	1.36 \pm 0.90 ^{/2}	<i>0.74 \pm 0.50</i> ^{/2}	<i>0.80 \pm 0.47</i> ^{/3}
BkF	<i>0.50 \pm 0.43</i> ^{/11}	0.88 \pm 0.75 ^{/3}	<i>0.40 \pm 0.31</i> ^{/2}	<i>0.43 \pm 0.30</i> ^{/3}
BaP	<i>0.48 \pm 0.39</i> ^{/2}	1.01 \pm 0.81 ^{/2}	<i>0.45 \pm 0.30</i> ^{/2}	<i>0.46 \pm 0.30</i> ^{/2}
DBA	<i>0.86 \pm 0.50</i> ^{/1}	1.61 \pm 0.96 ^{/2}	<i>0.75 \pm 0.53</i> ^{/1}	<i>0.82 \pm 0.46</i> ^{/2}
IND	<i>0.12 \pm 0.07</i> ^{/5}	0.19 \pm 0.11 ^{/2}	<i>0.10 \pm 0.06</i> ^{/5}	<i>0.10 \pm 0.05</i> ^{/4}
BPER	<i>0.70 \pm 0.40</i> ^{/1}	1.23 \pm 0.67 ^{/2}	<i>0.74 \pm 0.42</i> ^{/1}	<i>0.80 \pm 0.36</i> ^{/2}
Sum	<i>3.97 \pm 2.53</i> ^{/1}	6.93 \pm 4.16 ^{/2}	<i>3.58 \pm 2.03</i> ^{/1}	<i>3.82 \pm 1.81</i> ^{/2}
Carcinogenic[‡]	<i>3.18 \pm 2.12</i> ^{/1}	5.57 \pm 3.51 ^{/2}	<i>2.71 \pm 1.61</i> ^{/1}	<i>2.88 \pm 1.46</i> ^{/2}
Non carcinogenic[‡]	0.17 \pm 0.11 ^{/1}	0.23 \pm 0.16 ^{/2}	0.22 \pm 0.15 ^{/1}	0.28 \pm 0.22 ^{/2}
Total	<i>4.04 \pm 2.55</i> ^{/1}	7.03 \pm 4.18 ^{/2}	<i>3.68 \pm 2.06</i> ^{/1}	<i>3.96 \pm 1.84</i> ^{/2}

^{*/n} number of non detected or incomplete data

[†] Groups of number in *italic* and/or **bold** are not significant different ($p > 0.05$)

[‡] Carcinogenic PAHs are BaA, CHR, BbF, BkF, BaP, DBA and IND

Non-carcinogenic PAHs are NAP, ACY, ACE, FLU, PHE, ANT, FLA, PYR and BPER

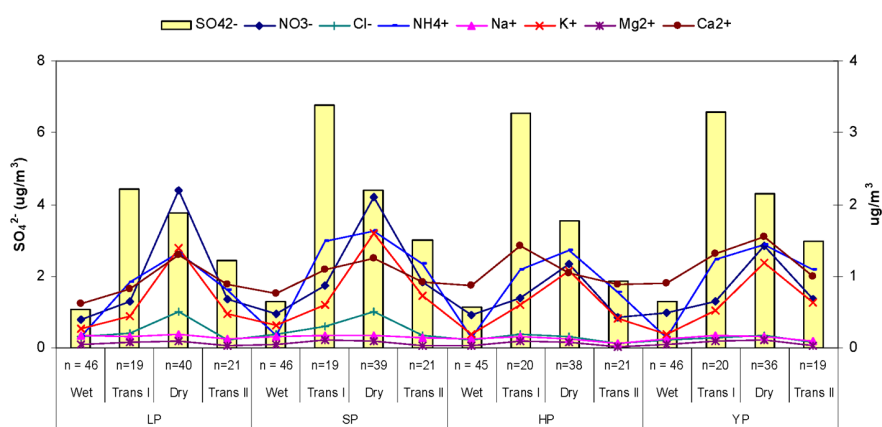
**Figure 2.** Spatial and temporal variations of ion concentrations ($\mu\text{g}/\text{m}^3$).

Table 4. Ratio of carcinogenic and non-carcinogenic PM₁₀-bound PAHs.

Sampling site	% Non-carcinogenic PAHs	% Carcinogenic PAHs*
LP	21.3	78.7
SP	20.8	79.2
HP	26.4	73.6
YP	27.3	72.7
Bangkok [15]	28.6	71.4

*According to US.EPA [18]; B2: probable human carcinogen (BaA, CHR, BbF, BkF, BaP, IND and DBA)

Table 5. Comparison of mean PAH concentrations in Chiang Mai, Lamphun and Bangkok, Thailand.

City	Study period	Location	Mean concentration (ng/m ³)	Reference
Chiang Mai	Jun 05 - Jun 06	Roadside area	1.3-12.2	This study
Lamphun	Jun 05 - Jun 06	Roadside area	1.7-7.4	This study
Chiang Mai	Jun - Nov 04	Traffic area Community area Rural area	7.6-16.6 3.9-9.1 2.7-8.4	[13]
Bangkok ^a	Nov 03 - Jan 04	Rural area Roadside area	7.2-10.0 10.1-28.1	[14]
Bangkok	Nov 02 - Apr 03	Roadsides	12.59±0.94	[15]
Bangkok ^b	Mar 01	Roadside area General area	50-53 11-12	[16]
Pathumthani (40 km north of Bangkok)	Jun 1996 - Apr 1997	Road site	17.4	[17]

^a Sum of concentrations of 18 PAHs: PHE, ANT, 1-methyl PHE, 2-methyl PHE, 3-methyl PHE, 9-methyl PHE, FLA, PYR, BaA, CHR, BbF, BkF, BeP, BaP, IND, BPER and coronene.

^b Sum of concentrations of 11 PAHs: ANT, PHE, PYR, BaA, CHR, BbF, BkF, BaP, IND, DBA and BPER

except YP station (45%) had pH value less than 5.6. Specifically, half of the samples from SP station was in the lower pH range value (<4.0-5.0). Seasonal variation of the pH values illustrated that low pH values were inspected

in dry season especially in March and April.

Average (SD) concentrations (ng/m³) of PM₁₀-bound ions in each season and sampling site are shown in Tables 6-7 and Figure 2. Both anions (SO₄²⁻, NO₃⁻, and Cl⁻) and cations

(NH₄⁺, Na⁺, K⁺, Mg²⁺ and Ca²⁺) were significantly higher in dry period (Dec-Mar) and transition period I (Oct-Nov) than those in other seasons (Table 6). The dominant anion and cation were SO₄²⁻ and NH₄⁺, respectively. There was a strong correlation between NH₄⁺ and SO₄²⁻ ($r = 0.953$), followed by Na⁺ and SO₄²⁻ ($r = 0.651$) and K⁺ and Cl⁻ ($r = 0.606$). It suggested that the main acidity of dry deposition in this region was due to H₂SO₄, which was neutralized by NH₄⁺ [19]. Noticeably, K⁺; biomarker of vegetative burning, was significantly higher in dry season. Therefore, it can be concluded that biomass burning took place in the area during dry season. Moreover, SP site had the highest potassium concentration (Table 7). This is probably due to high frequency or large area of open burning.

Table 8 illustrates major ion composition of PM₁₀ samples in this study in comparison with other studies, which were 1) ion composition of dry deposition collected by 4-stages filter pack sampler of Mae Hia

sampling site, Muang District, Chiang Mai during Oct 05 - Sep 06 [20] and 2) PM₁₀-bound ions in Bangkok area during Feb 02 - Jan 03 [21]. It was found that concentrations of SO₄²⁻, NO₃⁻, NH₄⁺ and Ca²⁺ detected in this study were approximately 2 times higher than those in Mae Hia. This is because Mae Hia is located in sub-urban area with lower human activities than the stations of this study. When compare the results of this study with Bangkok, it reveals that NO₃⁻ and NH₄⁺ concentrations were almost the same, while SO₄²⁻ of this study was slightly higher. Cl⁻ content in Bangkok area was 7-10 times higher than that found in this study. This must be related with distance from sea.

3.4 Elemental Analysis of PM₁₀ Sample by Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES)

Mean concentrations of elements and metals were high in dry season. High toxic metals including lead (Pb), mercury (Hg), cadmium (Cd) and arsenic (As), were detected

Table 6. Mean concentrations (ng/m³) ± SD of PM₁₀-bound ions in each season.

Ion ^{*†}	Dec – Mar (n = 160)	Apr – May (n = 84)	Jun – Sep (n = 184)	Oct – Nov (n = 80)
SO ₄ ²⁻	4.02 ± 2.39	2.56 ± 1.92 ^{/2}	1.20 ± 0.97 ^{/2}	6.04 ± 5.35 ^{/2}
NO ₃ ⁻	1.84 ± 1.31	0.68 ± 0.61 ^{/2}	0.46 ± 0.24 ^{/7}	0.71 ± 0.34 ^{/2}
Cl ⁻	0.33 ± 0.33	0.11 ± 0.10 ^{/2}	0.15 ± 0.11 ^{/1}	0.20 ± 0.15 ^{/2}
Anions	6.21 ± 3.09	3.35 ± 2.44 ^{/2}	1.79 ± 1.10 ^{/1}	6.95 ± 5.35 ^{/2}
NH ₄ ⁺	1.45 ± 1.22	0.96 ± 0.78 ^{/17}	0.15 ± 0.16 ^{/7}	1.17 ± 1.06 ^{/4}
Na ⁺	0.17 ± 0.09 ^{/3}	0.11 ± 0.09 ^{/2}	0.15 ± 0.11 ^{/4}	0.16 ± 0.11 ^{/2}
K ⁺	1.38 ± 0.65	0.56 ± 0.50 ^{/2}	0.24 ± 0.13 ^{/1}	0.55 ± 0.46 ^{/2}
Mg ²⁺	0.09 ± 0.17 ^{/3}	0.03 ± 0.02 ^{/2}	0.04 ± 0.04 ^{/2}	0.09 ± 0.04 ^{/2}
Ca ²⁺	1.29 ± 0.52	0.92 ± 0.39 ^{/2}	0.79 ± 0.29 ^{/1}	1.17 ± 0.43 ^{/2}
Cations	4.38 ± 1.89	2.41 ± 1.55 ^{/2}	1.36 ± 0.48 ^{/1}	3.11 ± 1.31 ^{/2}
Total ions	10.59 ± 4.62	5.76 ± 3.87 ^{/2}	3.14 ± 1.49 ^{/1}	10.07 ± 6.56 ^{/2}

^{*/n} number of non detected or incomplete data

[†] Groups of number in *italic* and/or **bold** are not significant different ($p > 0.05$)

Table 7. Mean concentrations (ng/m³) ± SD of PM₁₀-bound ions in each sampling site.

Ion ^{*†}	LP (n=127)	SP (n=127)	HP (n=127)	YP (n=127)
SO ₄ ²⁻	2.67 ± 2.62 ^{/2}	3.39 ± 3.40 ^{/1}	2.86 ± 3.16 ^{/1}	3.37 ± 3.45 ^{/2}
NO ₃ ⁻	1.07 ± 1.21 ^{/4}	1.16 ± 1.09 ^{/3}	0.78 ± 0.78 ^{/2}	0.91 ± 0.87 ^{/2}
Cl ⁻	0.27 ± 0.28 ^{/1}	0.31 ± 0.30 ^{/1}	0.13 ± 0.11 ^{/1}	0.13 ± 0.10 ^{/2}
Anions	3.98 ± 3.42 ^{/1}	4.84 ± 3.98 ^{/1}	3.76 ± 3.44 ^{/1}	4.42 ± 3.79 ^{/2}
NH ₄ ⁺	0.76 ± 0.92 ^{/6}	1.00 ± 1.09 ^{/8}	0.79 ± 1.00 ^{/7}	0.89 ± 1.13 ^{/7}
Na ⁺	0.17 ± 0.12 ^{/1}	0.16 ± 0.10 ^{/3}	0.12 ± 0.08 ^{/3}	0.14 ± 0.09 ^{/4}
K ⁺	0.69 ± 0.62 ^{/1}	0.84 ± 0.73 ^{/1}	0.59 ± 0.62 ^{/1}	0.68 ± 0.67 ^{/2}
Mg ²⁺	0.07 ± 0.11 ^{/2}	0.07 ± 0.08 ^{/2}	0.06 ± 0.08 ^{/3}	0.07 ± 0.14 ^{/2}
Ca ²⁺	0.91 ± 0.48 ^{/1}	1.00 ± 0.43 ^{/1}	1.02 ± 0.39 ^{/1}	1.19 ± 0.52 ^{/2}
Cations	2.56 ± 1.77 ^{/1}	3.02 ± 1.91 ^{/1}	2.55 ± 1.69 ^{/1}	2.93 ± 2.03 ^{/2}
Total ions	6.54 ± 4.99 ^{/1}	7.85 ± 5.64 ^{/1}	6.31 ± 4.83 ^{/1}	7.35 ± 5.51 ^{/2}

^{*/n} number of non detected or incomplete data

[†] Groups of number in *italic* and/or **bold** are not significant different (p > 0.05)

Table 8. Mean concentrations (µg/m³) ± SD of PM₁₀-bound ions in Chiang Mai and Bangkok, Thailand.

Ion	This research (Jun 05 – Jun 06)		Chiang Mai (Oct 05 – Sep 06)*	Bangkok (Feb 02 – Jan 03) [21]	
	Min ± SD	Max ± SD		Min ± SD	Max ± SD
SO ₄ ²⁻	2.67±2.62	3.37±3.42	1.55±1.52	1.79±0.59	2.37±0.72
NO ₃ ⁻	0.73±0.65	1.13±1.04	0.69±1.04	1.16±0.55	1.45±0.66
Cl ⁻	0.13±0.11	0.31±0.30	0.29±0.76	1.29±0.60	2.00±0.91
NH ₄ ⁺	0.76±0.92	1.00±1.09	0.45±0.50	0.62±0.31	0.94±0.62
Na ⁺	0.12±0.08	0.17±0.12	0.19±0.30	-	-
K ⁺	0.56±0.57	0.83±0.71	0.86±2.07	-	-
Mg ²⁺	0.06±0.08	0.07±0.14	0.16±0.34	-	-
Ca ²⁺	0.91±0.48	1.18±0.53	0.69±1.06	-	-

* Filter pack samples

only in some samples and found to be high in dry season as well as in transition period (Oct-Nov). There was no significant difference of

element concentrations in terms of sampling site. Exception was found in case of copper (Cu), which was significantly higher in SP

station than other sites.

Element concentrations found in this study were compared with the study in Bangkok area, which 14 elements were determined from 4 areas including Din Daeng, Chankasaem, Ban Somdej and Bangna, during Feb 02 - Jan 03 [21] (Table 9).

It was found that mean concentration of almost all elements found in Bangkok area was higher than those in this study. This is probably because sources of elemental emission in Bangkok were higher both in term of variations and number.

Table 9. Mean concentrations ($\mu\text{g}/\text{m}^3$) \pm SD of elements found in this study and Bangkok, Thailand.

Element	This research (Jun 05 – Jun 06)	Bangkok (Feb 02 – Jan 03) [21]
Al	0.266 \pm 0.188 - 0.313 \pm 0.426	1.307 \pm 0.776 – 3.015 \pm 2.730
As	0.012 \pm 0.001 - 0.015 \pm 0.005	0.184 \pm 0.131 – 0.319 \pm 0.140
Ba	0.008 \pm 0.009 - 0.012 \pm 0.010	<0.001 \pm 0.001
Ca	1.128 \pm 1.177 - 1.669 \pm 1.211	1.886 \pm 1.512 – 4.790 \pm 2.379
Cd	0.001 \pm 0.002	<0.001 \pm 0.001
Cr	0.014 \pm 0.017 - 0.016 \pm 0.015	0.096 \pm 0.051 – 0.138 \pm 0.087
Cu	0.011 \pm 0.009 - 0.024 \pm 0.029	0.047 \pm 0.022 – 0.086 \pm 0.041
Fe	0.288 \pm 0.239 - 0.373 \pm 0.381	1.325 \pm 0.692 – 2.126 \pm 0.916
Hg	0.024 \pm 0.025 - 0.027 \pm 0.024	-
K	0.674 \pm 0.748 - 0.920 \pm 0.978	0.622 \pm 0.471 – 1.206 \pm 0.720
Mg	0.112 \pm 0.091 - 0.140 \pm 0.104	0.494 \pm 0.266 – 0.826 \pm 0.320
Mn	0.016 \pm 0.012 - 0.019 \pm 0.014	0.067 \pm 0.040 – 0.088 \pm 0.095
Ni	0.006 \pm 0.007 - 0.014 \pm 0.021	0.213 \pm 0.212 – 0.269 \pm 0.203
P	0.008 \pm 0.008 - 0.026 \pm 0.033	-
Pb	0.035 \pm 0.026 - 0.049 \pm 0.078	0.125 \pm 0.116 – 0.218 \pm 0.154
Si	0.901 \pm 0.677 - 1.032 \pm 0.745	-
Sr	0.003 \pm 0.003	-
Ti	0.007 \pm 0.006	-
V	0.006 \pm 0.005	0.799 \pm 0.382 – 1.132 \pm 0.509
Zn	0.069 \pm 0.072 - 0.201 \pm 1.023	0.647 \pm 0.351 – 0.838 \pm 0.470

3.5 Carbon Analysis of PM₁₀ Sample by CHN-S/O Elemental Analyzer

Spatial and temporal variations of mean carbon concentrations are shown in Figure 3.

It was found that the distribution pattern of carbon content in all stations was almost the same with the notice that SP station had higher carbon content than the others. High

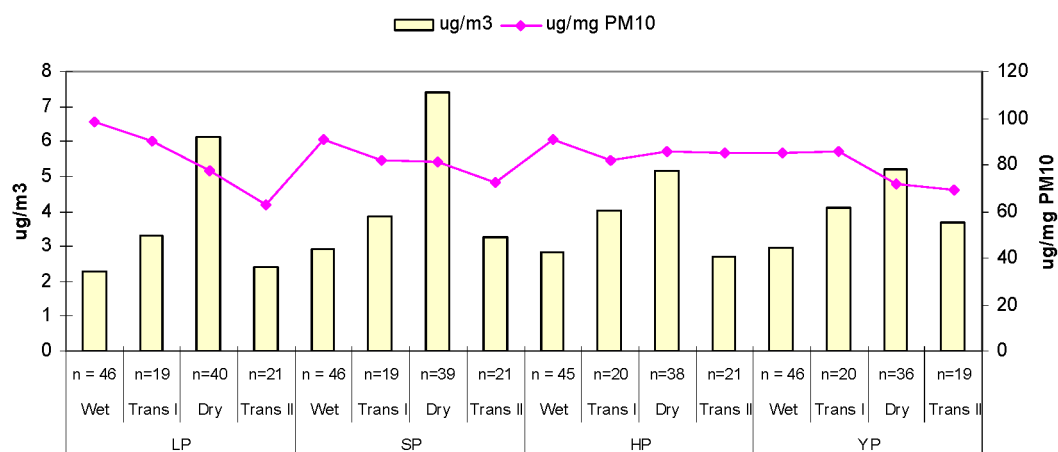


Figure 3. Spatial and temporal variations of mean carbon concentrations.

concentration of carbon was found in dry season especially in March, while in rainy season the carbon content was low. Correlation of carbon content with PM₁₀ weight (Table 10) reveals that there was a strong correlation of these two factors in dry season and transition period (Apr-May). The correlation was also strong in all sampling sites. It can be concluded that carbon content was positively correlated to PM₁₀ weight. However, this consumption can not be used for rainy season, in which the correlation was low. This is probably due to low concentrations of both PM₁₀ and high

variation of carbon values, therefore the correlation was not obviously observed.

Carbon concentrations found in this study were also compared with the study in Bangkok, which was a determination of carbon content in PM_{2.5} [21]. They were 38.5±19.3, 21.7±12.7, 21.9±13.3 and 17.6±11.0 µg/m³ in Din Daeng, Chankasaem, Ban Somdej and Bangna, respectively. The contents found were 4-8 times higher than those in this study. This is probably due to high number of carbon sources in Bangkok.

Table 10. Correlation of carbon (µg/m³) and PM₁₀ weight (mg).

Sampling site	r	Season	r
LP	0.861	Dry (Dec-Mar)	0.849
SP	0.682	Transition (Apr-May)	0.836
HP	0.784	Rainy (Jun-Sep)	0.208
YP	0.798	Transition (Oct-Nov)	0.445

4. CONCLUSIONS

Chemical composition of PM₁₀ samples including PAHs, dissolved ions, metals and elemental carbon was detected from roadside of four sampling stations of Chiang Mai and Lamphun Provinces for one year. It was found that PM₁₀ concentration as well as its chemical

composition was significantly higher in dry season than other seasons. Apart from that most of the composition i.e. high molecular weight PAHs as well as carcinogenic, major ions and carbon were positively correlated with PM₁₀ weight. There was no significant difference of the composition of PM₁₀ found

among the sampling sites. However, PM₁₀-bound PAHs is exceptional, because they were significantly higher at SP site than the other sites. This is probably due to local activities such as open burning of biomass, etc. and traffic density in the area. It can be concluded that temporal variation plays more important roll than spatial variation in this study.

ACKNOWLEDGEMENT

Financial support from the Thailand Research Fund (TRF) is gratefully acknowledged.

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