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นางสาว นฤมล   เที่ยงวิริยะ

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PHYSICAL AND CHEMICAL CHARACTERISTICS OF PARTICULATE MATTER AT VARIOUS SIZES IN CHIANG MAI AMBIENT AIR

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ผู้วิจัยได้ทำการเก็บตัวอย่างอนุภาคฝุ่นจากจุดเก็บตัวอย่าง 3 จุด ภายในจังหวัดเชียงใหม่อันได้แก่ จุดเก็บที่ 1 หน้าโรงเรียนยุพราชวิทยาลัย จุดเก็บที่ 2 หน้าโรงพยาบาลเทศบาลนครเชียงใหม่ และจุดเก็บที่ 3 หน้าที่ว่าการอำเภอสารภี และทำการศึกษาโดยแบ่งอนุภาคฝุ่นเป็น 5 ช่วงขนาด อันได้แก่ ฝุ่น PM>10, $PM_{2.5-10}$, $PM_{1.0-2.5}$, $PM_{0.5-1.0}$และ $PM_{0.1-0.5}$ไมโครเมตร โดยใช้เครื่อง High Volume Cascade Impactor เริ่มเก็บตัวอย่างตั้งแต่กลางเดือนมิถุนายน ปี พ.ศ.2548 ถึง เดือน มกราคม ปี พ.ศ.2549 โดย ได้นำตัวอย่างไปหาปริมาณฝุ่นและการกระจายของฝุ่นแต่ละขนาดโดยวิธีการชั่ง จากนั้นจึงนำไปหาปริมาณสารองค์ประกอบที่อยู่ในอนุภาคฝุ่น อันได้แก่ ไอออนบวก ไอออนลบ (Na^+, NH_4^+ ,K^+ ,Mg^{2+} ,Ca^{2+} ,Cl^-, NO_3^-, SO_4^{2-}, and PO_4^{3-}) โดยเครื่อง Ion Chromatography และ โลหะ (Al, B, Ba, Ca, Fe, K, Li, Mg, Mn, Na, Pb, Sr, Ti and Zn) โดยเครื่อง Inductively Coupled Plasma-Optical Emission Spectroscopy ในขั้นตอนสุดท้าย ได้ศึกษาถึงความสัมพันธ์ระหว่างปริมาณฝุ่นแต่ละขนาดกับจุดเก็บตัวอย่างและช่วงเวลาการเก็บตัวอย่างโดยใช้โปรแกรมทางสถิติวิเคราะห์

ผลการศึกษาพบว่าปริมาณฝุ่น PM_{10} เฉลี่ยในรอบ 24 ชั่วโมงของจุดเก็บที่ 1, 2 และ 3 อยู่ในช่วงความเข้มข้น 29.74-79.38(48.68) , 30.87-109.81(58.88) และ 30.71-92.94(60.99) มค.ก/ลบ.ม ตามลำดับ และปริมาณฝุ่น $PM_{2.5}$ เฉลี่ยในรอบ 24 ชั่วโมงอยู่ในช่วงความเข้มข้น 14.14-44.05(25.62), 13.87-63.55(31.40) และ 18.11-68.26(37.15) มค.ก/ลบ.ม ตามลำดับ ซึ่งพบว่าปริมาณฝุ่น $PM_{2.5}$ ที่จุดเก็บที่ 3 เกินค่ามาตรฐานของ US.EPA การศึกษาองค์ประกอบทางเคมีของฝุ่นแต่ละขนาดพบว่าในอนุภาคฝุ่นหยาบ($PM_{2.5-10}$) มีความเข้มข้นโลหะรวมมากกว่ากรณีอนุภาคฝุ่นละเอียด($PM_{0.1-2.5}$) โดยพบเป็นสัดส่วนของ PM>10:$PM_{2.5-10}$:$PM_{0.1-2.5}$ เท่ากับ 36:44:20 ตามลำดับ ในทางกลับกันเมื่อพิจารณาความเข้มข้นของไอออนรวมในฝุ่น พบว่าฝุ่นละเอียดมีความเข้มข้นไอออนรวมมากกว่าฝุ่นหยาบ โดยสัดส่วนที่พบใน PM>10:$PM_{2.5-10}$:$PM_{0.1-2.5}$ เท่ากับ 18:28:54 สำหรับไอออนลบ และ 26:15:59 สำหรับไอออนบวก ตามลำดับ โดยองค์ประกอบทางเคมีที่พบมากสำหรับการศึกษาครั้งนี้ ได้แก่ แคลเซียม อลูมิเนียม เหล็ก คลอไรด์ ไนเตรท ซัลเฟต แอมโมเนียม และ โปแตสเซียม การศึกษาหาความสัมพันธ์ระหว่างปริมาณฝุ่นแต่ละขนาดกับจุดเก็บตัวอย่างและช่วงเวลาการเก็บ พบว่าปริมาณฝุ่นแต่ละขนาดมีความสัมพันธ์กันอย่างมีนัยสำคัญ ($r= 0.353-0.840$, $p<0.05$) เมื่อพิจารณาจากจุดเก็บพบว่า ความเข้มข้นของอนุภาคฝุ่นละเอียดที่เก็บได้จากจุดเก็บที่ 1 มีความแตกต่างจากที่เก็บได้จากจุดเก็บที่ 3 อย่างมีนัยสำคัญ ($F= 3.569$, $p<0.05$) ความเข้มข้นของอนุภาคฝุ่นที่เก็บได้ในฤดูแล้งสูงกว่าที่เก็บได้จากฤดูฝนในทุกขนาดอนุภาค และมีความแตกต่างอย่างมีนัยสำคัญ ($F= 5.124-30.159$, $p<0.05$) เมื่อพิจารณาความสัมพันธ์ระหว่างความเข้มข้นสารองค์ประกอบในอนุภาคฝุ่นกับจุดเก็บตัวอย่างและช่วงเวลาการเก็บ พบว่า จุดเก็บที่ 1 และ 3 มีความแตกต่างของความเข้มข้นของสารองค์ประกอบบางตัวอย่างมีนัยสำคัญ ($F= 5.879-6.059$, $p<0.05$) นอกจากนี้ฤดูกาลมีผลต่อความเข้มข้นของสารองค์ประกอบในฝุ่นอย่างมีนัยสำคัญเช่นกัน ($F= 4.121-23.286$, $p<0.05$) ส่วนการศึกษาการกระจายตัวของอนุภาคฝุ่นในจังหวัดเชียงใหม่ครั้งนี้ พบว่า การกระจายตัวของฝุ่นเป็นแบบ bi-modal และสามารถแยกลักษณะการกระจายตัวของฝุ่นได้เป็น 2 กลุ่ม คือ กลุ่มที่อยู่ในตัวเมืองเชียงใหม่ (จุดเก็บที่ 1, 2) และ ที่อยู่นอกเมือง (จุดเก็บที่ 3) โดยจุดเก็บที่ 1 และ 2 มีการกระจายตัวของฝุ่นเป็นแบบเดียวกัน แต่จุดเก็บที่ 3 พบสัดส่วนของฝุ่นละเอียดค่อนข้างสูง ทำให้กราฟการกระจายตัวของอนุภาคฝุ่นมีจุดยอดจุดที่สูงกว่าอยู่ในช่วงของอนุภาค 0.5-1.0 ไมโครเมตร ในขณะที่จุดอื่นๆ มีจุดยอดในช่วงของอนุภาค 2.5-10 ไมโครเมตร

สาขาวิชา การจัดการสิ่งแวดล้อม (สหสาขาวิชา) ลายมือชื่อนิสิต.....นฤมล เที่ยงวิริยะ.....
ปีการศึกษา 2549 ลายมือชื่ออาจารย์ที่ปรึกษา.....
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

4789473720: MAJOR ENVIRONMENTAL MANAGEMENT

KEY WORD: CASCADE IMPACTOR/ AIR POLLUTANT/ SIZE DISTRIBUTION/ PARTICULATE MATTER/ AMBIENT AIR/ CHIANG MAI AIR

NARUMON TIANGVIRAYA: PHYSICAL AND CHEMICAL CHARACTERISTICS OF PARTICULATE MATTER AT VARIOUS SIZES IN CHIANG MAI AMBIENT AIR. THESIS ADVISOR: ASSOC. PROF. DR. KHAJORNSAK SOPAJAREE, THESIS CO ADVISOR: DR. NARES CHUERSUWAN, 205 pp. ISBN 974-14-1783-7.

Particulate Matter samples of Chiang Mai ambient air were collected from three sampling sites (site 1: Yuparaj School, site 2: municipality hospital and site 3: the district office of Sarapee), and fractionated into five size fractions (PM>10, $PM_{2.5-10}$, $PM_{1.0-2.5}$, $PM_{0.5-1.0}$ and $PM_{0.1-0.5}\mu m$) with a high volume cascade impactor during mid-June 2005 to January 2006. The quantity and size distribution of the samples were investigated by gravimetric method using analytical balance. Ions (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+} ,Cl^-, ,NO_3^-, SO_4^{2-} and PO_4^{3-}) and metals (Al, B, Ba, Ca, Fe, K, Li, Mg, Mn, Na, Pb, Sr, Ti and Zn) were chemical compositions of the samples which have been analyzed. The techniques used for ions analyzing (anions and cations) and metals analyzing was Ion Chromatography and Inductively coupled Plasma-Optical Emission Spectroscopy, respectively. Finally, the relationship between each size fractions of PM and the sampling sites were investigated as well as the temporal variations by a Statistical Program.

The average 24-hr PM_{10} concentrations during the sampling period at the sampling site 1, 2and 3 were 29.74-79.38(48.68), 30.87-109.81(58.88) and 30.71-92.94(60.99) $\mu g/m^3$, respectively. In addition, the average 24-hr $PM_{2.5}$ concentrations were 14.14-44.05(25.62), 13.87-63.55(31.40) and 18.11-68.26(37.15) $\mu g/m^3$, respectively. It was noted that $PM_{2.5}$ concentrations at sampling site 3 exceeded the standard daily average $PM_{2.5}$ of US.EPA. Metal components were highly found in coarse particle ($PM_{2.5-10}$) than in fine particle ($PM_{0.1-2.5}$). The portion of PM>10:$PM_{2.5-10}$:$PM_{0.1-2.5}$ was 36:44:20. Conversely, ions were found in fine particle more than in coarse particle. The portion of PM>10:$PM_{2.5-10}$:$PM_{0.1-2.5}$ was 18:28:54 and 26:15:59 for anions and cations, respectively. The dominant compositions in PM observed in this study were Ca, Al, Fe, Cl^-, NO_3^-, SO_4^{2-}, NH_4^+ and K^+. Moreover, the study of relationship between the level of PM concentrations, the sampling sites and temporal variations found that each size fractions of PM had high correlation to other fractions ($r= 0.353-0.840$, $p<0.05$). It was found that concentrations of fine particle collected from site 1 were significantly different from the concentrations at site 3 ($F= 3.569$, $p<0.05$). The concentrations of PM during dry season were higher than the concentrations collected in wet season for all size fractions and were significantly different ($F= 5.124-30.159$, $p<0.05$). The study of relationship between the concentrations of PM's compositions, the sampling sites and temporal variations found that site 1 and site 3 had different quantity of some compositions at the significance level of 0.05 ($F= 5.875-6.059$, $p<0.05$). Seasonal variations also caused significantly different in concentrations of some PM's compositions ($F= 4.121-23.286$, $p<0.05$). The study of size distribution of particulate matter in Chiang Mai indicated that the type of distribution was bi-modal and there were 2 groups of distribution patterns. Sampling site 1 and 2 (city areas) had the same pattern of distribution but it was different at sampling site 3 (rural areas). Since there was highly in proportion of fine particle at sampling site 3, then the size distribution of PM in this area had a higher peak of the bi-modal distribution at around 0.5-1.0 µm while the others had a higher peak at around 2.5-10 µm.

Field of study: Environmental management	Student's signature....................
(Interdisciplinary Program)	Advisor's signature....................
Academic year 2006	Co-advisor's signature....................

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Most of all, gratitude goes to my parents for their love and inspiration throughout my life.

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LIST OF ABBREVIATIONS

TSP	Total Suspended Particle
PM	Particulate matter
PM_{total}	PM size fraction of larger than 0.1 micrometers (according to the study)
PM_{10}	Particulate matter less than 10 micrometer
$PM_{2.5}$	Particulate matter less than 2.5 micrometer
HVCI	High Volume Cascade Impactor
OSHA	Occupational Safety and Health Administration
WHO	World Health Organization
US.EPA	United State. Environmental Protection Agency
NAAQS	National Ambient Air Quality Standard
PCD	Pollution Control Department
IC	Ion Chromatography
ICP-OES	Inductively Coupled-Plasma-Optical Emission Spectroscopy
SFPM	Summed Fraction Particulate Matter
PUF	Poly Urethane Foam
STDEV	Standard deviation
PAH	Polycyclic Aromatic Hydrocarbon
Na^+	Sodium ion
NH_4^+	Ammonium ion
K^+	Potassium ion

Mg^{2+}	Magnesium ion
Ca^{2+}	Calcium ion
Cl^{-}	Chloride ion
NO_3^{-}	Nitrate ion
SO_4^{2-}	Sulfate ion
PO_4^{3-}	Phosphate ion
Li^{+}	Lithium ion
Br^{-}	Bromide ion
F^{-}	Fluoride ion
NO_2^{-}	Nitrite ion
Al	Aluminum
B	Boron
Ba	Barium
Ca	Calcium
Fe	Ferrous
K	Potassium
Li	Lithium
Mg	Magnesium
Mn	Manganese
Na	Sodium

Pb	Lead
Sr	Strontium
Ti	Titanium
Zn	Zinc

CHAPTER I

INTRODUCTION

1.1 General

Problems associated with the presence of airborne particles, such as health problems (e.g. morbidity, respiratory symptoms, lung growth and immune system deficiency; Kappos, et al., 2004) and haze problems, are typical environmental issues in urban cities. The chemical composition and rate of deposition of these particles vary significantly with size of particles. In addition, different aerosol emission sources tend to have different aerosol mass size ranges (Chan, et al., 1999). The characteristics of each size-fractioned and the elemental constituents with particulate matter (PM) (Becker, et al., 2005) may in part, account for the seasonal variations in PM and the induced adverse health effects related to lung inflammation. Therefore, detailed information on the chemical composition of airborne particles in the different size ranges is essential for societal health and environmental assessment, as well as the source identification and apportionment of these particles.

Chiang Mai, the second largest city of Thailand, is located at latitude 99˚E and longitude 16˚N in the North. The large population of over 1,600,850 inhabitants accommodates an area of approximately 20,107.057 km^2. The highest density of which is in the downtown area, at 1,568 person/km^2 (Department of Provincial Administration, 2001). According to the Department of Land Transportation, the number of vehicles registered in Chiang Mai between 1994-2003 (483,260 to

933,733) nearly doubled and at present, the amount of public cars registered is as low as 0.1% while private cars are becoming more popular (Department of Land Transport, 2006). Thus, the roads are mostly congested by a large number of motor vehicles used for both public and private transportation. In addition, the construction of highways and buildings enhance the congestion throughout the city. There are also a great number of small-scale factories located in the area that have contributed to the pollution of Chiang Mai ambient air, which can cause serious health effects to people who are exposed to the pollutants. Thus, the issue of air pollutants is of a great concern to Thailand, especially in Chiang Mai area.

Previous study found that the daily average amount of PM_{10} (particulate matter less than 10 microns) in Chiang Mai is 2 times higher than that of the National Ambient Air Quality Standard (NAAQS) of the United States Environmental Protection Agency (US.EPA). (Phongtape Wiwatanadate, 2005) The annual average and daily average PM_{10} concentration of NAAQS is 50 $\mu g/m^3$ and 150 $\mu g/m^3$, respectively. Whereas, the annual average and daily average of $PM_{2.5}$ (particulate matter less than 2.5 microns) is 15 $\mu g/m^3$ and 65 $\mu g/m^3$, respectively. For the standard of Pollution Control Department of Thailand (PCD), the daily average PM_{10} standard is 120 $\mu g/m^3$.

The relationship between the numbers of respiratory related hospital admissions has significantly increased with the increasing quantity of particulate matter being inhaled by residents. Figure 1.1 shows the number of patient cases with respiratory disease in Chiang Mai during the year 1990 to 2002 with increased from 300,000 cases to 700,000 cases.

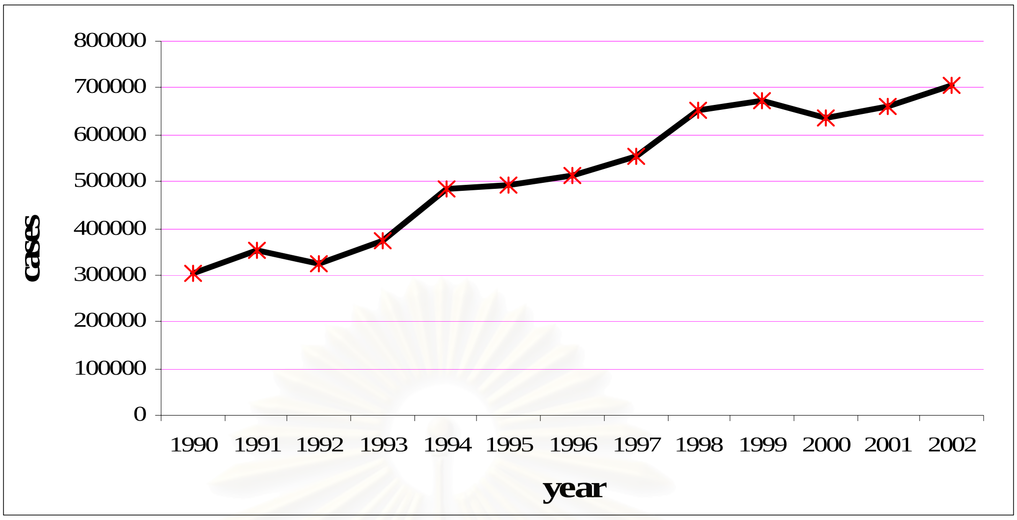


Figure 1.1 Number of patient cases with respiratory disease in Chiang Mai

(Source: Chiang Mai Provincial Public Health Office, 2005)

In addition, many researches mention that ultrafine particles are more toxic than coarse particles because of the large surface area available for biological interactions with lung cells (fine particles can penetrate deep into the lungs). The penetration of particulate matter through each part of the lung is shown in Figure 1.2. The smaller particulate matter has more potential to penetrate into the lung than the larger ones. Also the effect of the physicochemical characteristics of coarse, fine, and ultrafine particles on mortality and other outcomes need to be examined separately. Nevertheless, the lack of data about particulate matter, especially of ultra-fine size which many researchers have found to be more toxic to human health, is still a major problem.

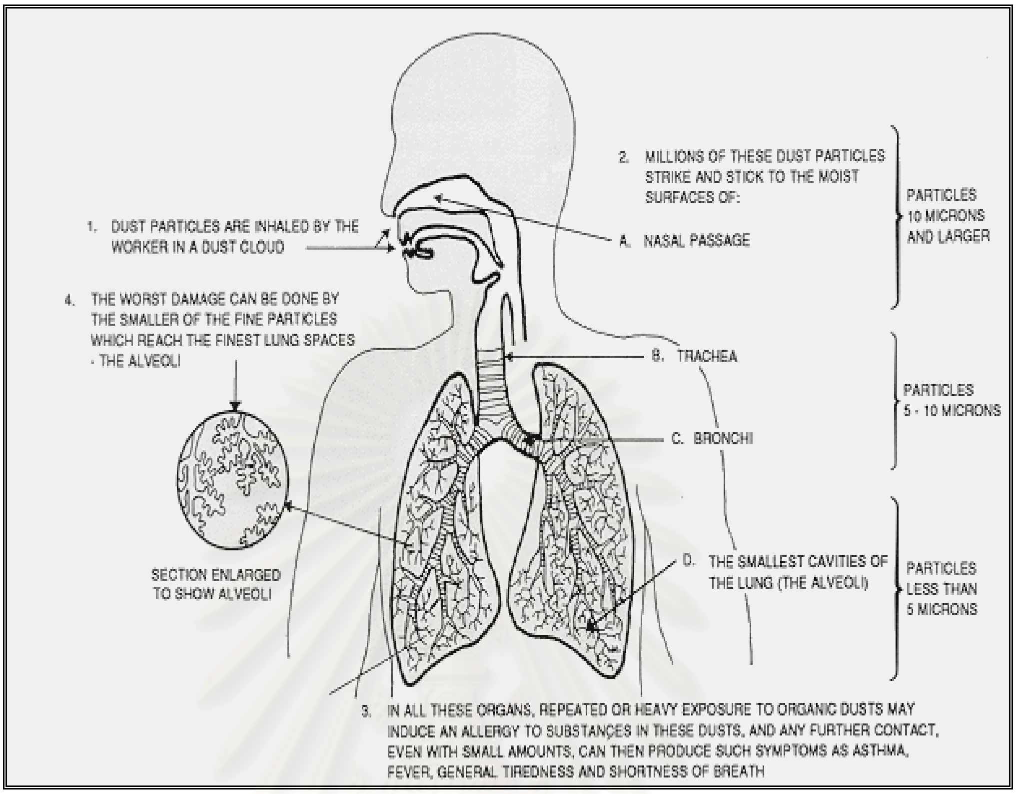


Figure 1.2 Penetration of particulates matter at various size fractions though the lung. (Source: Choinière and Munroe, 1993)

In order to mitigate these problems, the size fraction of ambient air particulate matter and chemical compositions at each size fraction in Chiang Mai ambient air has been investigated in this study. The investigation concentrated on 3 sampling sites based on medical records, which identified the existence of respiratory diseases. The particulate matter were collected by a High Volume Cascade Impactor (HVCI, Chemvol model 2400; Rupprecht & Patashnick Co.,Inc.), which is has a normal flow rate of 760±40 liter/minute. The device can separate particulate matter into 5 size-selection stages; the first stage is on the top of the device which used for separating the particulate matter that are larger than 10 micron, and the following stages are used for separating the particulate matter that are larger than 2.5, 1.0, 0.5 and 0.1 micron, respectively. The particulate matter from each size fraction then were investigated for their mass by the gravimetric method. Metals compositions on particulate matter were analyzed by Inductively Couple Plasma-Optical Emission Spectroscopy (ICP-OES). Ions compositions (cations and anions) on PM were analyzed by Ion Chromatography (IC). Afterwards the data was analyzed to find the size fraction and relationships between the quantity and quality of particulate matter associated with the site and duration of collected sampling.

1.2 Objectives of the study

The objectives of the study can be summarized as follows:

1. To determine the level of concentration and quality and chemical compositions of PM at various size fractions from 3 different sampling sites in Chiang Mai.
2. To determine the size distribution of PM at 3 different sampling sites in Chiang Mai.
3. To study the effects of the location and temporal variation (defined by season, weekday/weekend) on the level of concentration and chemical compositions of particulate matter of various size fractions.

1.3 Hypothesis

1. The level of concentration and chemical compositions of particulate matter at various size fractions are different depending on the sampling sites of collection, sources of PM, and time of sampling.
2. The pollutants, such as heavy metals and ions, could be found in fine particulate matter much more than in course particulate matter because of the larger surface area available for other components' adhesion.

1.4 Scopes of the study

1.4.1 Selection of sampling sites

There are 3 sampling sites: Yuparaj School, Municipality Hospital, and the District Office of Sarapee. Sampling sites were chosen based on the existing medical data of health records with respect to respiratory disease and allergy symptoms and also the level of traffic transportation in Chiang Mai areas.

1.4.2 Collection of the samples

High Volume Cascade Impactor (HVCI) were utilized for PM collection, which has five stages of different cut point sizes of 10, 2.5, 1.0, 0.5, and 0.1 µm. The HVCI operated at the normal flow rate of 760±40 liter/minute for 24 hours in collecting period. There were 15 times of sampling from each site from mid-June 2005 to January 2006. The sampling was taken every 15 day randomly. Poly Urethane Foam (PUF) was used as a impaction substrate for collecting the PM.

1.4.3 Analysis of the samples

After collection, the samples (PUF and PM) were weighted for finding the amount of PM and then the values were calculated to find the concentration of PM in terms of µg/m^3. The PUF have been extracted to identify and quantify the composition of the PM, which are ions (anions and cations) and metals. Table 1.1 shows the parameters, methods and main devices used in the analytical procedure.

Table 1.1 Parameters, Methods and Devices in the analytical procedure

Parameter	**Method**	**Device/Model**
Size distribution	Gravimetric Method	Microbalance/ Mettler Toledo AG 285
Metals	Compendium Method IO-3.4	ICP-OES/VISTA-MPXaxial Varian
Ions (Cation and Anion)	Method advised by Guidance Document of HVCI (ChemVol2400)	IC/ Dionex

1.4.4 Analysis of the data and interpretation

Data were analyzed by the statistical software named "Statistical Package for the Social Sciences" or SPSS on the followings:

a. To determine the correlation of each size fraction on mass of the PM

b. To compare particulate matter quantities and chemical compositions on each size fraction of the different temporal variations

c. To compare particulate matter quantities and chemical compositions on each size fraction of the different sites

1.5 Benefit of the studies

1.5.1 Amount and chemical compositions of particulate matter at various size fractions and their portion could be investigated and further interpreted to aid decision-making by policy-makers.

1.5.2 The relationship between the effects of location and temporal variations on the level concentration and chemical compositions of particulate matter at various size fractions could be measured and used as a rough estimation for strategic pollution prevention and/or policies.

CHAPTER II

BACKGROUND AND LITERATURE REVIEWS

2.1 Particle Size and Size Distribution

2.1.1 Theory of particle size

The ability to collect particles depends strongly on the particle size. The particle size is primarily dependent on how the particle was created and is difficult to define in terms that accurately represent the types of particles of interest. The difficulty stems from the fact that particles exist in a wide variety of shapes, not just spheres. In the case of spherical particles, the definition of particle size is easy: it is simply the diameter. For the irregularly shaped particles, there are a variety of ways to define the size.

For example, when measuring the size of particles on a microscope slide, size can be based on the particle width that divides the particle into equal areas (Martin's diameter) or the maximum edge-to-edge distance of the particle (Feret's diameter) as shown in Figure 2.1

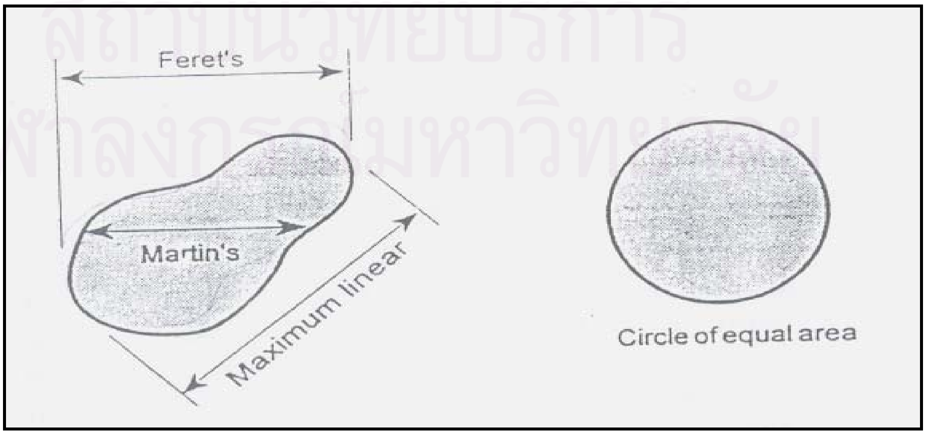


Figure 2.1 Martin's and Feret's definitions of particle size (Source: Faculty of Environmental Engineering, Chiang Mai University, 1998)

When categorizing particles on a slide by diameter size, the microscopist should consistently apply the same measuring method to all particles on the slide.

Neither of these microscopically based size definitions, however, is directly related to how particles behave in a fluid such as air. The particle size definition that is most useful for evaluating particle motion in a fluid is termed the aerodynamic diameter. It takes into account the particle density as shown in Equation 2.1

$$d_p = d\sqrt{(\rho_p C_c)} \qquad (2.1)$$

Where d_p = aerodynamic particle diameter (μm)

d = actual particle diameter (μm)

ρ_p = particle density (gm/cm3)

Cc = Cunningham slip correction factor

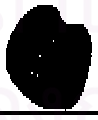
The aerodynamic diameter is determined by inertial sampling devices such as the Cascade Impactor. Particles that appear to be different in physical size and shape can have the same aerodynamics. Conversely, some particles that appear to be visually similar can have some what different aerodynamic diameters as illustrated in Table 2.1 and Table 2.2, respectively.

Table 2.1 Aerodynamic diameters of differently shaped particles

Aerodynamic Diameters of Differently Shaped Particles			
	solid sphere	ρ_p = 1.8 d = 1.4	d_p = 2 µm
	hollow sphere	ρ_p = 0.48 d = 2.80	
	irregular shape	ρ_p = 2.1 d = 1.3	

(Source: Faculty of Environmental Engineering, Chiang Mai University, 1998)

Table 2.2 Aerodynamic diameters of particles with different densities

Aerodynamic Diameters of Particle with Different Densities		
	ρ = 1 d = 2	d_p = 2.09
	ρ = 2 d = 2	d_p = 2.95
	ρ = 3 d = 2	d_p = 3.62

(Source: Faculty of Environmental Engineering, Chiang Mai University, 1998)

The term “aerodynamic diameter” is used for all particles including the fibers and particle clusters shown in Figure 2.2

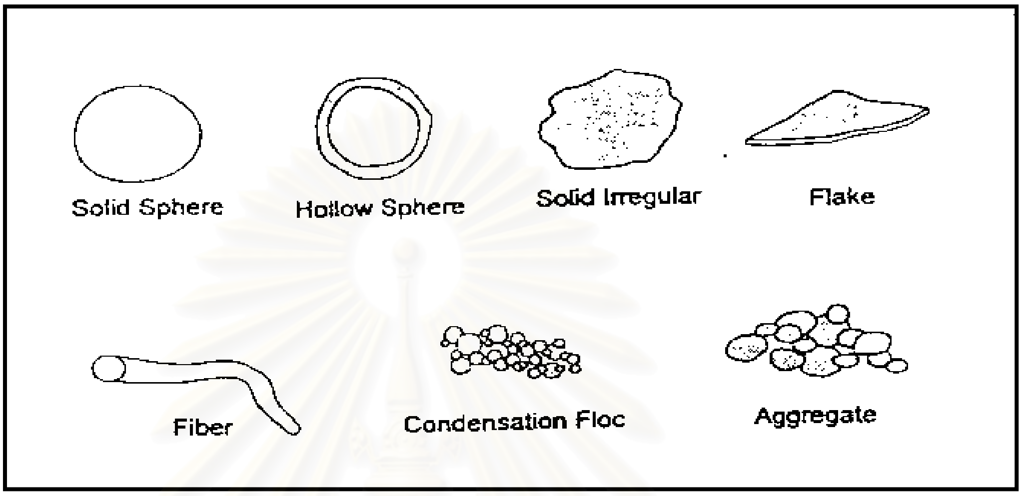


Figure 2.2 Different shapes of particles
(Source: Faculty of Environmental Engineering, Chiang Mai University, 1998)

2.1.2 Particle size distribution

Particulate emissions from both manmade and natural sources do not consist of any particles of any one size. Instead, they are composed of particles over a relatively wide size range. One of the simplest means of describing a particle size distribution is a histogram as shown in Figure 2.3. This simply shows the number of particles in a set of arbitrary size ranges specified on the horizontal axis. The terms used to characterize the particle size distribution are shown in Figure 2.3.

The median particle size divides the frequency distribution in half: 50% of the aerosol mass has particles with a large diameter, and 50% of the aerosol mass has particles with a smaller diameter. The mean is the mathematical average of the distribution. The value of the mean is sensitive to the quantities of particulate at the extreme lower and upper ends of the distribution.

For many manmade sources, the observed particulate matter distribution approximates a lognormal distribution. When the log of the particle diameter is plotted against the frequency of occurrence, a normal bell-shaped curve is generated as shown in Figure 2.4. This type of distribution can be described in terms of the geometric mean diameter, which is calculated simply by summing the logs of frequency observations and dividing by the number of size categories. Both the geometric mean and the standard deviation of a lognormal distribution can be determined by plotting the distribution data on log-probability paper. The geometric mean is the particle diameter that is equivalent to the 50 percent probability point. The diversity of the particle sizes is described by the standard deviation which is determined as equation 2.2 and 2.3.

$$\sigma_g = \frac{d_{50}}{d_{15.78}} \qquad (2.2)$$

$$\sigma_g = \frac{d_{84.13}}{d_{50}} \qquad (2.3)$$

Where σ_g = standard derivation of particle mass distribution

d_{50} = median sized particle

$d_{15.78}$, $d_{84.13}$ = diameter of particle that is equal to or greater than 15.78% or 84.13% of the mass of particles present

Different aerosol emission sources tend to have different aerosol mass size ranges. Chan, et al., 1999 found that the size geometric mean of aerosol mass is 0.96 μm in the samples collected from an industrial/residential site, and is 1.74 μm in the samples collected from a suburban site. The size geometric mean of concentrations of chemical components related to human activities ranges from 0.16 to 0.57 μm. Thus, the particle which is smaller than PM 2.5 should be investigated.

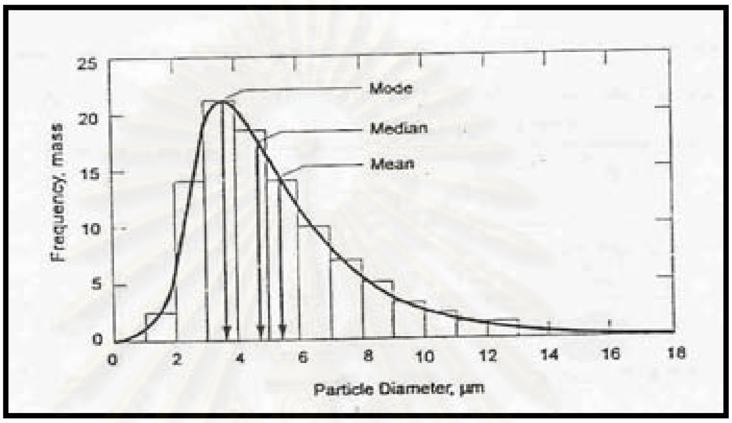


Figure 2.3 Aerosol Distributions
(Source: Faculty of Environmental Engineering, Chiang Mai University, 1998)

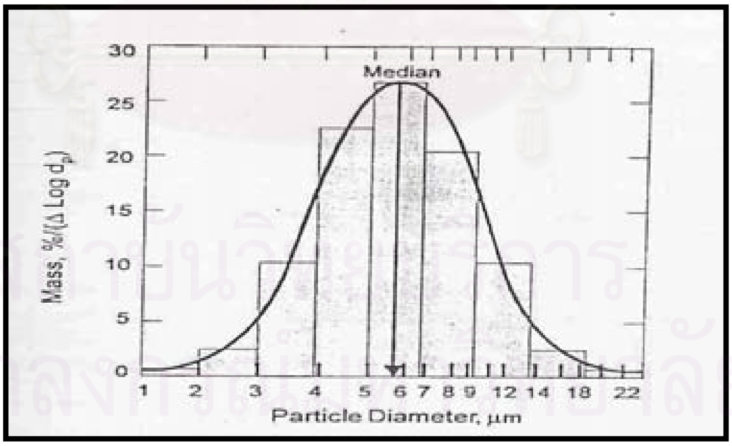


Figure 2.4 Histogram of a lognormal size distributions
(Source: Faculty of Environmental Engineering, Chiang Mai University, 1998)

Namdeo and Bell, 2004 analyzed temporal and seasonal variations of PM_{10} and $PM_{2.5}$ levels at one urban roadside, one urban background and one rural monitoring location. Levels of PM_{10}, $PM_{2.5}$ and coarse fractions of particulates were compared. In addition, particulate levels were compared with NO_2 and CO concentrations. The study concluded that PM_{10} and $PM_{2.5}$ were closely related at urban locations. Diurnal variations in $PM_{2.5}/PM_{10}$ ratio showed the influence of vehicular emission and movement on size distribution. This ratio was higher in the winter than in the summer, indicating a build-up or longer residence time of finer particulates or washout due to wet weather in the winter. The result was similar to the result of Kuhlbusch et al., 1999 and Salma, Maenhaut and Zaray, 2002.

2.2 The Amount and Size Distribution of Particulate Matter Associated with Health Effect.

Recent studies have pointed to evidence that fine particles in the air could be significant contributors to respiratory and cardiovascular diseases as well mortality. Epidemiologists looking at the health effects of particulate pollution need more information from various receptor locations to improve the understanding of this problem. Detailed information on temporal, spatial and size distributions of particulate pollution in urban areas is also important for air quality modelers as well as being an aid to decision and policy makers of local authorities.

A working group representing science and involved industry was constituted. Its results are summarized in this paper, which mainly is based on the reviews by Wichmann et al. (2000), as well as on data on ambient concentrations of particulate matter measured in Germany (Kappos et al., 2004) . The review shows that during the past 10 years many new epidemiological and toxicological studies on the health effects of particulate matter (PM) have been published. In summary, long-term exposure against PM for years or decades is associated with elevated total, cardiovascular, and infant mortality. Morbidity, the respiratory symptom, lung growth, and functioning of the immune system are affected.

Short-term studies show consistent correlations of exposure to daily concentrations of PM with mortality and morbidity on the same day or the subsequent days. Patients with asthma, pneumonia, and other respiratory diseases as well as patients with cardio-vascular diseases and diabetes are especially affected. The strongest associations are found for $PM_{2.5}$ followed by PM_{10}, with no indication of a threshold value for the health effects. The database for ultra fine particles is too small to make a final conclusion. The results of many researches are the same the world over, such as in Australia (Neubergera et al., 2004) and the UK (Namdeo and Bell, 2004)

In addition, the study of Becker et al. (2005) showed the health effects from different sizes of PM. Coarse PM ($PM_{2.5-10}$) was the most potent in inducing cytokine but was not Reactive Oxygen Species (ROS) than fine ($PM_{2.5}$) or ultrafine ($PM<_{0.1}$) PM . The study also investigated PM from different seasons. The results are as follows: different seasonal samples of PM had different effects to health and could affect different organs. In alveolar macrophages, the October coarse PM was the most potent stimulator for interleukin-6 (IL-6) release, while the July PM consistently stimulated the highest ROS production. In normal human bronchial epithelial cells, the January and the October PM were consistently the strongest stimulators of interleukin-8 (IL-8) and ROS, respectively.

2.3 Characteristics of Particulate Matter

2.3.1 Composition of particulate matter

Airborne particle matter is a complex mixture of substances. The particles vary in mass, size and other physical and chemical properties. Recent studies involving particle transport and transformation strongly suggest that atmospheric particles commonly occur in two distinct modes: the fine (<2.5 µm) mode and the coarse (2.5-10 µm) mode. The fine or accumulate mode (also termed respirable particulate matter) is attributed to the growth of particles from the gas phase and subsequent agglomeration, while the coarse mode is made of mechanically abraded or ground particles. Particles that have grown in the gas phase (either because of condensation, transformation, or combustion) occur initially as very fine nuclei-0.05 µm. These particles tend to grow rapidly to accumulation mode particles around 0.5, µm which are relatively stable in the air. Because of their initially gaseous origin, particle sizes in this range include inorganic ions such as sulfate, nitrate, ammonia, combustion-form carbon, organic aerosols, metals and other combustion products. Coarse particles, on the other hand, are produced mainly by mechanical forces such as crushing and abrasion. Coarse particles, therefore, normally consist of finely divided minerals such as oxides of aluminum, silicon, iron, calcium, and potassium. Coarse particles of soil or dust mostly result from entrainment by the motion of air or from other mechanical actions within their area.

Measurements of chemical composition are important to identifying the various sources contributing to the aerosol as well as its effect. Since the size of these particles is normally > 2.5 µm, their retention time in the air parcel is shorter than the fine particle fraction.

Many researches show that there are many kinds of pollutants in particulate matter such as heavy metals (Calcium, Iron, Barium, Cadmium, Aluminum, Magnesium, Copper, Lead, Titanium, Nickel, Manganese, Zinc and Silicon) (Somsiri Jaipium, 1997, Chan et al.,1999, Suwanit Thongnoon, 2004, Becker et al., 2005), ions (NO_x, SO_x, NH_4^+, Na^+, Ca^+, Cl^-, F^-,S^-, K^-, Br^-) (Chan et al.,1999, Kouyoumdjian and Saliba, 2006, Johansson et al., 2005,), PAHs and Organic matters (Pajaree Thongsanit et al., 2002, Johansson et al., 2005).

2.3.2 Hazards of PMs' composition

Air pollution threatens the health of human beings and other living things on the planet. While often invisible, pollutants in the air create smog and acid rain, cause cancer or other serious health effects, diminish the protective ozone layer in the upper atmosphere, and contribute to the potential for world climate change. Following is a description of each pollutant contained in particulate matter, along with their sources, effects and some regulations.

2.3.2.1 Hazards of Ions

a. Nitrogen Oxides (NOx)

Description: A light brown gas at lower concentrations; in higher concentrations it becomes an important component of an unpleasant looking brown, urban haze.

Sources: The result of burning fuels in utilities, industrial boilers, and automobiles.

Health effects: It can cause increased breathing difficulty for asthmatics.

b. Sulfur Oxides (SO_x)

Description: A colorless gas, odorless at low concentrations but pungent at high concentrations. It is generated through the combustion of fuels such as natural gas and coal and reacts in the atmosphere to form acid rain.

Sources: It is emitted largely from industrial, institutional, utility, and residential furnaces and boilers, as well as petroleum refineries, smelters, paper mills, and chemical plants.

Health effects: It aggravates heart and lung disease symptoms; obstructs breathing (especially in combination with other pollutants); and increases the incidence of acute respiratory diseases including coughs and colds, asthma, bronchitis, and emphysema.

2.3.2.2 Hazards of Metals

a. Aluminum (Al)

Description: A very reactive element. Aluminum metal is light in weight and silvery-white in appearance. Pure aluminum is very soft

Sources: Aluminum is the most abundant metal and the third most abundant element, after oxygen and silicon, in the earth's crust Used in the industries that produce antacids, astringents, buffered aspirin, food additives, antiperspirants, water treatment plants, furnace linings, explosives and fireworks. Levels of aluminum in the air generally range from 0.005–0.18 ng/m³ of air; Most of the aluminum in the air is in the form of small suspended particles of soil (dust). Aluminum levels in urban and industrial areas can range from 0.4 to 10 ng/m³.

*Health effects***:** Breathing large amounts of aluminum dusts can cause lung problems, such as coughing or chances that show up in chest aluminum-rays. People may get skin rashes from the aluminum compounds in some underarm antiperspirants. Rats and hamsters showed signs of lung damage after breathing very large amounts of aluminum as chlorohydrate or pure metal dust.

b. Barium (Ba)

*Description***:** Barium is a silvery-white metal that takes on a silver-yellow color when exposed to air.

*Sources***:** Emission from industries of oil and gas (which use Ba as drilling mud), paints, bricks, tiles, glass, rubber, ceramics, insect and rat poisons, and additives for oils and fuels , paper manufacturing, , hazardous waste sites and sugar refining

*Health effects***:** There is no reliable information about the possible health effects in humans who are exposed to barium by breathing or by direct skin contact. Health effects might be similar to those seen after eating or drinking barium (i.e. vomiting, abdominal cramps, diarrhea, difficulties in breathing, increased or decreased blood pressure, numbness around the face, and muscle weakness).

The Occupational Safety and Health Administration (OSHA) has a legally enforceable occupational exposure limit of 0.5 mg of soluble barium compounds per cubic meter (m^3) of air averaged over an 8-hour work day. The OSHA 8-hour exposure limit for barium sulfate dust in air is 15 mg/m^3 for total dust. The National Institute for Occupational Safety and Health (NIOSH) considers exposure to barium chloride levels of 50 mg/m^3 and higher as immediately dangerous to life or health.

c. Cadmium (Cd)

Description: It is a soft, silver-white metal that occurs naturally in the earth's crust. It has no recognizable taste or odor. Cadmium is most often present in nature as complex oxides, sulfides, and carbonates in zinc, lead, and copper ores

Sources: Cadmium compounds are often found in or attached to small particles present in air. Soils and rocks contain varying amounts of cadmium. Other source of emission comes from smoking cigarettes, hazardous waste sites or factories that make cadmium products such as batteries, coatings, or plastics.

Health Effects: Breathing air with very high levels of cadmium can severely damage the lungs and may cause death. Breathing air with lower levels of cadmium over long periods of time (for years) results in a build-up of cadmium in the kidney, and if sufficiently high, may result in kidney disease. Other effects that may occur after breathing cadmium for a long time are lung damage and fragile bones.

d. Chromium (Cr)

Description: No known taste or odor is associated with chromium compounds, steel-gray solid with a high melting point

Sources: Emission come from rocks, volcanic dust and gases, industries which manufacture metals and alloys, chrome plating, dyes and pigments, leather tanning, and wood preserving.

Health effects: Breathing in high levels (greater than 2 $\mu g/m^3$) can cause irritation to the nose, such as runny nose, sneezing, itching, nosebleeds, ulcers, and holes in the nasal septum. Long-term exposure to chromium has been associated with lung cancer.

The OSHA regulates chromium levels in the workplace air. The occupational exposure limits for an 8-hour workday, 40-hour workweek are 500 µg chromium/m^3 for water-soluble chromic (chromium (III)) or chromous [chromium (II)] salts and 1,000 µg chromium/m^3 for metallic chromium (chromium (0)) and insoluble salts. The level of chromium trioxide (chromic acid) and other chromium (VI) compounds in the workplace air should not be higher than 52 µg chromium (VI)/m^3 for any period of time.

e. Copper (Cu)

*Description***:** It is a reddish metal that occurs naturally in rock, soil, water, sediment, and at low levels, air.

*Sources***:** Its average concentration in the earth's crust is about 50 parts copper per million parts soil (ppm). Copper is primarily used as the metal or alloy in the manufacturing of wire, sheet metal, pipe, and other metal products. Copper compounds are most commonly used in agriculture to treat plant diseases, like mildew, or for water treatment and as preservatives for wood, leather, and fabrics.

*Health Effects***:** Long-term exposure to copper dust irritates the nose, mouth, and eyes, and causes headaches, dizziness, nausea, and diarrhea.

The OSHA has set a limit of 0.1 milligrams/cubic meter (mg/m^3) for copper fumes (vapor generated from heating copper) and 1.0 mg/m^3 for copper dusts (fine metallic copper particles) and mists (aerosols of soluble copper) in workroom air to protect workers during an 8-hour work shift (40-hour workweek).

f. Manganese (Mn)

Description: It is a silver-colored metal that has no special taste or smell.

Sources: In nature, levels of manganese in air are usually about 0.00002 mg/m^3 of air. Emissions come from the burning of gasoline in automobiles.

Health effects: Inhalation of manganese from the air showed signs of neurological problems. The neurological problems were most significant in the people aged 50 years and older. The effect on men is impotence and in women, decreases ability to reproduce.

The OSHA has set a limit of 5 mg/m^3 for the average amount of manganese in workplace air over an 8-hour workday.

g. Lead (Pb)

Description: It is a toxic, heavy, low-melting, and bluish-gray metal that makes up a portion of particulate matter.

Sources: Emissions come from transportation sources using lead in their fuels, coal combustion, smelters, motor vehicle battery plants, the combustion of garbage containing lead products, deterioration of lead paint, lead refining and processing plants, and other miscellaneous industrial processes.

Health effects: Breathing in, or swallowing airborne dust and dirt, is a way humans can be exposed to lead. Lead can affect almost every organ system in the body, but the central nervous system is the most sensitive one. Behavioral abnormalities, which include decreased learning ability and hyperactivity, have been demonstrated in children exposed to lead. Lead can also damage the kidneys and the reproductive system, and it causes anemia, a blood disorder. Pregnant women are also susceptible to the ill effects of lead, which can cause miscarriages, still births, and deaths of newborns.

The US.EPA requires that the concentration of lead in air that the public breathes be no higher than 1.5 micrograms per cubic meter (µg/m^3) averaged over 3 months. EPA regulations no longer allow lead in gasoline. The Clean Air Act Amendments (CAAA) of 1990 banned the sale of leaded gasoline as of December 31, 1995.

h. Zinc (Zn)

Description: It is a bluish-white, shiny metal. Powdered zinc is explosive and may burst into flames if stored in damp places.

Sources: In nature, zinc is the most common element in the Earth's crust. Emission occurs from industries which manufacture paints, ceramics, rubber, drug, diaper, dry cell batteries, preserving wood and in the manufacturing and dyeing of fabrics.

Health effects: Inhaling large amounts of zinc (as zinc dust or fumes from smelting or welding) can cause a specific short-term disease called metal fume fever, which is generally reversible once exposure to zinc ceases. However, very little is known about the long-term effects of breathing zinc dust or fumes.

2.3.2.3 Hazards of other pollutants

a. Hazardous Air Pollutants (HAPs)

*Description***:** Pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects. Such pollutants include arsenic, asbestos, mercury, and benzene.

*Sources***:** Some sources of HAPs include power plants (hydrochloric and hydrofluoric acids), solvents and glues (hexane), gasoline distribution (hexane), industrial processes, motor vehicle emissions and fuels, building materials containing asbestos, natural sources (volcanoes and forest fires), and painting operations.

*Health effects***:** They are known or suspected to cause cancer, respiratory effects, birth defects, and reproductive and other serious health effects. Some can cause death or serious injury if accidentally released in large amounts. Some HAPs are immediately dangerous to human health in small quantities; some cause health problems if the exposure extends over a longer period of time. The degree to which HAP affects a person's health depends on many factors, including the quantity of the pollutant, the duration and frequency of the exposures, the toxicity of the chemical, and the person's state of health and susceptibility.

2.4 Situation of Chiang Mai's Air and Critical Effects from PM

As a city that is surrounded by high hills, with calm and dry weather, Chiang Mai's geographic features tend to trap pollutants from rising above or away from the city. Moreover, the increasing number of cars and motorbikes resulting from inconvenient public transportation, the transporting of construction materials, together with garbage and yard waste burning (open burning) both in and around the city are the main causes of the rise of fine particles, especially PM_{10}, since 1997. From February-March, the amount of fine particles is higher than the standard set by the Department of Pollution Control (120 $\mu g/m^3$) and the Environmental Protection Agency of United States of America (150 $\mu g/m^3$). (Phongtape Wiwatanadate, 2005)

According to the numbers of cars registered in Chiang Mai during 1994-2003, the amount rose from 483,260 to 933,773 which is up 93.22% or almost double. The following 2 years later, year 2004-2005, private cars reached 1,247,625 or 33% higher than in 2003. The number of registered vehicles as of 31st January 2006, as shown in Table 2.3, is 1,247,625; 329,601 of which are private cars and 914,933 of which are motorbikes. There are only 1,305 public cars registered (Department of Land Transport, 2006). As can be seen, presently the number of public cars registered is as low as 0.1%, while the use of private cars is very popular. The combustion from vehicles also causes fine particulate matter. Chan et al. (1999) found that vehicular exhausts explain almost all the aerosol mass in the <0.61 μm fractions.

Records of cancer patients in hospitals in Chiang Mai reveal that lung cancer causes the highest number of all kinds of cancer and the number of patients from asthma, allergy and respiratory problems continues to increase. It is also notable that the number of non-smoking patients also keeps rising (Chiang Mai Provincial Public Health Office, 2005; Martin et al., 1991)

Table 2.3 Number of Cars Registered in Chiang Mai as of 31st January 2006

The number of car registered in Chiang Mai as of 31st January 2006		
Type of Car	**Number**	**Percentage (%)**
Private Car	**329,601**	**26.4**
Public Car	**1,305**	**0.1**
Motorbike	**914,933**	**73.3**
Others	**1,786**	**0.1**
total	**1,247,625**	**100**

(Source: Department of Land Transport, 2006)

In addition, the Pollution Control Department (PCD) has been monitoring the PM_{10} concentrations in some provinces of Thailand since 25th March 1997 and recorded the days which have PM_{10} exceeding the PM_{10} standard of the PCD (120 $\mu g/m^3$, average in a 24 hour-period) . Figure 2.5 presents that the number of days selected provinces have PM_{10} exceeding than the standard, and Chiang Mai is the fourth highest of all monitored areas. These numbers were presented on 11th September 2006. When compared with the provinces that ranked higher, Samut Prakarn, Saraburi and Lampang, Chiang Mai is more critical because the former three provinces are industrial provinces but Chiang Mai is not an industrial area. Thus, this province must be looked at closer.

Somsiri Jaipium (1997) studied the amount of heavy metals in the air of Bangkok and some big cities from 1993 to 1997, the results of which are displayed in Table 2.4.

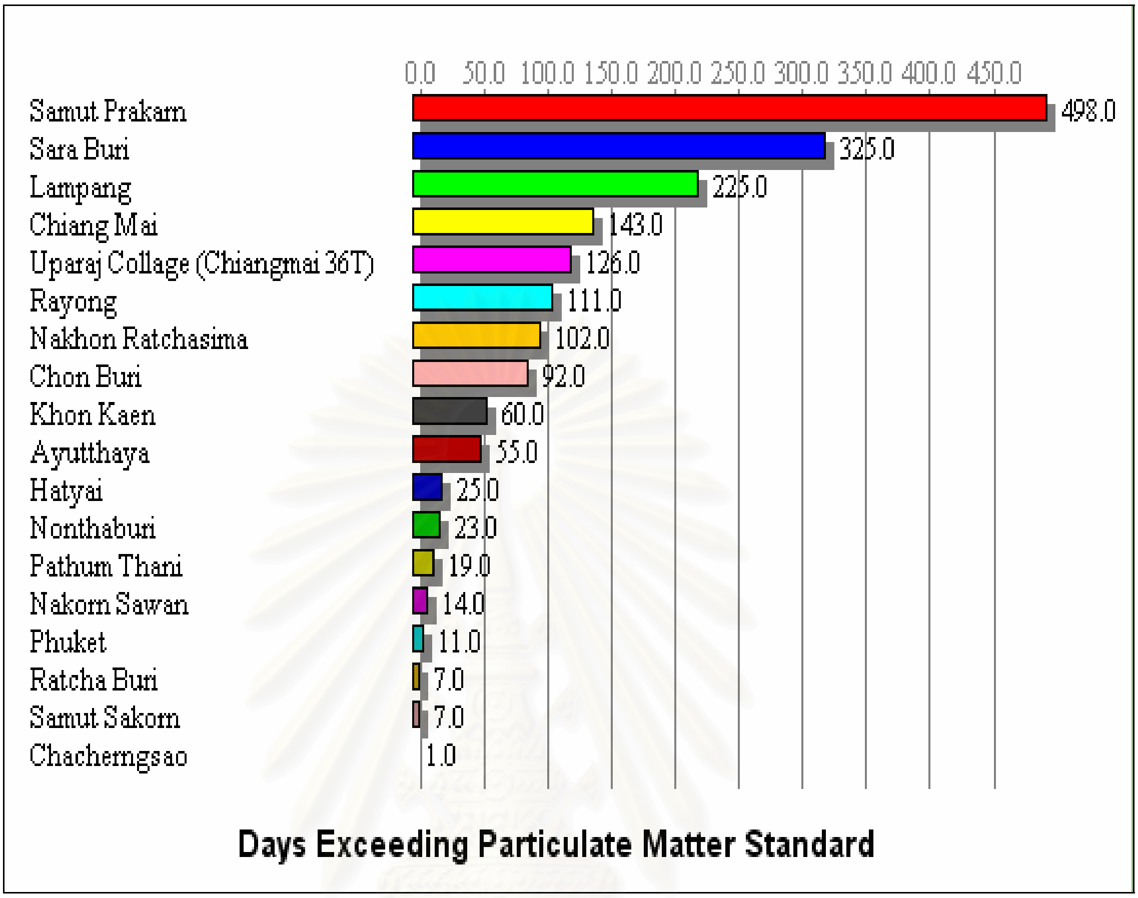


Figure 2.5 Day exceeding the PM_{10} standard since 25th March 1997 to 11th September 2006 (Source: Pollution Control department, 2006)

When comparing Figure 2.5 with Table 2.4, it seems that there is relationship between the number of days exceeding PM_{10} and the amount of heavy metals ($\mu g/m^3$) present. The sites which have the most exceeding day such as Samut Prakarn and Saraburi also have higher concentrations of heavy metals than the cities which contained lower concentrations of heavy metals.

From the study of Somsiri Jaipium, it could be assumed that Chiang Mai might be at risk of having a high concentration of heavy metals in particulate matter, similar to those big cities which produced the highest number of exceeding days.

Table 2.4 Heavy Metals found in PM_{10} in some cities of Thailand in year 1997 ($\mu g/m^3$)

(Source: Somsiri Jaipium, 1997)

Site / Heavy metal	BKK	Samut Pakan	Sara buri	Ayuth taya	Nonta buri	Patum thani	Nakon sawan	Rath buri	Samut sakorn
Fe	1.44	1.57	1.44	0.92	-	1.06	0.55	0.48	0.89
Mn	0.07	0.14	0.05	0.06	0.04	0.05	0.04	0.02	0.05
Cu	0.06	0.06	0.01	0.02	0.02	0.04	0.03	0.01	0.04
Zn	0.21	0.39	0.41	0.16	0.16	0.17	0.01	0.04	0.18
Pb	0.07	-	-	0.03	0.06	-	-	0.09	-
Cr	0.007	0.008	0.01	0	0.01	0.006	0.002	0	0.007
Cd	0.001	0.001	0	0	0	0.001	0	0	0.001

2.5 Application of the Chemvol Model 2400, High Volume Cascade Impactor for Collecting Air Samples

2.5.1 Cascade Impactor Theory

A Cascade Impactor is an instrument used for the classification of aerosols according to size and for their subsequent chemical analysis. Air is drawn through a series of orifices of decreasing size; the air flow is normal to collecting surfaces on which aerosols are collected by inertial impaction. The particles, separated stepwise by their momentum differences into a number of size ranges, are collected stimulatory. The mechanism of the Cascade Impactor is shown in Figure 2.6

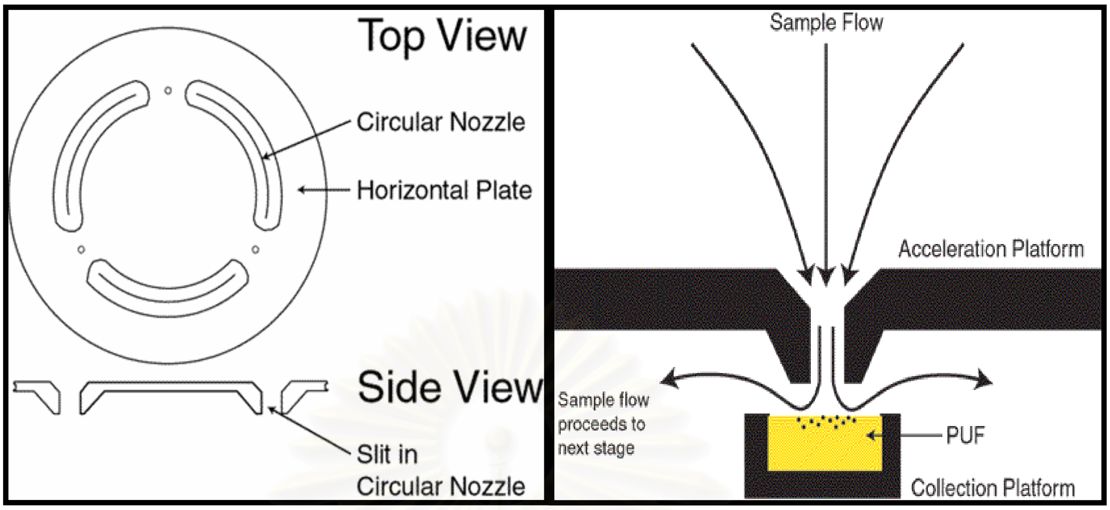


Figure 2.6 Mechanism of Cascade Impactor
(Source: www.thermo.com/eThermo/CMA/PDFs/Product/productPDF_27477.pdf)

2.5.2 The development of the High Volume Cascade Impactor

The Harvard University School of Public Health developed and patented a new High Volume Cascade Impactor (HVCI), Chemvol Model 2400, manufactured by Rupprecht & Patashnick Co., Inc. (R&P). It is a high-volume air sampler that has the capability of classifying ambient particulate matter by an aerodynamic diameter.

This new HVCI model was designed to overcome the problem of the previously high volume sampler model. The former models were not suitable for classifying particulate matter at high flow rates. For example, filtration methods such as the high volume sampler, which operates at the flow rate of 1000 l/min, require relatively large filters (20.3*25.4cm). As a result, these collection media also require relatively large quantities of solvents to recover the collected particulate matter. This severely limits their usefulness for both toxicological and characterization studies.

In contrast, conventional inertial impactors have the ability to focus the collected particulate matter on relatively small surfaces. These small surfaces allow the user to recover particulate matter from impaction surfaces using relatively small extract volumes. However, when fast-moving particulate matter impact a hard surface, they often reenter the air stream and are carried off to the next collection stage, or are lost from the process entirely. This is often referred to as a “bounce-off” loss.

To overcome the bounce-off and low-capacity issue, the Chemvol sampler uses polyurethane foam (PUF) as an impaction substrate. Although such porous foams were recently suggested as preselective inlets, they experienced bounce-off losses of solid particulate matter. However, the large pores and relatively low overall density characteristic of PUF allows particles to be collected using the conventional impaction process. Polyurethane foam produce processes with negligible particulate matter bounce-off losses because particulate matter can impinge onto the substrate with a possible gradual decrease of particle velocity. Because of their highly specific surface area, these substrates present a high-collection capacity and can be used to collect milligram to gram quantities of particulate matter materials (Demokritou et al, 2002; Dunbar, Kataya and Tiangbe, 2005).

These are the advantages of the PUF substrate which are reported to make it better than previous filters:

- The porosity of the PUF material decreases the strength of the collision between particles and the collection substrate. This eliminates bounce-off, re-entrainment and breakup losses of particles. PUF has very high particle collection efficiency over a large range of particle sizes, even under conditions of heavy particle loading.

- Polyurethane foam is inert, and is appropriate for a wide variety of physical, chemical and toxicological analyses.
- No oil or grease coating is required for particle impaction, so potential interferences from impurities in such coatings can be avoided in chemical, biological and toxicological analyses.
- PUF material allows for significantly longer sampling durations than filters, as well as a greater mass loading capability. At the high flow rate of 800 l/min, a large mass of PM can be collected in a short time on the small collection substrate, facilitating recovery of particles for analysis. The length of the round slit is approximately 30 cm. Collected samples can easily be extracted using small amounts of water or organic solvents.
- A loading capacity of 1.8 g without a degradation in collection efficiency permits sampling periods of several weeks at an average PM-10 concentration of 100 micrograms per cubic meter.

2.6 Related studies

2.6.1 Factors affecting the amount and characteristics of particulate matter

Pitz et al. (2001) studied the changes of ambient particle size distribution in East Germany between 1993 and 1999. Their studies found that the particle sizes clearly shifted to smaller particle sizes within the six-year period. This was caused by changes of the most prominent sources, traffic and domestic heating, since formerly dominating industries in Bitterfeld and Hettstedt had vanished grossly.

Sturm et al. (2002) measured PM near the roadside and found that when the traffic load increased the size distribution changes. This effected from the rapid coagulation of the smallest particles with the accumulation mode.

Begum, Biswas and Hopke (2006) studied the temporal variations and spatial distribution of ambient $PM_{2.5}$ and PM_{10} concentrations in Dhaka, Bangladesh. The study found that a characteristic seasonal variation was observed for coarse as well as fine particles with elevated concentrations during the winter. The reasons for the high peaks during the winter were not only the seasonal fluctuations of the emissions, but also meteorological effects especially wind direction. The study also found that during the wintertime in Dhaka, Bangladesh, the wind comes mainly from the north and northwest directions. It presented that the fraction of PM is influenced by wind coming from the northwestern direction. In Dhaka, the largest traffic corridors extend toward the north and south, and two such corridors were situated to the west of the sampling sites. On the other hand, a lot of brick fields (which used both coal and wood as main fuels and operate only in winter due to meteorological condition) had grown up around Dhaka, especially in the northwest and southeast side of the city. Therefore, emissions from various kinds of automobiles and the brick kilns were believed to be the two major contributors to the severe air pollution during the winter in Dhaka.

Cabada et al. (2004) found that season affects the characteristics of PM. During the summer the ultrafine mass was composed of 50% carbonaceous material (organic material and elemental carbon) and 50% inorganic (mainly sulfate and ammonium); during the winter these percentages are 70% and 30%, respectively. The losses in percent of organic material during the summer are due to volatilization and bounce-off.

Pajaree Thongsanit and Wanida Jinsart (2004) studied the chemical characterization and source apportionment of fine air particles in Phitsanulok. The study found that the highest concentration occurs during the dry (winter) period (Oct.-Jan.). The high activities and traffic densities throughout the year was related to the high concentration of particulate matter. The study also indicated that source strengths and removal processes are both important. The ratio of PM_{10} concentrations in wet and dry seasons at the high traffic densities, middle traffic densities and low traffic densities site were 0.91, 0.64 and 0.51, respectively. This finding reflects the traffic densities of the roadside sites. When the important airborne particulate matter sources in Phitsanulok and Bangkok were compared, it was found that in Phisanulok, the major sources of PM came from mobile sources, biomass burning and road dust, but in Bangkok, automobiles were the major sources.

He et al. (2006) found that different organic compounds presented different seasonal characteristics, reflecting their different dominant emission sources, such as coal combustion, biomass burning and cooking emission. The abundance and origin of these organic compounds were discussed and revealed seasonal air pollution characteristics of Beijing.

2.6.2 Characteristics of PM in Thailand

PM_{10}: It was reported that 60 per cent by weight of TSP in Bangkok is PM_{10} (Supat Wangwongwatana and Punya Warapetcharayut, 2001). In 2000, 24-hour average concentrations of roadside ambient PM_{10} in Bangkok ranged from 27-244.4 µg/m3 with an annual average of 82.6 µg/m^3. 206 out of the 1,613 observations, representing 12.8 percent, had concentrations exceeding the standard of 120 µg /m3. The annual average concentration of 82.6 µg/m^3 also exceeded the standard of 50 µg/m^3. It was reported that PM_{10} in Phitsanulok collected across the period June 2003 to January 2004 was found to vary from a minimum value of 53.06 µg/$m^3$to a maximum value of 170.50 µg/m^3 (Pajaree Thongsanit and Wanida Jinsart, 2004).

Lead: High concentrations of roadside ambient lead were observed prior to 1992 but the levels started declining progressively since then as a result of the aggressive lead phase-out program introduced in 1990. The current roadside ambient lead concentrations are much lower than the WHO's recommended guideline which is 0.5 µg/ m^3 for annual average concentration. The maximum monthly average concentration of roadside ambient lead observed in 2003 was only 0.24 µg/m^3, which is only one-seventh of Thailand's standard of 1.5 µg/ m^3. The annual average concentration was reported to be 0.09 µg/ m^3. (Supat Wangwongwatana, 2004)

O_3: It was observed in the year 2003 that 0.25 percent of hourly ambient O_3 concentrations exceeding the ambient air quality standards of 100 ppb, mostly in the areas downwind from the centre of Bangkok. (Supat Wangwongwatana, 2004) This indicates that Bangkok may start to experience photochemical smog problem, which require more studies and analyses in detail to gain a better understanding of the situation and the associated photochemical reactions.

NO_2, SO_2: The average concentrations of SO_2 for 1-hour and 24–hour periods are 0.0-104.0 ppb and 0.0-31.9 ppb, respectively. The average concentration of NO_2 for 1 hour is 0.0-169.0 ppb**.** (Supat Wangwongwatana, 2004)

$PM_{2.5}$ /PM_{10}: The ratio of $PM_{2.5}$ and PM_{10} of Bangkok in the year 2001 was 0.33-0.53 (Supat Wangwongwatana and Punya Warapetcharayut, 2001). Coefficient of relation between $PM_{2.5}$ and PM_{10} of Bangkok was 0.979 (Rapeepat Krerkkaiwal and Wanida Jinsart, 2000). Ratio between $PM_{2.5}$ and PM_{10} was considerable vary among sites, the mean $PM_{2.5}$ to PM_{10} ratio in Bangkok was 0.74, suburban was 0.65 and Ayutthaya was 0.60 (Samarnchai Loetkamonwit and Wanida Jinsart, 2000).

Other pollutants: Pajaree Thongsanit and Wanida Jinsart (2004) studied the particulate matter at a Phitsanulok roadside and found that there was primarily organic carbon (OC), Elemental Carbon (EC) and Ca, at 29.33 ± 9.40 $\mu g/m^3$ 42.28 ± 16.57 $\mu g/m^3$ and 9.57 ± 5.47 $\mu g/m^3$, respectively. The major elements were Si, Al, Fe, K and S. In comparison, the OC, EC and Ca compositions of fine particulate matter of Bangkok sites were 24.86 ± 8.23 $\mu g/m^3$ 71.21 ± 25.37 $\mu g/m^3$ and 4.03 ± 1.79 $\mu g/m^3$, respectively. The major elements were Na, Si, S, K and Fe. OC/EC ratios of Phitsanulok and Bangkok samples are 0.693 and 0.349, respectively. Samarnchai Loetkamonwit and Wanida Jinsart (2000) studied the composition of $PM_{2.5}$ which was collected from Bangkok. The study found that the quantity of trace element composition in $PM_{2.5}$ has

Potassium 1.3892 μg/m^3, Zinc 0.4529 μg/m^3, Manganese 0.1518 μg/m^3, Lead μg/$m^3$and copper 0.0095 μg/m^3.

2.6.3 Policy and measures taken to monitor and improve air quality in Thailand

Supat Wangwongwatana and Punya Warapetcharayut (2001) analyzed the pollution management in Thailand. The development of the management was described as follows:

- The first act for the control and conservation of national environmental quality in Thailand was the Enhancement and Conservation of National Environmental Quality Act of 1975.
- The primary ambient air quality standard was established in 1981.
- Monitoring of ambient air quality in Thailand has been carried out since 1983 after the 1981 NPAAQS were promulgated and subsequently revised in 1995.
- The first on-line and real-time continuous air quality monitoring system in Thailand was installed in 1987.
- The 1981 NAAQS were revised in 1995. It took into account the latest information on human health impact of key pollutants such as CO, NO_2, SO_2, PM_{10}, TSP, Pb, and O_3.
- In October of 1996, the Department of Pollution Control installed three new on-line roadside ambient air quality monitoring stations continuously measuring CO, TSP, PM10, Pb, SO_2, NOx, O_3 and HC. These new stations

are also equipped with 10-metre meteorological masts measuring wind speed and direction, temperature, humidity and solar radiation.

- Present management to achieve the targets, a concerted cooperative effort is being made by the government, industries, public and non-governmental organizations to restore the quality of the air in Bangkok. A number of measures have been adopted to mitigate air pollution problems, particularly those caused by the transport sector. They are aimed not only at exhaust gas emission controls but also at the improvement of fuel quality and engine specification, implementation of an in-use vehicle inspection and maintenance program, public transport improvement through mass transit systems, and the improvement of traffic conditions through better traffic management.

CHAPTER III

METHODOLOGY

To study the physical and chemical characteristics of particulate matter at various size fractions in Chiang Mai ambient air, these following steps were conducted.

3.1 Selection of the Sampling Method

High Volume Cascade Impactor (HVCI) that utilizes Poly Urethane Foam (PUF) as the collection medium was used for collecting PM. This impactor contains five stages with decreasing cut-point sizes of PM 10, 2.5, 1.0, 0.5 and 0.1 micrometers, respectively. There are three different sizes of PUF substrates. The largest size is used for the first stage and called “P1.” The medium size is used for the second stage and called “P2.”The smallest size is used for third, fourth and fifth stage and called “P3.” The properties of the PUF used in all experiments with the HVCI are detailed in Table 3.1.

From Table 3.1, it can be concluded that there were three sizes of PUF which were used for classifying the PM in the five size-fractionated stages. Size-fractionated particles of 2.5-10 μm can be defined as coarse and size-fractionated particles of 0.1-2.5 can be defined as fine particles. PM_{10} means the summed PM from the second stage to the fifth stage of the Cascade Impactor ($PM_{0.1\text{-}10}$). $PM_{2.5}$ means the summed PM from the third stage to the fifth stage of the Cascade Impactor ($PM_{0.1\text{-}2.5}$). The assumption of this study was to neglect the particles which have a fractionated size of less than 0.1 µm, which known as “ultrafine” due to the limitation of the instrument.

Table 3.1 Properties of PUF used in all experiments with HVCI

Stage	**Name**	**Size range (µm)**	**PM category**	**Size (inch)**		Normalized Volume& surface area
				Inside diameter	Outside diameter	
1. PM-10	P1	>10	-	3.5	6.5	6
2. PM-2.5	P2	2.5-10	Coarse PM	4.5	5.5	2
3. PM-1.0 4. PM-0.5 5. PM-0.1	P3	1.0-2.5 0.5-1.0 0.1-0.5	Fine PM	4.75	5.25	1

The major feature of the HVCI is its ability to rapidly collect large amounts of particles (mg to g-level) onto small and inert pieces of impaction substrates without the use of adhesives. Figure 3.1 shows the set up of different sizes of the PUF and size-fractionated Cascade Impactor used in the study. The first stage is at the most upper portion and the fifth stage is at the bottom as shown.

A fully assembled HVCI, which includes the sampler, flow measurement system, tripod, flexible pipe and pump, is shown in Figure 3.2

Figure 3.1 Different sizes of PUF and the size-fractionated Cascade Impactor

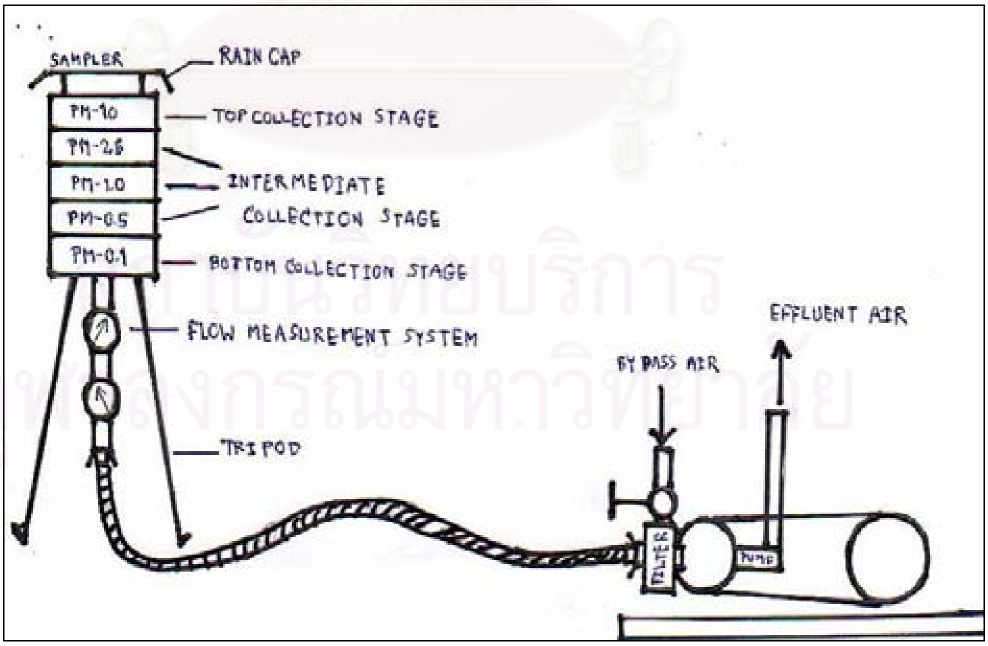


Figure 3.2 A fully assembled HVCI which includes the sampler, flow measurement system, tripod, flexible pipe and pump

3.2 Selection of the Sampling Sites

There were three sampling sites in this study. Particulate matter from ambient air samples were collected at three sites in Chiang Mai, a map of the sampling sites is shown as Figure 3.3 All sites were chosen based on the existing medical health records with respect to respiratory diseases and allergy symptoms (Zhang,1996) and the also based on the traffic on the main road of Chiang Mai (Chiang Mai University, Information Technology Service Center[CMU,ITSC],1995) Site 1, Yuparaj Wittayalai School, is located at 1.5 meters above ground level and 3 meters from the intersection. This site is in the middle of town and located in a large community area, which includes institutions and schools. The amount of cars that used the road is 20,452 car/day. (CMU, ITSC, 1995) Site 2, the Municipality Hospital, is set at 1.5 meters above ground level and 50 meters from the busy main road of Tapae and about 50 meters from the biggest market. This site is in the downtown area which includes Chiang Mai’s biggest market, other businesses and a large commercial area. The amount of cars that used the road is 21,862 car/day. (CMU, ITSC, 1995) Site 3, is located in front of the District Office of Sarapee, it is 1.5 meters above ground level and 3 meters from the main road (Chiang Mai-Lampoon). The amount of cars that used the road is 30,277 car/day. (CMU, ITSC, 1995) This site is not in the city since it is located 18 kilometers southeast from the town of Chiang Mai, but Sarapee is also a big community. Zhang (1996) also indicated that the most polluted areas were in Chiang Mai’s city and in Sarapee district. The important issue about the outside of the city is that farmers always burn biomass while people in the city do not. This might be a reason that air pollutant outside the city is a great number.

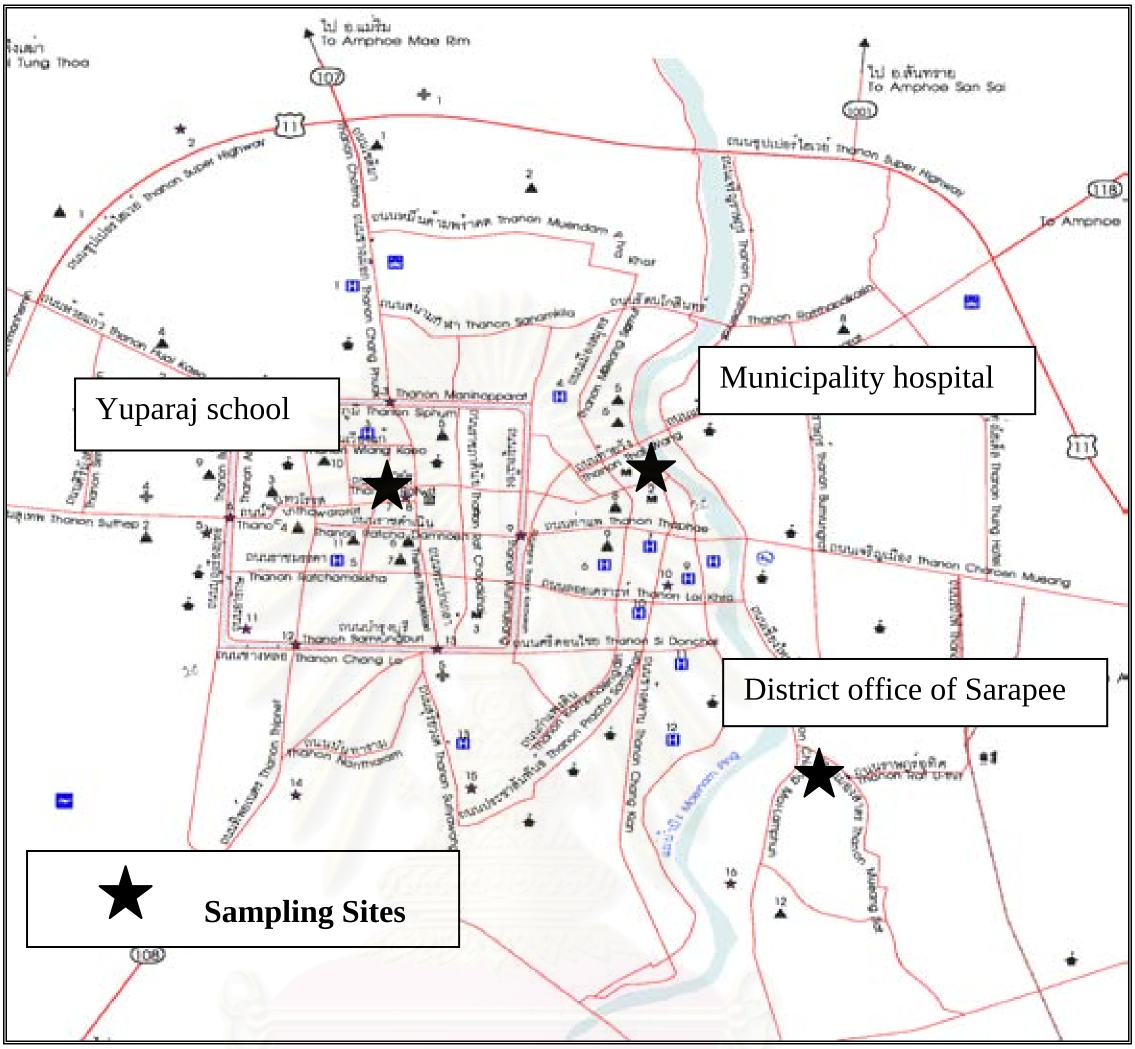


Figure 3.3 Map of Sampling Sites in Chiang Mai area.

Figure 3.4 shows the sampler and all devices used in sampling PM at the three sampling sites. The devices were installed near the main road because it has been estimated that this ambient air quality standard is likely to be exceeded at the roadside sites. Also, many Chiang Mai residents spend at roadside locations and need to use the road everyday. The crowded of city, the buildings, also the reason that the device have to be installed near the roadside for underestimated prevention.

Figure 3.4 Three sampling sites of the study

3.3 Duration and Number of Sampling

The samples were taken over a 24-hour period every 15 days randomly across mid-June 2005 until January 2006 with appropriate recognition of seasonal changes: the rainy season or wet season (mid-June 2005 to October 2005), and the winter season or dry season (November 2005 to January 2006). Samples were collected 15 times form each site which accounts for the total number of 225 PUF samples from the field. Since the sampling period was random, both on weekends and weekdays, pollution counts were compared in order to observe for relationships between the samples taken.

3.4 Sampling

3.4.1 Pre-sampling Method

3.4.1.1 All glassware and tools were cleaned before they were used to prepare the PUF for the analysis procedure. Then, the substrate holders were cleaned. The PUF substrates were cleaned with milli-Q water and Methanol to ensure that the extraction process removed materials that were polar and non-polar and dried in Fume hood. From this step, 10 % of each size of the PUF substrates, used as a blank, was collected in order to check it with the post-field PUF in analytical step.

The Standard of Practice (SOP) before sampling is described step-by-steps as follows:

A. Cleaning the glassware and tools: The Thermal Cleaning Procedure

B. Cleaning the Substrates Holders

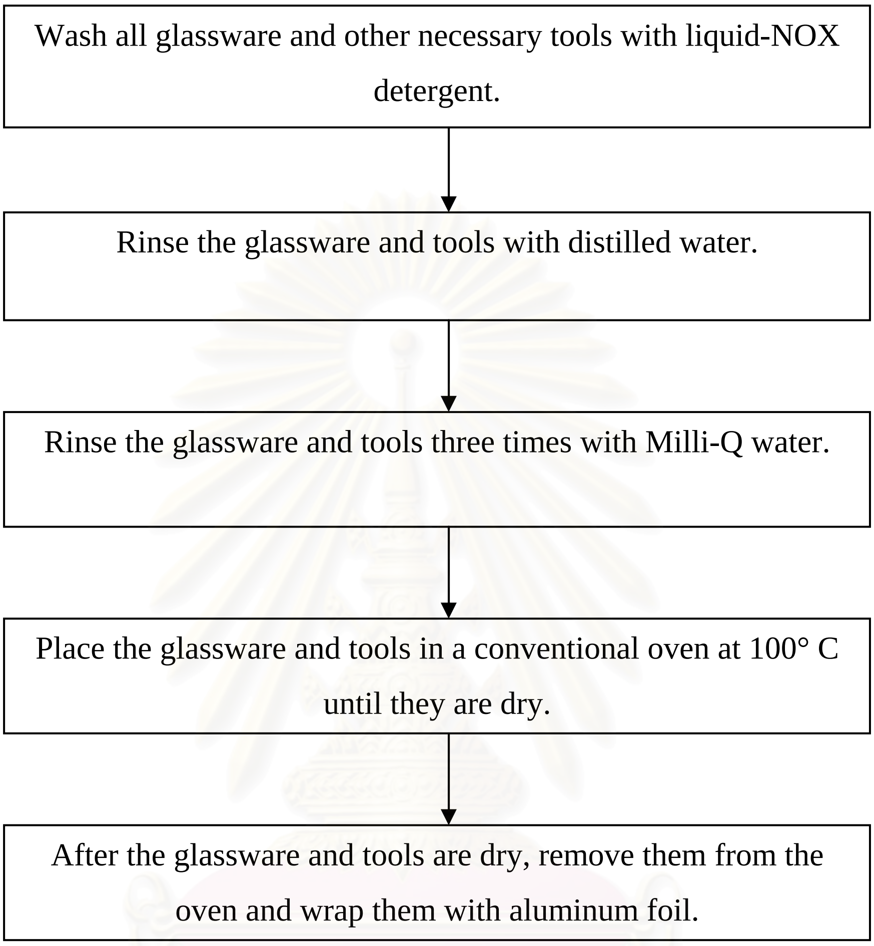
C. Cleaning the PUF Substrates

Tools and materials required for these procedures:

5000 ml beakers
Non-serrated stainless steel forceps
Clean stainless-steel basket
Ultrasonic bath Model: Elma-Transonic digitals
Clean-air positive-flow
Ultra-pure water (Milli-Q water type I)
Methanol (99.9%)
Oven
Liquid-NOX detergent
Powder-free groves
Aluminum foil

The method used for cleaning the glassware and other instruments that were used for loading the ChemVol sampler and performing the subsequent analysis on the PUF substrates was thermal cleaning (recommended by R&P).

Figures 3.5, 3.6 and 3.7 show the Standard of Practice (SOP) of A, B and C to prepare the samples before sampling.



Wash all glassware and other necessary tools with liquid-NOX detergent.

Rinse the glassware and tools with distilled water.

Rinse the glassware and tools three times with Milli-Q water.

Place the glassware and tools in a conventional oven at 100° C until they are dry.

After the glassware and tools are dry, remove them from the oven and wrap them with aluminum foil.

Figure 3.5 Standard of Practice for performing the thermal cleaning procedure

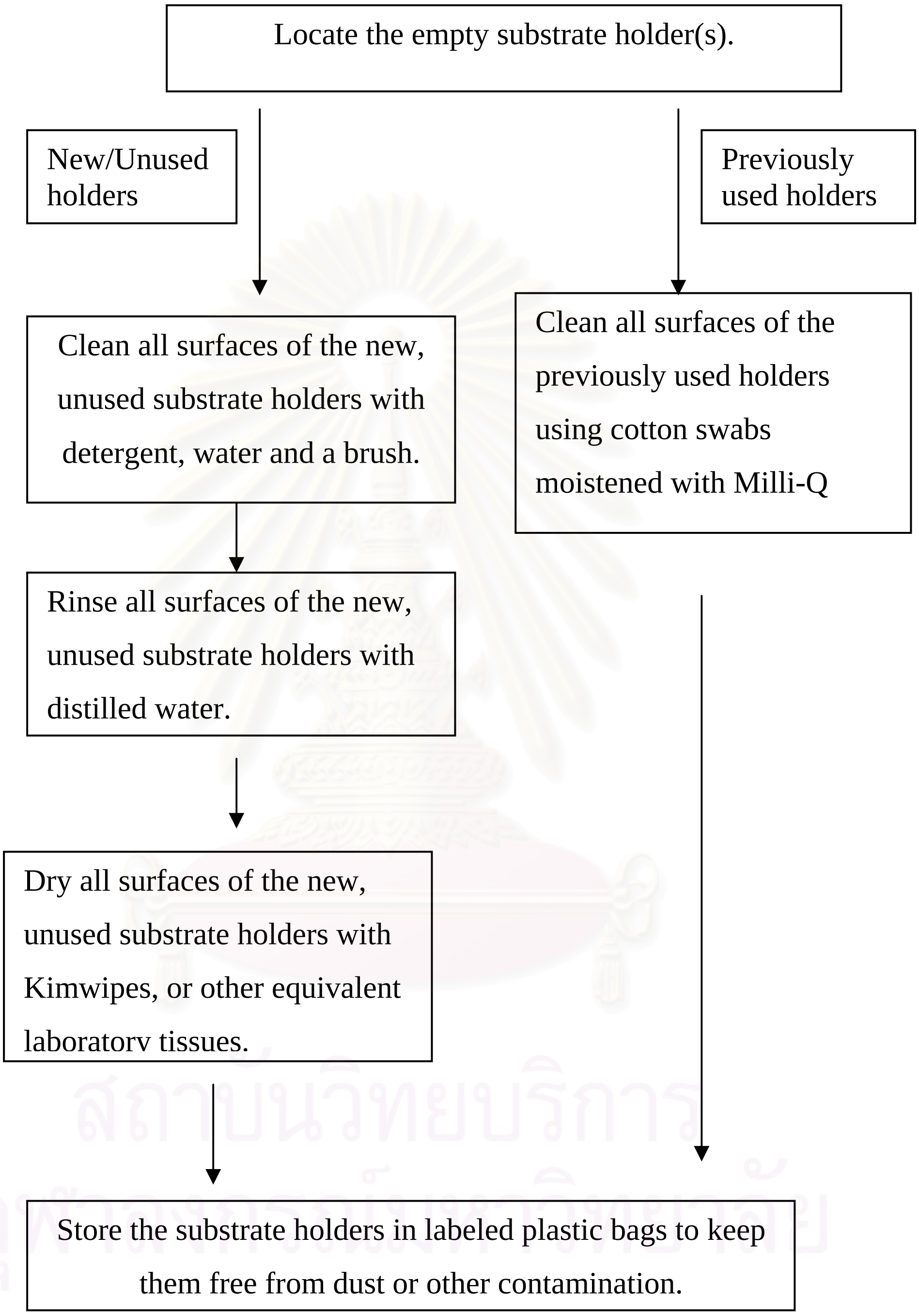
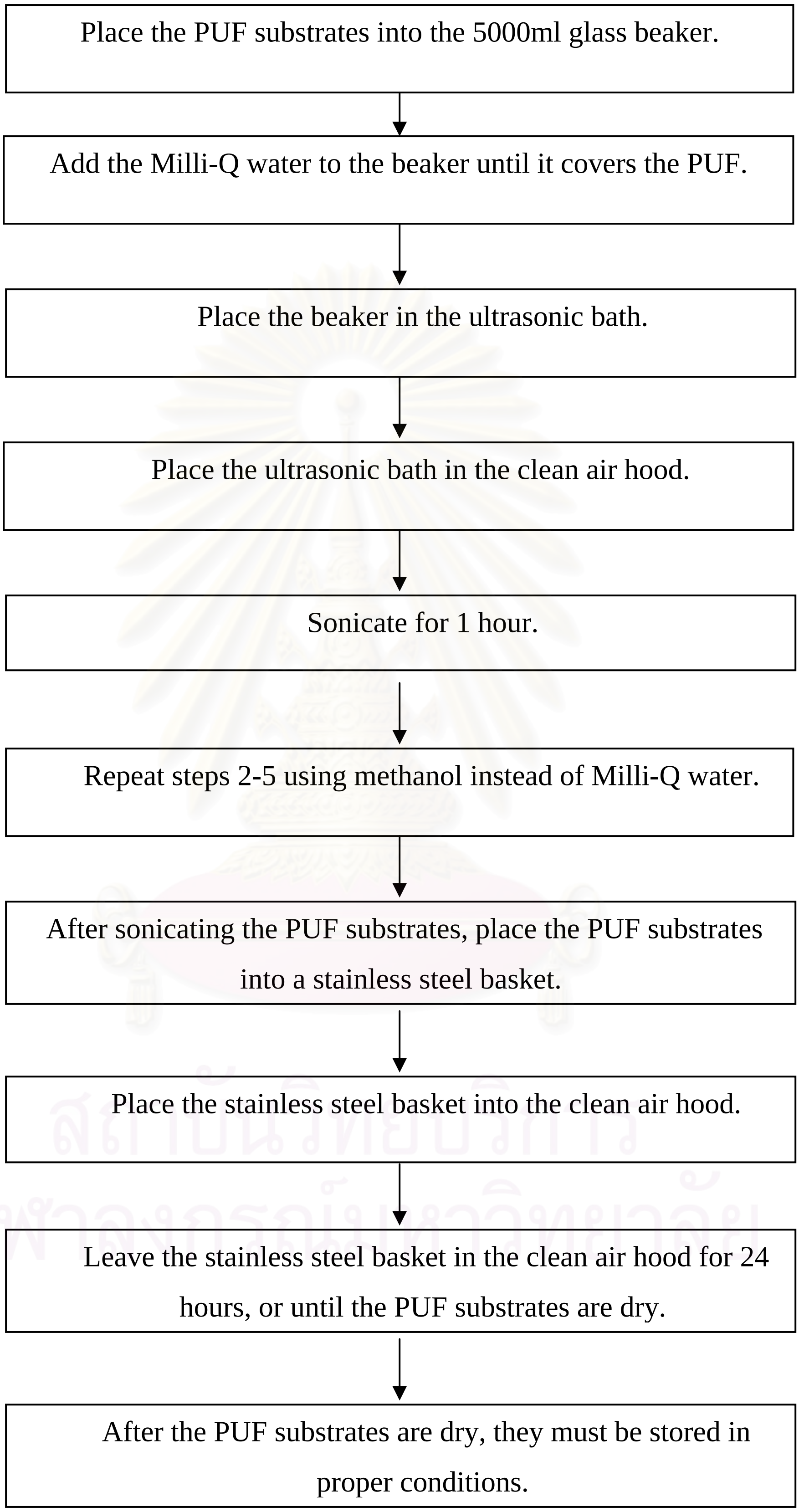


Figure 3.6 Standard of Practice for cleaning the substrate holders



Place the PUF substrates into the 5000ml glass beaker.

Add the Milli-Q water to the beaker until it covers the PUF.

Place the beaker in the ultrasonic bath.

Place the ultrasonic bath in the clean air hood.

Sonicate for 1 hour.

Repeat steps 2-5 using methanol instead of Milli-Q water.

After sonicating the PUF substrates, place the PUF substrates into a stainless steel basket.

Place the stainless steel basket into the clean air hood.

Leave the stainless steel basket in the clean air hood for 24 hours, or until the PUF substrates are dry.

After the PUF substrates are dry, they must be stored in proper conditions.

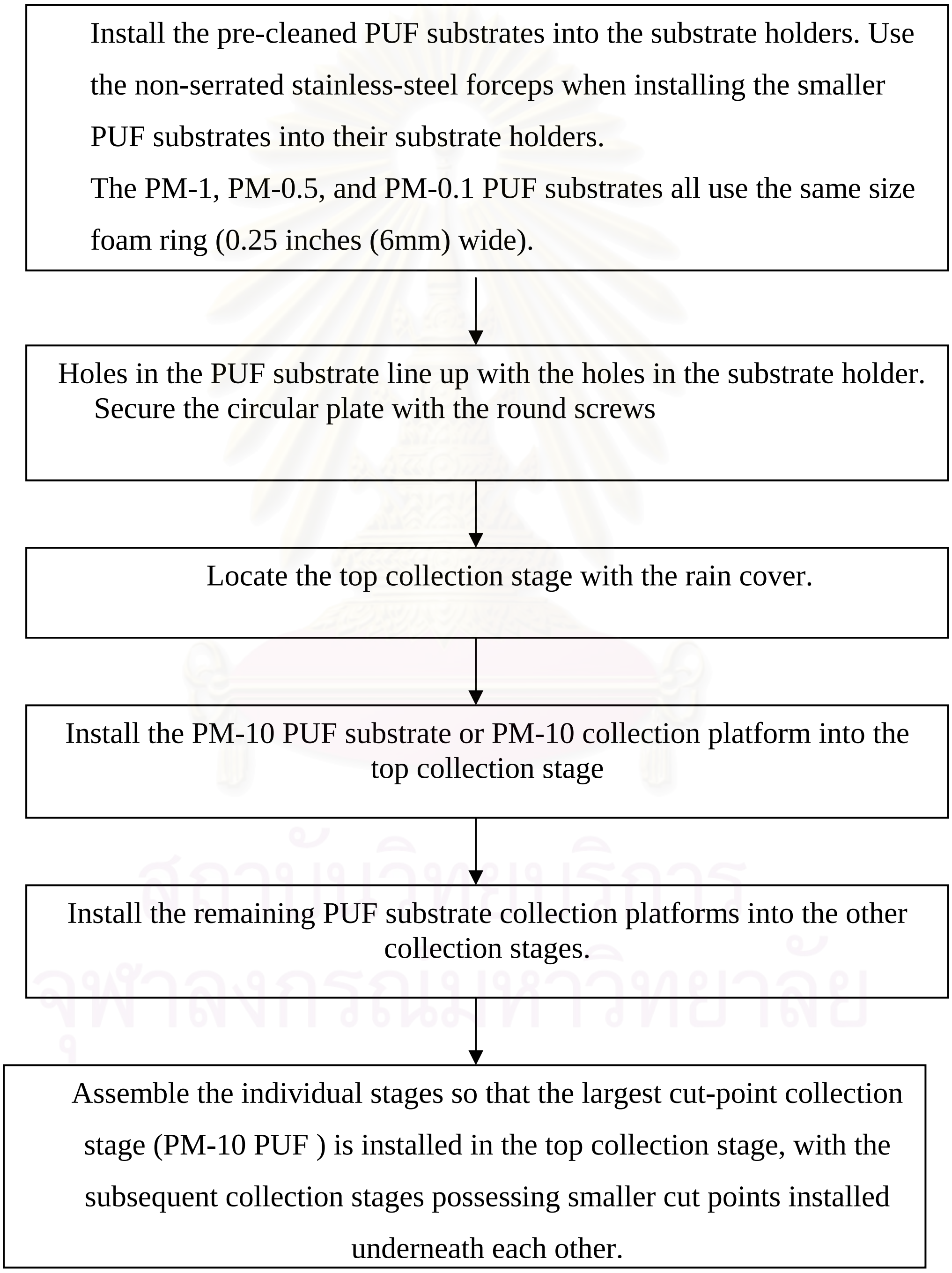
Figure 3.7 Standard of Practice for cleaning the PUF substrates

Note: It is important to wear powder-free gloves at all times. Rinse the gloves with Milli-Q water and dry the gloves by wiping them with Kimwipes. Ultra-sonication technique was used for cleaning the glassware that was used IC analyzing. The glassware was sonicated 3 times, with distilled water in the first time and milli-Q water ASTM type I for other two times. Dry it at room temperature.

3.4.1.2. The PUF substrates were kept in the desicators which controlled the temperature at 25±3 ºC and humidity at 45±5% for at least 24 hours, and then they were pre-weighed five times per sample, labeled and the data were recorded. The analytical balance was sensitive to 0.01 mg with a special designed arm Model: Mettler Toledo AG 285 as shown in Figure 3.8. Finally, the PUF substrates were kept in labeled zip-bags and in desiccators. In this step, each size of the PUF substrate, used as weighing blank, were weighed to check for error in weighing before and after sampling. The procedure for the weighing of filters is based on 40 CFR 50 (Appendix J).

Figure 3.8 Analytical Balance (Mettler Toledo AG 285) with a special designed arm installed in Desiccators

3.4.1.3. The PUF substrates were assembled with the substrate holders in the laboratory room with controlled temperature to prevent the effects of the condition at the sites. Figure 3.9 shows the diagram for assembling the collection stages.



Install the pre-cleaned PUF substrates into the substrate holders. Use the non-serrated stainless-steel forceps when installing the smaller PUF substrates into their substrate holders.
The PM-1, PM-0.5, and PM-0.1 PUF substrates all use the same size foam ring (0.25 inches (6mm) wide).

Holes in the PUF substrate line up with the holes in the substrate holder. Secure the circular plate with the round screws

Locate the top collection stage with the rain cover.

Install the PM-10 PUF substrate or PM-10 collection platform into the top collection stage

Install the remaining PUF substrate collection platforms into the other collection stages.

Assemble the individual stages so that the largest cut-point collection stage (PM-10 PUF) is installed in the top collection stage, with the subsequent collection stages possessing smaller cut points installed underneath each other.

Figure 3.9 Standard of Practice for assembling the collection stages

3.4.1.4. The tripod, air pump, and pressure gauges were checked before sampling.

3.4.2 Sampling Method

1. All equipments were contained in cloth-bags and transported by car to the sites.
2. The sampler was installed onto the tripod and the pump was set up. The steps to install the sampler onto the tripod and to set up the pump are shown in Figure 3.10
3. The pump was set to be turned on automatically at 10 a.m. and it will be turned off automatically at 10 a.m. on the following day (after 24-hour sampling). The normal flowrate for operation was 760±40 liter/minute. The data of pressure losses from the pressure gauges, the conditions such as traffic, wind, rain were recorded for further calculation.

3.4.3 Post-sampling Method

1. After 24 hours, the pump automatically turned off. Each part was disassembled and brought back to the laboratory.

2. The post-field PUF substrates were taken out from the substrate holders and kept at least 24 hours in desiccators which maintained the same condition present before the sampling.

4. The PUF substrates were post-weighed, recorded and kept in the labeled zip-bags for further analysis.

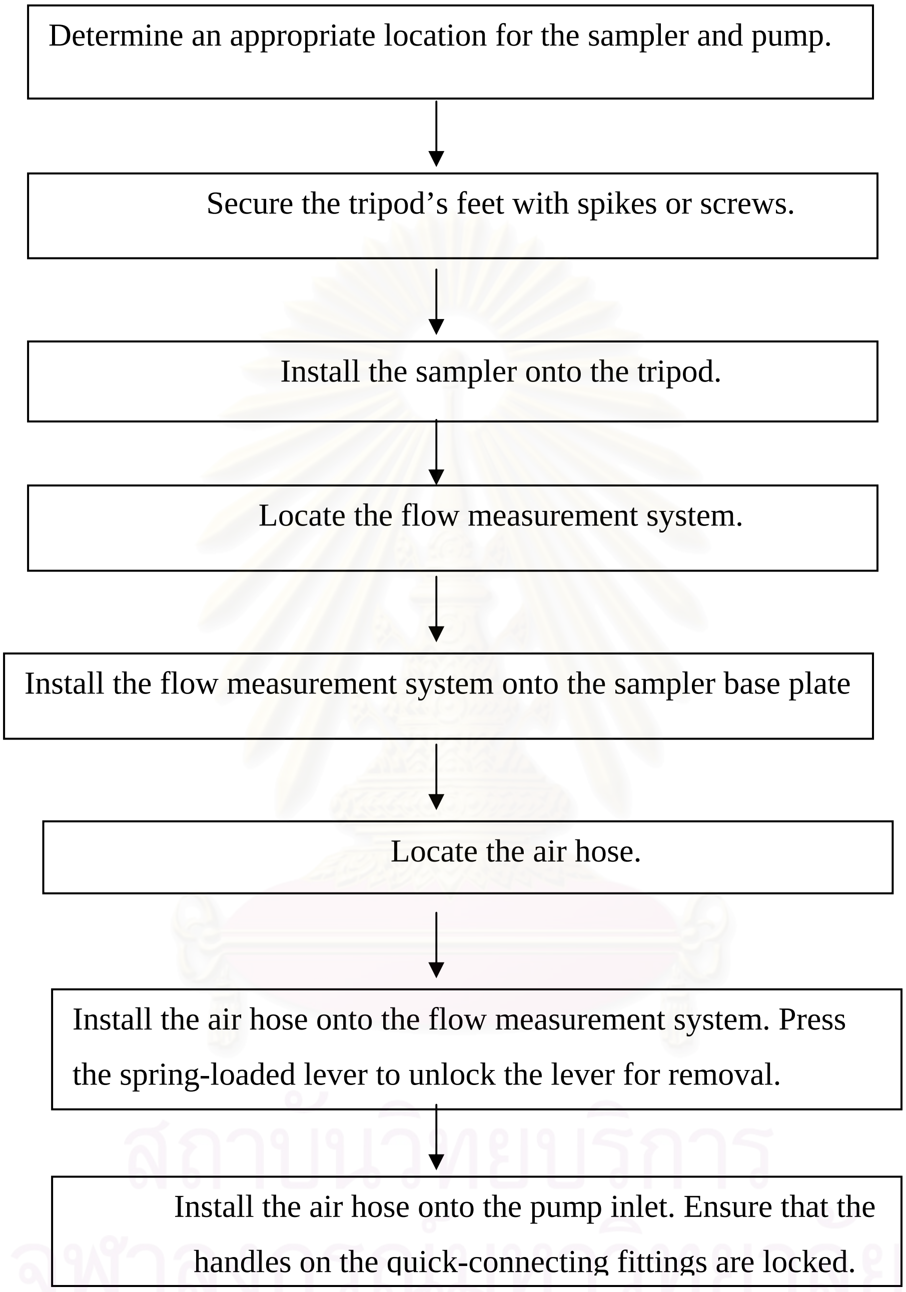


Figure 3.10 Standard of Practice for installing the sampler on the tripod

3.5 Analyses of the Samples

3.5.1 Ions

Ion Chromatography (IC) was used to analyze the quantity and type of ions. A mixed standard of cation, containing Li^+, Na^+, $NH4^+$, K^+, Mg^{++}, and Ca^{++} and a mixed standard of anions, containing F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-} , PO_4^{3-} and Br^- were used as a standard for ions.

The extraction technique used was sonication in an ultrasonic bath which was referred in the guidance book of this model of HVCI. The PUF substrates were divided into 3 equally strips, the 1st strip used for ions analysis, was cut into small pieces and put in the test tube with a cap. It was extracted with a little amount of methanol and milli-Q water. Then, it was sonicated for 1 hour, and allowed to cool down at room temperature. Then, it was analyzed with Ion Chromatography. The method is detailed in Appendix A: The extraction technique of the PUF substrates (A-1 Extraction technique of the PUF for ions analysis and steps for analysis). Table 3.2 shows the method and number of samples for ions analysis.

3.5.2 Metals

Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) was used to analyze the quantity and type of heavy metals. The mixed standard for Heavy Metals was prepared.

Table 3.2 Method and number of samples for ion analysis

Extraction Technique	Analyzing technique/ Device	Type of ion	No. of sample
Sonicate 1 hours in ultrasonic bath with methanol and milli-Q water	Ion Chromatography by IC device: Dionex	Anion	225 samples from (mid-June-January)
		Cation	225 samples from (mid-June-January)

The extraction technique was adapted from the Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air, Compendium Method IO-3.1: The Selection, Preparation and Extraction of Filter Material. This method referred to hot acid extraction with 5.55% HNO_3/16.75%HCl used as the extraction solution. The 2nd strip of PUF substrates were cut into small pieces and put into the test tube. The extraction solution was added into the samples and then the test tubes were placed in the digestion device.

The analysis of metals with ICP-OES is based on Compendium Methods for the Determination of Inorganic Compounds in Ambient Air, Compendium Method IO-3.4: The Determination of Metals in Ambient Particulate Matter using Inductively Coupled Plasma (ICP) Spectroscopy. The extraction technique of the PUF for metal analysis and the steps for analysis are detailed in Appendix A: the extraction technique of the PUF (A-2 extraction technique of the PUF for metals analysis and steps for analysis). Table 3.3 shows the methods and number of samples used for the metals analysis.

Table 3.3 Method and number of samples for metals analysis

Extraction Technique	**Analyzing technique/ device**	**No. of sample**
Hot acid Extraction (5.55% HNO_3/16.75%HCl)	ICP-OES By ICP-OES model VISTA-MPXaxial Varian	15 samples from mid-June- September
		120 samples from October-January

3.6 Analyses of the Data

3.6.1 Concentration of particulate matter

After post-field substrate final weights had been obtained, the concentration of particulate matter was calculated by these following equations. Each PUF was weighted for 5 times and averaged.

$$\text{Mass concentration of PM } (\mu g/m^3) = \frac{\left(w_f - w_i\right)*10^6}{V_{std}} \qquad (3.1)$$

Where

W_i = initial weight of clean PUF substrate, g

W_f = final weight of exposed PUF substrate, g

V_{std} = air volume sampled, converted to standard conditions (25 ºC and

760 mm.Hg) std m^3

10^6 = conversion of g to µg

To obtain V_{std}, the data of ambient temperature, absolute ambient pressure and pressure losses, both major and minor, were required for air volume calculation.

The ambient temperature values and absolute ambient pressure values were collected from two source: the values used for Site 1 (Yuparaj school) and Site 2 (Municipality hospital) were from the Meteorology Department of Chiang Mai and the values used for site 3 (the district office of Sarapee) were from the Meteorology Department of Lumpoon province, since Sarapee is closer to Lumpoon than Chiang Mai. The pressure losses were read from the pressure gauges. Then, all data was put to the flowmeter calculation system to get standard flows, which were already converted to standard conditions (25 ºC and 760 mm.Hg) SLPM (standard liter per minute). The result of the standard flow through the sampler was multiplied by 1.44 to convert the standard liter per minute to cubic meters per day. Then, this value was used as V_{std} in the mass concentration calculation as the equation referred above. Figure 3.11 shows the flowmeter calculation systems. This program was attached with the Chemvol device. An example of the calculation the quantity of PM is shown in Appendix B-1: Calculation for the quantity of the PM.

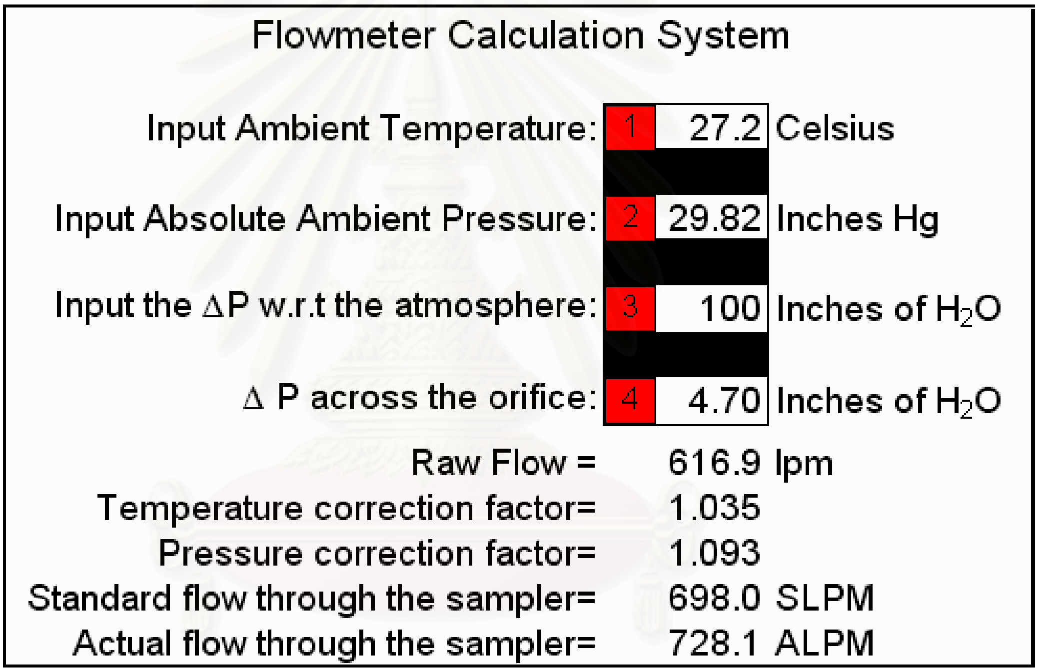
From the Flowmeter Calculation System, these following data need to be added:

1. Average ambient temperature during the sampling period (24 hours) which was gotten from meteorological department

2. Absolute ambient pressure during the sampling period (24 hours) which was gotten from meteorological department

3. Pressure losses with respect to atmosphere which was read from the pressure gauge

4. Pressure losses across the orifice which was read from the pressure gauge


Flowmeter Calculation System

Input Ambient Temperature: 1 27.2 Celsius

Input Absolute Ambient Pressure: 2 29.82 Inches Hg

Input the ∆P w.r.t the atmosphere: 3 100 Inches of H_2O

∆ P across the orifice: 4 4.70 Inches of H_2O

Raw Flow = 616.9 lpm

Temperature correction factor= 1.035

Pressure correction factor= 1.093

Standard flow through the sampler= 698.0 SLPM

Actual flow through the sampler= 728.1 ALPM

Figure 3.11 Flowmeter Calculation System

From this calculation, the standard flow and actual flow was shown. The flow rate of actual flow should be in the range of 760±40 liter/minutes; if not the error values must be calculated. The calculation for flow data and air volume were illustrated in Appendix C. (Table C-1: Meteorological Data, HVCI’s Pressure Losses, Flowrate, and Air Volume)

The results of the quantity of each of the size-fractionated particulate matter (five sizes) within each station were compared and analyzed for the relationship of each size-fractionation of the PM.

The results of the quantity of PM from different stations were compared and analyzed for the relationship and the effects of the sampling sites and duration of the sampling time (between wet season and dry season and between weekdays and weekends).

3.6.2 Compositions of particulate matter

3.6.2.1 Ions

After the post-field substrates had been extracted for ion chromatography, the amount of ions was calculated by following equation.

$$C = \left(\frac{(mg.ion/L)(V_f)(3) - F_m}{g.PM} \right) \tag{3.2}$$

where

C = ion concentration in PM, mg.ion/g.PM

mg.ion/L = ion concentration determined from Ion Chromatography(IC)

V_f = final extraction volume, L/strip (0.12, 0.04 and 0.02 for P1, P2 and P3, respectively)

3 = no. of strip

F_m = average concentration of blank substrates, μg

g.PM = amount of particulate matter, g

The obtained data of the amount and type of ions were compared between each size fractions and between the different sampling sites. In addition, it was compared due to the effects of the duration of the sampling time as well. The data was aslo used to find the relationship of the PM at various size ranges and the ions which are affected by the sampling sites and duration by the F-test using the SPSS program (Statistical Package for the Social Sciences). An example of calculating the quantity of ions is shown in Appendix B-2: Calculation for the quantity of ions.

3.6.2.2 Metals

After the post-field substrates had been extracted for ICP, the amount of metals was calculated in the same way as the amount of ion. Any relationship was determined in the same manner as the ions. The details of the calculation are shown in Appendix B-3: Calculation for the quantity of heavy metals.

3.6.3 Hinderance

Ion Chromatograph had been out of order since January 2006. Therefore, some of the PUF substrates cannot be analyzed. The problem occurred with the machine in the part of cation chromatography consequently the PUF substrates used as collection media during November 2005 to January 2006 had not been analyzed until April 2006. Anyhow, the PUF substrate was kept in proper conditions and analyzed in 6 months after sampling, thus, the data still can be acceptable. In addition, the device was checked to be sure that it will work properly as well.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Particulate Matter at Various Size Fractions in Chiang Mai: Effects of the Sampling Sites and Time Duration on Particulate Matter Concentrations.

Graphical representations of the investigation on the quantity of particulate matter at various size fractions at the 3 sampling sites in Chiang Mai and the effects of the sampling sites and time duration (mid-June 2005 until January 2006) are presented in this section and tabulated in Appendix D

4.1.1 Concentrations of particulate matter at various size fractions in Chiang Mai of the collection sites compared

A statistical summary of the daily PM data at various size fractions (PM larger than 10 micrometer, $PM_{2.5\text{-}10}$, $PM_{1.0\text{-}2.5}$, $PM_{0.5\text{-}1.0}$, $PM_{0.1\text{-}0.5}$ micrometer) from the three sites across the period of mid-June 2005 to January 2006 is shown in Tables 4.1, 4.2 and 4.3 for Site 1, Site 2, and Site 3, respectively. The number of samples per site across the study (N), along with the minimum, maximum, mean and standard deviation for each size fraction and PM size-category are given. The daily average concentrations are presented in mass of PM per volume of sampling air (µg/m^3) at the standard temperature of 25ºC, and pressure of 1 ATM. The data varies; for example, the average daily concentration of PM larger than 10 micrometer has a minimum concentration of 10.91 µg/m^3 at Yuparaj School that can be compared to a maximum concentration of 72.57 µg/m^3 at the municipality hospital. The concentration of PM within the size range of 2.5-10 micrometers had a minimum concentration of 10.45 µg/m^3 at the district office of Sarapee compared to a maximum concentration of 66.94 µg/m^3 at the municipality hospital. The concentration of PM size fraction 1.0-2.5 micrometers had a minimum concentration of 5.90 µg/m^3 at Yuparaj School compared to a maximum concentration of 32.07 µg/m^3 at the district office of Sarapee. The concentration of PM within the size range of 0.5-1.0 micrometers had a minimum concentration of 2.82 µg/m^3 at Yuparaj School compared to a maximum concentration of 23.69 µg/m^3 at the district office of Sarapee and the smallest sizes of 0.1-0.5 micrometers had a minimum concentration of 3.59 µg/m^3 at the municipality hospital compared to a maximum concentration of 23.69 µg/m^3 at the district office of Sarapee.

It can be noted that the daily average concentration of coarse particles (2.5-10 µm), which was found at the municipality hospital, was highest at a concentration of 27.479 µg/m^3. The daily average concentration of fine particles (0.1-2.5µm), which was found at the district office of Sarapee, was highest at a concentration of 25.618 µg/m^3 (average of the summed PM $_{0.1\text{-}2.5}$).

The tables also show that the standard deviation at the municipality hospital was the highest amongst the sites. This may have been caused by the location of this site in the downtown area, which includes the biggest market of the city, construction on Tapae Road, and the location of all major city festivals. The PM categories in Table 4.1, 4.2, and 4.3 did not include ultrafine particle sizes (PM<0.1 micrometer) due to the limitations of the cascade impactor.

Table 4.1 Statistical summary of daily average PM concentrations at the various size fractions (µg/m^3) at Site1 Yuparaj School

Site 1	**N**	**Min.**	**Max.**	**Mean**	**STDEV.**	**PM category**
PM≥10	15	10.91	46.38	25.880	9.559	-
PM$_{2.5-10}$	15	13.68	35.33	23.065	6.461	Coarse PM
PM$_{1.0-2.5}$	15	5.90	17.91	11.283	3.809	Fine PM (<2.5 µm)
PM$_{0.5-1.0}$	15	2.82	15.35	8.224	3.600	
PM$_{0.1-0.5}$	15	3.93	13.92	6.111	2.907	

Table 4.2 Statistical summary of daily average PM concentrations at the various size fractions (µg/m^3) at Site 2 the municipality hospital

Site 2	**N**	**Min.**	**Max.**	**Mean**	**STDEV.**	**PM category**
PM≥10	15	18.11	72.57	30.021	14.668	-
PM$_{2.5-10}$	15	14.96	66.94	27.479	13.730	Coarse PM
PM$_{1.0-2.5}$	15	6.00	28.83	13.907	6.978	Fine PM (<2.5 µm)
PM$_{0.5-1.0}$	15	4.06	21.21	10.428	4.971	
PM$_{0.1-0.5}$	15	3.59	13.51	7.070	2.947	

Table 4.3 Statistical summary of daily average PM concentrations at the various size fractions (µg/m^3) at Site 3 the district office of Sarapee

Site 3	**N**	**Min.**	**Max.**	**Mean**	**STDEV.**	**PM category**
PM≥10	15	11.26	39.19	24.697	8.513	-
PM$_{2.5-10}$	15	10.45	36.72	23.845	8.576	Coarse PM
PM$_{1.0-2.5}$	15	7.00	32.07	15.633	7.470	Fine PM (<2.5 µm)
PM$_{0.5-1.0}$	15	5.69	23.69	13.195	6.369	
PM$_{0.1-0.5}$	15	4.17	15.52	8.319	4.075	

Where N = number of samples

Min. = Mininum PM concentration

Max. = Maximun PM concentration

STDEV=Standard deviation

Figure 4.1 shows the daily concentrations of the particulate matter at various size fractions from the three sampling sites across the period of mid-June 2005 to January 2006. The vertical axis shows the daily concentration of PM at each of the size ranges (µg/m^3) and the horizontal axis details the sampling times at a three sampling sites. The vertical dotted lines separate the durations of the wet season (Jun-Sep) and dry season (Oct-Jan). The result from this part shows that the concentration of PM in each size fraction decreases when the aerodynamic diameter of the particulate is smaller. Moreover, there were some effects resulting from the time duration and the sampling site on the quantity of PM as shown.

For summed concentrations of 5 fractions at the same sampling site, a difference was seen due to the day of the sampling. It can be seen from Figure 4.1 that between June-September, which is referred to as the wet season, there was lower PM concentrations than in the later months of October through January, which is referred to as the dry season. The amount of precipitation during the study period is shown in Appendix C. The lowest amount of PM at Yuparaj was collected on a Sunday. The 7th August 2005 reading at the municipality hospital presented a low PM concentration collected on a Sunday as well. . This is due to some of the main roads in the city being closed during a weekly evening walking street event (street market) held on Sundays in Chiang Mai. Thus, there is light transportation on Sundays in the city. For the district office of Sarapee, the trend of the concentrations was a gradually increased across the sampling period without any change on Sundays. This site was not near any walking street event and the road’s weekend and weekday use was similar. This may support the low amounts of PM on Sundays at the Yuparaj School and municipality hospital sites, which were affected by the Sunday activities, in particular the lack of traffic. The concentrations of PM and the sampling time durations are compared and discussed further in 4.1.2.

According to Figure 4.1, there was also a difference in the amount of PM of each size fraction at the municipality hospital, which has more variables than the other sites due to the greater number of activities in the surrounding area.

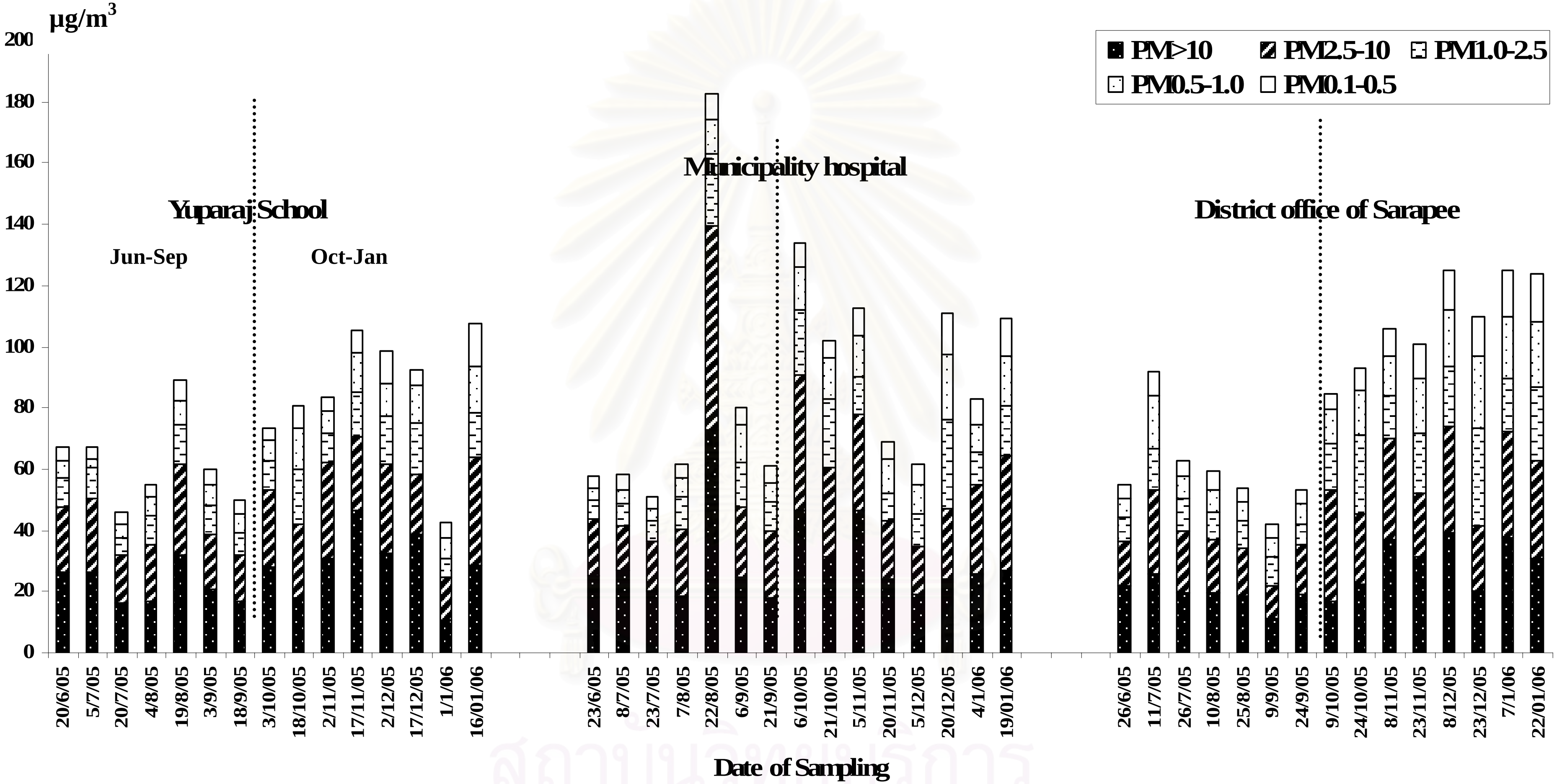
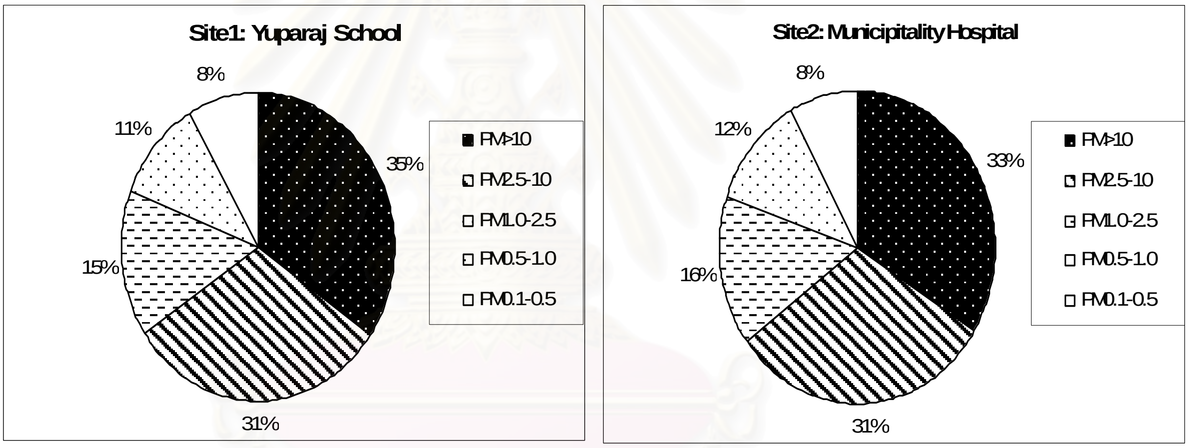
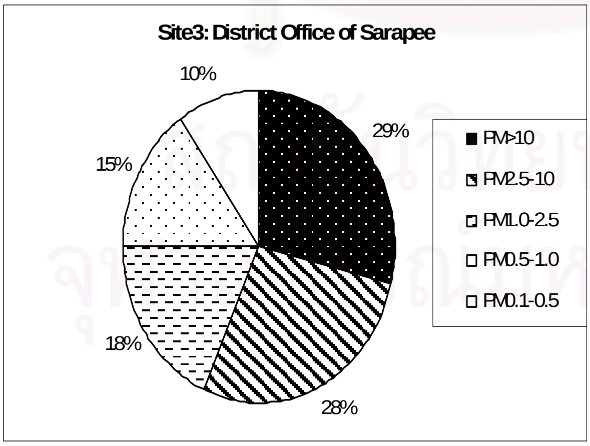


Figure 4.1 Amounts of daily concentrations of PM at the various size fractions at the three sites across the period of mid-June 2005-January 2006

It can be noted that the PM concentration in the August sample from the municipality hospital was extremely high compared to the rest of the samples. This could be due to the construction of a school near the sampling site (about 30 meters) where the land was being prepared for the foundation of the school, especially since there was no "net" to prevent the fugitive dust from spreading. Thus, the construction might have contributed dust to the ambient air and could have had an effect the HVCI device, which was located nearby. This reason could be supported by the quantities of PM in the following days, which decreased even though the construction was ongoing. When the land preparation--which generated a great amount of dust--ended, there was no further effect on the PM quantity in the ambient air at the municipality hospital. In addition, a net was installed later to prevent the spread of fugitive dust. For the district office of Sarapee, the bar of the total amount of the 5 fractions increased by the series of time because the activities in this area did not vary as much as those of the two other sites. The main activity is agriculture. There is no big industry in the area, no street event on Sundays, no big commercial area, etc. Meteorological conditions were the dominant factor that affected the concentrations of PM in this area.

Figure 4.2 presents the size-fractionated proportions of particulate matter (percentage) at the three sampling sites. The size-fractionated proportions of Yuparaj School and the municipality hospital were not much different, but it can be seen that the proportions from the district office of Sarapee were obviously different from those of the other two sampling sites. Higher percentages of coarse particles ($PM_{2.5-10}$) were found at both Yuparaj School and the municipality hospital than at the district office of Sarapee at the values of 31%, 31% and 28%, respectively. Conversely, the highest proportion of fine particles (PM $_{0.1\text{-}2.5}$) at 43% was present at district office of Sarapee, while Yuparaj School and the municipality hospital listed 34% and 36%, respectively, for fine particles. The ratio of PM $_{2.5}$/ PM $_{10}$ from each sampling site equaled to 0.526, 0.533 and 0.609 for sampling sites 1, 2 and 3, respectively. The higher this ratio value is, the more hazards to human health are present since fine particles have a greater ability of penetrating deeply into the lung. According to the study, the PM $_{2.5}$/ PM $_{10}$ ratio at the district office of Sarapee was the highest among the sites. Thus, people in this area are at a higher risk of respiratory problems.





Sampling site	**PM $_{2.5}$/ PM $_{10}$**
1: Yuparaj school	0.526
2. municipality hospital	0.533
3. district office of Sarapee	0.609

Figure 4.2 Proportion (%) of PM concentrations found at the three sampling sites in Chiang Mai

Since the $PM_{2.5}$ /PM_{10} ratio in Bangkok in the year 2001 (referred to in the study of Supat Wangwongwatana and Punya Warapetcharayut, 2001) was in the range of 0.33-0.53, the district office of Sarapee registered a higher $PM_{2.5}$ /PM_{10} proportion than one registered in Bangkok. Samarnchai Loetkamonwit and Wanida Jinsart (2000) found that the mean $PM_{2.5}$ to PM_{10} ratio in Bangkok was 0.74 in the suburban area it was 0.65, and in Ayutthaya it was 0.60 which indicated that $PM_{2.5}$ was dominant in the urban area. The results of the study show a discrepancy to that finding since the level of $PM_{2.5}$ was highest in Sarapee, which is a suburban area. The reason for this could be the fact that Yuparaj School and the municipality hospital are located in busy areas, which include many activities such as businesses, public transportation, road construction and cooking. These activities could contribute a great amount of PM. Most of these activities generate coarse PM such as construction and road dust from traffic. The main activity at Sarapee is agriculture. Farmers always burn agricultural waste, especially during dry season, because they have to prepare the land for the following rainy season. This is the reason why PM sharply increased during the dry season. This critical situation occurs all over this primarily agricultural country, as open burning is quite popular in rural areas (Pollution Control Department, 2005). The burning process generates a great amount of fine PM which may explain why Sarapee district is faced with such a high fine PM problem.

Figures 3.3 and 3.4 show the respective PM_{10} and $PM_{2.5}$ concentrations from all three sampling sites during the study period. The average 24-hour standard lines of the US.EPA and the Thai PCD were shown for the purpose of comparison. It should be noted however, that there is no Thai PCD standard for $PM_{2.5}$.

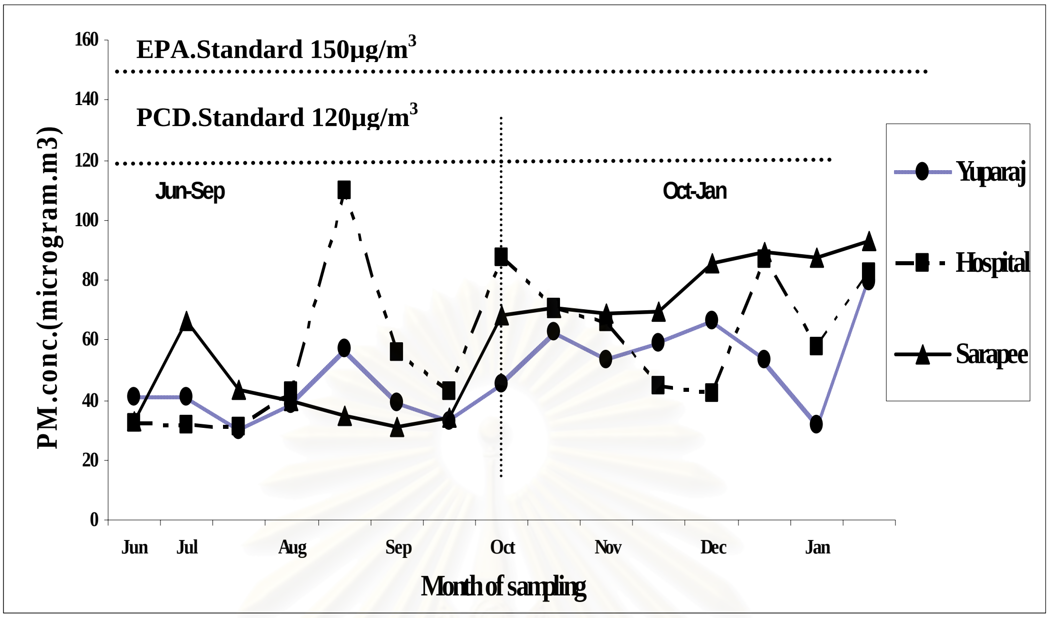


Figure 4.3 The amount of PM_{10} at the three sampling sites across the period of mid-June2005 until January 2006

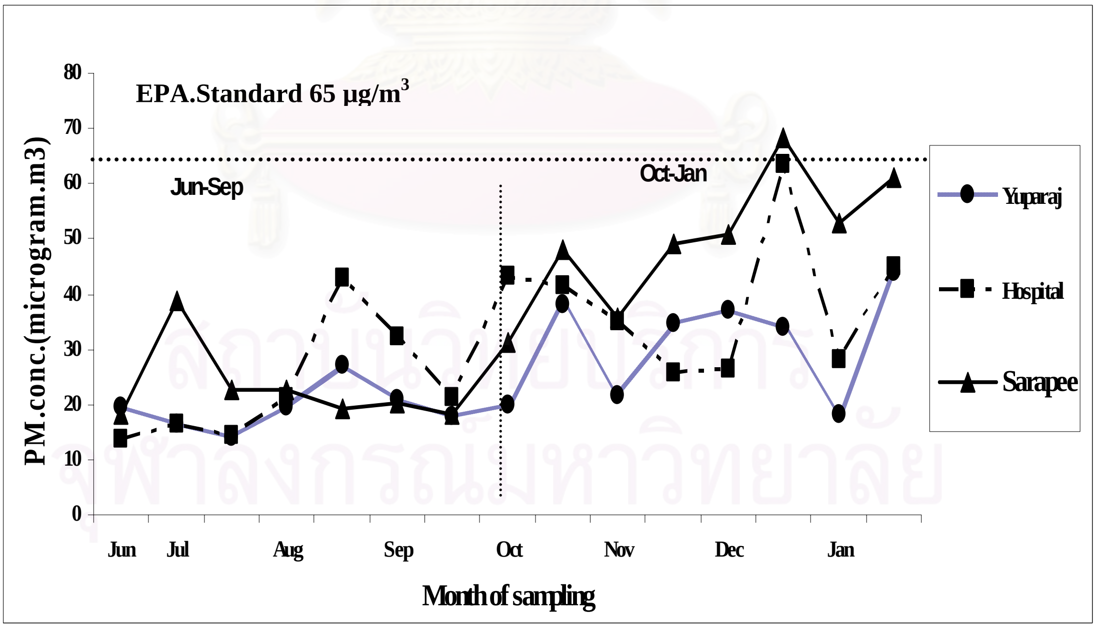


Figure 4.4 The amount of $PM_{2.5}$ at the three sampling sites across the period of mid-June2005 until January 2006

The US.EPA standards for PM_{10} and $PM_{2.5}$ in a 24-hour period are less than 150 µg/m^3 and 65 µg/m^3, respectively. The Thai Pollution Control Department (PCD) standard for PM_{10} in a 24-hour period is less than 120 µg/m^3. From mid-June 2005 until January 2006, the amount of PM_{10} for all sampling sites did not exceed the standards of both the US.EPA and Thailand. However, the concentration of $PM_{2.5}$ at the district office of Sarapee, was higher than the standard of the US.EPA in late December (23 Dec. 2005), during which time the $PM_{2.5}$ concentration was 68.26 µg/m^3. At the municipality hospital, the $PM_{2.5}$ concentration of 63.55 µg/m^3 on 20 Dec. 2005 almost exceeded the standard.

One reason that the quantity of particles did not exceed the standard during the wet season was due to the rain that occurred during this period. Chiang Mai also had flooding three times during the wet season that may have caused the “precipitation” of PM from ambient air. Nevertheless, the PM trends from all three sites indicate that it would continue to rise during the following dry season and exceed the standard concentration soon. Since the study was performed over an 8-month period, the concentrations of PM could not be compared with the annual average standard of the US.EPA which is 50 µg/m^3 and 15 µg/m^3 for PM_{10} and $PM_{2.5,}$ respectively. According to this study, 67% of the $PM_{2.5}$ concentration was higher than the annual average standard of the US.EPA and 46% of the obtained data was two times higher than the standard. Although the study period was not a full year, the tentative amount of $PM_{2.5}$ in the rest of year (Feb-May 2006), which is the dry season, can be estimated to be the same or higher than that of January 2006.

4.1.2 Concentrations of particulate matter of various size fractions at different temporal variations

The study of the PM concentrations at different durations of time was divided into 2 groups. **Group (1)** included the wet season and dry season. In this study, the wet season was from mid-June to September and the dry season was from October to January. A season's duration can express the effects of rain and other meteorological conditions which can change during the season. **Group (2)** included the weekdays and weekend. The study time was separated by weekdays and weekends to find the discrepancies in the effects of activities during the week.

4.1.2.1 Wet season and dry season

Table 4.4 and 4.5 presents statistical summaries on the quantities of PM during the wet season and dry season. The number of samples per season (N), minimum concentration, maximum concentration, mean and standard deviation for each season are given. As a general observation, the daily average concentration of coarse PM that occurred during the wet season ranged from10.45-66.94 µg/m^3 (mean 21.34 µg/m^3). The daily concentrations of fine PM that occurred during the wet season ranged from 12.31-49.15 µg/m^3 (mean 21.87 µg/m^3). The daily concentrations of coarse and fine PM occurred during the dry season ranged from 13.68-44.39 µg/m^3 (mean 27.82 µg/m^3) and 16.65-71.28 µg/m^3 (mean 39.68 µg/m^3), respectively. For all size fractions, the mean concentrations of PM during the dry season were higher than in the wet season. The daily average concentrations of PM$_{2.5}$ (fine particle fractions) at all the three sampling sites from the study in wet season and dry season were lower

Table 4.4 Statistical summary of daily average PM concentrations defined as wet season

Wet season	N	Min.	Max.	Mean	Std. Deviation	PM category
PM≥10	21	11.26	72.57	23.590	12.158	-
$PM_{2.5-10}$	21	10.45	66.94	21.340	11.420	Coarse PM
$PM_{1.0-2.5}$	21	5.90	23.42	9.918	3.826	Fine PM (<2.5 µm)
$PM_{0.5-1.0}$	21	2.82	17.60	6.942	3.318	
$PM_{0.1-0.5}$	21	3.59	8.13	5.013	1.211	

Table 4.5 Statistical summary of daily average PM concentrations defined as dry season

Dry season	N	Min.	Max.	Mean	Std. Deviation	PM category
PM≥10	24	10.91	46.61	29.732	9.694	-
$PM_{2.5-10}$	24	13.68	44.39	27.822	7.635	Coarse
$PM_{1.0-2.5}$	24	6.19	32.07	16.837	6.531	Fine PM (<2.5 µm)
$PM_{0.5-1.0}$	24	6.53	23.69	13.830	4.800	
$PM_{0.1-0.5}$	24	3.93	15.52	9.051	3.595	

than those observed at Dindang, Bangkok. The Dindang site which represented the roadside atmosphere, its average $PM_{2.5}$ equaled to 65.35±18.7 µg/m^3 in the wet season and 129.56±38.9 µg/m^3 in the dry season (Samarnchai Loetkamonwit and Wanida Jinsart, 2000).

Figure 4.5 shows the proportion (%) of PM concentrations found in each size fraction during both the wet season and dry season. In the wet season, the larger particles (PM>10 and $PM_{2.5-10}$ micrometers) seemed to be dominant. In the dry season, the proportion of particles larger than 10 µm was reduced and the proportion of finer particle increased. The size fraction that increased the most amongst all the size fractions during the dry period was 0.1-0.5 µm which increased by 4%. Other fractions, 2.5-10, 1.0-2.5 and 0.5-1.0 µm, increased by 3%, 2% and 1%, respectively. The $PM_{2.5}/PM_{10}$ ratios of the wet season and dry season were 0.50 and 0.59, respectively, demonstrating an increase of almost 10%.

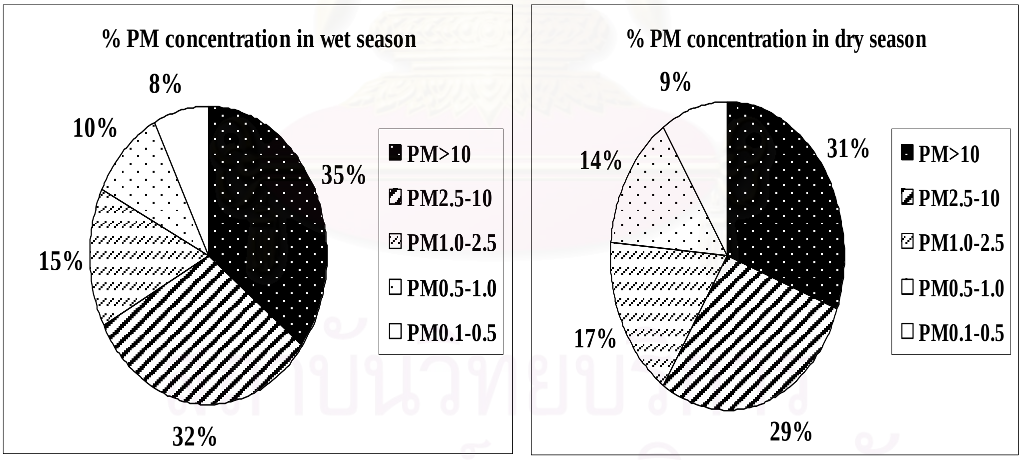


Figure 4.5 Proportion (%) of PM concentrations found in the wet season and dry season for all sampling sites

From Figures 4.3 and 4.4 in the former part, it can be seen that during the second part (Oct-Jan), the concentration of PM_{10} rose minimally while the concentration of $PM_{2.5}$ rose substantially. Therefore, the increase in the ratio of $PM_{2.5}$ / PM_{10} during the dry season resulted from the increase of the $PM_{2.5}$ concentration. The increase in the proportion of particle-size fractions less than 10 µm should be viewed as a serious situation since they have critical affects on human health.

The seasonal PM variations for each size range are shown in Figure 4.6. It was noted that the median concentrations of all sizes of PM was higher in the dry season than in the wet season. The range of PM concentrations in the dry season was also wider than that of the wet season. The lower bar and upper bar shows the first and third quartiles concentrations, respectively. The box-width presents 50% concentration of all the data.

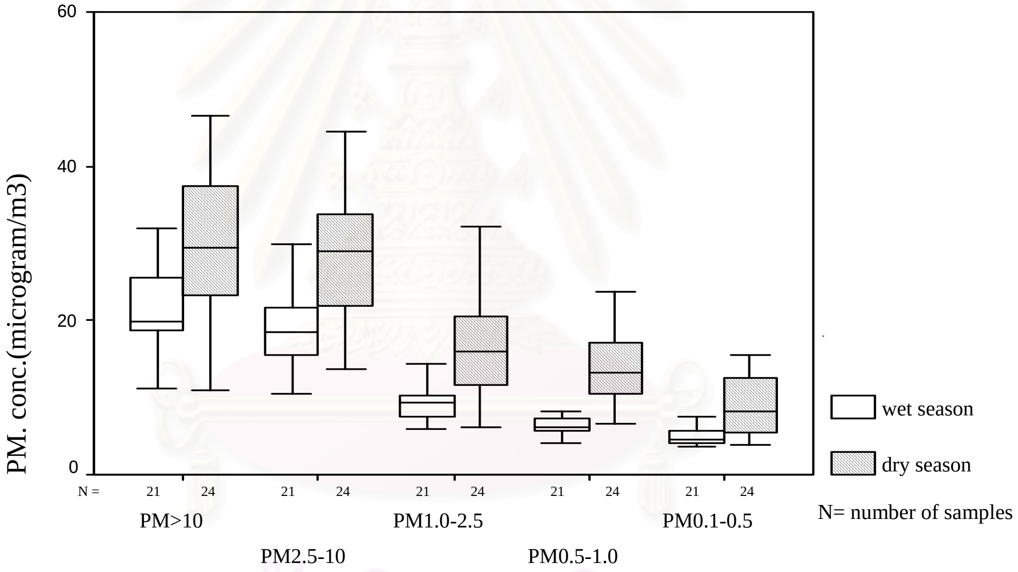


Figure 4.6 Seasonal PM variations (June 2005- Jan.2006) at the three sampling sites in Chiang Mai

In conclusion for this section, the daily average concentrations of PM during the dry period were higher than those of the wet period for all the size fractions. The proportion of particle sizes less than 10 µm increased during the dry season also.

These results might have been affected by the seasonal changes. During the wet season, the PM concentrations might have been affected by the rain because rain has the potential to remove the PM in the ambient air; this is also known as "wash out." During the dry season, which has little rain, the coarse particles could restrict themselves through the sedimentation process since they are higher in mass than the fine particles. The fine particles need the process of diffusion and coagulation to agglomerate the particle prior to sedimentation therefore fine particles can exist in the air longer than coarse particles and accumulate in the air daily.

4.1.2.2 Weekday and weekend

The aim of weekday and weekend segregation was to study the effects of activities during the week on the PM concentrations.

Tables 4.6 and 4.7 show statistical summaries of the daily PM concentrations at various size fractions (µg/m^3) during the weekday and weekend. It can be concluded that the mean PM concentrations at the various size fractions during the weekday and weekend were relatively the same, but the PM concentrations during the weekday were slightly higher than those measured on the weekend.

The maximum PM concentration was found in the size fractions of PM>10 for both the weekday and weekend samples, with concentrations of 72.57 µg/m^3 and 46.61 µg/m^3, respectively. The minimum PM concentration was found for the smallest size fractions for both the samples collected on the weekday and weekend at the concentrations of 3.81 µg/m^3 and 3.59 µg/m^3, respectively.

Table 4.6 Statistical summary of the daily average PM concentrations at the various size fractions (µg/m^3) during weekday

Weekday	N	Min.	Max.	Mean	Std. Deviation	PM category
PM≥10	32	11.26	72.57	27.711	11.558	-
$PM_{2.5-10}$	32	10.45	66.94	25.860	10.584	Coarse
$PM_{1.0-2.5}$	32	5.90	32.07	14.444	6.686	Fine PM (<2.5 µm)
$PM_{0.5-1.0}$	32	2.82	23.69	10.821	5.412	
$PM_{0.1-0.5}$	32	3.81	13.92	7.337	3.180	

Table 4.7 Statistical summary of the daily PM concentrations at the various size fractions (µg/m^3) during weekend

Weekend	N	Minimum	Maximum	Mean	Std. Deviation	PM category
PM≥10	13	10.91	46.61	24.786	10.489	-
$PM_{2.5-10}$	13	13.68	36.72	22.178	8.274	Coarse
$PM_{1.0-2.5}$	13	6.19	24.18	11.549	5.376	Fine PM (<2.5 µm)
$PM_{0.5-1.0}$	13	4.29	21.40	10.112	5.543	
$PM_{0.1-0.5}$	13	3.59	15.52	6.748	4.006	

The average concentrations of coarse PM and fine PM on the weekday were 25.86 µg/m^3 and 32.60 µg/m^3, respectively. The average concentrations of coarse PM and fine PM on the weekend were 22.18 µg/m^3 and 28.41 µg/m^3, respectively. The $PM_{2.5}$/ PM_{10} ratio for both the weekday and weekend was 0.56. The size fractions of

PM concentrations in the week varied by each day (Monday to Sunday), a comparison of the three sampling sites is shown in Figure 4.7. The vertical axis shows the concentrations of PM in each size range. The horizontal axis shows the sampling time consisting of the day of the week and date of the year. The days of the week were divided from Monday to Sunday and the date was from mid-June2005 until January 2006. The first size-fractionated bar in each group of days was in the wet season. The second and the third bar (if any) were in the dry season. According to the figure, the PM concentrations collected on Sundays from Yuparaj School and the municipality hospital were lower than those of the other days of the week during the same period. However, PM concentrations increased in dry season without effect of the day at the district office of Sarapee.

Due to less general activity on weekends than weekdays (e.g., school is out and less people work on weekends), the weekends tended to be less busy than the weekdays in terms of traffic. Moreover, in Chiang Mai city, a major street near Yuparaj School and the municipality hospital is closed to vehicles every Sunday because of a street market event. This closure of the road to vehicles might have affected the PM concentration on the weekends, especially on Sunday. Thus, in the weekend, the loading of traffic on Saturday and Sunday was different.

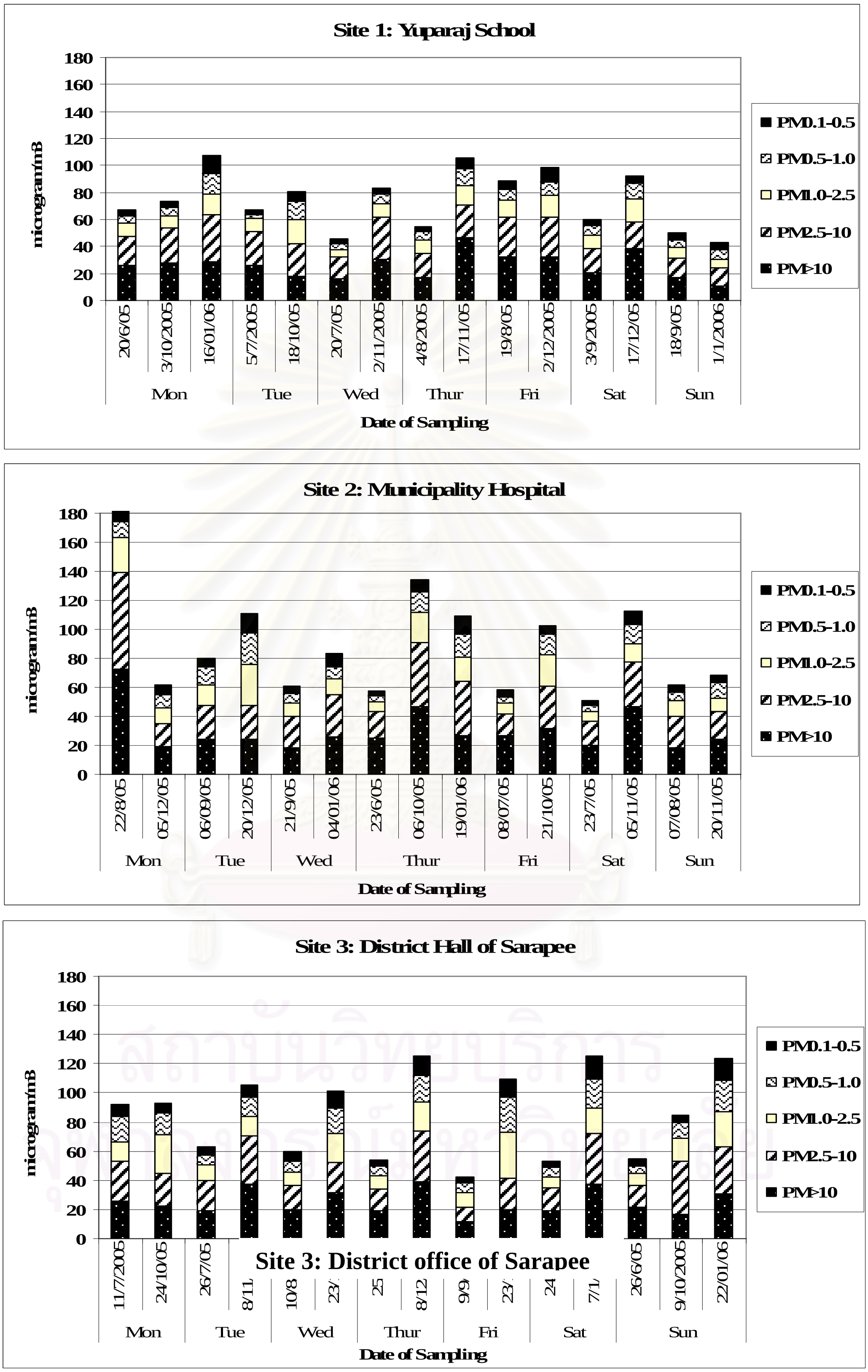


Figure 4.7 Concentrations at various size fractions defined by the day during the week.

Figure 4.8 shows the PM concentrations (combination of all three sampling sites) at various size fractions varied by the weekday, Saturday and Sunday. The figure shows that the median concentrations on weekdays were slightly higher than those that occurred on Sunday.

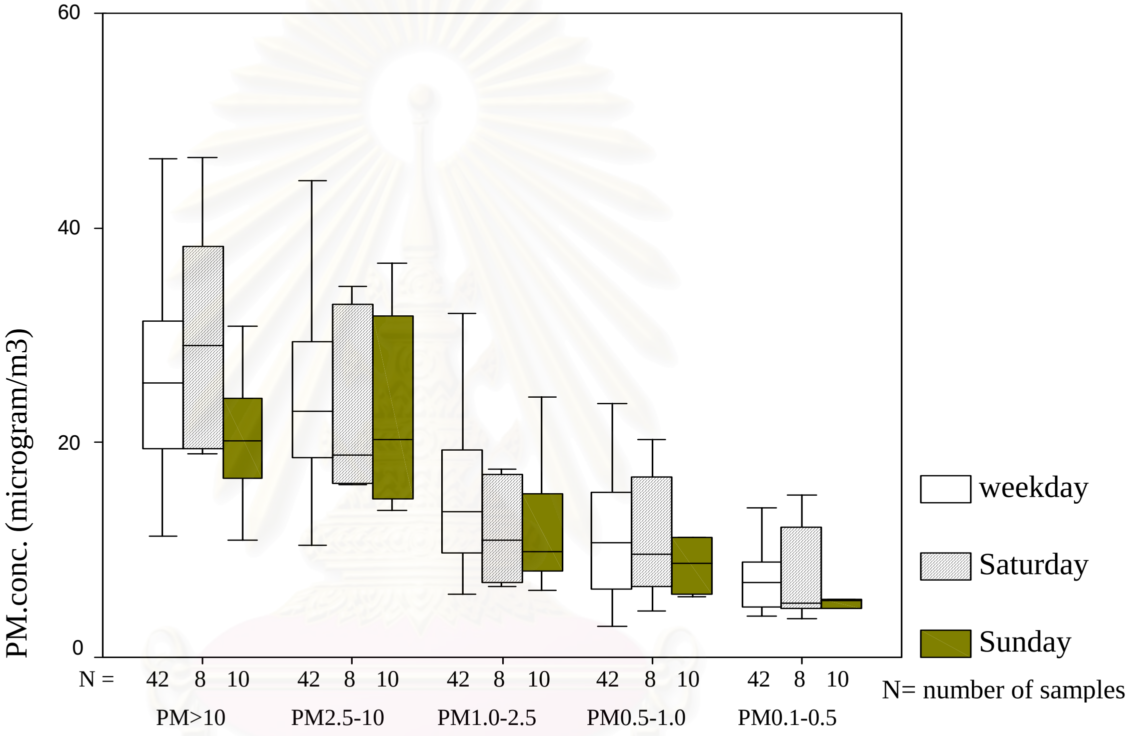


Figure 4.8 Weekday and weekend PM variations (June 2005- Jan.2006) at the three sampling sites in Chiang Mai

To clarify the effects of traffic during the weekend, an individual comparison of Saturday and Sunday was conducted. Figure 4.9 presents the PM concentrations (combination of $PM_{0.1-10}$) separated by Saturday and Sunday and also separated by the sampling sites during the sampling period.

As can be seen from the figure, by far the larger median daily weekend concentration of Yuparaj School and the municipality hospital occurred on Saturday in comparison to Sunday. At the same time, there was merely a small difference in the concentrations of PM collected on Saturday and Sunday at the district office of Sarapee. The mean concentrations of PM total for Yuparaj School were 76 and 46 μg/m^3 for Saturday and Sunday, respectively. The mean concentrations of PM total for the municipality hospital were 81 and 65 μg/m^3 for Saturday and Sunday, respectively. The mean concentrations of total PM for the district office of Sarapee were 89 and 87 μg/m^3 for Saturday and Sunday, respectively. All of those concentrations are shown in Figure 4.10. The reason for the difference is that the road near Yuparaj School and the municipality hospital has normal usage on Saturdays but is closed for Sunday: thus, there were lower PM concentrations on Sundays.

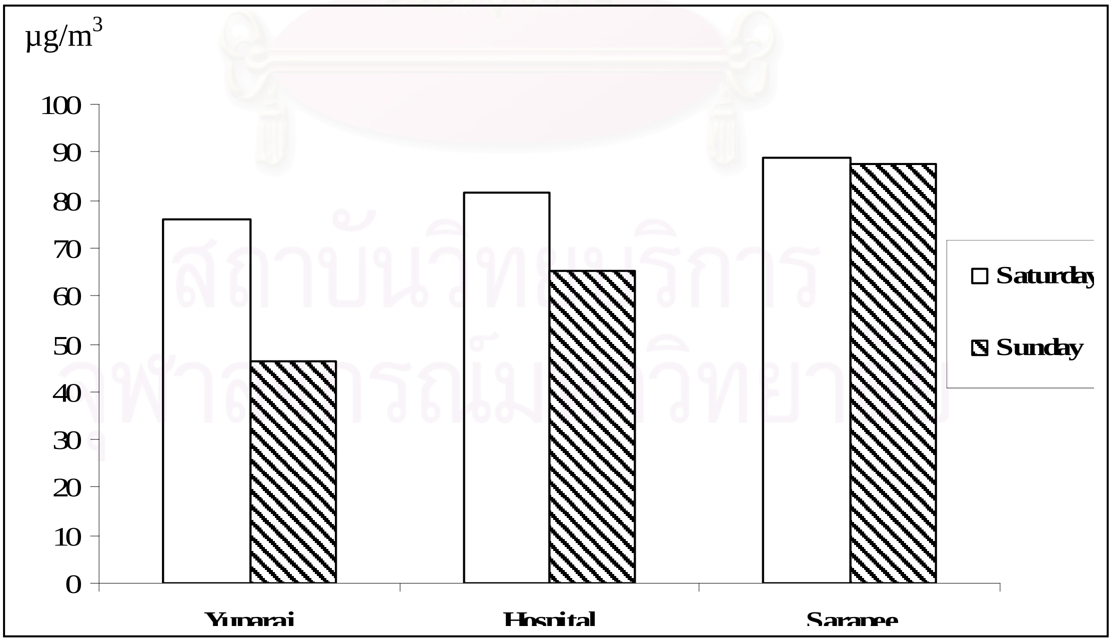


Figure 4.9 PM concentrations (combination of $PM_{0.1-10}$) on Saturdays and Sundays during the sampling period

In addition, the road was used normally at the district office of Sarapee both on Saturdays and Sundays; as a result, there was no big difference in its PM concentrations. This result might have been affected by the traffic loading and activities which differed on Saturdays and Sundays. However, there was no significant decrease between sampling sites.

4.2 Compositions of PM at Various Size fractions in Chiang Mai Ambient Air

Graphical representations on the compositions of the particulate matter (including cations, anions and some metals) at various size fractions at the 3 sampling sites in Chiang Mai are presented in this section. Also presented how the sites and time affected the compositions from mid-June 2005 until January 2006. A table can be seen in Appendix E.

4.2.1 Ions Concentrations

During the study period**,** all samples from the field (225 samples) were investigated for their PM ion compositions at various PM size fractions. Six cations (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+} and Li^+) and seven anions (F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, Br^- and NO_2^-) were identified and quantified. The data reported here are only for ions which were detected using ion chromatography. Ion chromatography showed that Li^+ was an undetected cation, while NO_2^- and Br^- were undetected anions. F^- ion was disturbed by the extraction solution so this study did not concentrate on it.

The summaries of the ion analysis performed at all the sites are shown in Table 4.8. The table presents a statistical analysis of the summed ion concentrations, expressed in unit of milligram of ion per gram of particulate matter. The arithmetic mean, standard variation, and the maximum and the minimum of both types of ion concentrations (anion and cation), were calculated for each PM size fraction (larger than 10 micrometer, $PM_{2.5-10}$, $PM_{1.0-2.5}$, $PM_{0.5-1.0}$, $PM_{0.10.5}$ µm) that was collected from the three sampling sites in Chiang Mai Province during the study period.

It was found that, fine PM contained more ions than coarse PM. The ratio of the anion concentrations contained in coarse and fine PM for all sampling sites equaled 0.490, 0.504, 0.598 for sampling sites 1, 2 and 3, respectively. The highest mean concentration of anions was found in the PM2.5-10 µm size fraction of (coarse PM) at the concentration of 91.36, 80.21 and 98.76 mg.ion/g.PM at sampling sites 1, 2 and 3, respectively.

The highest concentration of cations were found in the largest size fraction ($PM \geq 10$) at all of the three sampling sites. The highest concentration was 50.68 mg.ion/g.PM at the district office of Sarapee. The lowest concentration was found in the smallest size ($PM_{0.1-0.5}$) at the value of 24.48 mg.ion/g.PM at the municipality hospital. The ratio of the cation concentration for coarse and fine PM for sampling sites 1, 2 and 3 equaled 0.235, 0.212 and 0.301, respectively. This ratios show that the amounts of anion found in fine PM is almost double the amount found in coarse PM and the amounts of cations found in fine PM is about 4 times the amount found in coarse PM.

Table 4.8 Statistical summary of summed daily ion concentrations at the various size fractions (mg.ion/g.PM) during the study

		Site1: Yuparaj		**Site2: Hospital**		**Site 3:Sarapee**	
		ANION	**CATION**	**ANION**	**CATION**	**ANION**	**CATION**
Size 1 (PM>10)	**Mean**	58.43	46.07	57.11	47.75	53.31	50.68
	STDEV.	60.11	29.20	50.79	35.77	41.97	31.05
	Maximum	226.01	100.96	135.68	135.74	149.04	123.44
	Minimum	3.69	7.04	6.05	6.23	7.56	8.08
Size 2 (PM$_{2.5-10}$)	**Mean**	91.36	29.57	80.21	24.48	98.76	30.84
	STDEV.	39.38	22.08	47.64	15.16	69.56	26.00
	Maximum	181.42	82.95	158.74	52.46	288.77	92.27
	Minimum	23.49	3.69	0.00	3.63	17.28	4.78
Size 3 (PM$_{1.0-2.5}$)	**Mean**	66.71	45.69	68.39	45.32	62.98	36.51
	STDEV.	36.53	19.83	34.03	19.49	43.49	18.74
	Maximum	167.02	86.78	132.18	71.54	154.55	70.52
	Minimum	13.17	6.91	7.66	9.74	8.49	5.38
Size 4 (PM$_{0.5-1.0}$)	**Mean**	62.38	45.92	53.39	37.88	55.63	32.55
	STDEV.	39.74	29.16	28.42	15.10	25.69	14.65
	Maximum	147.71	132.90	99.20	66.45	96.21	66.05
	Minimum	9.62	11.20	9.84	14.52	12.51	6.39
Size 5 (PM$_{0.1-0.5}$)	**Mean**	57.47	34.11	37.28	32.42	46.53	33.51
	STDEV.	50.22	19.48	31.27	17.77	47.52	12.17
	Maximum	195.50	78.64	92.45	65.08	173.00	62.28
	Minimum	12.54	12.50	5.01	8.20	5.32	17.18

Note: the number of samples for each type of ion is 225

Figure 4.10 summarizes the size-fractionated anion and cation concentrations (mg/g) which were found in PM at the three sampling sites. The ion concentrations shown here are daily average sums of the anions and cations divided by their site of collection.

From the figure, the highest concentration of the daily average for anions was contained in 2.5-10 µm PM (coarse PM), but the same PM fraction also contained the lowest daily average concentration of cations. The figure also shows that more anions were found in PM than cations. It can be noticed that different particle sizes contained the different kinds of ions and also different concentrations.

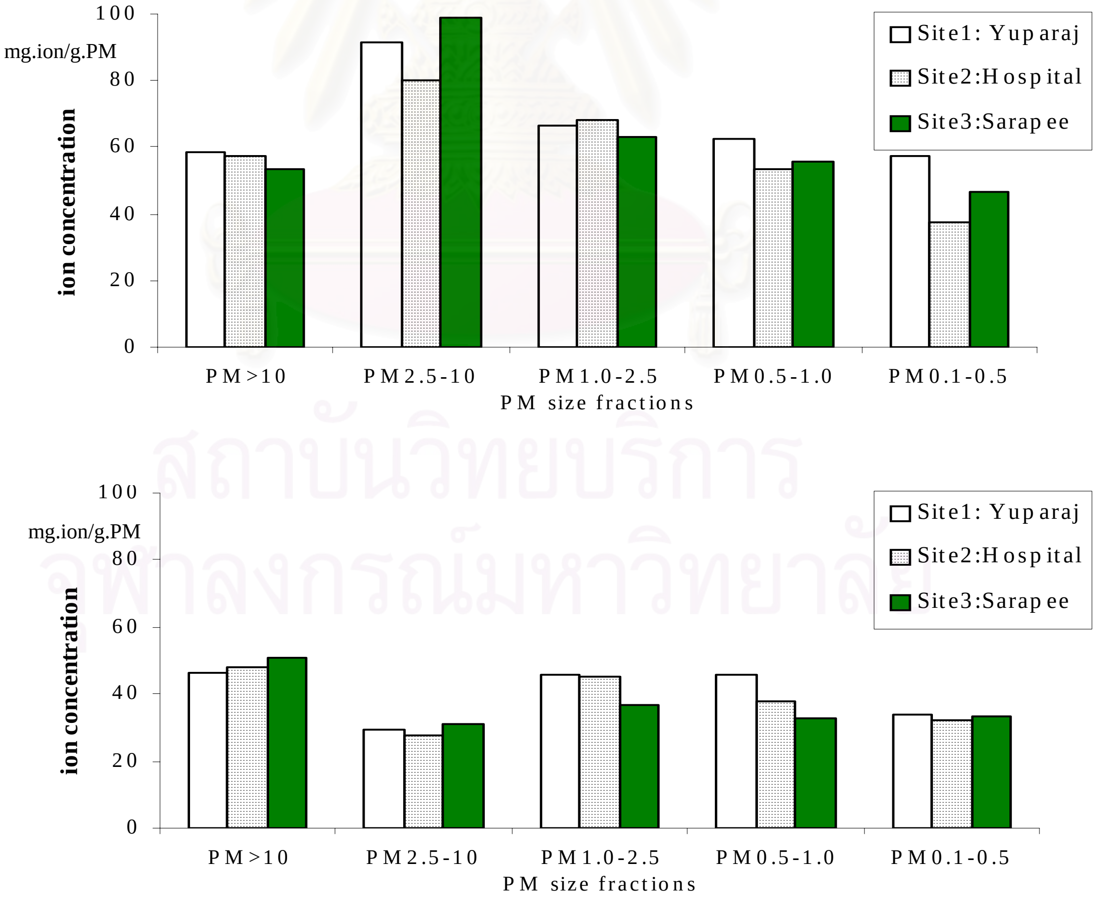


Figure 4.10 Size-fractionated ion concentrations (mg.ion/g.pM) at the three sampling sites in Chiang Mai across the study period.

The summed ions concentration, expressed in the unit of µg ions per cubic meter of air, in Chiang Mai by series of time is shown in Figure 4.12. From the study, there was a higher concentration of anions in the PM than cations. However, there appears to be no clear relationship between season and ion concentrations. Thus, other factors should be concerned.

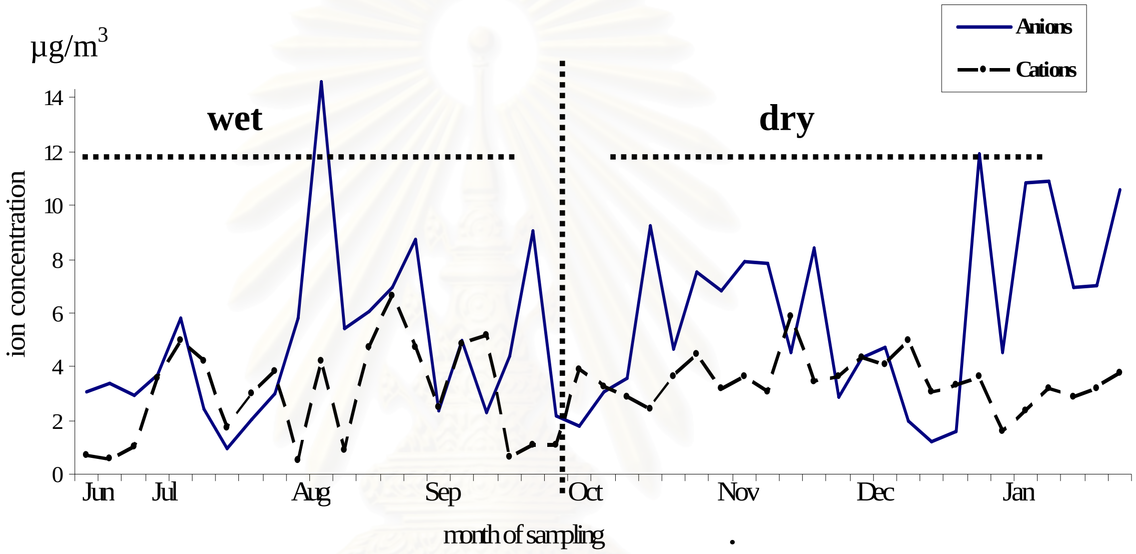


Figure 4.11 Summed ion concentrations (µg/m^3) by series of time

The summed ion concentrations expressed in mg of ion per 1g of PM in Chiang Mai by series of time is shown in Figure 4.12. From the study, anion concentrations were higher than cation concentrations. During the dry season, the anion concentrations were almost double the concentrations produced during the wet season, while the cation concentrations only slightly increased during the dry season.

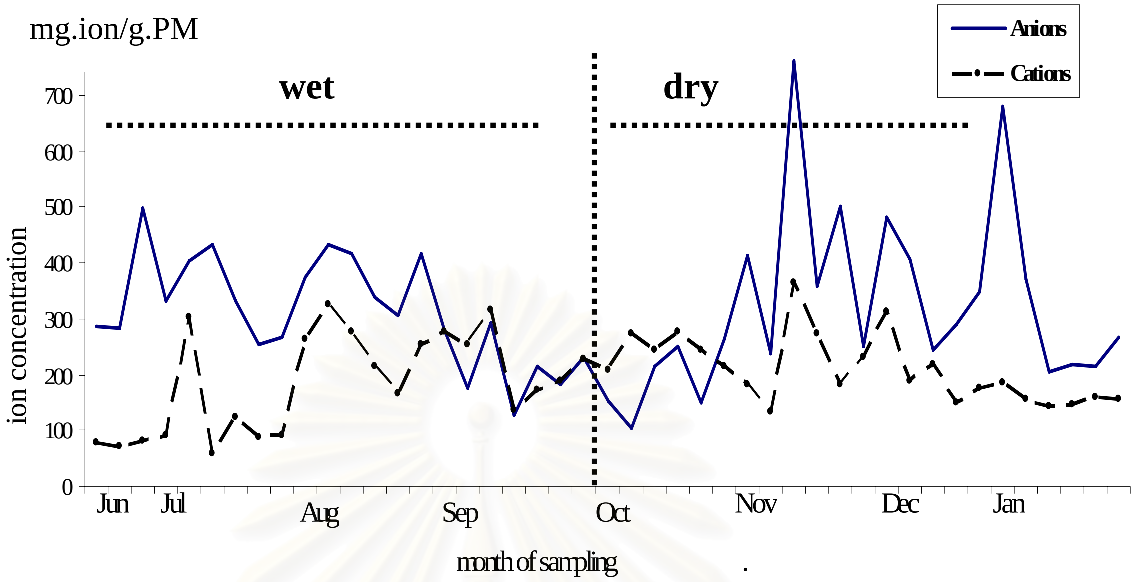


Figure 4.12 Summed ion concentrations (mg of ion/1g of PM) by series of time

Figures 4.13 and 4.14 present the percentages of ions which can be extracted from the PUF. The study found that summed anion at all the sampling sites in Chiang Mai had a relation to the sizes of the PM as shown in Figure 4.13.About 28% of anions were found in the coarse PM and 54 % in fine PM. Anion compound concentrations in fine PM were found to decrease with the decreasing sizes of the PM as shown. Thus, it can be concluded that the average amount of anion in the fine PM was more than of the fine PM.

Also, summed cations at all the in Chiang Mai had a relation to the sizes of the PM as shown in Figure 4.14. It can be seen that about 15% of cations were found in coarse PM and 59 % in fine PM. Cation compound concentrations in fine PM were found to decrease with the decreasing sizes of the PM as shown. Thus, it can be concluded that the average amount of cations in the fine PM was much more than in the coarse PM.

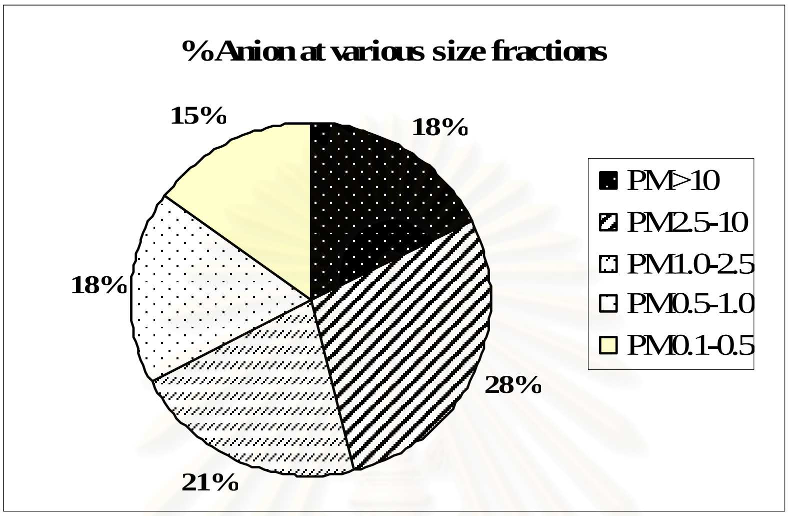


Figure 4.13 Summed daily anion concentrations at the various size fractions (mg/g) across the study period

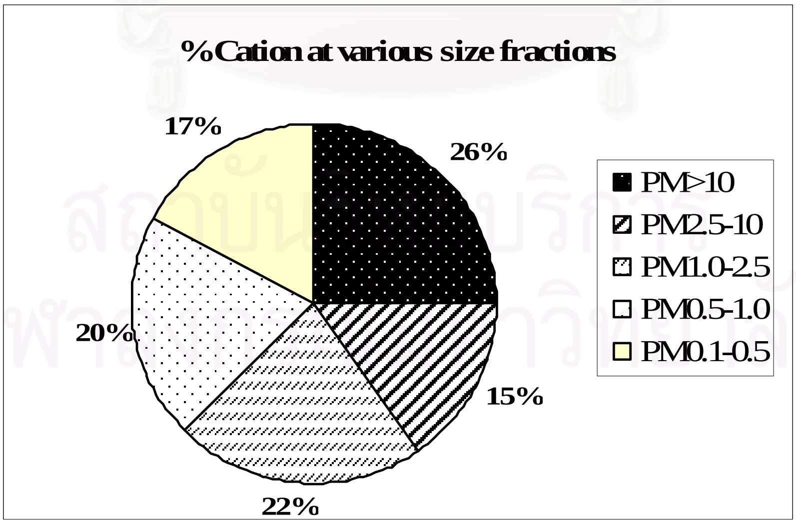


Figure 4.14 Summed daily cation concentrations at the various size fractions (mg/g) across the study period

In addition, 26% of the cations was found with particles larger than 10 micrometer while it was only 18% of the anions was found with PM>10 µm. This may be the result of the size of the ions. Cations are larger in diameter than anions; consequently, it might have attached with more of the larger particles as compared to the anions. In addition, as far as the ions attaching with $PM_{2.5}$ was concerned, 82% and 74% of anion and cation, respectively, were found in this size fractions. This could be used to explain about “acid rain”. Since anions such as nitrite, nitrate and sulfate have the quality of acid and when they appear in high quantities in the air it can cause the acid rain.

Figures 4.15 and 4.16 show the proportion (%) of summed anion concentrations during the wet season and dry season and the proportion (%) of summed cation concentrations during the wet season and dry season, respectively

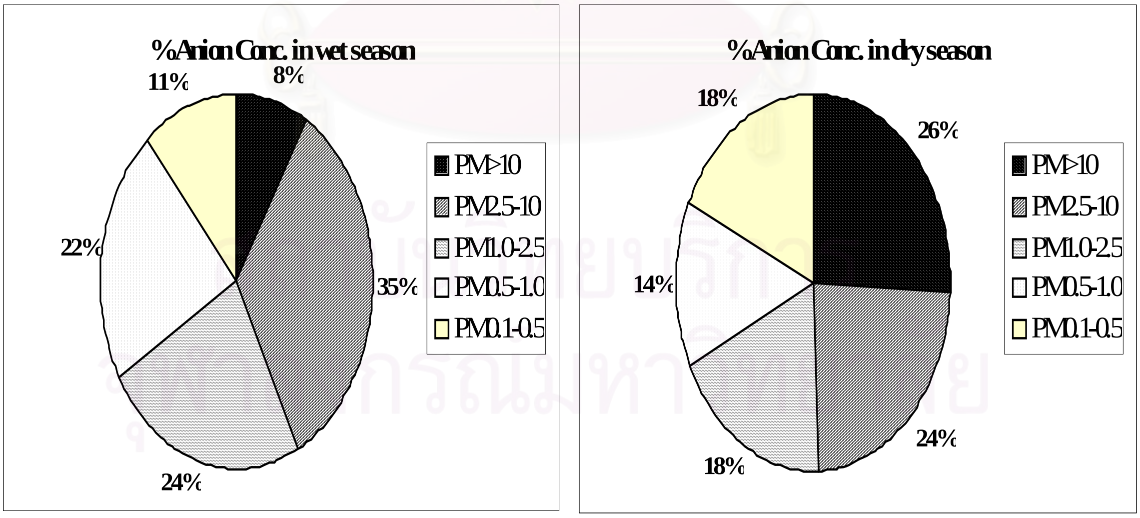


Figure 4.15 Proportion (%) of summed anion concentrations (mg/g) during the wet season and dry season

Figure 4.15 shows that anions were more often found in larger-size fractions (PM>2.5 µm) during the dry season but found in smaller-size fractions ($PM_{0.1-2.5}$) during the wet season. Figure 4.16 shows that cations were found in larger-size fractions (PM>2.5 µm) during the wet season but found in smaller-size fractions ($PM_{0.1-2.5}$) during the dry season.

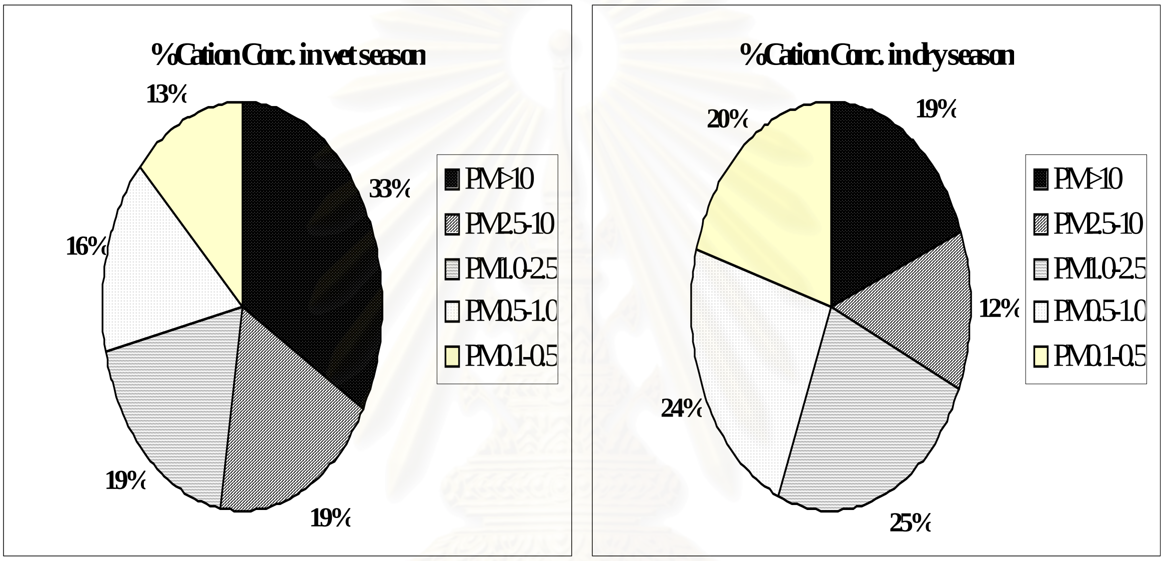


Figure 4.16 Proportion (%) of summed cation concentrations (mg/g) during the wet season and dry season

The results of study show that seasonal variations had different effects to different kinds of ions. In the dry season, there are more anion pollutants in the larger-size fractions and more cation pollutants in the smaller-size fractions. Table 4.9 shows a statistical summary of the ions concentrations contained in SFPM (summed fractions of PM) during the wet and dry seasons in Chiang Mai. The unit is expressed in terms of milligrams ion per gram of PM.

Table 4.9 Statistical summary of ion concentrations contained in SFPM during the wet and dry seasons in Chiang Mai (The average concentration $\underline{+}$ Standard Deviation (SD) mg/g)

Chemical Compositions	**Sampling Sites**					
	Yuparaj		**Hospital**		**Sarapee**	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
SFPM (μg/m^3)	61.97±14.39	85.58±21.16	78.80±46.54	97.74±24.62	59.63±15.60	79.08±10.73
Cl^-	68.69±61.21	190.67±216.53	84.75±64.99	113.47±78.62	135.02±103.92	135.31±115.06
NO_3^-	126.49±41.32	118.69±71.17	118.92±26.78	125.94±50.30	101.33±16.96	104.14±58.52
SO_4^{2-}	100.60±32.99	60.98±29.93	85.88±27.22	61.75±55.56	124.78±45.49	36.95±28.61
PO_4^{3-}	0.69±0.68	0.92±1.14	0.59±1.01	0.67±0.84	1.78±1.65	0.82±0.83
Na^+	13.63±5.03	10.76±8.90	14.02±8.70	10.31±13.82	18.34±11.61	8.23±5.13
NH_4^+	13.70±15.09	46.84±29.96	12.35±17.37	54.74±40.42	7.64±9.75	53.68±41.50
K^+	31.36±8.28	78.05±74.38	33.27±14.13	49.73±15.34	43.34±15.95	47.20±9.05
Mg^{2+}	1.72±1.61	1.25±0.99	1.72±1.29	1.18±1.03	2.61±2.08	1.60±1.15
Ca^{2+}	109.42±76.97	92.07±26.16	102.30±78.42	98.67±18.32	108.95±82.16	76.20±12.60
No.of sample	21	24	21	24	21	24

According to the table, the SFPM of all the sampling sites was higher during the dry season than in the wet season. Cl^- NH_4^+ and K^+ increased during the dry season**,** especially NH_4^+ which was much higher than in the wet period. However, some ions decreased such as SO_4^{2-} Na^+ Mg^{2+} and $Ca2^+$ especially SO_4^{2-} which decreased a lot during the dry period. In addition, it also can be noticed that Cl^- concentrations at the Yuparaj School and municipality hospital decreased severely during the dry season compared with that of the wet season. The Sarapee's site concentration did not differ during the two seasons. This difference in the sites might be due to the effects of the constructions (building and road) that was taking place near sites 1 and 2 as described previously.

The individual daily average of ions at all sampling sites are presented in Figure 4.17. The patterns at all the three sampling sites were similar. There were not much variations in the concentrations of ions between the sampling sites. The dominant anion species that were observed in the study were Cl^- NO^{3-} and SO_4^{2-} and the dominant cation species was Ca^{2+}. The dominant anion species, Cl^- , was dominant at Yuparaj School and the district office of Sarapee but the dominant cation species, Ca^{2+}, was dominant at Yuparaj School and the municipality hospital.

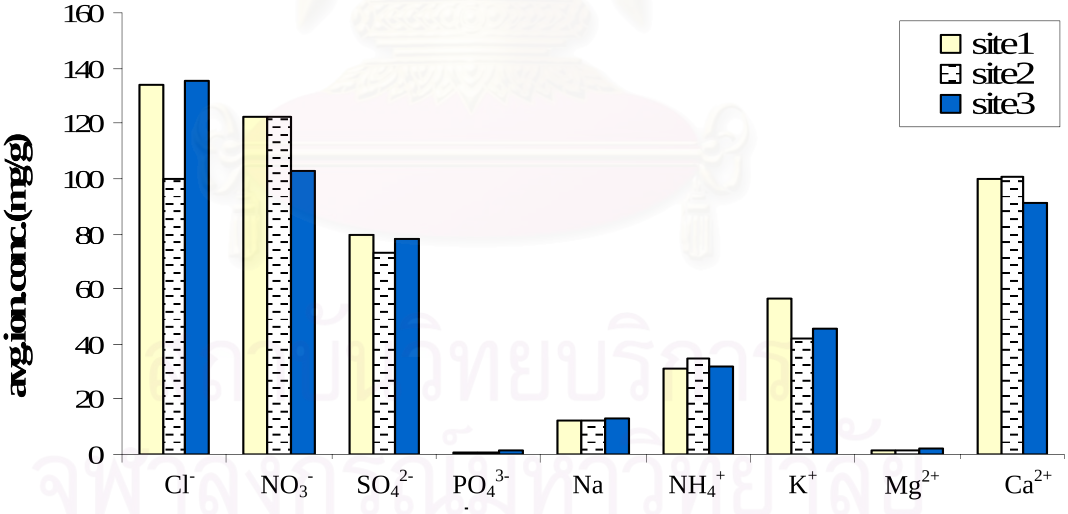


Figure 4.17 Ambient profiles of the ion species at all sampling sites across the study period.

The following figures present a comparison of each ion at the various size fractions and collection sites. Figures 4.18-4.21 show anion comparisons. Figures

4.22-4.26 show cation comparisons. The figures plot the ion concentrations from mid-June 2005 until January 2006, and each line represents ion concentrations from each fraction. The concentrations were expressed in units of milligrams of ion per 1 gram of PM. The site’s effects on the ion concentrations are also depicted in these figures. Among the concentration of ions, Cl^- was the dominant anion and Ca^{2+} was the dominant cation.

From the figures, it can be noticed that the concentrations of both types of ions across the study period contained no pattern. Some ion concentrations increased more during the dry season than in the wet season, namely Cl^- $NH4^+$and K^+, and some increased during the flooding period (from late August to the beginning of October), particularly SO_4^{2-} and Ca^{2+}. Conversely, Mg^{2+} decreased during the flooding period and the others has no clear trend. In Figured 4.18, it can be seen that the Cl^- ion was totally reduced from September (9) to October (10). The sharp decrease of the Cl^- ion during this period might have occurred due to flooding. At that time, Chiang Mai flooded 3 times and transportation was inhibited. Thus, pollutants most likely were deduced.

When the Cl^- ion concentrations were compared in each size range, the Cl^- ion was found to be most prevalent in particles larger than 10 micrometers and size-fractions of 2.5-10 micrometers. In addition, it can be seen that the Cl^- ion was dominant in $PM_{2.5-10}$ during the wet season and in PM≥10 micrometers during the dry season. This might be due to the effects shown in Figure 4.15, which shows that the anion proportion of PM≥10 micrometers in the dry season was higher than that of the wet season, while the anion proportion of $PM_{2.5-10}$ was deduced during the dry period. Between the sampling sites, Cl^- ion was the most prevalent at the district office of

Sarapee, nevertheless the pattern of the line was for the most part the same for all the sampling sites. These might be due to the fact that there are more small industries in Sarapee areas than in the town. Some of these industries generate Cl^- -ion such as organic chemistry and paper.

Figure 4.19 presents the NO_3^- concentrations of the three sampling sites. Among the size fractions, NO_3^- ion was found to be most prevalent in $PM_{0.5\text{-}1.0}$ during the wet season, and it became dominant in $PM_{0.1\text{-}0.5}$ during the dry season. Its concentration minimally increased during the dry season.

Figure 4.20 presents the SO_4^{2-} concentrations. It was dominant in the fraction of 1.0-2.5 micrometers along the study period. At the hospital areas, the concentration increased a lot during the flooding period.

Figure 4.21 presents the PO_4^{3-} concentrations. It shows that PO_4^{3-} was the anion which had the lowest concentration in this study. There was no trend along the study period as well, but it was dominant in the fraction of 2.5-10 micrometers during the wet season. It became dominant in the smaller fraction of 0.5-2.5 micrometers during the dry period.

The study of these anions found that most anions were prevalent in the larger size fractions during the wet season, but became dominant in the smaller size fractions during the dry season.

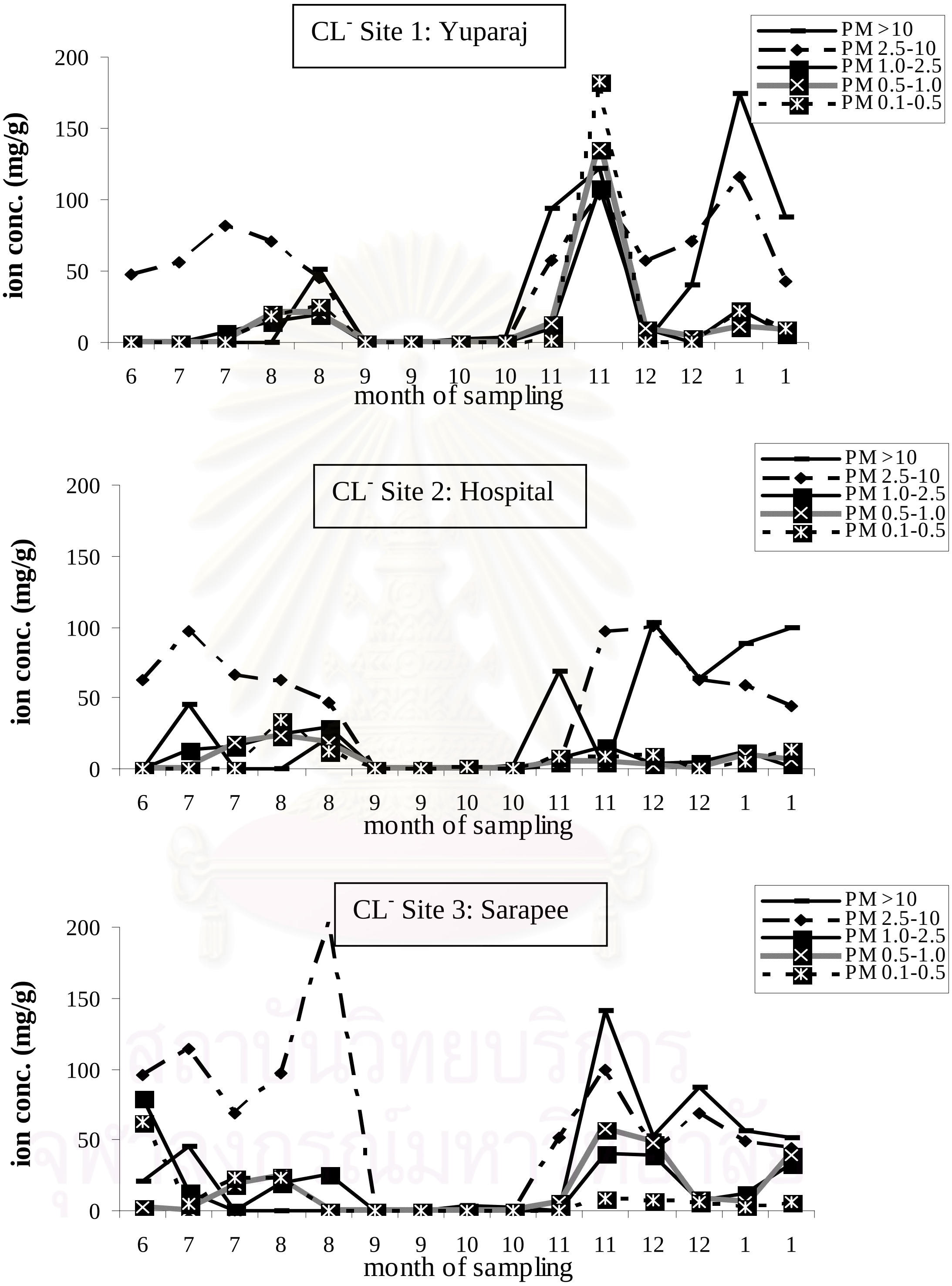


Figure 4.18 Comparison of Cl$^-$ ions at the various size fractions at all sampling sites.

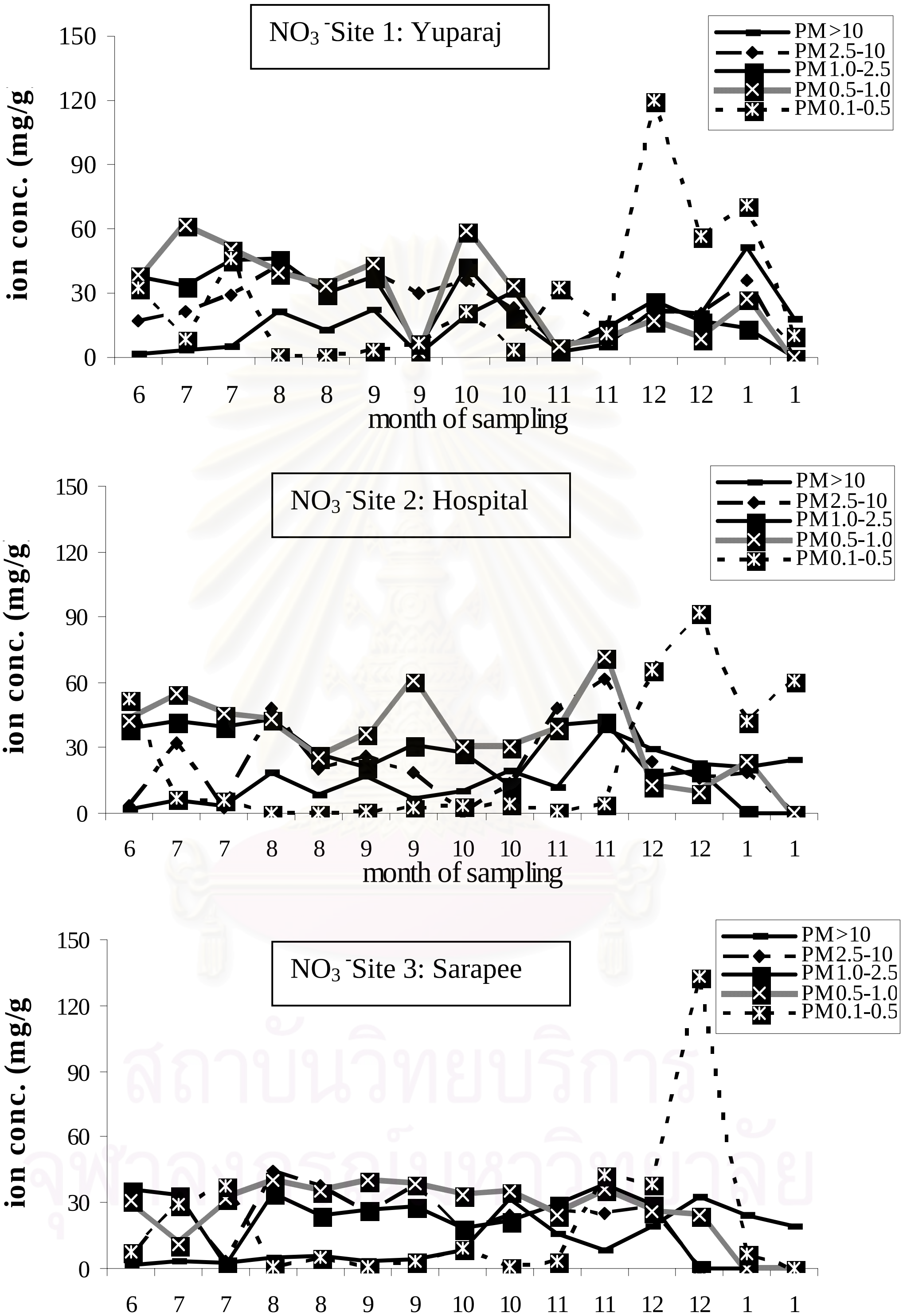


Figure 4.19 Comparison of NO_3^- ions at the various size fractions at all sampling sites.

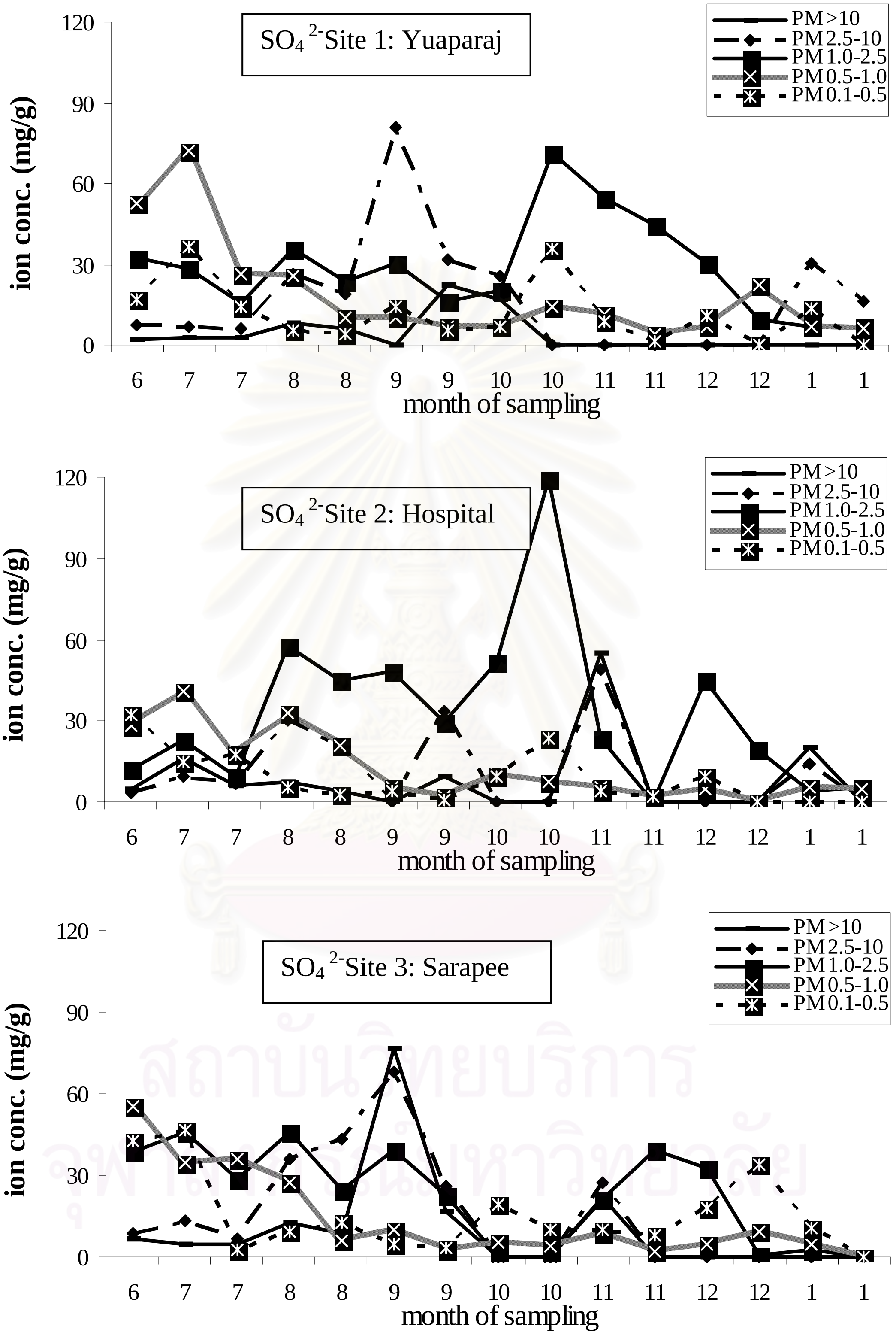


Figure 4.20 Comparison of SO_4^{2-} ions at the various size fractions at all sampling sites

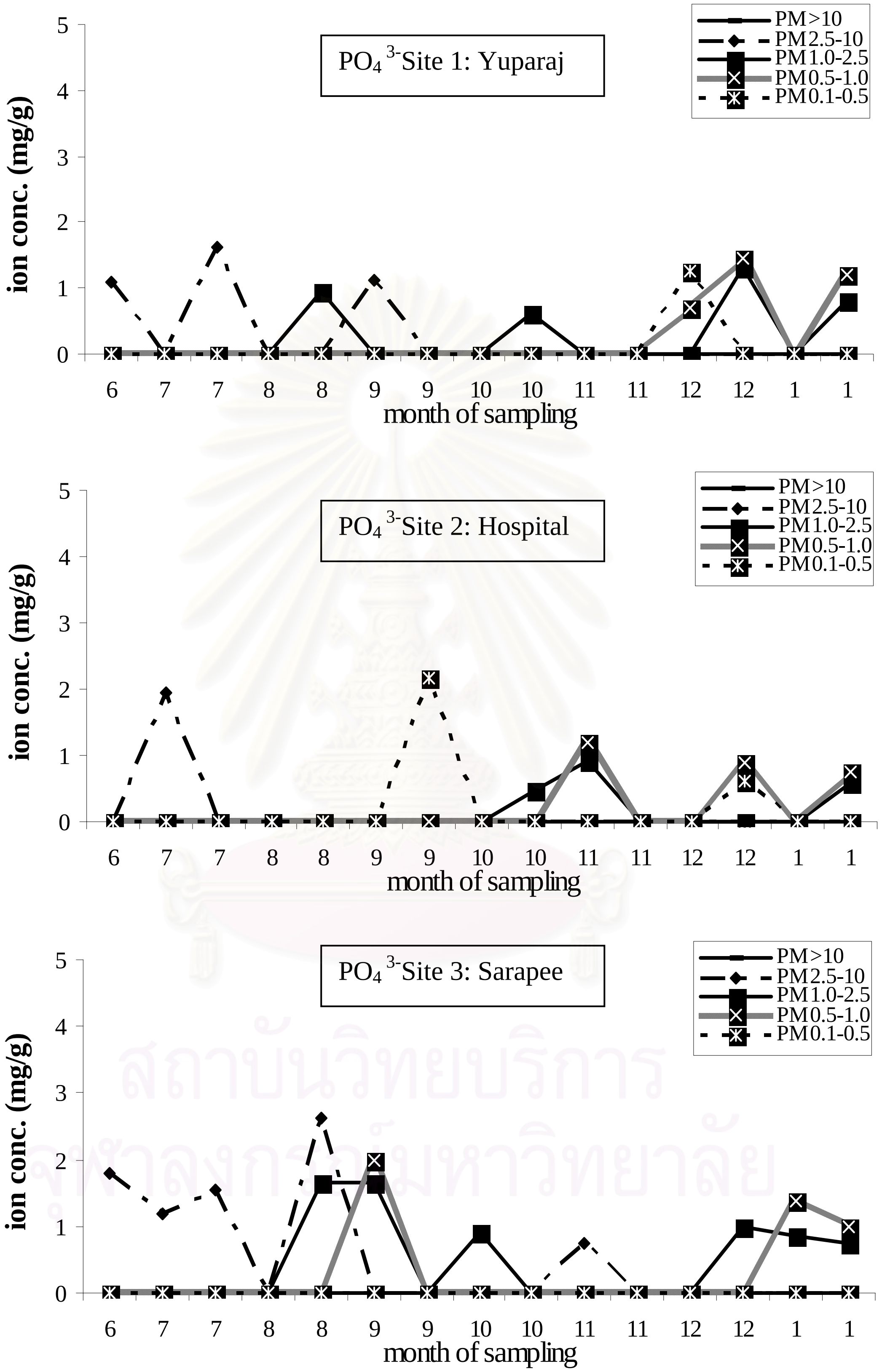


Figure 4.21 Comparison of PO_4^{2-} ions at the various size fractions at all sampling sites

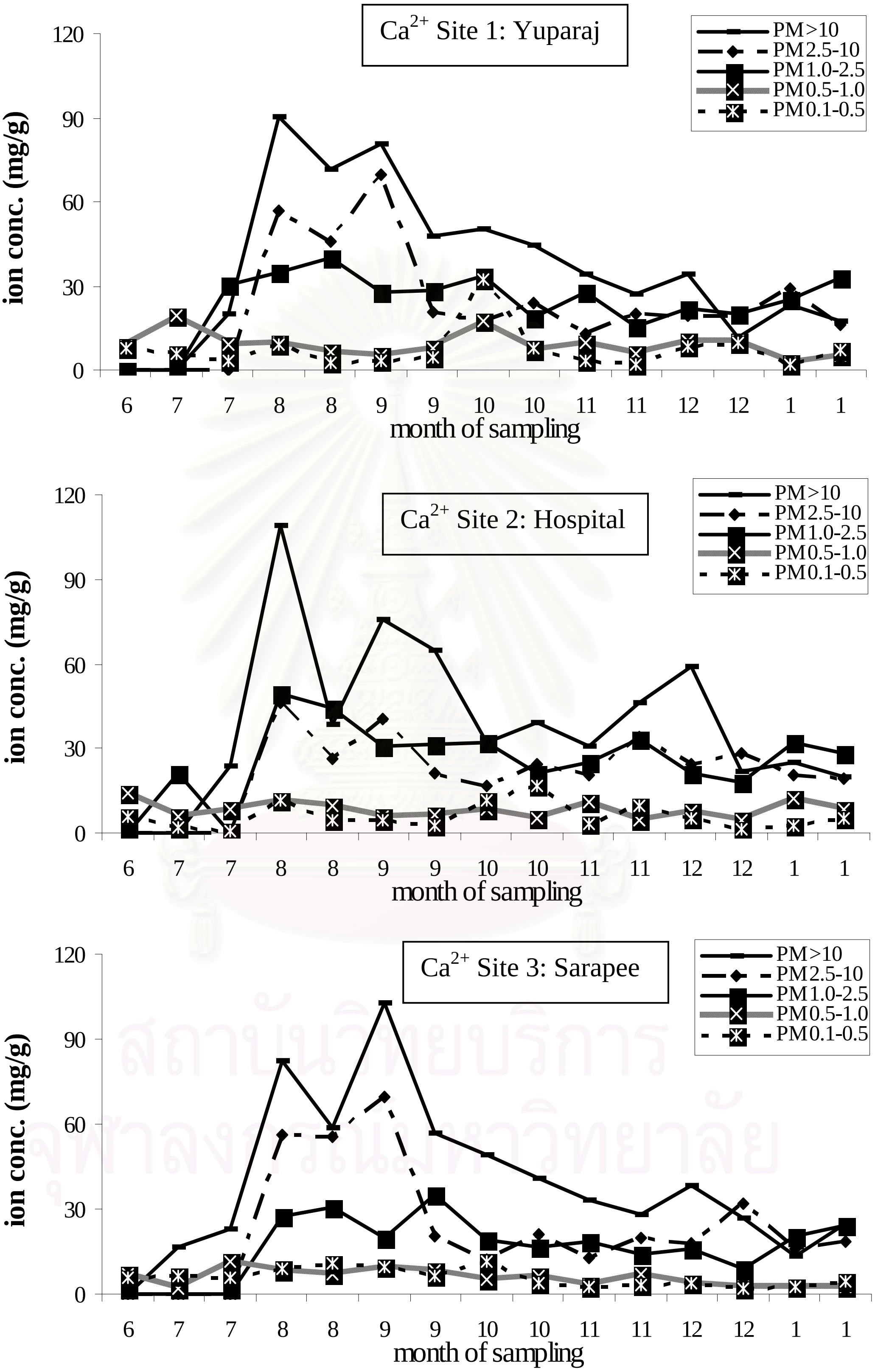


Figure 4.22 Comparison of Ca^{++} ions at the various size fractions at all sampling sites

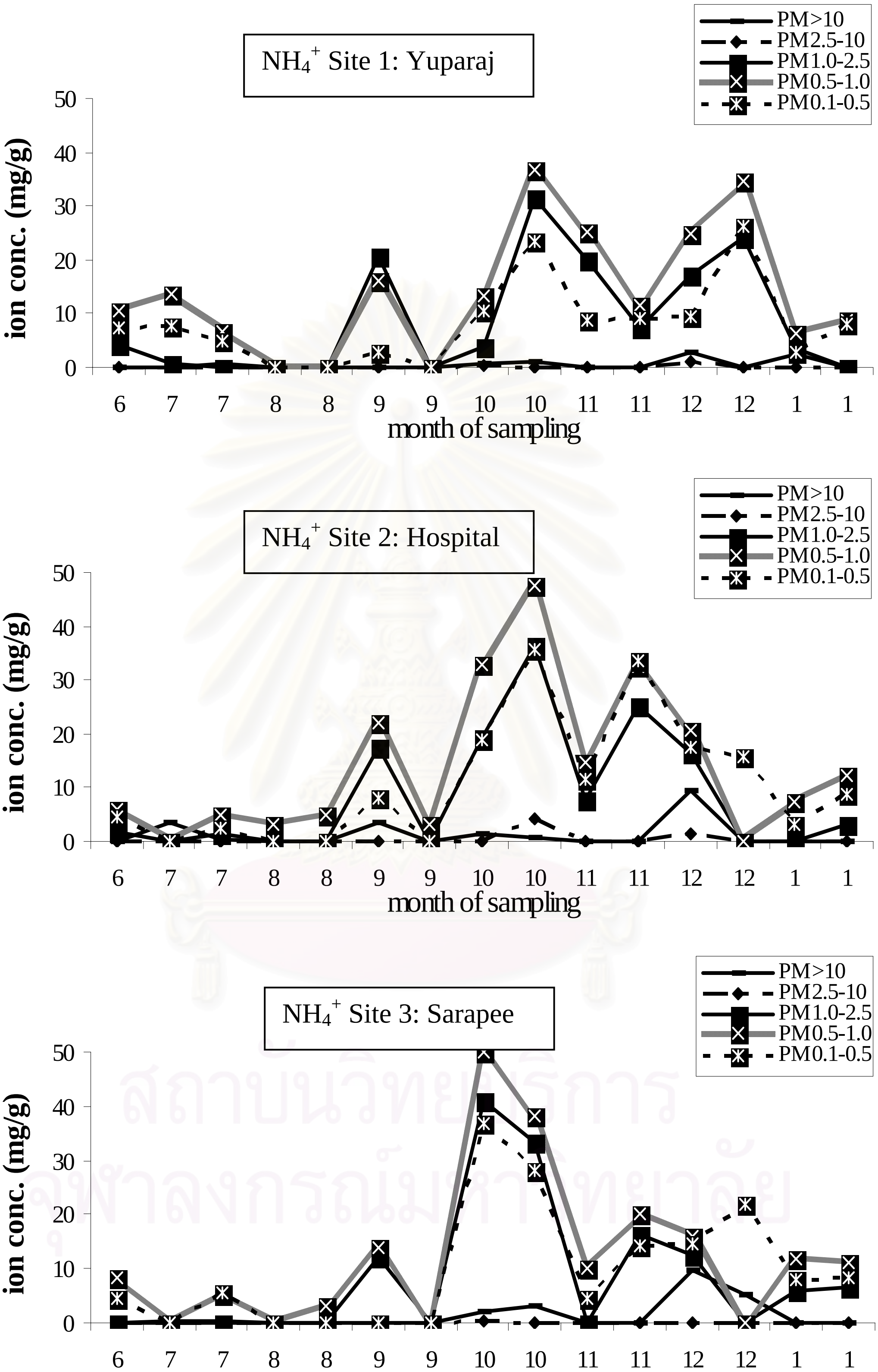
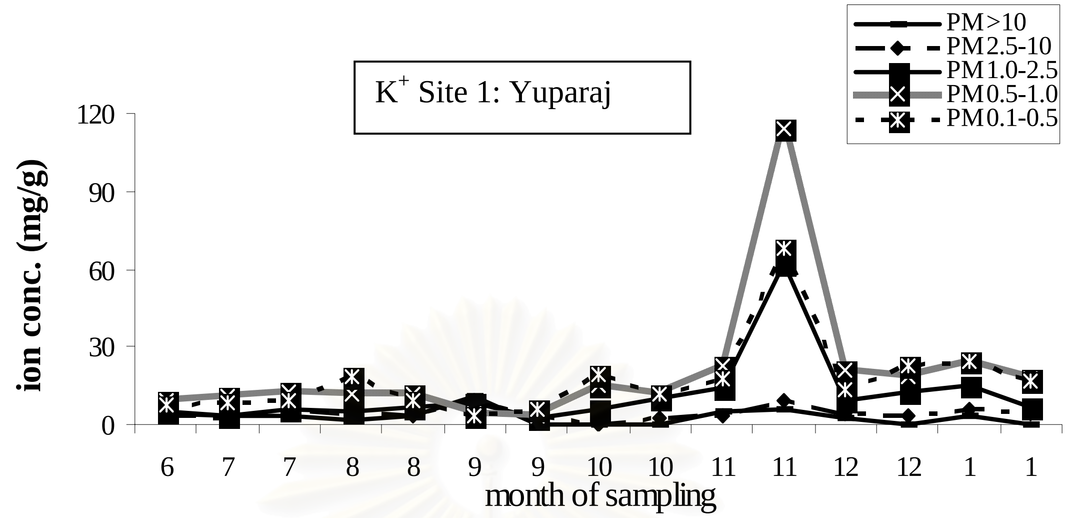
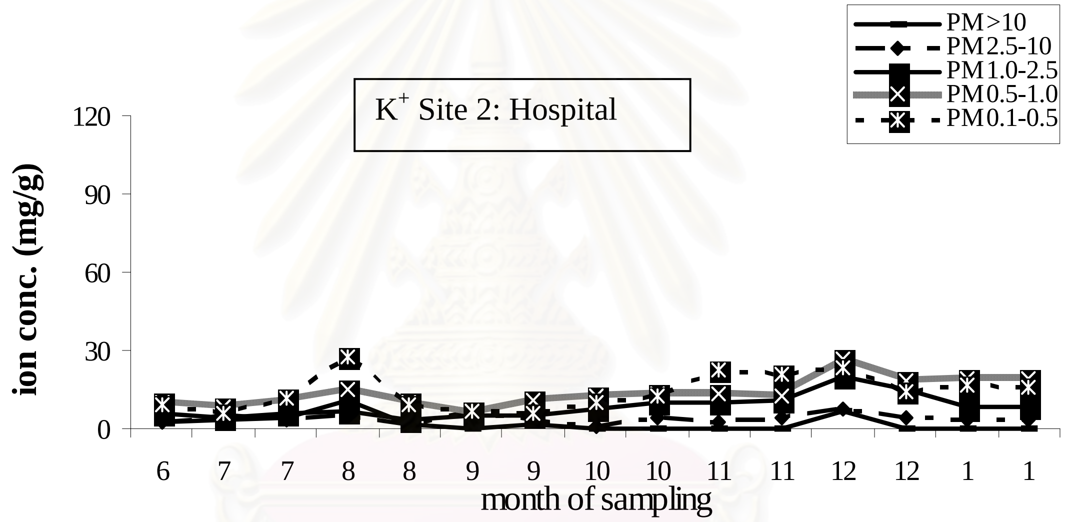


Figure 4.23 Comparison of NH_4^+ ions at the various size fractions at all sampling sites





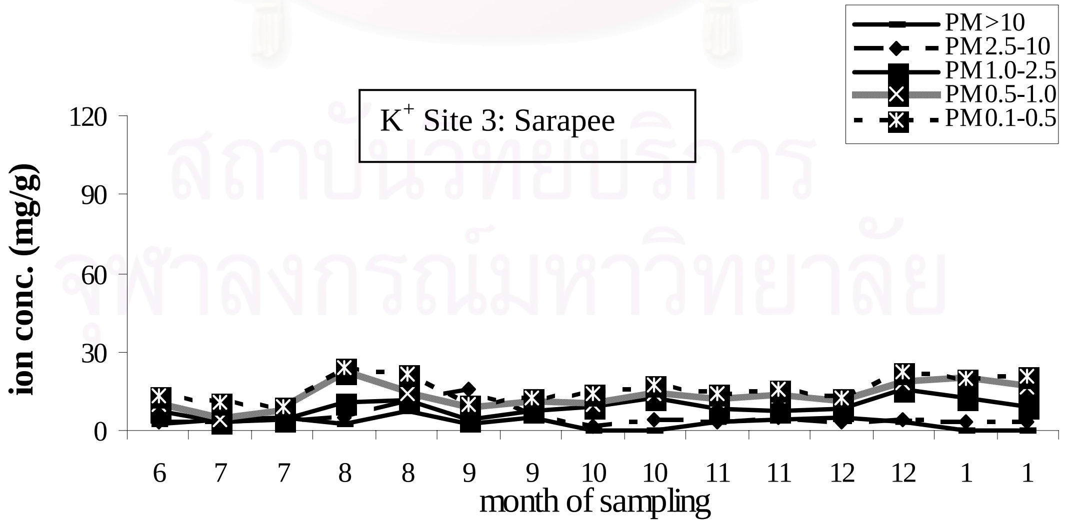


Figure 4.24 Comparison of K^+ ions at the various size fractions at all sampling sites

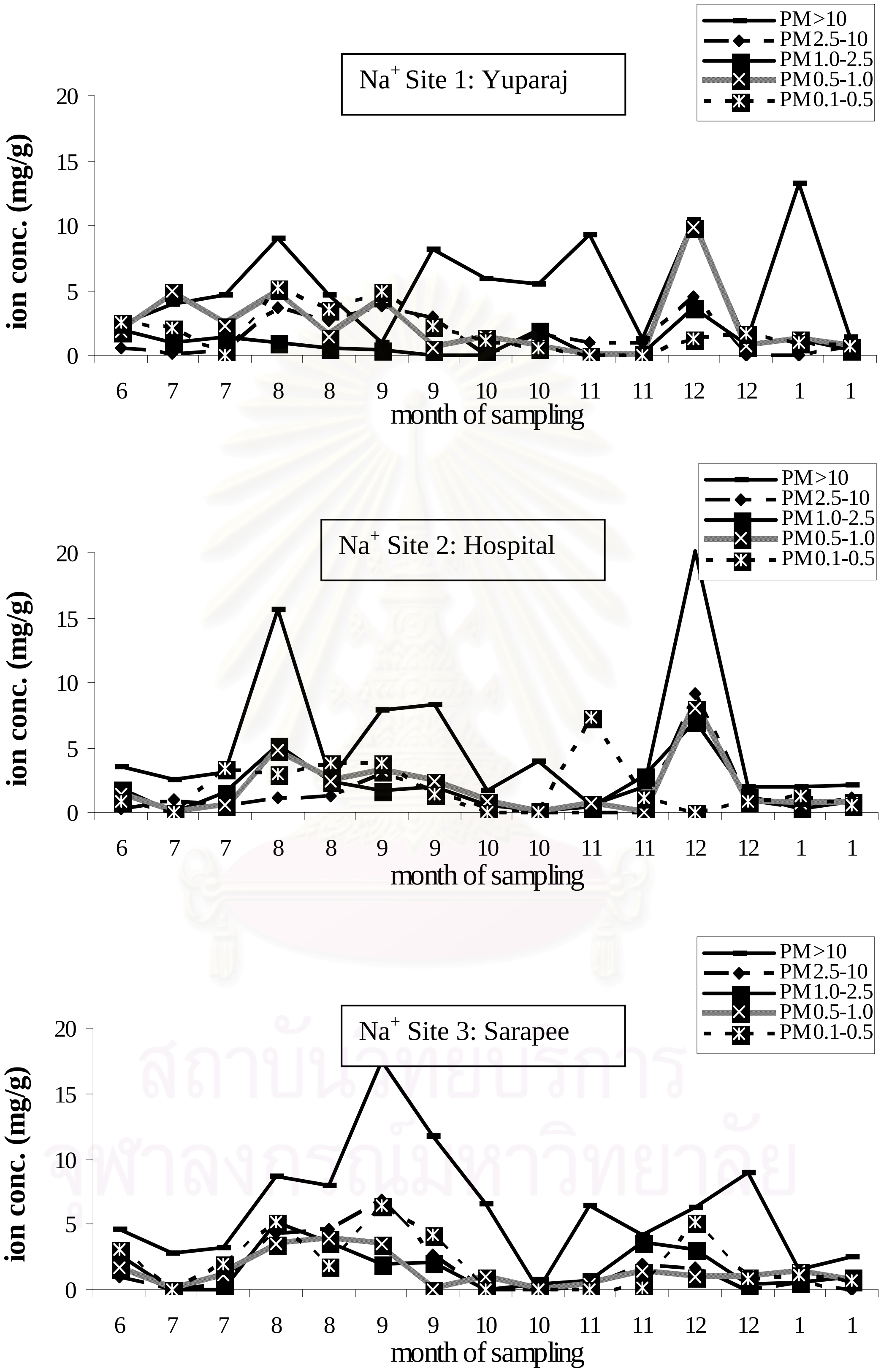
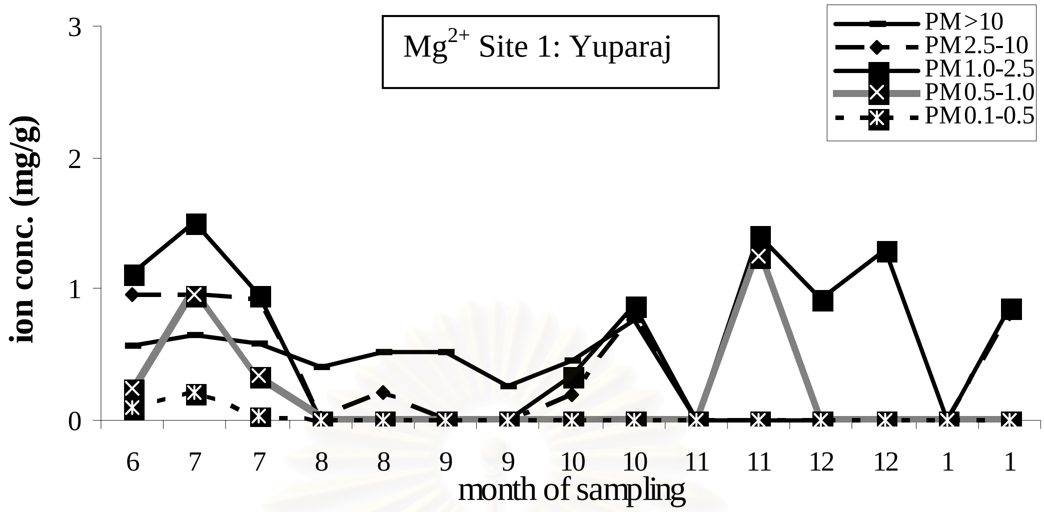
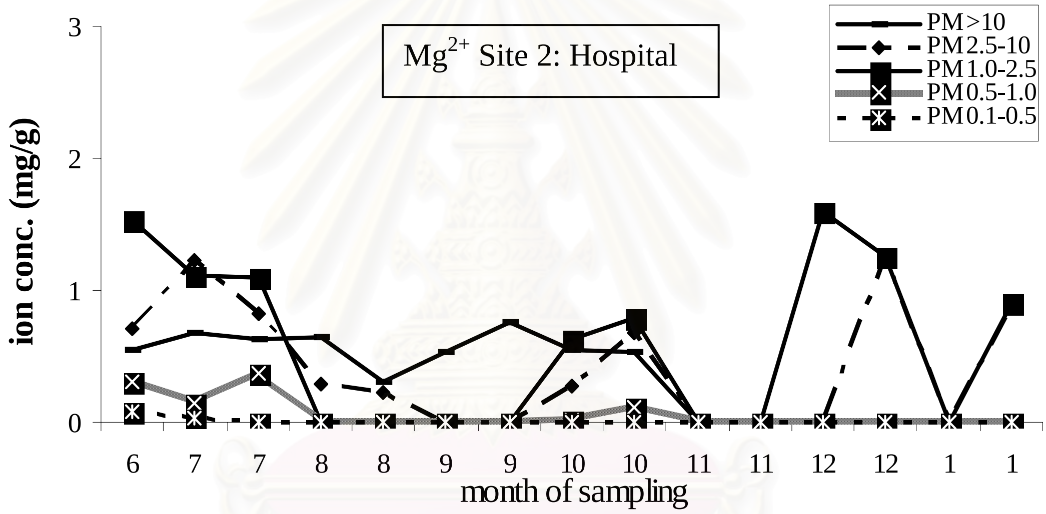


Figure 4.25 Comparison of Na^+ ions at the various size fractions at all sampling sites





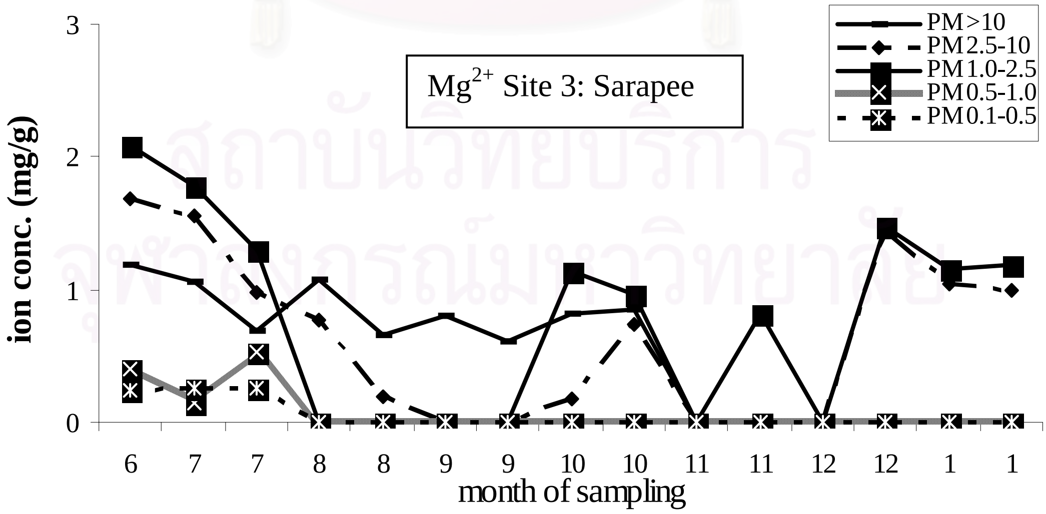


Figure 4.26 Comparison of Mg^{2+} ions at the various size fractions at all sampling sites

Figure 4.21-4.26 shows cation concentrations. To compare the cation species, the Ca^{2+} ion was found to be the most prevalent in the larger- sized fractions (PM>10 µm) and the fractions size of 2.5-10 and 1.0-2.5 µm, respectively. In addition, it can be seen that Ca^{2+} ions seem to remain unaffected by flooding in contrary to Cl^- ions. The highest concentration of Ca^{2+} ions was found during August and September, month of the wet season. The lines dropped from October onward, the flooding period, and did not rise after that period. Between the sampling sites, the Ca^{2+} ion was found to be the most dominant at the municipality hospital and Yuparaj School, but the pattern of the line was practically the same as Cl^- at all sampling sites This Ca^{2+} ion could be prevalent in the air because Ca^{2+} is the fifth element and the third most abundant metal in the earth's crust and it is used widely in many kinds of industry as well.

Figure 4.23 presents the NH_4^+ concentrations. Its concentration increased during the dry season and was prevalent in the fractions of 0.5-1.0, 1.0-2.5 and 0.1-0.5 micrometers, respectively. NH_4^+ emissions come from sources such as fertilizers and the combustion of fossil fuels, that's why there was a higher concentration at the hospital than others because of the activities in the outdoor market which is near the sampling site. The fermentation of organic waste or food waste causes strong smell there. Nevertheless, the trends of concentrations from the three different sites were generally the same.

Figure 4.24 presents the K^+ concentrations. Its concentration increased sharply in late of November at Yuparaj School. This might have been due to the Loy Kra-tong festival which was held on 15th -17th November 2005. During that day, the sampling was taken at the Yuparaj site and the main road was closed. People let off fireworks and firecrackers. On that day, the concentration of K^+ was about 4 times higher than that of other periods of the study. There was lot of soot on the PUF-10. This might have been from the firecrackers as well. Moreover, the ion was dominant in the small size fractions of 0.1-1.0 micrometers. To check the assumptions about K^+, we found that the firecrackers are composed of pyrotechnic powder, which contains potassium chlorate or potassium perchlorate. Figure 4.19 was considered again. It shows that during late of November, the Cl^- concentration sharply increased in all size fractions, especially the small fractions of 0.1-0.5 and 0.5-1.0 micrometers. These could be supported the assumption that both K^+ and Cl^-, increased due to the use of the firecrackers and fireworks during the Loy kra-tong festival.

Figure 4.25 presents the Na^+ concentrations. Where comparing its concentrations at the three sampling sites, a bit of a different trend was noticed, but it was similarity prevalent in the largest size fractions of PM>10 micrometers.

Figure 4.26 presentsthe Mg^{2+} concentrations. It was found to be prevalent at the size fraction of 1.0-2.5 micrometers at all the sampling sites and also decreased during the flooding period.

The study of the cations found that Ca^{2+} and Na^+ were prevalent in PM>10 micrometers while NH_4^+ K^+ and Mg^{2+} were prevalent in the smaller fractions of 0.1-2.5 micrometers. For the most part, changes in the cation concentrations at the three sites from the wet season to the dry season were similar, except, for when there was a high loading of activity or extreme events near the sampling site, such as a big festival, street event or construction activity. These events caused differences in the concentrations of the PM and also its compositions.

4.2.2 Metals Concentrations

During this study period**,** some samples from the field were chosen for investigation for their metal compositions at the various size fractions. During the wet season, the highest concentration of PM from each sampling sites were chosen for investigation. During the dry season, all samples were analyzed. A 22 metal mixed-standard was used to identify and quantify the metals. The mixed-standard contained Ag, Al, B, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, In, K, Li, Mg, Mn, Na, Pb, Sr, Ti and Zn. This data only contains the metals that could be detected by the ICP device. In this study, 14 metals were detected by the device: Al, B, Ba, Ca, Fe, K, Li, Mg, Mn, Na, Pb, Sr, Ti and Zn.

The statistical summary of the daily summed metal concentrations is shown in Table 4.10 in the same manner of the ion analysis, as unit of milligram of metal per 1 gram of PM.

From the value of the mean concentrations of the metals found in this study, it can be seen that most of the metal's maximum values were found in $PM_{2.5-10}$ at the three sampling sites: 165.11 mg/g, 170.49 mg/g and 135.04 mg/g for Yuparaj School, municipality hospital and district office of Sarapee, respectively.

Metal concentrations in fraction size 1 and size 2 were relatively similar and for fine PM (particles in fraction sizes 3, 4 and 5), the concentration of the metals was relatively low, as shown in the table. The standard variation of sampling site 2 varied more than the other sites and this site also had the highest metal concentrations for all particle sizes. This might have been due to the high level of activity near the sampling site; for example the Municipality Hospital is located downtown where there are many kinds of activities that can generate PM and lead to no significances difference in the pollutant concentrations among the different size fractions.

Table 4.10 Statistical summary of summed daily metal concentrations at the various size fractions (mg.metal/g.PM) during the study

		Site1: Yuparaj	**Site2: Hospital**	**Site 3:Sarapee**
Size 1 **(PM>10)**	**Mean**	113.64	147.59	118.23
	STDEV.	45.60	68.73	49.70
	Maximum	187.50	208.04	192.22
	Minimum	37.97	29.82	48.15
Size 2 **(PM$_{2.5-10}$)**	**Mean**	165.11	170.49	135.04
	STDEV.	37.17	58.12	35.05
	Maximum	229.13	259.88	182.09
	Minimum	101.48	55.53	65.97
Size 3 **(PM$_{1.0-2.5}$)**	**Mean**	47.54	53.55	31.22
	STDEV.	19.62	24.40	13.51
	Maximum	85.70	102.74	60.40
	Minimum	25.84	26.50	17.56
Size 4 **(PM$_{0.5-1.0)}$**	**Mean**	9.26	12.98	5.38
	STDEV.	5.97	19.20	3.47
	Maximum	22.72	62.75	11.63
	Minimum	4.21	2.69	1.87
Size 5 **(PM$_{0.1-0.5}$)**	**Mean**	9.55	16.57	12.68
	STDEV.	10.63	37.46	11.12
	Maximum	35.93	116.09	28.81
	Minimum	1.29	0.26	0.82

Note: the number of sample for metals analysis is 135

Figure 4.27 presents the percent proportion of summed metals which can be extracted from the PUF collected during dry season. The study found that the summed metals from all of the sampling sites were associated with the size-fractioned samples as shown. 44% of the summed metals were found in coarse particles while only 20% of the summed metals were found in fine particulate matter. 36% were found in particulate size fractions of more than 10 µm.

The study shows that metals mostly attach with the larger sized PM fractions, while ions were mostly found with the smaller sized fractions

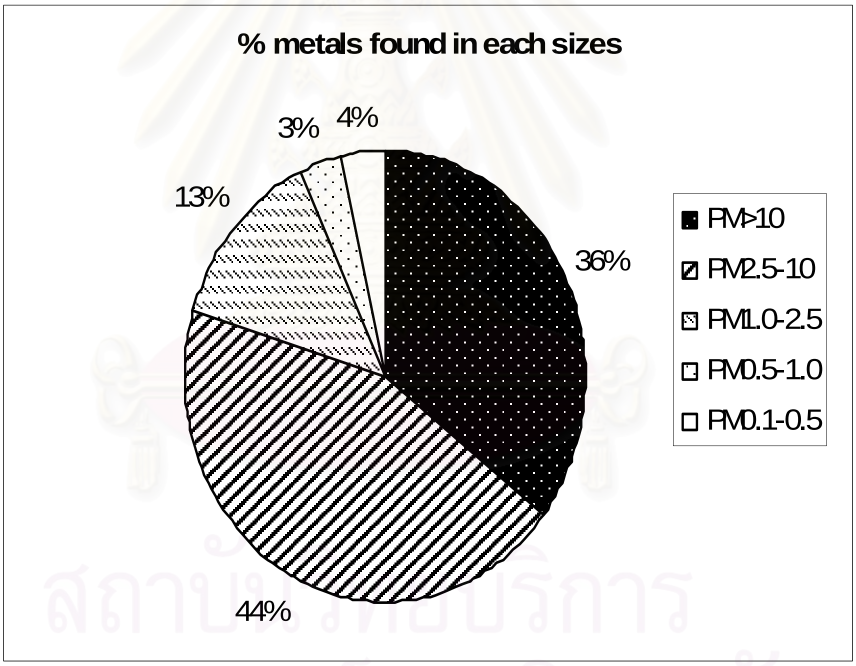


Figure 4.27 Summed daily metal concentrations at the various size fractions (mg/g) across the dry period

The individual daily metal averages of the sampling sites during the dry period are presented in Figure 4.28. From the figure, it can be seen that Ca was become the most prevalent metal species in the Chiang Mai’s ambient air observed in the study.

The highest concentration was found at the municipality hospital. This result was the same for Ca^{2+} which was the most dominant cation species and also found in the highest concentration at the municipality hospital. Other dominant metals species which were dominant in Chiang Mai's ambient air were Al, Fe, K, Mg, Na, B and Zn, respectively. Higher concentrations of pollutants were found in town, at sites 1 and 2, than at the Sarapee site.

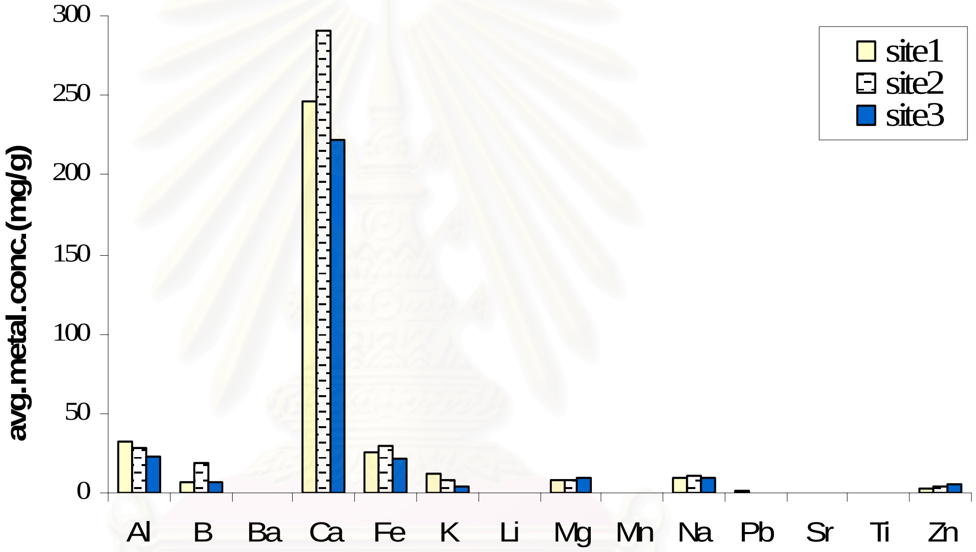


Figure 4.28 The ambient profiles of the metals at the three sampling sites across the dry period.

Metals from the three sampling sites were compared between each size range in Figures 4.29-4.42. Figure 4.29 presents the Al metal concentrations. It was contained mostly in coarse PM (PM2.5-10 micrometers) at the three sampling sites. Since the metals have been analyzed in the dry season, the line of concentration of the graph did not change much.

Other metals, which are presented in Figures 4.30-4.42, were mostly contained in the larger size fractions of coarse particle and PM>10 micrometers, such as Ca, Ba, Fe, Li, Mg, K, Sr and Zn. Some became most prevalent in the small sized PM fractions, such as B, Mn, Pb and Ti.

The pattern of lines for each size fraction was a bit different between the sampling sites. The district office of Sarapee always had lower concentrations of metals than the other two sites, which were located in the town. This confirms that of the activities in the town generate more metals than those of the rural area. However, none of the metals exceed the limit of the OSHA, mentioned in Chapter II.

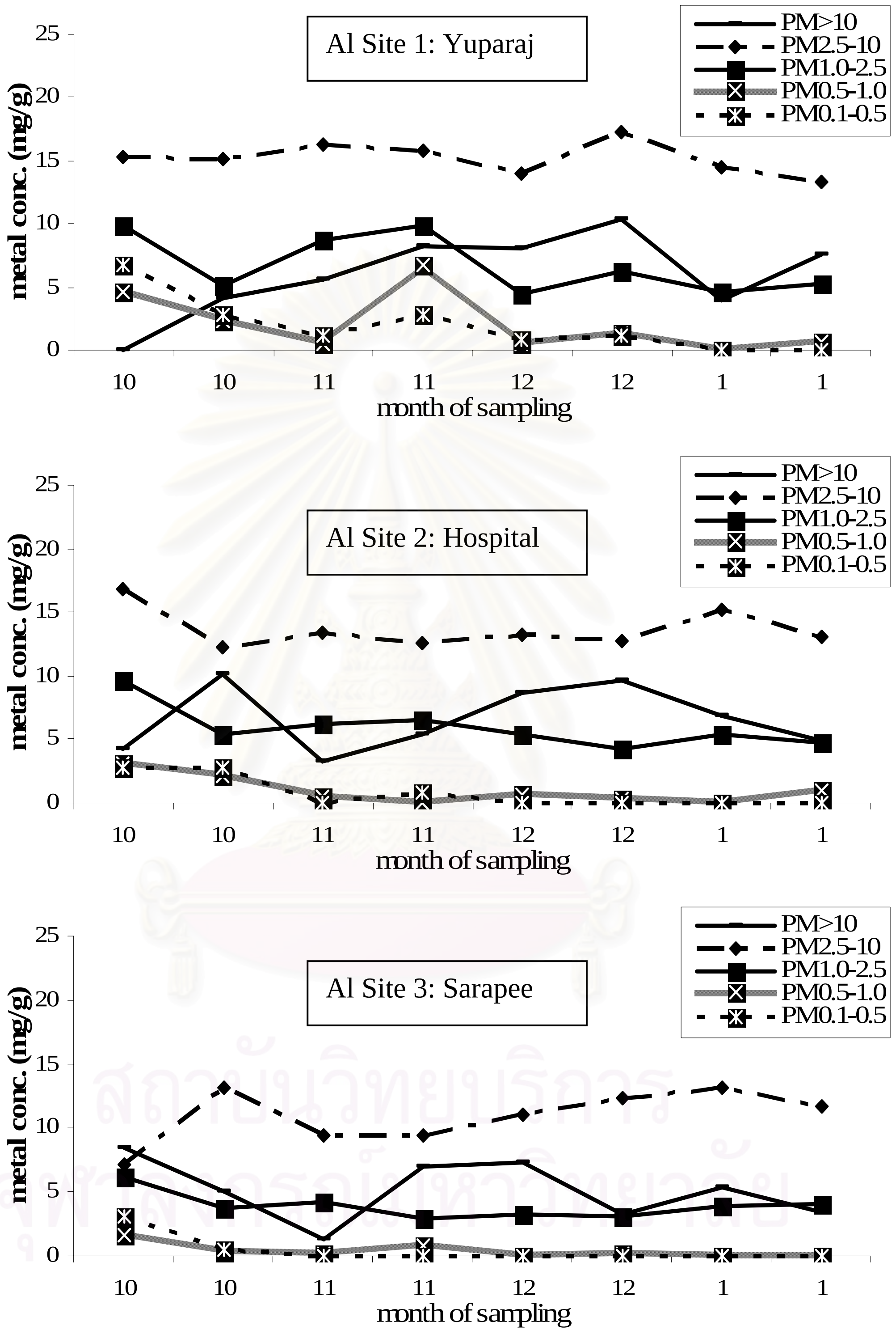


Figure 4.29 Comparison of Al concentrations at various size fractions at all sampling sites.

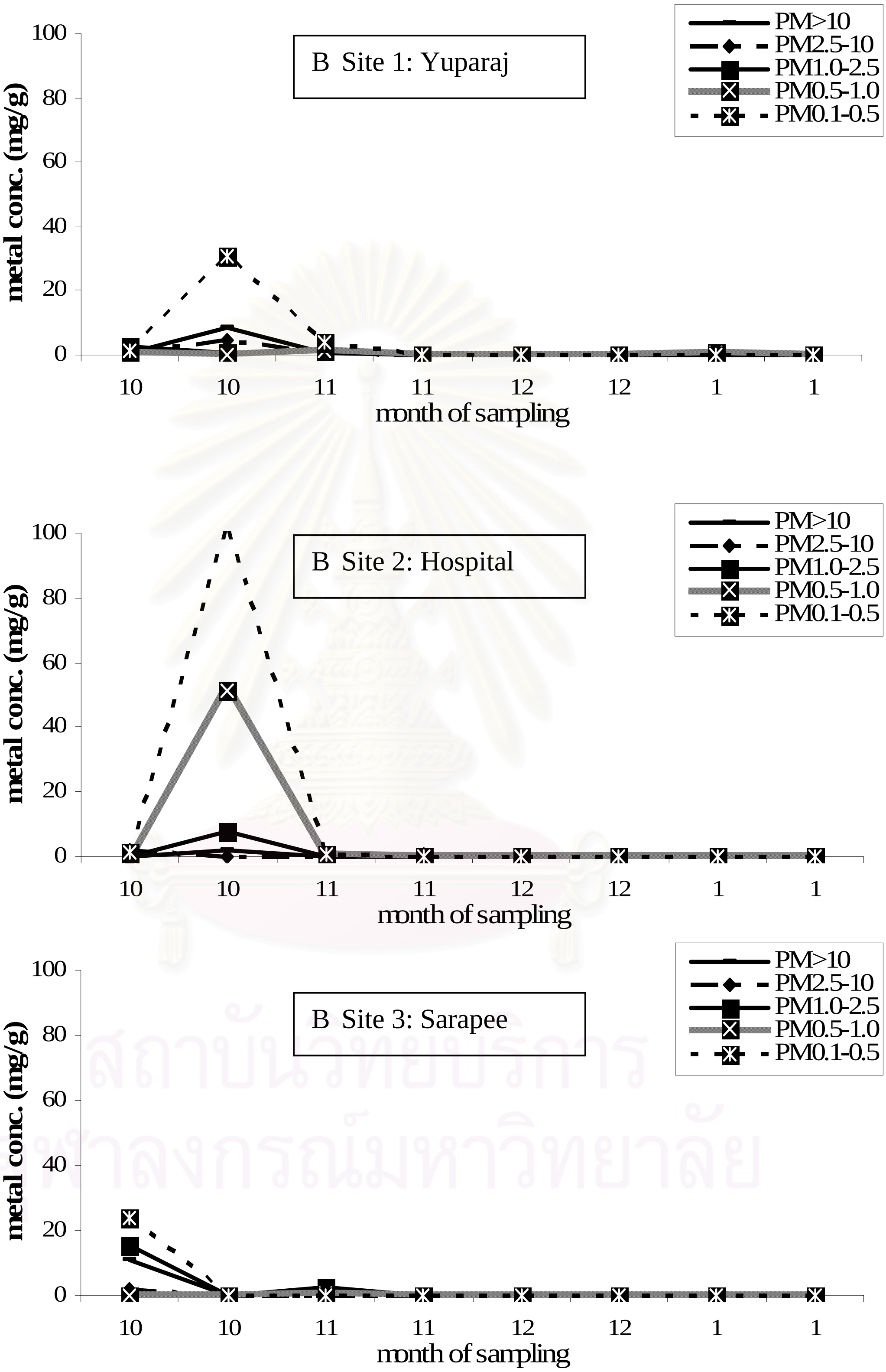


Figure 4.30 Comparison of B concentrations at various size fractions at all sampling sites.

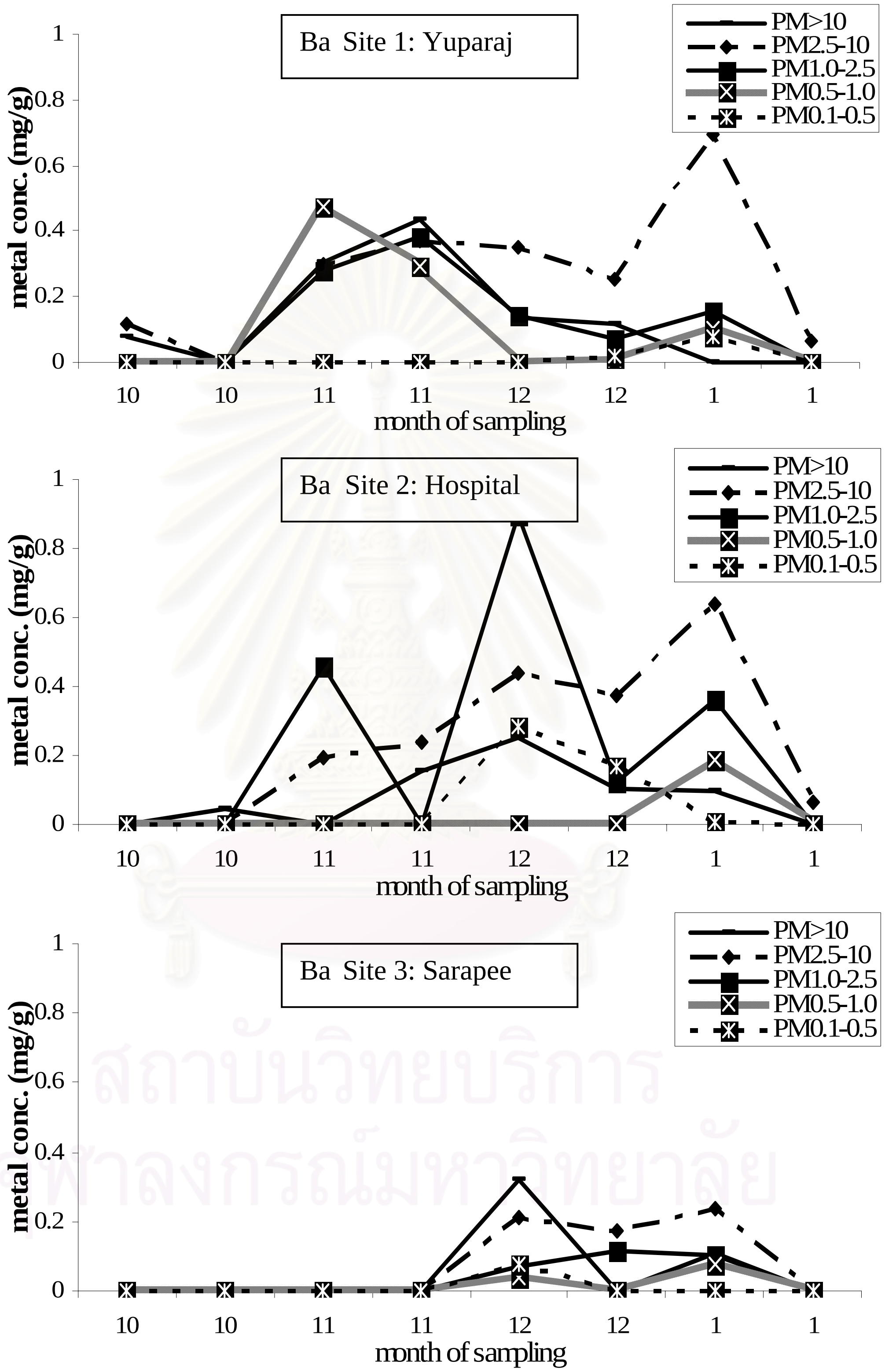


Figure 4.31 Comparison of Ba concentrations at various size fractions at all sampling sites.

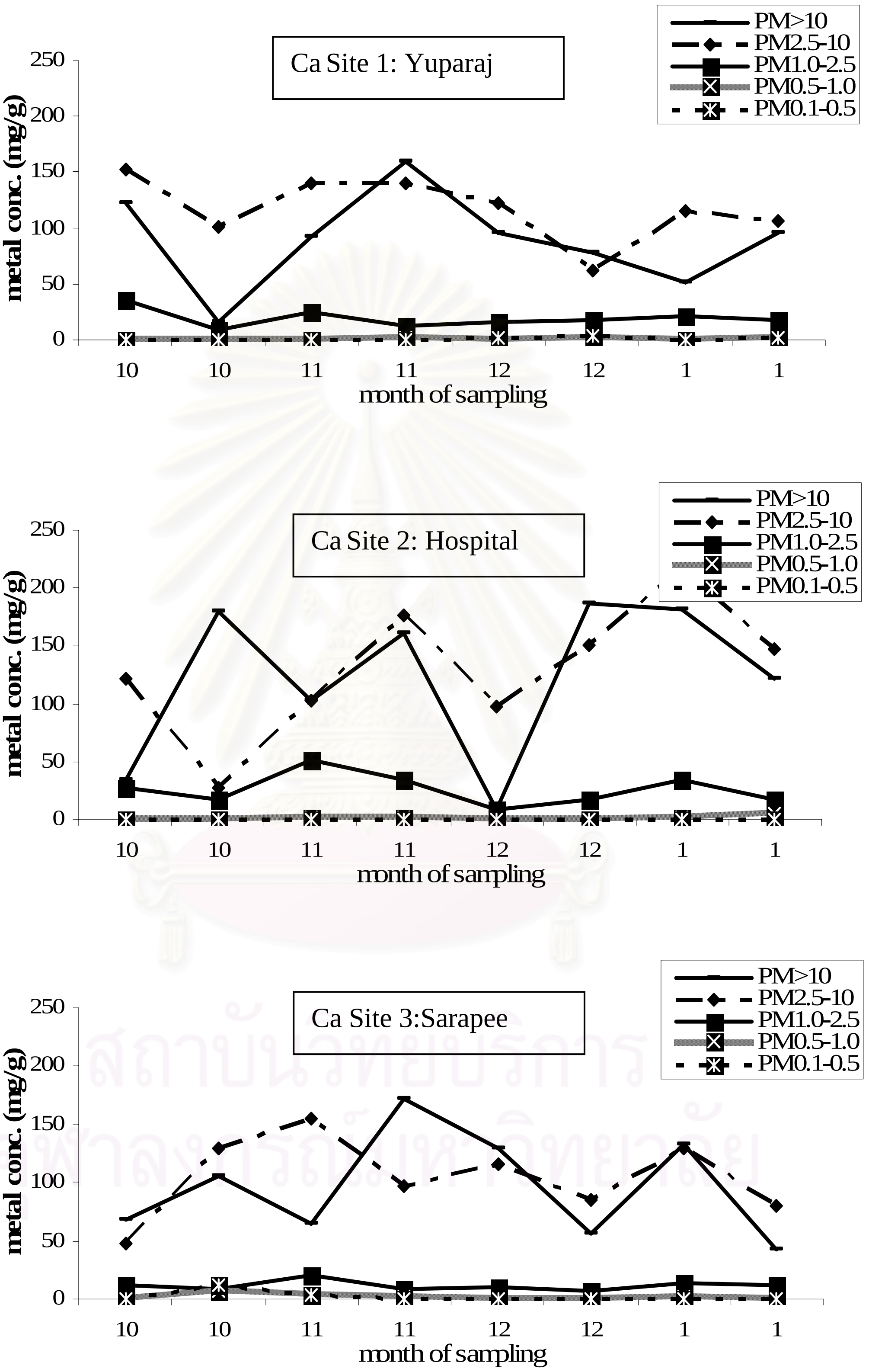


Figure 4.32 Comparison of Ca concentrations at various size fractions at all sampling sites.

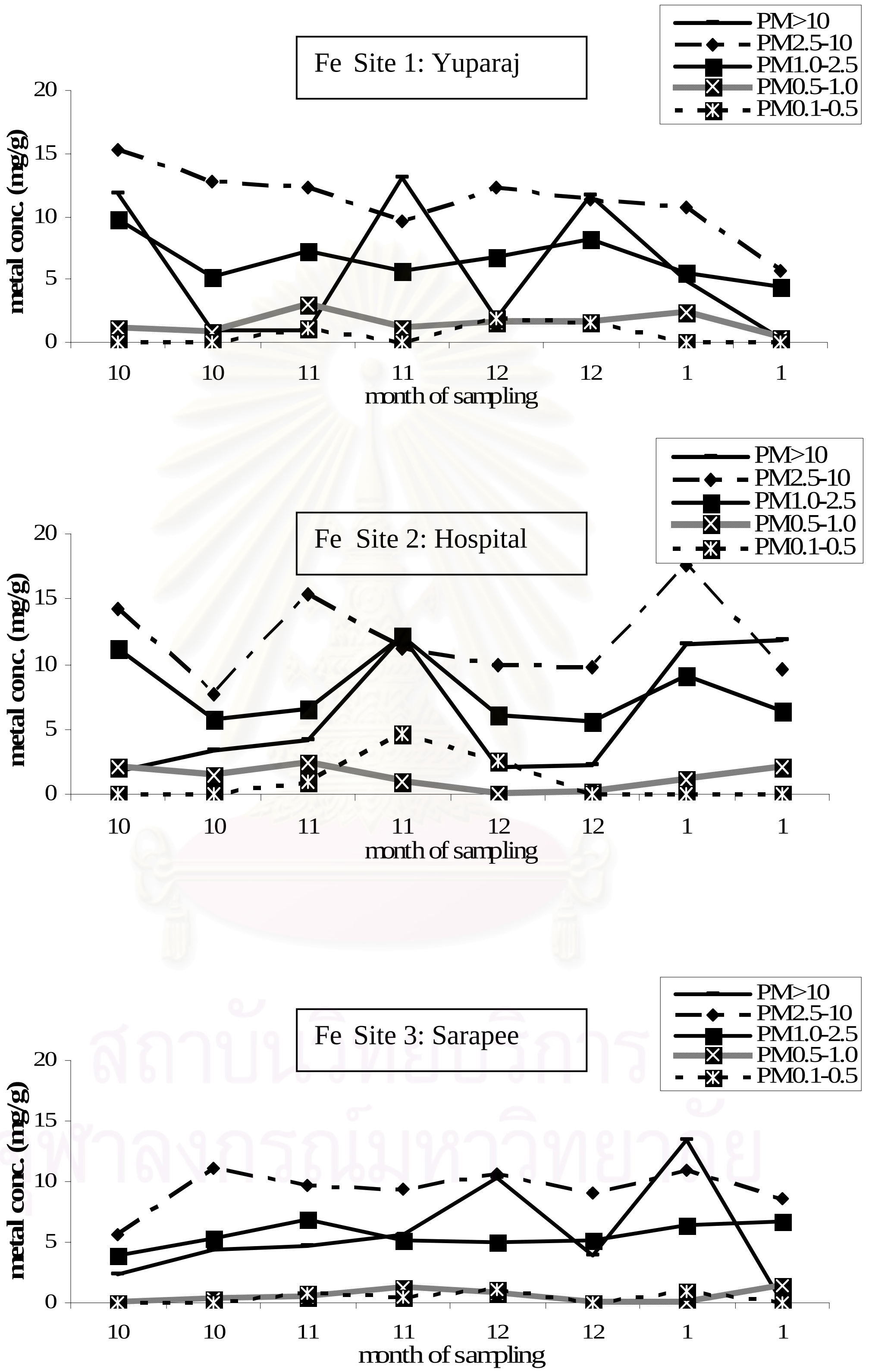


Figure 4.33 Comparison of Fe concentrations at various size fractions at all sampling sites.

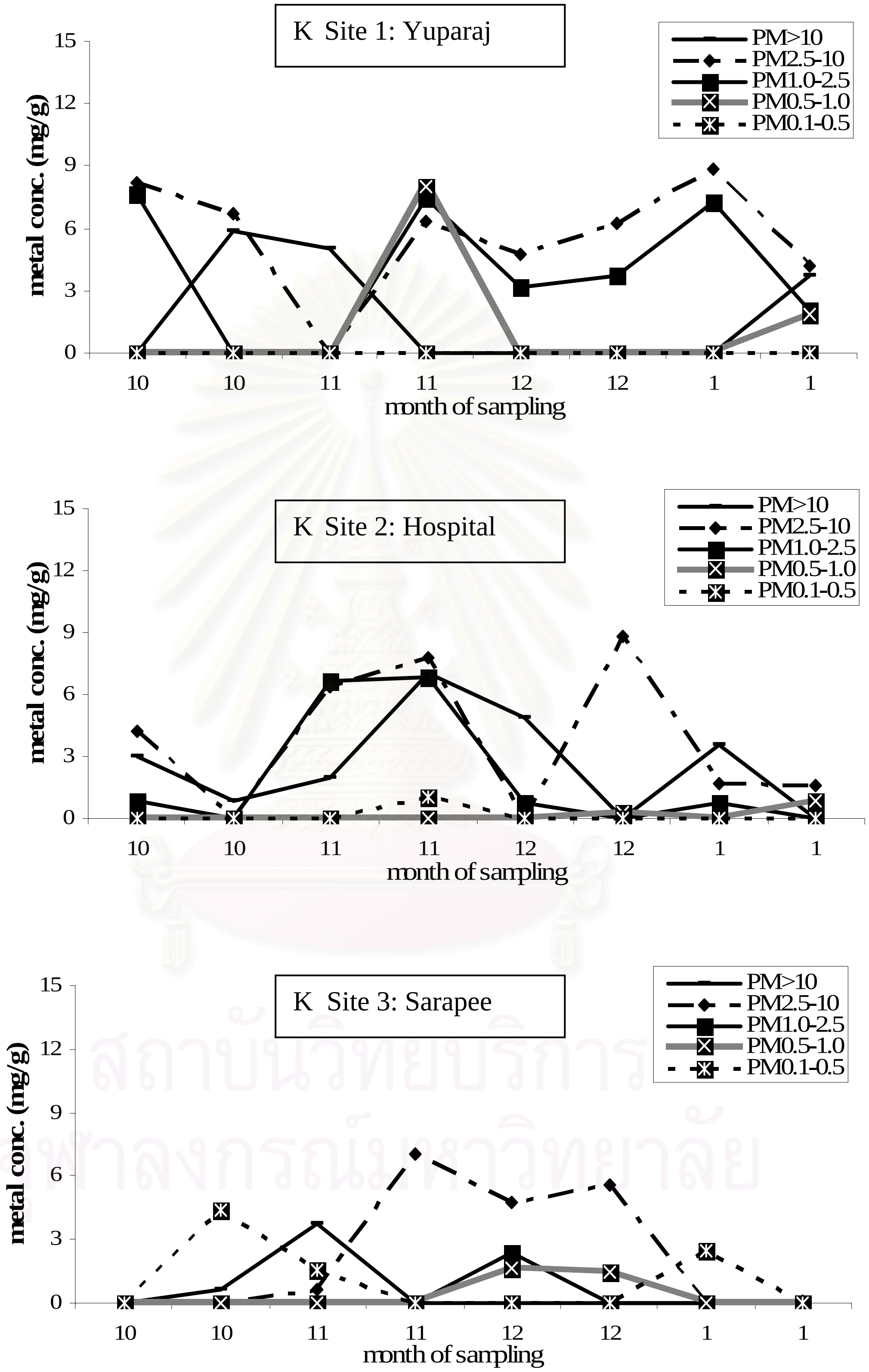


Figure 4.34 Comparison of K concentrations at various size fractions at all sampling sites.

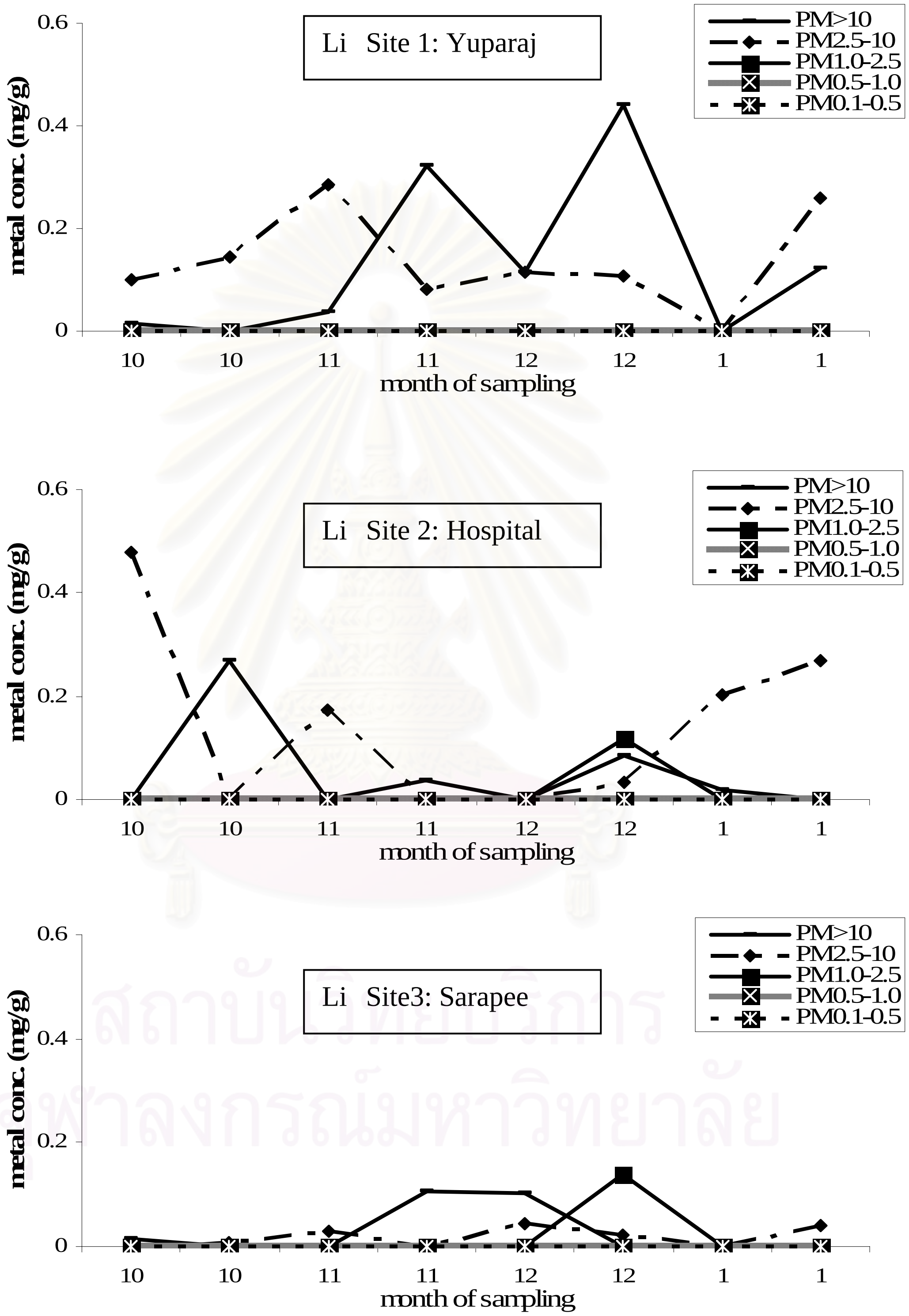


Figure 4.35 Comparison of Li concentrations at various size fractions at all sampling sites.

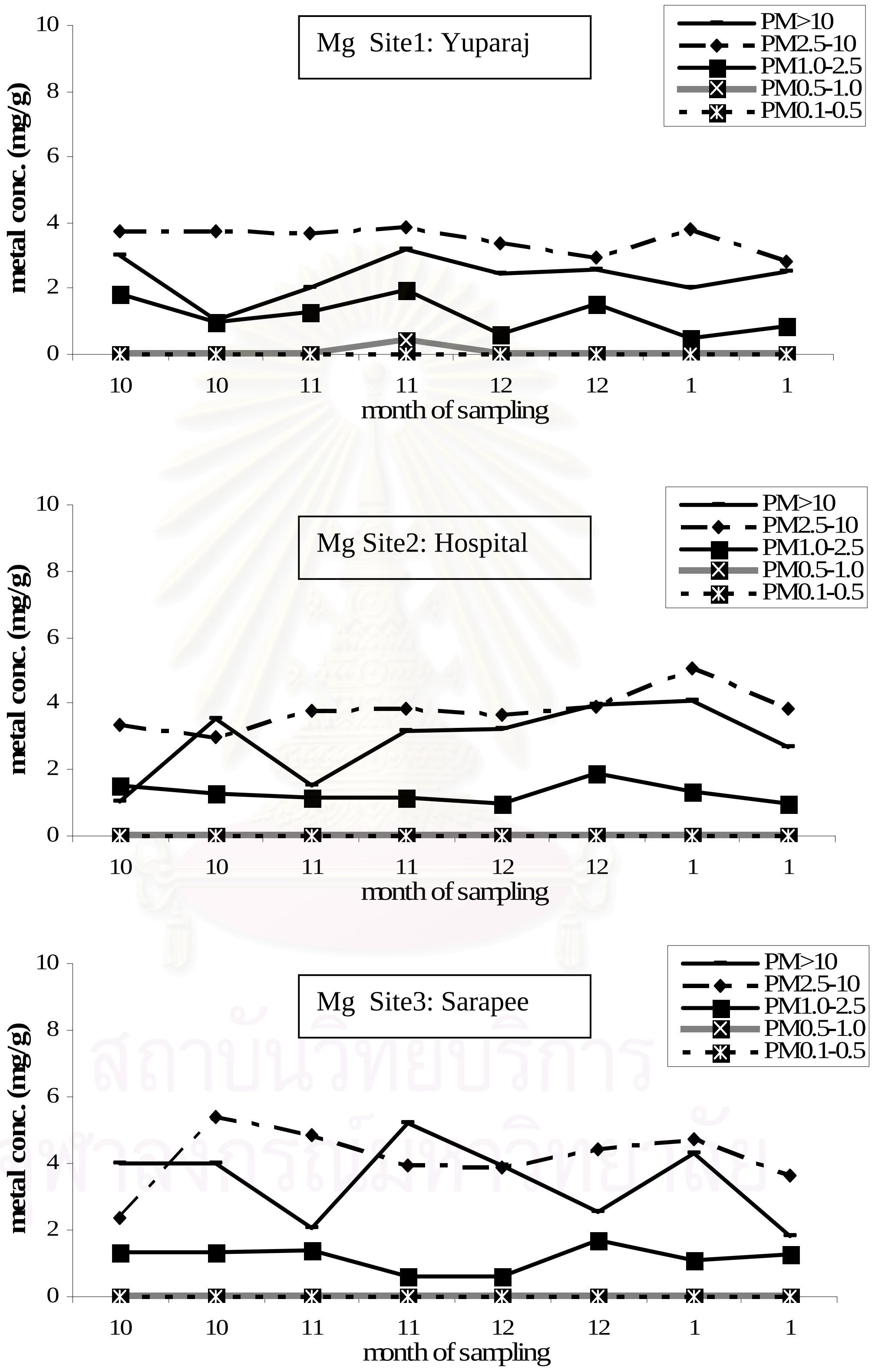


Figure 4.36 Comparison of Mg concentrations at various size fractions at all sampling sites.

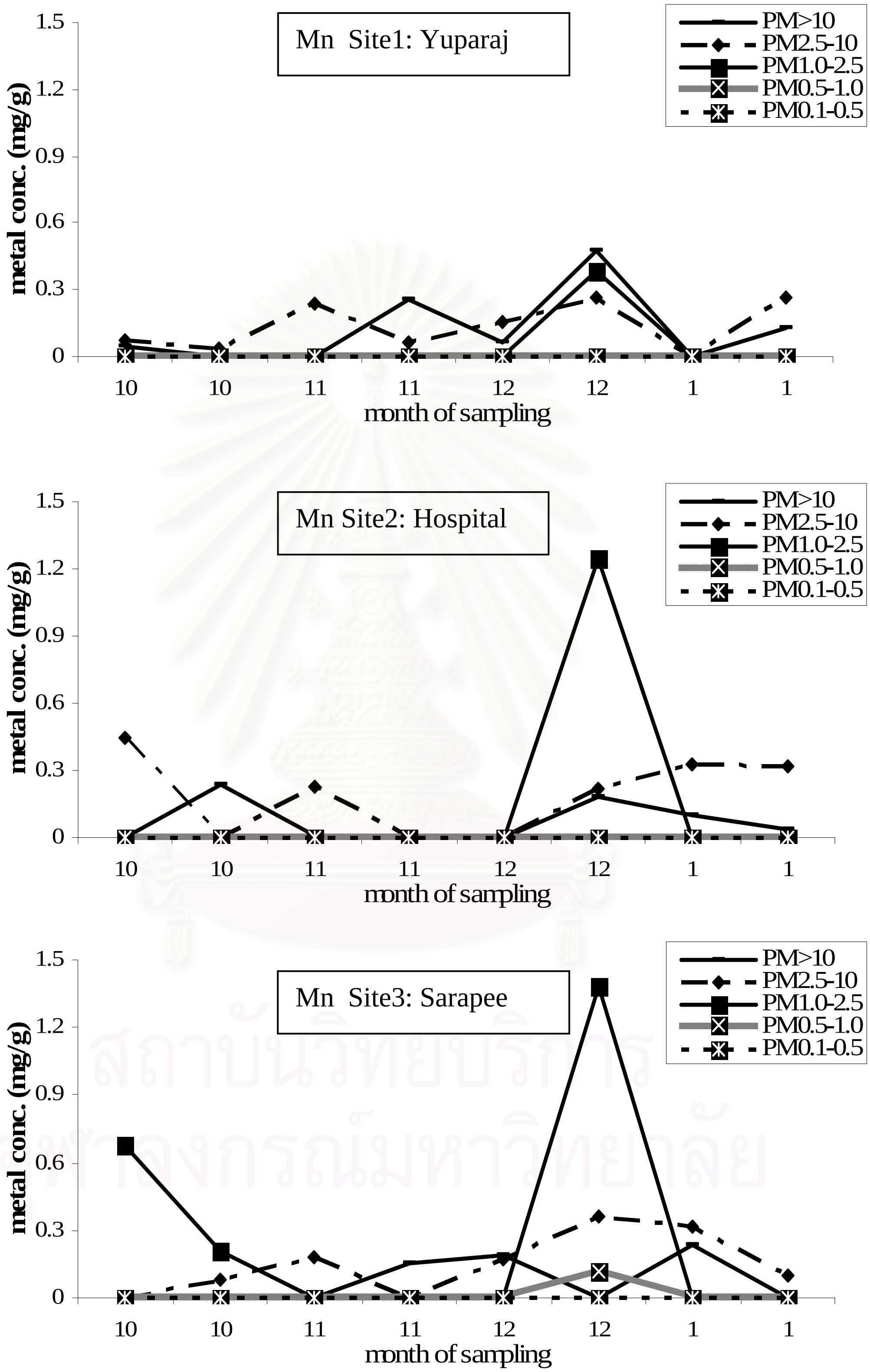


Figure 4.37 Comparison of Mn concentrations at various size fractions at all sampling sites.

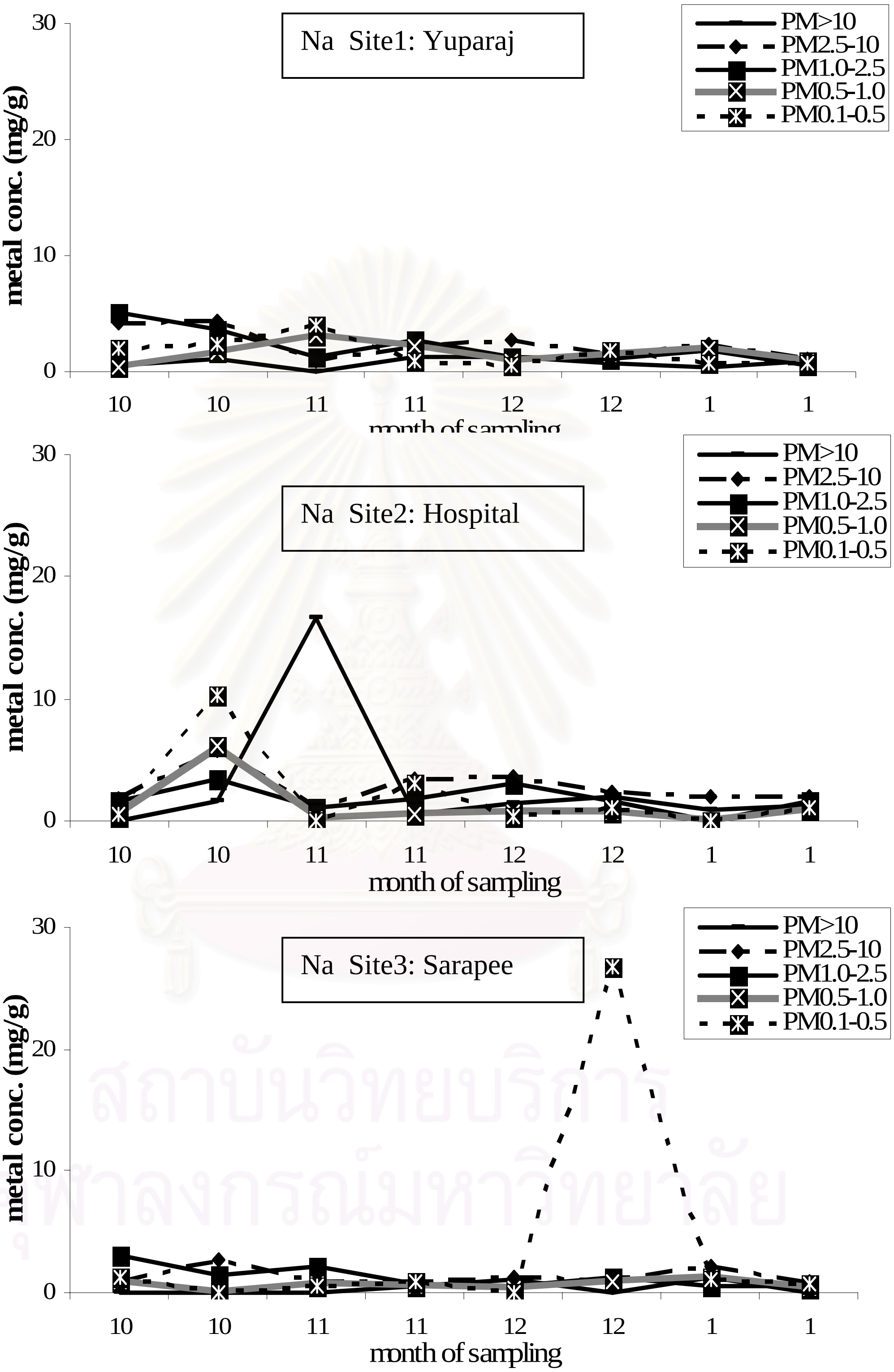


Figure 4.38 Comparison of Na concentrations at various size fractions at all sampling sites

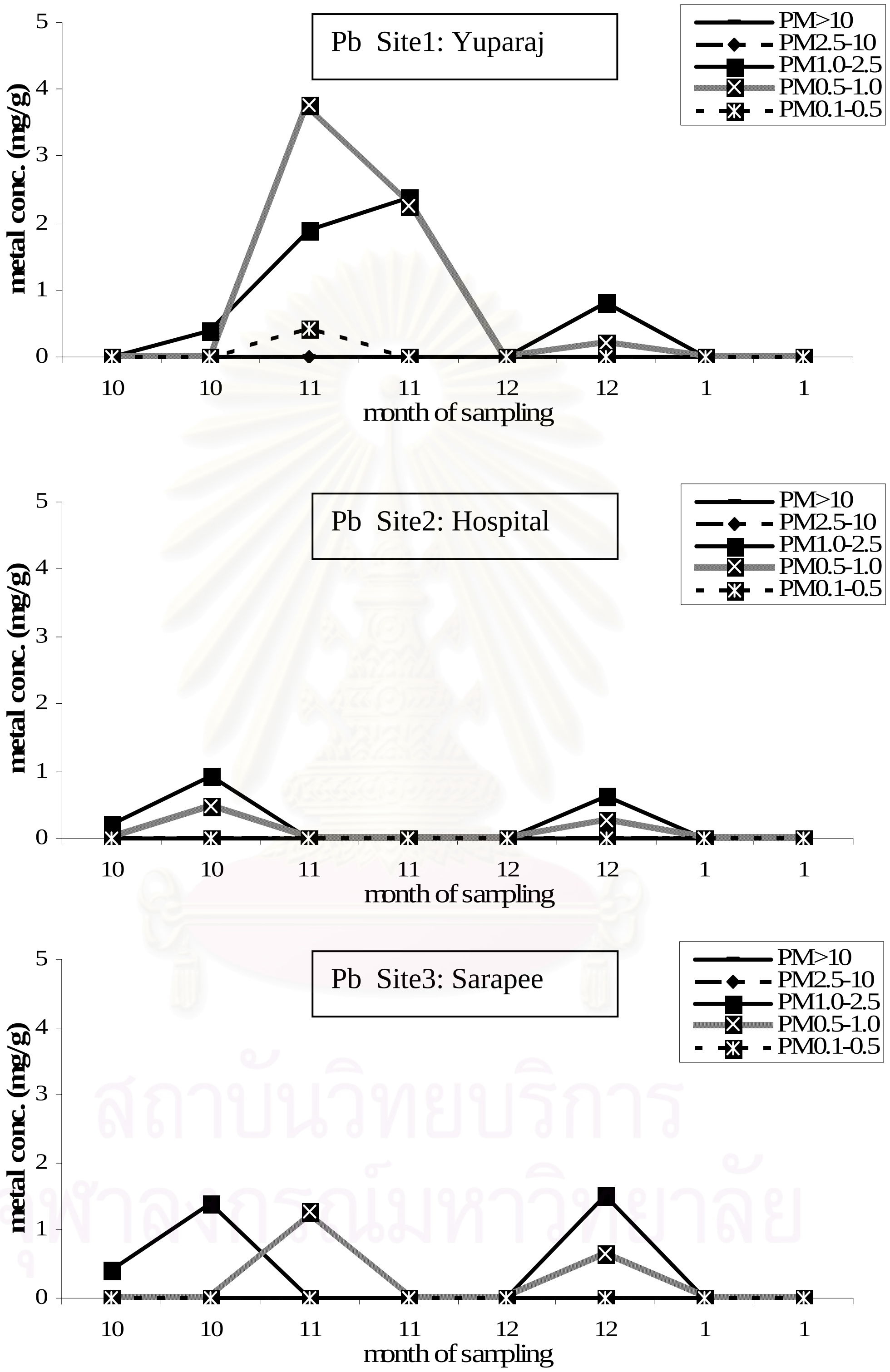
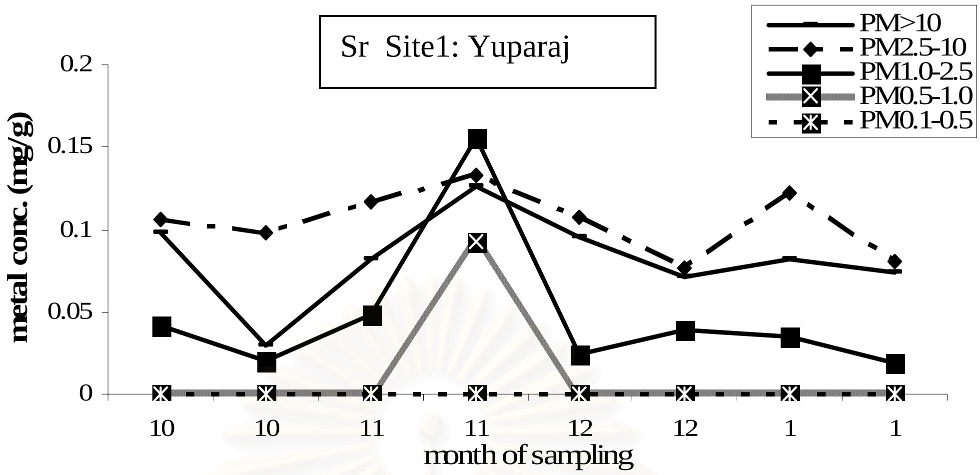
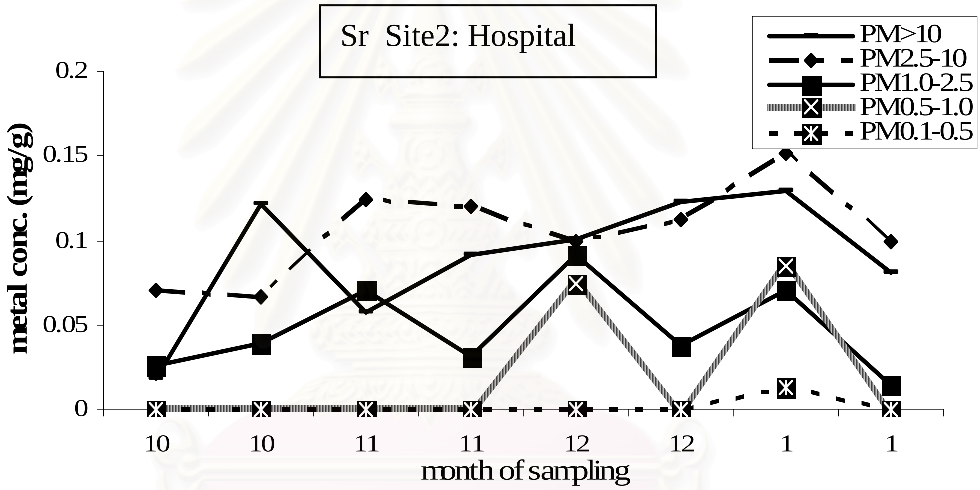


Figure 4.39 Comparison of Pb concentrations at various size fractions at all sampling sites





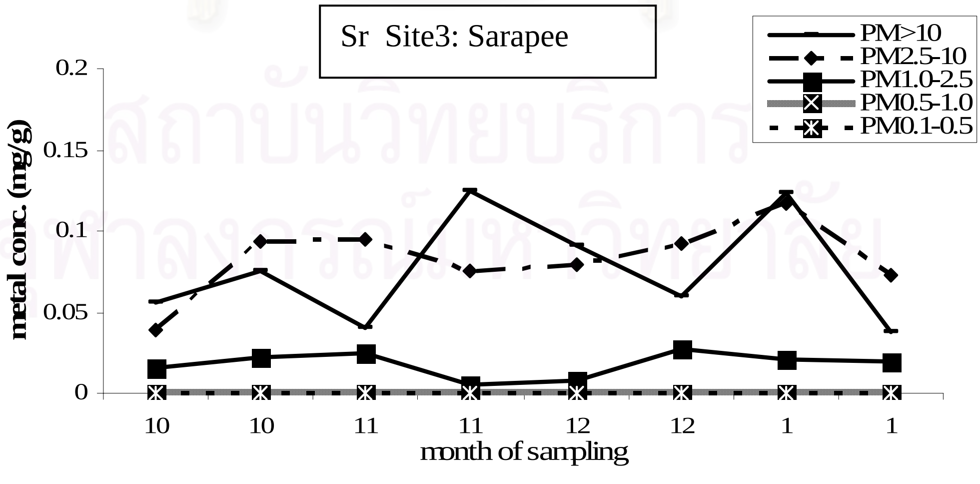


Figure 4.40 Comparison of Sr concentrations at various size fractions at all sampling sites

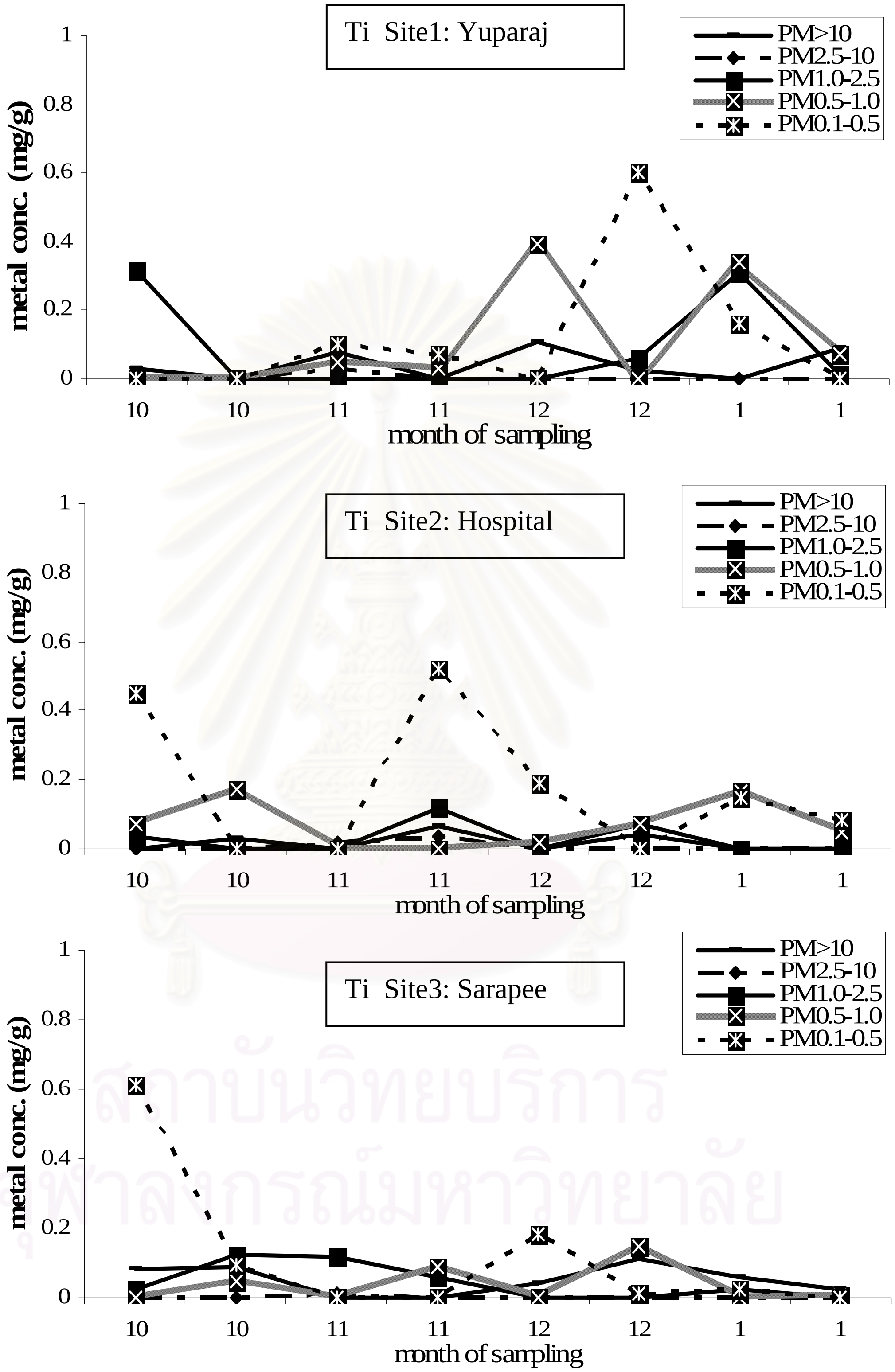


Figure 4.41 Comparison of Ti concentrations at various size fractions at all sampling sites

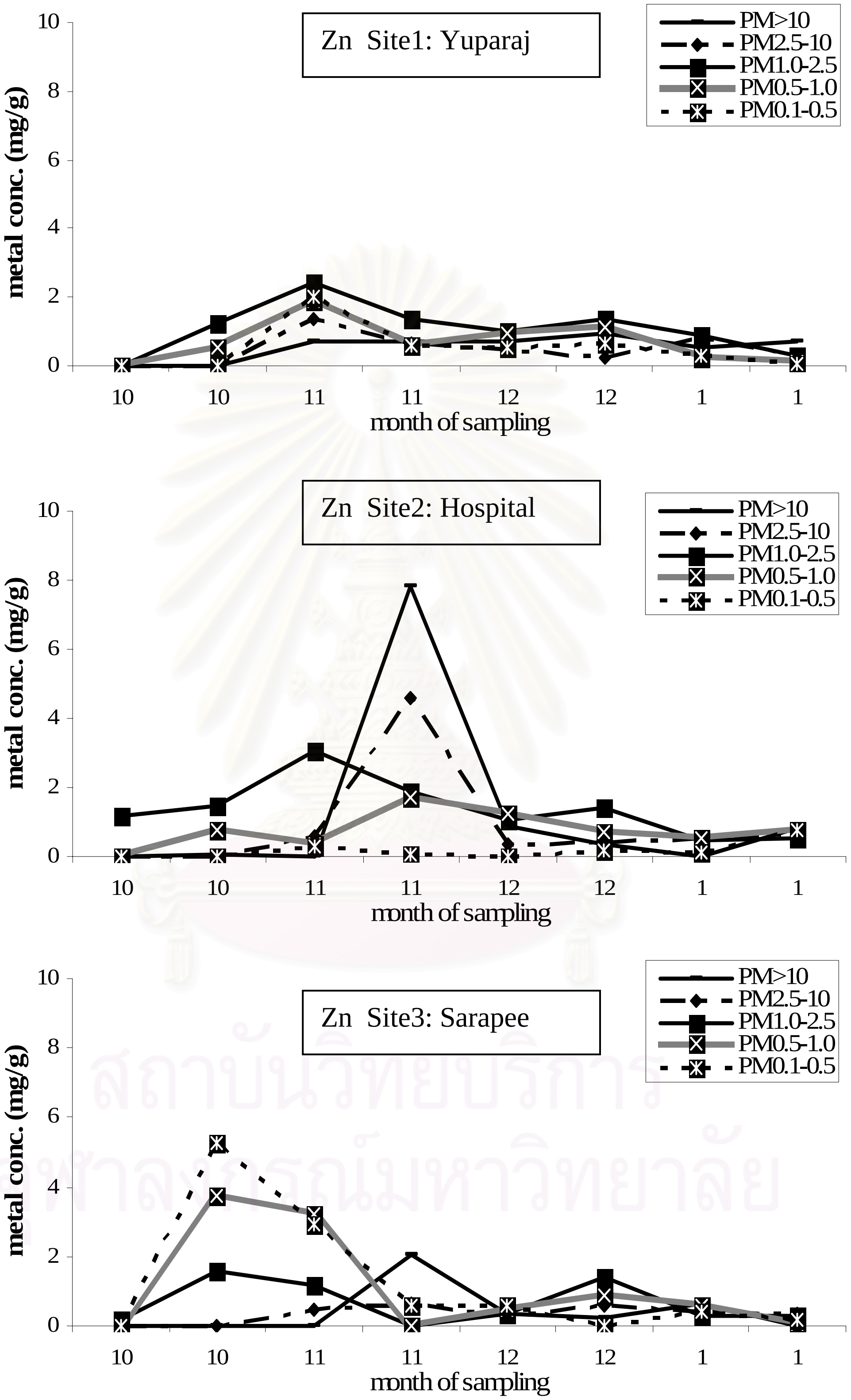


Figure 4.42 Comparison of Zn concentrations at various size fractions at all sampling sites

4.3 Relationship of Particulate Matter at Various Size fractions with Sampling Sites and Temporal Variations

4.3.1 Correlation of PM at various size fractions

The Pearson Product Moment Correlation Coefficient was used to compare the relationship between each size fraction of PM. When the normality assumption was taken, Table 4.11 shows the correlation between each size of PM by Pearson's correlation. The concentration of each size fraction was combined with the PM concentrations of the three sampling sites with ignorance of duration variations.

From Table 4.11 the coefficient (in the row of the Pearson Correlation) was relatively high for all pairs of particle size fractions. Higher coefficient values indicated more relationship between the particles sizes. For example PM size fractions of larger than 10 µm had a greater correlation with PM size fractions of 2.5-10 micrometers than with PM sizes fraction of 1.0-0.5 micrometers with the correlation coefficients of 0.791 and 0.409, respectively ($r= 0.791, 0.409: p<0.05$). The statistical significances for all pairs were less than 0.05. The table also shows that PM_{10} had a high correlation with the PM_{total} or it can be termed as SFPM (summed size-fractionated PM) with r = 0.958. Other fractions, 2.5-10, >10, 1.0-2.5, 0.5-1.0 and 0.1-0.5, correlated with the SFPM at the value of r = 0.840, 0.877, 0.775, 0.745 and 0.724, respectively.

Table 4.11 Correlation between the various sizes of PM

Correlations

		PM>10	PM2.5-10	PM1.0-2.5	PM0.5-1.0	PM0.1-0.5	PMtotal	PM10	PM2.5
PM>10	Pearson Correlation	1	.791**	.409**	.353*	.370*	.840**	.649**	.406**
	Sig. (2-tailed)	.	.000	.005	.017	.012	.000	.000	.006
	N	45	45	45	45	45	45	45	45
PM2.5-10	Pearson Correlation	.791**	1	.498**	.429**	.475**	.877**	.811**	.499**
	Sig. (2-tailed)	.000	.	.000	.003	.001	.000	.000	.000
	N	45	45	45	45	45	45	45	45
PM1.0-2.5	Pearson Correlation	.409**	.498**	1	.857**	.699**	.775**	.871**	.940**
	Sig. (2-tailed)	.005	.000	.	.000	.000	.000	.000	.000
	N	45	45	45	45	45	45	45	45
PM0.5-1.0	Pearson Correlation	.353*	.429**	.857**	1	.869**	.745**	.859**	.971**
	Sig. (2-tailed)	.017	.003	.000	.	.000	.000	.000	.000
	N	45	45	45	45	45	45	45	45
PM0.1-0.5	Pearson Correlation	.370*	.475**	.699**	.869**	1	.724**	.820**	.881**
	Sig. (2-tailed)	.012	.001	.000	.000	.	.000	.000	.000
	N	45	45	45	45	45	45	45	45
PMtotal	Pearson Correlation	.840**	.877**	.775**	.745**	.724**	1	.958**	.803**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.000	.000
	N	45	45	45	45	45	45	45	45
PM10	Pearson Correlation	.649**	.811**	.871**	.859**	.820**	.958**	1	.912**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.	.000
	N	45	45	45	45	45	45	45	45
PM2.5	Pearson Correlation	.406**	.499**	.940**	.971**	.881**	.803**	.912**	1
	Sig. (2-tailed)	.006	.000	.000	.000	.000	.000	.000	.
	N	45	45	45	45	45	45	45	45

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Since a very respectable correlation between PM_{10} and the SFPM was observed (Pearson r = 0.958, n = 45), Figure 4.43 is an example of a PM scatter diagram that shows for showing the correlation between PM_{10} and SFPM. The linear regression of SFPM and PM_{10} can be formulated as y = 1.344x+7.511, where y = the SFPM concentration and x = the PM_{10} concentration. From the correlation graph, R^2 = 0.917. This suggests that about 92% of the variation in the SFPM can be explained by the variations in PM_{10}.

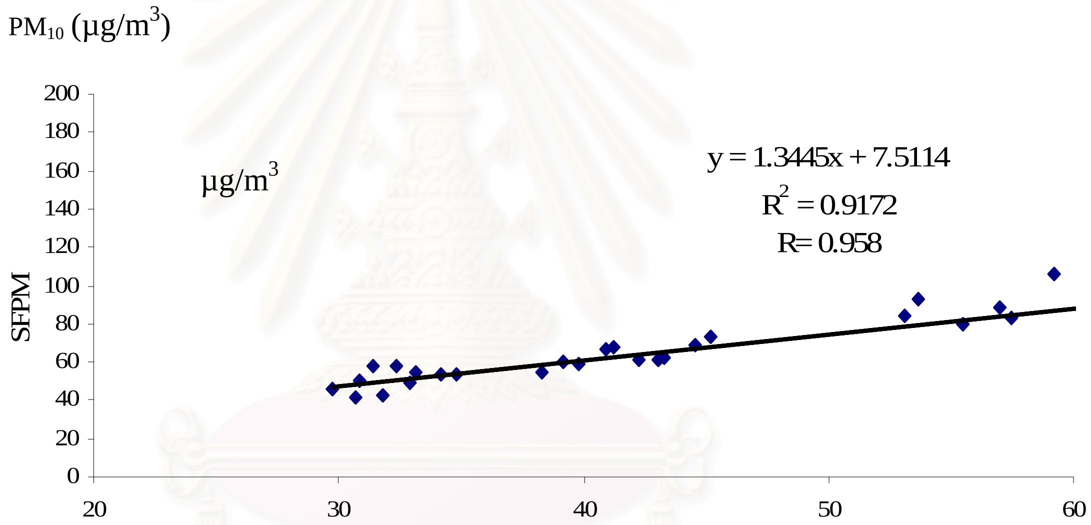


Figure 4.43 Scatter diagram of the correlation between PM_{10} and the SFPM at the three sampling sites in Chiang Mai.

4.3.2 Comparison of the size-fractionated particulate matter and the sampling sites

One way-ANOVA (analysis of variance between groups) was the statistical method used in the study to compare the way the variation of each size of PM was related by the sampling site and temporal variations.

Table 4.12 shows the description of mean concentration, standard deviation, standard error, maximum concentration, minimum concentration and the number of samples (N) for all size fractions of the sample compared by sampling sites.

Table 4.12 Statistical summary of different fractions of PM concentrations among the sampling sites

		N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
PMtotal	**Yuparaj**	15	74.564	21.478	5.546	42.680	107.700
	Hospital	15	88.905	36.427	9.405	50.800	182.370
	Sarapee	15	85.690	29.294	7.564	41.970	125.030
	Total	45	83.053	29.675	4.424	41.970	182.370
PM10	**Yuparaj**	15	48.683	14.364	3.709	29.740	79.380
	Hospital	15	58.884	24.151	6.236	30.870	109.800
	Sarapee	15	60.993	22.846	5.899	30.710	92.940
	Total	45	56.187	21.139	3.151	29.740	109.800
PM2.5	**Yuparaj**	15	25.618	9.470	2.445	14.140	44.050
	Hospital	15	31.405	13.872	3.582	13.870	63.550
	Sarapee	15	37.148	16.925	4.370	18.110	68.260
	Total	45	31.390	14.268	2.127	13.870	68.260
PM>10	**Yuparaj**	15	25.881	9.559	2.468	10.910	46.380
	Hospital	15	30.021	14.668	3.787	18.110	72.570
	Sarapee	15	24.697	8.513	2.198	11.260	39.190
	Total	45	26.866	11.221	1.673	10.910	72.570
PM2.5-10	**Yuparaj**	15	23.065	6.461	1.668	13.680	35.330
	Hospital	15	27.479	13.730	3.545	14.960	66.940
	Sarapee	15	23.845	8.576	2.214	10.450	36.720
	Total	45	24.797	10.022	1.494	10.450	66.940
PM1.0-2.5	**Yuparaj**	15	11.283	3.809	.983	5.900	17.910
	Hospital	15	13.907	6.978	1.802	6.000	28.830
	Sarapee	15	15.633	7.470	1.929	7.000	32.070
	Total	45	13.608	6.414	.956	5.900	32.070
PM0.5-1.0	**Yuparaj**	15	8.224	3.600	.929	2.820	15.350
	Hospital	15	10.428	4.971	1.284	4.060	21.210
	Sarapee	15	13.195	6.369	1.644	5.690	23.690
	Total	45	10.616	5.397	.804	2.820	23.690
PM0.1-0.5	**Yuparaj**	15	6.111	2.907	.751	3.930	13.920
	Hospital	15	7.070	2.947	.761	3.590	13.510
	Sarapee	15	8.319	4.075	1.052	4.170	15.520
	Total	45	7.167	3.402	.507	3.590	15.520

From this table, the mean concentrations were shown but could not determine the difference of the mean values. Thus, the ANOVA was used to define the difference as shown in Table 4.13.

Table 4.13 Relationship of PM concentrations on the sampling sites

		Sum of Squares	df	Mean Square	F	Sig.
PMtotal	Between Groups	1699.00	2	849.50	.963	.390
	Within Groups	37048.92	42	882.12		
	Total	38747.92	44			
PM10	Between Groups	1300.19	2	650.10	1.487	.238
	Within Groups	18361.55	42	437.18		
	Total	19661.75	44			
PM2.5	Between Groups	997.06	2	498.53	2.630	.084
	Within Groups	7960.12	42	189.53		
	Total	8957.18	44			
PM>10	Between Groups	234.50	2	117.25	.928	.403
	Within Groups	5305.84	42	126.33		
	Total	5540.34	44			
PM2.5-10	Between Groups	166.49	2	83.24	.822	.446
	Within Groups	4253.29	42	101.27		
	Total	4419.78	44			
PM1.0-2.5	Between Groups	143.93	2	71.96	1.814	.175
	Within Groups	1665.93	42	39.67		
	Total	1809.86	44			
PM0.5-1.0	Between Groups	186.15	2	93.07	3.569	.037
	Within Groups	1095.24	42	26.08		
	Total	1281.39	44			
PM0.1-0.5	Between Groups	36.80	2	18.40	1.636	.207
	Within Groups	472.45	42	11.25		
	Total	509.25	44			

The standard variations of the mean PM concentrations from each size fraction were compared with others among the same group of sampling site and then, they were compared with others in different groups. To reach the reliability 95% ($p<0.05$), the significance of F was considered. If the significance of F was less than 0.05, there was a difference in mean concentration of PM at the significance level of 0.05. From the table, only the PM size fraction of 0.5-1.0 has a significance level less than 0.05. It means sampling sites related the PM concentrations at the 0.5-1.0 micrometer-size fraction at the significance level of 0.05 ($F= 3.569$, $p<0.05$)

Table 4.14 shows the Post Hoc test the analysis of the mean of PM concentrations for each pair of sampling sites. The table shows the relation of the particulate size fraction of 0.5-1.0 micrometers. This size fraction was the only one that registered a significant difference among the sampling sites. The other fractions had no significance at the level of 0.05. From Table 4.14, the mean concentration of PM size fraction 0.5-1.0 µm from each pair of the sampling sites was compared. The mean difference shows how much of the difference on the mean concentration for each pair of sampling site. The minus sign shows that the mean concentration of site (I) is less than the mean concentration of site (J). For example; Yuparaj School has less $PM_{0.5-1.0}$ than the municipality hospital equal to 2.204. The significances of F, determined by the pairing of Yuparaj School and the district office of Sarapee was 0.038, which is less than 0.05. This means the null hypothesis which assumed that $\mu1 = \mu2 =\mu3 = …. = \mu n$ was refused. Thus, the mean concentration of $PM_{0.5-1.0}$ at site 1 was different from the mean concentration at site 3. On the other hand, the mean of $PM_{0.5-1.0}$ from site 1 and site 3 was a paired difference. In this case, then site of the samplings had a relationship on the mean concentrations of $PM_{0.5-1.0}$ (F= 3.569, $p<0.05$).

Table 4.14 Post Hoc test for the relationship of the locations on concentrations of PM at the size fraction of 0.5-1.0 micrometers

(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Yuparaj	Hospital	-2.204	1.865	.503	-6.936	2.528
	Sarapee	-4.971*	1.865	.038	-9.703	-.239
Hospital	Yuparaj	2.204	1.865	.503	-2.528	6.936
	Sarapee	-2.767	1.865	.342	-7.499	1.965
Sarapee	Yuparaj	4.971*	1.865	.038	.239	9.703
	Hospital	2.767	1.865	.342	-1.965	7.499

*. The mean difference is significant at the .05 level.

4.3.3 Comparison of the size-fractionated particulate matter and temporal variations

a) Wet season/dry season

By the same method of topic 4.3.2, Table 4.15 shows an analysis of the variance of PM concentrations related by the season changing. For all size fractions with the exception of the particle size fractions of larger than 10 µm, there were significant relation of the wet season and dry season on size-fractionated PM concentrations. The value of F for the size fraction of 2.5-10, 1.0-2.5, 0.5-1.0, 0.1-0.5, PM_{10} , $PM_{2.5}$ and PM_{total} equaled 5.124, 18.102, 30.46, 24.05, 21.87, 28.45 and 15.77 which the significances of F equaled to 0.029, 0.000, 0 .000, 0.000, 0.000, 0.000, and 0.000, respectively (F= 5.124-30.46, $p<0.05$). The results for this part indicated that the temporal variations which defined by the wet season and the dry season, related the quantity of PM at the significance level of 0.05 (F= 5.124-30.459, $p<0.05$). This could be used as a pollution prevention strategy for the seasonal changes, as there will be also changes in the quantity of PM.

Table 4.15 Relationship of PM concentrations on the temporal variations: wet season and dry season

		Sum of Squares	df	Mean Square	F	Sig.
PMtotal	Between Groups	10397.79	1	10397.79	15.771	.000
	Within Groups	28350.13	43	659.31		
	Total	38747.92	44			
PM10	Between Groups	6628.30	1	6628.30	21.868	.000
	Within Groups	13033.44	43	303.10		
	Total	19661.75	44			
PM2.5	Between Groups	3566.60	1	3566.60	28.450	.000
	Within Groups	5390.59	43	125.36		
	Total	8957.18	44			
PM>10	Between Groups	422.51	1	422.51	3.550	.066
	Within Groups	5117.83	43	119.02		
	Total	5540.34	44			
PM2.5-10	Between Groups	470.60	1	470.60	5.124	.029
	Within Groups	3949.17	43	91.84		
	Total	4419.78	44			
PM1.0-2.5	Between Groups	536.18	1	536.18	18.102	.000
	Within Groups	1273.68	43	29.62		
	Total	1809.86	44			
PM0.5-1.0	Between Groups	531.32	1	531.32	30.459	.000
	Within Groups	750.07	43	17.44		
	Total	1281.39	44			
PM0.1-0.5	Between Groups	182.66	1	182.66	24.049	.000
	Within Groups	326.59	43	7.60		
	Total	509.25	44			

b) Weekday/weekend

To compare the temporal variations of the days of the week defined as weekdays, plus Saturday and Sunday, ANOVA was used to define the differences again.

Table 4.16 Relationship of PM concentrations on the temporal variations: weekdays plus Saturday and Sunday

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
PMtotal	Between Groups	1611.40	2	805.70	.911	.410
	Within Groups	37136.52	42	884.20		
	Total	38747.92	44			
PM10	Between Groups	591.59	2	295.79	.651	.526
	Within Groups	19070.16	42	454.05		
	Total	19661.75	44			
PM2.5	Between Groups	170.24	2	85.12	.407	.668
	Within Groups	8786.94	42	209.21		
	Total	8957.18	44			
PM>10	Between Groups	432.98	2	216.49	1.780	.181
	Within Groups	5107.36	42	121.60		
	Total	5540.34	44			
PM2.5-10	Between Groups	127.57	2	63.79	.624	.541
	Within Groups	4292.20	42	102.20		
	Total	4419.77	44			
PM1.0-2.5	Between Groups	77.47	2	38.73	.939	.399
	Within Groups	1732.39	42	41.25		
	Total	1809.86	44			
PM0.5-1.0	Between Groups	7.68	2	3.84	.127	.881
	Within Groups	1273.71	42	30.33		
	Total	1281.39	44			
PM0.1-0.5	Between Groups	4.30	2	2.15	.179	.837
	Within Groups	504.95	42	12.02		
	Total	509.25	44			

Table 4.16 shows the analysis of variance of the PM concentrations related by the days of the week. As can be seen from table, the significances value of F are

larger than 0.05 for all PM size fractions thus, there was insignificantly difference on PM concentration of either the weekday or weekend. However, it can be seen that the PM concentrations of each sizes was decreased on Sundays as already shown in Figure 4.8. The results for this part indicated that the temporal variations, defined by the weekdays plus Saturday and Sunday did not relate the quantity of PM at the significant level of 0.05.

4.3.4 Comparison of the particulate matter' pollutants and the sampling sites

To compare the pollutants contained in PM, the One-way ANOVA method was again used. Each pollutant was combined with all size fractions of PM per day and per site. For example, each concentration of Chloride (Cl^-) represents Cl^- which was summed from the size fractions 1-5 at one sampling site. Table 4.17 shows the relationship of PM's composition (ions) on the sampling sites.

From Table 4.17, all detected ions both anions and cations in the study were found for the relationship with the sampling sites. It was found that the F values for all types of ions were too small and the significances were higher than 0.05. The results for this part indicated that the sampling sites did not relate to the quantity of PM at the significant level of 0.05.

Table 4.17 Relationship of PM's composition (ions) on the sampling sites

		Sum of Squares	df	Mean Square	F	Sig.
Chloride	Between Groups	11842.63	2	5921.31	.391	.679
	Within Groups	635401.01	42	15128.60		
	Total	647243.64	44			
Nitrate	Between Groups	3867.97	2	1933.98	.865	.428
	Within Groups	93862.82	42	2234.83		
	Total	97730.78	44			
Sulfate	Between Groups	341.43	2	170.71	.076	.927
	Within Groups	93837.10	42	2234.22		
	Total	94178.53	44			
Phosphate	Between Groups	3.24	2	1.62	1.423	.252
	Within Groups	47.87	42	1.14		
	Total	51.11	44			
Sodium	Between Groups	7.64	2	3.82	.041	.960
	Within Groups	3953.50	42	94.13		
	Total	3961.14	44			
Ammonium	Between Groups	105.92	2	52.96	.043	.958
	Within Groups	52245.93	42	1243.95		
	Total	52351.85	44			
Potassium	Between Groups	1656.23	2	828.12	.653	.526
	Within Groups	53289.22	42	1268.79		
	Total	54945.45	44			
Magnesium	Between Groups	3.89	2	1.94	1.007	.374
	Within Groups	81.00	42	1.93		
	Total	84.89	44			
Calcium	Between Groups	772.18	2	386.09	.128	.880
	Within Groups	126379.13	42	3009.03		
	Total	127151.31	44			

Table 4.18 shows an analysis of the variance in PM compositions (metals) related with the sampling sites. From the table, it can be seen that there were two metals related with the sampling sites; aluminum (Al) and potassium (K) at the significances level of 0.05 (F= 6.059, 5.875, $p < 0.05$). The Post Hoc test was also used to define the difference of the mean concentration for the metals compared by sampling sites as illustrated in Table 4.19.

Table 4.18 Relationship of PM’s composition (metals) on the sampling sites

		Sum of Squares	df	Mean Square	F	Sig.
Al	Between Groups	395.77	2	197.89	6.059	.007
	Within Groups	783.86	24	32.66		
	Total	1179.63	26			
B	Between Groups	1002.09	2	501.04	.435	.652
	Within Groups	27653.89	24	1152.25		
	Total	28655.98	26			
Ba	Between Groups	.98	2	.49	1.875	.175
	Within Groups	6.25	24	.26		
	Total	7.23	26			
Ca	Between Groups	21621.70	2	10810.85	1.460	.252
	Within Groups	177723.4	24	7405.14		
	Total	199345.1	26			
Fe	Between Groups	275.17	2	137.58	2.347	.117
	Within Groups	1406.83	24	58.62		
	Total	1682.00	26			
K	Between Groups	314.72	2	157.36	5.875	.008
	Within Groups	642.79	24	26.78		
	Total	957.51	26			
Li	Between Groups	.50	2	.25	1.910	.170
	Within Groups	3.15	24	.13		
	Total	3.66	26			
Mg	Between Groups	31.47	2	15.74	2.148	.139
	Within Groups	175.83	24	7.33		
	Total	207.31	26			
Mn	Between Groups	.18	2	.09	.393	.679
	Within Groups	5.56	24	.23		
	Total	5.75	26			
Na	Between Groups	13.53	2	6.77	.115	.891
	Within Groups	1406.28	24	58.59		
	Total	1419.81	26			
Pb	Between Groups	5.46	2	2.73	1.284	.295
	Within Groups	51.06	24	2.13		
	Total	56.53	26			
Sr	Between Groups	.01	2	.01	.491	.618
	Within Groups	.27	24	.01		
	Total	.28	26			
Ti	Between Groups	.12	2	.06	.981	.389
	Within Groups	1.43	24	.06		
	Total	1.55	26			
Zn	Between Groups	14.54	2	7.27	.442	.648
	Within Groups	395.07	24	16.46		
	Total	409.61	26			

Table 4.19 Post Hoc test for the relationship of the locations to the concentrations of metals (Al and K)

Dependent Variable	(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Al	Yuparaj	Hospital	2.888	2.694	.571	-4.141	9.916
		Sarapee	9.171*	2.694	.009	2.143	16.199
	Hospital	Yuparaj	-2.888	2.694	.571	-9.916	4.141
		Sarapee	6.283	2.694	.086	-.745	13.312
	Sarapee	Yuparaj	-9.171*	2.694	.009	-16.199	-2.143
		Hospital	-6.283	2.694	.086	-13.312	.745
K	Yuparaj	Hospital	4.059	2.440	.270	-2.305	10.424
		Sarapee	8.362*	2.440	.008	1.997	14.726
	Hospital	Yuparaj	-4.059	2.440	.270	-10.424	2.305
		Sarapee	4.303	2.440	.232	-2.062	10.667
	Sarapee	Yuparaj	-8.362*	2.440	.008	-14.726	-1.997
		Hospital	-4.303	2.440	.232	-10.667	2.062

*. The mean difference is significant at the .05 level.

As can been seen in Table 4.19, the independent variables are Al and K. The Post Hoc test showed the analysis of the mean of the metals concentrations for each pair a sampling site. The mean difference shows how much a difference each sampling site has on the mean concentration for each pair. The minus sign shows that the mean concentration of the site (I) is less than the mean concentration of the site (J). For example the mean concentration of Al at the municipality hospital was 2.888 mg/g less than which occurred at Yuparaj School. The significance level less than 0.05, this means the null hypothesis was refused. Thus, the mean concentration of Al from site 1 was different from that of site 3 at the significant level of 0.05. This result was the same with K metal that Yuparaj School and the district office of Sarapee is the paired difference at the significance level of 0.05. Therefore, the sampling sites, especially site 1 and site 3, related with the mean concentrations of Al and K (F= 6.059, 5.875, $p<0.05$).

4.3.5 Comparison of the particulate matter' pollutants and temporal variations

a) Wet season/ dry season

The pollutants which were compared here during the wet season and dry season were only for the ion species because metals could not be detected during the wet season. By using ANOVA, the ions which had the relationship with the temporal variations were determined as illustrated in Table 4.20

The study found that SO_4^{2-} (Sulfate), Na^+ (Sodium), NH_4^+ (Ammonium), and K^+ (Potassium) had significant differences in their variation of mean concentrations compared by wet season and dry season (F=18.750, 4.121, 23.286 and 4.866, $p< 0.05$), for SO_4^{2-}, Na^+, $NH4^+$ and K^+, respectively. The conclusion, the temporal variations defined as the wet season and dry season related with some of the ions within the PM at the significant level of 0.05.

b) Weekday/weekend

To compare temporal variations effects on the PM's pollutants of the days during the week which were defined as weekday, Saturday and Sunday, ANOVA was used to define the difference again.

Table 4.20 Relationship of PM's compositions (ions) on the temporal variations: wet and dry season

		Sum of Squares	df	Mean Square	F	Sig.
Chloride	Between Groups	28370.37	1	28370.37	1.971	.168
	Within Groups	618873.27	43	14392.40		
	Total	647243.64	44			
Nitrate	Between Groups	5.09	1	5.09	.002	.962
	Within Groups	97725.69	43	2272.69		
	Total	97730.78	44			
Sulfate	Between Groups	28596.34	1	28596.34	18.750	.000
	Within Groups	65582.19	43	1525.17		
	Total	94178.53	44			
Phosphate	Between Groups	.50	1	.50	.429	.516
	Within Groups	50.61	43	1.18		
	Total	51.11	44			
Sodium	Between Groups	346.44	1	346.44	4.121	.049
	Within Groups	3614.70	43	84.06		
	Total	3961.14	44			
Ammonium	Between Groups	18390.93	1	18390.93	23.286	.000
	Within Groups	33960.91	43	789.79		
	Total	52351.85	44			
Potassium	Between Groups	5585.83	1	5585.83	4.866	.033
	Within Groups	49359.63	43	1147.90		
	Total	54945.45	44			
Magnesium	Between Groups	5.06	1	5.06	2.726	.106
	Within Groups	79.83	43	1.86		
	Total	84.89	44			
Calcium	Between Groups	3593.91	1	3593.91	1.251	.270
	Within Groups	123557.40	43	2873.43		
	Total	127151.31	44			

Tables 4.21 and 4.22 show the analysis of variance of ions and metals concentrations related with the days of the week. As it can be seen from both tables, the significances level were larger than 0.05 for all pollutants. Thus, the days of the week did not have a significant relation on the pollutants' concentrations at a significant level of 0.05.

Table 4.21 Relationship of PM's compositions (ions) on the temporal variations: weekdays, Saturday and Sunday

		Sum of Squares	df	Mean Square	F	Sig.
Chloride	Between Groups	21325.77	2	10662.88	.715	.495
	Within Groups	625917.87	42	14902.81		
	Total	647243.64	44			
Nitrate	Between Groups	443.81	2	221.90	.096	.909
	Within Groups	97286.97	42	2316.36		
	Total	97730.78	44			
Sulfate	Between Groups	1292.93	2	646.46	.292	.748
	Within Groups	92885.60	42	2211.56		
	Total	94178.53	44			
Phosphate	Between Groups	1.84	2	.92	.783	.464
	Within Groups	49.28	42	1.17		
	Total	51.11	44			
Sodium	Between Groups	27.01	2	13.51	.144	.866
	Within Groups	3934.13	42	93.67		
	Total	3961.14	44			
Ammonium	Between Groups	407.37	2	203.68	.165	.849
	Within Groups	51944.48	42	1236.77		
	Total	52351.85	44			
Potassium	Between Groups	89.21	2	44.61	.034	.966
	Within Groups	54856.24	42	1306.10		
	Total	54945.45	44			
Magnesium	Between Groups	1.26	2	.63	.316	.731
	Within Groups	83.63	42	1.99		
	Total	84.89	44			
Calcium	Between Groups	421.76	2	210.88	.070	.933
	Within Groups	126729.55	42	3017.37		
	Total	127151.31	44			

Table 4.22 Relationship of PM's compositions (metals) on the temporal variations: weekdays, Saturday and Sunday

		Sum of Squares	df	Mean Square	F	Sig.
Al	Between Groups	83.28	2	41.64	.912	.415
	Within Groups	1096.36	24	45.68		
	Total	1179.63	26			
B	Between Groups	360.76	2	180.38	.153	.859
	Within Groups	28295.22	24	1178.97		
	Total	28655.98	26			
Ba	Between Groups	.07	2	.04	.123	.884
	Within Groups	7.16	24	.30		
	Total	7.23	26			
Ca	Between Groups	13040.74	2	6520.37	.840	.444
	Within Groups	186304.35	24	7762.68		
	Total	199345.09	26			
Fe	Between Groups	153.99	2	77.00	1.209	.316
	Within Groups	1528.01	24	63.67		
	Total	1682.00	26			
K	Between Groups	12.40	2	6.20	.157	.855
	Within Groups	945.11	24	39.38		
	Total	957.51	26			
Li	Between Groups	.24	2	.12	.843	.443
	Within Groups	3.42	24	.14		
	Total	3.66	26			
Mg	Between Groups	12.26	2	6.13	.754	.481
	Within Groups	195.05	24	8.13		
	Total	207.31	26			
Mn	Between Groups	.34	2	.17	.765	.477
	Within Groups	5.40	24	.23		
	Total	5.75	26			
Na	Between Groups	53.33	2	26.67	.468	.632
	Within Groups	1366.48	24	56.94		
	Total	1419.81	26			
Pb	Between Groups	2.78	2	1.39	.621	.546
	Within Groups	53.74	24	2.24		
	Total	56.53	26			
Sr	Between Groups	.02	2	.01	.853	.439
	Within Groups	.27	24	.01		
	Total	.28	26			
Ti	Between Groups	.33	2	.17	3.257	.056
	Within Groups	1.22	24	.05		
	Total	1.55	26			
Zn	Between Groups	4.82	2	2.41	.143	.868
	Within Groups	404.79	24	16.87		
	Total	409.61	26			

4.4 Size Distribution of PM in Chiang Mai

At all sampling sites, particles were sampled and collected in terms of five size fractions, based on the aerodynamic diameter of the particles. These fractions were 0.1-0.5, 0.5-1.0, 1.0-2.5, 2.5-10, and >10 µm. The concentrations of the size selected PM fractions at all the sampling sites are illustrated in Figure 4.44.

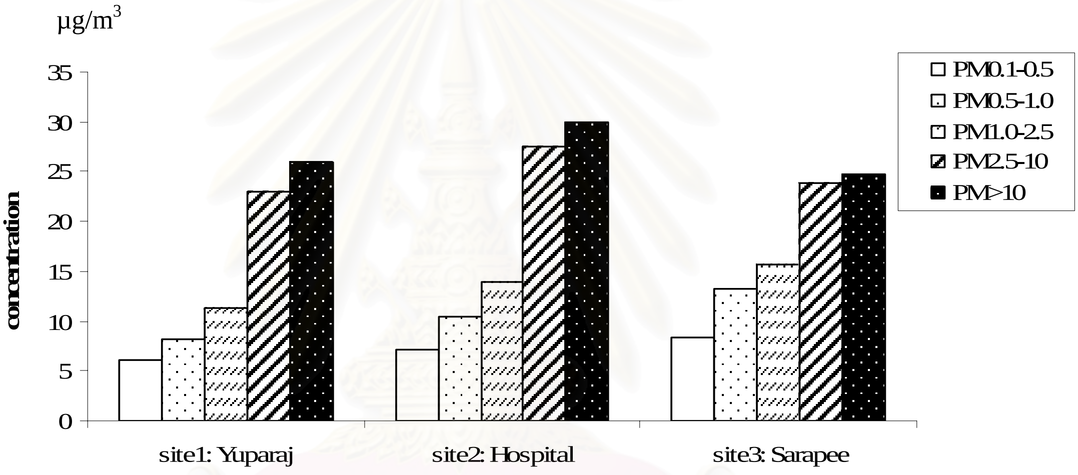


Figure 4.44 Size distributions of particulate matter at the three sampling sites in Chiang Mai province**.**

The PM collected by HVCI in this study presented the same pattern of PM size distribution for the three sampling sites. The odering of PM size distribution from high to low of the three sampling sites is as follows: size-fractionated PM larger than 10 µm > $PM_{2.5-10}$ > $PM_{1.0-2.5}$ > PM0.5$_{-1.0}$ > $PM_{0.1-0.5}$. But at the district office of Sarapee, the small fractions (3, 4 and 5) were higher than those of the other sites while the large fractions (1, 2) were less than those of the other sites. Consequently, its slope of the size distribution curve was not as high as Yuparaj School and the municipality hospital.

Since particle size distributions resulting from complex particle formation mechanisms or several simultaneous formation mechanisms so, its size distributions may not be lognormal. These distributions may exhibit more than one peak (multi-modal). Figure 4.45 presents log normal size distribution of PM at the three sampling sites. The horizontal axis is particle diameter plotted in logarithmic scale and the vertical axis is percentage of mass of PM divided by log of particle diameter. It can be noted that the size distributions of SFPM (% by weight) in Chiang Mai were bimodal, peaking at around particle size fractions 2 (0.5-1.0 μm) and 4 (2.5-10μm). From Figure 4.45, it can be seen that size distribution of PM from sampling site 1 and site 2 were the same pattern but the PM size distributions of sampling site 3 was different.

This also presents that the PM size distribution of the district office of Sarapee, a suburban areas had identical pattern different from those which was referred as urban areas. It might have been the results of the different activities head at and around each sampling site. Since the district office of Sarapee is located in an agricultural area without a high traffic load, most of the PM is probably generated from the farm and some of it from the road dust. Moreover, at the district office of Sarapee, its PM trends indicated that both source strengths and removal processes were important. Since Yuparaj school and the municipality hospital are located in the urban areas, which a high loading of traffic and a variety of activities, the PM concentration and its size distribution was found varied. It can be concluded that sites, sources and the time durations affected the patterns of PM size distribution.

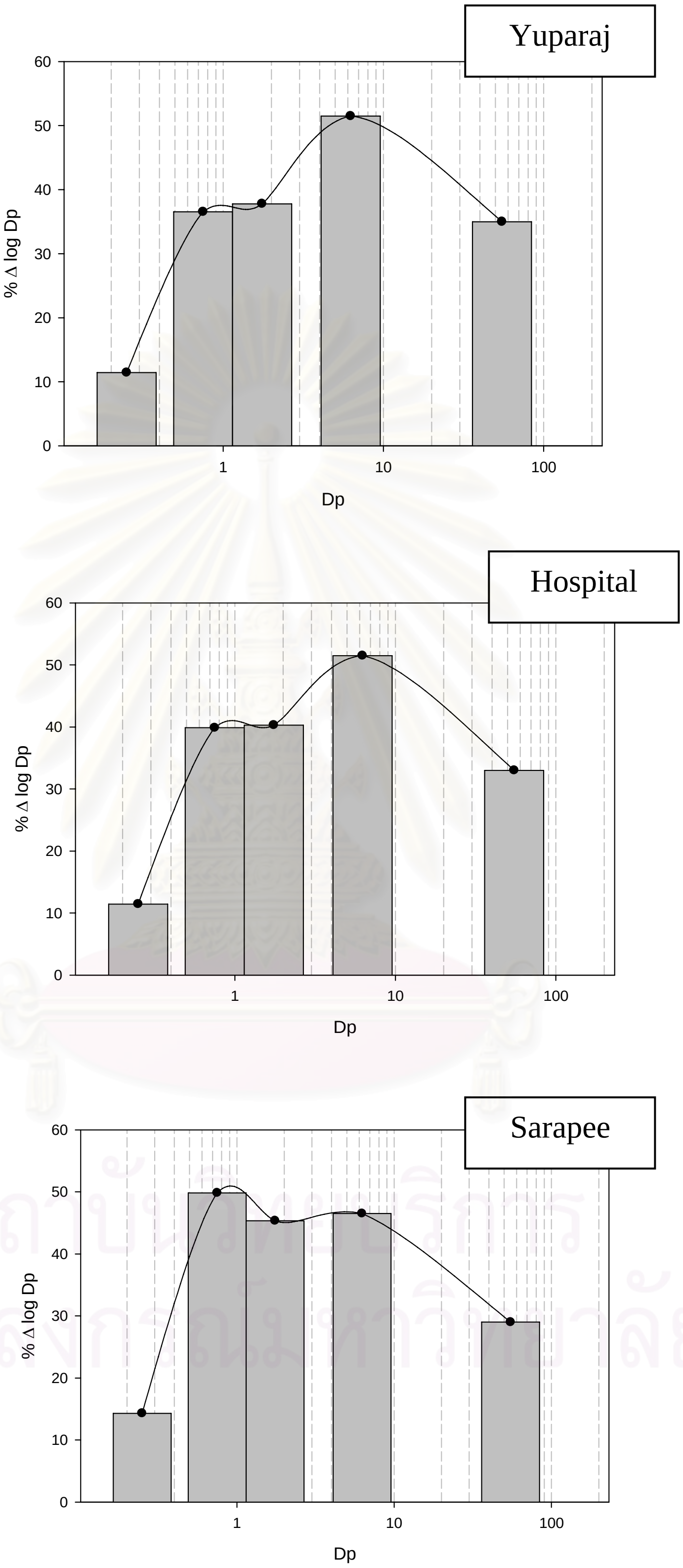


Figure 4.45 Log normal size distributions of PM at three sampling sites in Chiang Mai across the study period. (Mass, %/Δ log D_p)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A comprehensive study of ambient air particulate matter at various sizes associated with its composition (ions and metals) was undertaken in Chiang Mai province from mid-June 2005 until January 2006 by using a High Volume Cascade Impactor (HVCI model ChemVol 2400). All three sampling sites did not exceed the 24-hr NAAQS of the USEPA for PM_{10} (150 µg/m^3), but the 24-hr NAAQS of the USEPA for $PM_{2.5}$ (65 µg/m^3) was exceeded at sampling site 3, the district office of Sarapee in late December 2005. The PM concentrations of all the sites showed a trend of continual increase from the beginning of the study in June 2005 until its end in January 2006. The proportion of PM in each size range differed depending on the sampling sites. Sampling sites in the city, site1 and site 2, had relatively the same PM size proportions. Of all the PM that had been collected at site 1 and 2, 34 % and 36 % were fine PM (PM in size fractions 0.1-2.5) and 31 % was made of up coarse PM (PM in size fractions 2.5-10) for both sites. In the suburban area, site 3 (district office of Sarapee), there was a higher portion of fine particles. 41% of the PM at site 3 was made up of fine PM and 25% was made up of coarse PM. The $PM_{2.5}$ to PM_{10} ratio of site 1, 2 and 3 equaled to 0.53, 0.53 and 0.61, respectively.

The chemical compositions of the particulate matter were investigated to find their level of concentration. The compositions defined as ions (anions and cations) and metals in each of the size fractions comparing by the locations and temporal variations. . Ions were observed during both the wet season and dry season and metals were observed only during the dry season since there was less particulate matter during wet season and there was a lower concentration of pollutants to be detected. From the study, 54%, 28% and 18% of the summed anions found in fine fraction ($PM_{0.1-2.5}$), coarse fraction ($PM_{2.5-10}$) and in the PM size fraction larger than 10 micrometers respectively. With regard to summed cations, 59%, 15% and 26% were found in the fine fraction ($PM_{0.1-2.5}$), coarse fraction ($PM_{2.5-10}$) and in the PM size fraction larger than 10 micrometers, respectively. The study of heavy metals in PM found that 80% of summed metals in larger-size PM fractions (coarse and PM>10µm). This might the result of the sizes that metals species was bigger than the ions species which is gaseous origin. Thus, metals species adsorb more with PM larger sized fractions and ions species could be found more prevalent in smaller sized PM fractions. The major elements in Chiang Mai's air according to the study were Cl^-, $NO3^-$, SO_4^{2-}, Ca^{2+}, Al, Fe, K, Mg, Na, B and Zn. It was also found that the municipality hospital had higher in pollutants concentrations than the other sites. This might be from the high loading of activities in this area.

Seasonal variations were observed during the 8-month study period which included the wet and dry seasons. PM and its compositions (ions and metals) were also observed during the study. Other durations were defined as weekdays, Saturday and Sunday. The seasonal variation related with PM concentrations for the three sampling sites were noted. The $PM_{2.5}$/ PM_{10} ratio of Chiang Mai's air for the wet and dry season were 0.50 and 0.59, respectively. The results showed that the portion was increased during the dry season which caused an increase of $PM_{2.5}$. The PM for sampling sites 1 and 2, located in the downtown area, were especially related to weekdays, Saturday and Sunday due to high loading of activities and traffic.

A significant and positive relationship of the PM levels between the sampling sites and seasonal variations was observed by using a statistical program. It was found that each size fraction of PM correlated with other fractions of PM at significant level of 0.05 ($r = 0.353$-0.840, $p<0.05$). The sampling sites had relationship with PM concentrations and also the PM's chemical compositions. It was found that sampling sites 1 and 3 were the paired different effect to mean concentration of fine PM and its compositions at the significant level of 0.05. The pollutants which were related with the sampling sites were Al and K. Temporal variations defined as the wet season and dry season related with the compositions of PM at the significant level of 0.05. The pollutants which were related to the wet season and dry season were the SO_4^{2-} , Na^+, NH_4^+ and K^+. The temporal variations defined as weekday, Saturday and Sunday had no relationship the PM's compositions at the significant level of 0.05.

Moreover, the pattern of PM distribution at the three sampling sites was bi-modal like the PM's pattern of Bangkok. However, there was some different of the PM size distribution from sampling site 1, 2 and 3. Since there was higher in smaller PM fractions at site 3, thus the bi-modal curve had a peak at around the smaller size of 0.5-1.0 µm while the other sites had the peak at around the size of 2.5-10 µm

5.2 Recommendations

The study should extend for a year to see the effects of the temporal variations. The PM concentrations, especially of PM_{10} and $PM_{2.5}$ of in the recent study can be compared with only the average daily concentration standard of PM. Since the standard value of the average daily PM concentration value is much higher than the average annual concentration, then the PM concentration in this study did not reach the standard value. If the results from CHAPTER IV were compared with the average annual standard of the US.EPA the concentration of PM in this study would exceeded the limit. The PM_{10} concentrations at sites 2 and 3 exceeded the standard of 50 $\mu g/m^3$. The $PM_{2.5}$ concentrations of the study and average annual standard of the 3 sampling sites also exceeded the standard limit of the US.EPA by more than 2 times.

As there was an increase in the number of respiratory patients in Chiang Mai especially during the dry season, the study found that the PM quantity also increased during that time. The study also found that activities such as traffic, open burning and construction had a relation to the amounts of PM and pollutants. Thus, reducing health problems at the source of the pollution should be concern. For the suburban or rural areas, open burning which, produces fine particles, must be prohibited. There should be more responsible management of household or yard waste. For example, yard waste can be reused as compost. For a city or urban areas, it was clearly determined that street market events where the use of vehicles are prohibited, can add to the reductions in PM quantity and pollutants. Programs such as street markets should be lunched more frequently to cut back on the increase of polllution. Public transportation should also be re-managed since the number of public transportation vehicles registered in Chiang Mai makes up less than 1% of all registered vehicles. Environmentally-friendly education (e.g., on making compost, the benefits of public transportation, the negative effects of field burning, etc.) should be provided to all people, from farmers to students, to ensure that sustainable development and practices are emphasized and implemented, which in turn will decrease the negative effects of PM.

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APPENDICES

APPENDIX A

Extraction Technique of the PUF Substrates

A-1 Extraction technique of the PUF for ions analysis and steps for analysis

Substrate Extraction for Analysis of Water-Soluble Components

These extraction procedures are for aqueous extraction of polyurethane foam (PUF) P1, P2, and P3 substrates and ultrafine filter (ultrafilter). These extracts are suitable for analysis of water-soluble components. Note that the volumes of the substrate sizes are not the same and the extraction solvent volume is proportional to each substrate and filter size. Because these materials cannot be wetted directly with water, methanol is used to wet the surfaces prior to aqueous extraction

Tools and materials required for PUF substrates only:

Ultrasonic bath: the study used Model: Branson8510
25 ml culture tubes with PTFE-face rubber-lined cap
50 ml culture tubes with PTFE-face rubber-lined cap
150 culture tubes with PTFE-face rubber-lined cap
Disposable 1 ml plastic pipettes individually wrapped in paper/plastic.
Disposable 10 ml plastic pipettes individually wrapped in paper/plastic
Automated pipette
Tube rack(s) to hold culture tubes (must be plastic-coated or uncoated metal wire)
Labels for culture tubes.
Glass rods
Nonserrated stainless-steel forceps
Stainless-steel scissors
Thermometer
Timer
Watch glass (10 cm diameter)
Milli-Q grade water or equivalent
Methanol

Labware Washing

Wash the culture crystallizing dishes, flasks, graduated cylinder, and watch glass suing Liquinox detergent or equivalent; then rinse thoroughly with Millli-Q water. Sonicate all glassware with ultra-sonicbath by these following steps;

First step, sonicate with distill water for 1 hour.

Second step, sonicate with Milli-Q water for 1 hour.

Thrid step, sonicate with Milli-Q water for 1 hour.

Then, cover all items with Kimwipes and allow them to dry in room air.

Extraction PUF substrates with Milli-Q Water

1) Follow these steps to extract P1 PUF substrates with Milli-Q water:

Note: It is important to wear powder-free gloves at all times. Rinse the gloves with Milli-Q water and dry the gloves by wiping them with Kimwipes

1) Hold the P1 PUF substrate with the stainless-steel forceps.
2) Using the stainless-steel scissors, cut off 1/3 piece of the P1 PUF substrate.
3) Hold the 1/3 piece of the P1 PUF substrate with the stainless-steel forceps.
4) Using the stainless-steel scissors, cut the 1/3 piece of PUF into 32 pieces. Allow the small pieces to fall onto a watch glass. All of the pieces should be about the same size. For example, first cut 1/3 piece in half, then in quarters, then in eighths, then in sixteenths and finally in thirty-seconds.
5) Using the stainless-steel forceps, place the 32 PUF pieces into a labeled culture tube or other suitable glass laboratory vessel. If necessary, use a glass rod to push the PUF pieces down to the bottom of the extraction flask.
6) Clean the rod, forceps, scissors and watch glass with Milli-Q grade water between samples.
7) Add 6 ml of methanol to one flask using the pipette.

8) Place a cap on the flask, and then gently shake to evenly wet the PUF pieces with methanol.
9) Remove the cap and ,without delay (to minimize evaporation of methanol), pipette 120 ml of Milli-Q waterinto the culture tube (twelve 10 ml aliquots with the 10 ml pipette)
10) Use a clean, dry glass rod to disperse any small air bubbles in the PUF pieces that float near the top of the aqueous solution.
11) Replace the cap onto the top of the flask.
12) Place the flask (with the PUF pieces) in a rack
13) Return to the original P1 PUF substrate (that has a 1/3 piece cut out) and hold it with the stainless-steel forceps.
14) Using the stainless-steel scissors, cut off another 1/3 piece of the P1 PUF substrate.
15) Repeat steps 3-12 for the second 1/3 piece of the P1 PUF substrate.
16) Hold the last remaining 1/3 piece of the original P1 PUF substrate with the stainless-steel forceps.
17) Repeat steps 2-12 for the remaining 1/3 piece of the P1 PUF substrate.
18) Place the rack in the ultrasonic bath.
19) Begin to sonicate the flasks starting in the room temperature water.
20) Measure and record the temperature in the ultrasonic bath.
21) Sonicate the flasks for 60 minutes.
22) Check the temperature of the water in the ultrasonic bath periodically. If the water temperature rises above 30° C, change the water in the bath to keep the water temperature below 30° C.
23) Cover the flasks with Parafilm.
24) Store the covered flasks in a dark refrigerator, prior to analysis.

<u>2) Follow these steps to extract P2 PUF substrates with Milli-Q water:</u>

Note: It is important to wear powder-free gloves at all times. Rinse the gloves with Milli-Q water and dry the gloves by wiping them with Kimwipes

1) Hold the P2 PUF substrate with the stainless-steel forceps.
2) Using the stainless-steel scissors, cut off 1/3 piece of the P2 PUF substrate.
3) Hold the 1/3 piece of the P2 PUF substrate with the stainless-steel forceps.
4) Using the stainless-steel scissors, cut the 1/3 piece of PUF into 16 pieces. Allow the small pieces to fall onto a watch glass. All of the pieces should be about the same size. For example, first cut 1/3 piece in half, then in quarters, then in eighths, then in sixteenths and finally in thirty-seconds.
5) Using the stainless-steel forceps, place the 16 PUF pieces into a labeled culture tube or other suitable glass laboratory vessel. If necessary, use a glass rod to push the PUF pieces down to the bottom of the extraction flask.
6) Clean the rod, forceps, scissors and watch glass with Milli-Q grade water between samples.
7) Add 2 ml of methanol to one flask using the pipette.
8) Place a cap on the flask, and then gently shake to evenly wet the PUF pieces with methanol.
9) Remove the cap and ,without delay (to minimize evaporation of methanol), pipette 40 ml of Milli-Q waterinto the culture tube (four 10 ml aliquots with the 10 ml pipette)
10) Use a clean, dry glass rod to disperse any small air bubbles in the PUF pieces that float near the top of the aqueous solution.
11) Replace the cap onto the top of the flask.
12) Place the flask (with the PUF pieces) in a rack
13) Return to the original P2 PUF substrate (that has a 1/3 piece cut out) and hold it with the stainless-steel forceps.
14) Using the stainless-steel scissors, cut off another 1/3 piece of the P2 PUF substrate.
15) Repeat steps 3-12 for the second 1/3 piece of the P2 PUF substrate.
16) Hold the last remaining 1/3 piece of the original P2 PUF substrate with the stainless-steel forceps.

17) Repeat steps 2-12 for the remaining 1/3 piece of the P2 PUF substrate.
18) Place the rack in the ultrasonic bath.
19) Begin to sonicate the flasks starting in the room temperature water.
20) Measure and record the temperature in the ultrasonic bath.
21) Sonicate the flasks for 60 minutes.
22) Check the temperature of the water in the ultrasonic bath periodically. If the water temperature rises above 30° C, change the water in the bath to keep the water temperature below 30° C.
23) Cover the flasks with Parafilm.
24) Store the covered flasks in a dark refrigerator, prior to analysis.

<u>3) Follow these steps to extract P3 PUF substrates with Milli-Q water:</u>

Note: It is important to wear powder-free gloves at all times. Rinse the gloves with Milli-Q water and dry the gloves by wiping them with Kimwipes

1) Hold the P3 PUF substrate with the stainless-steel forceps.

2) Using the stainless-steel scissors, cut off 1/3 piece of the P3 PUF substrate.

3) Hold the 1/3 piece of the P3 PUF substrate with the stainless-steel forceps.

4) Using the stainless-steel scissors, cut the 1/3 piece of PUF into 8 pieces. Allow the small pieces to fall onto a watch glass. All of the pieces should be about the same size. For example, first cut 1/3 piece in half, then in quarters, then in eighths, then in sixteenths and finally in thirty-seconds.

5) Using the stainless-steel forceps, place the 8 PUF pieces into a labeled culture tube or other suitable glass laboratory vessel. If necessary, use a glass rod to push the PUF pieces down to the bottom of the extraction flask.

6) Clean the rod, forceps, scissors and watch glass with Milli-Q grade water between samples.

7) Add 1 ml of methanol to one flask using the pipette.

8) Place a cap on the flask, then gently shake to evenly wet the PUF pieces with methanol.

9) Remove the cap without delay (to minimize evaporation of methanol), pipette 20 ml of Milli-Q waterinto the culture tube (tw0 10 ml aliquots with the 10 ml pipette)

10) Use a clean, dry glass rod to disperse any small air bubbles in the PUF pieces that float near the top of the aqueous solution.

11) Replace the cap onto the top of the flask.

12) Place the flask (with the PUF pieces) in a rack

13) Return to the original P3 PUF substrate (that has a 1/3 piece cut out) and hold it with the stainless-steel forceps.

14) Using the stainless-steel scissors, cut off another 1/3 piece of the P3 PUF substrate.

15) Repeat steps 3-12 for the second 1/3 piece of the P3 PUF substrate.

16) Hold the last remaining 1/3 piece of the original P3 PUF substrate with the stainless-steel forceps.

17) Repeat steps 2-12 for the remaining 1/3 piece of the P3 PUF substrate.

18) Place the rack in the ultrasonic bath.

19) Begin to sonicate the flasks starting in the room temperature water.

20) Measure and record the temperature in the ultrasonic bath.

21) Sonicate the flasks for 60 minutes.

22) Check the temperature of the water in the ultrasonic bath periodically. If the water temperature rises above 30° C, change the water in the bath to keep the water temperature below 30° C.

23) Cover the flasks with Parafilm.

24) Store the covered flasks in a dark refrigerator, prior to analysis.

A-2 Extraction technique of the PUF for metals analysis and steps for analysis

The extraction technique used for extract metals from the post-field PUF substrate was Hot Acid Extraction recommended in Compendium Method IO-3.1 “Selection, Preparation and Extraction of Filter Material”. The analytical technique was used ICP-OES to identify and quantify the metals which recommended in Compendium Method IO-3.4 “Determination of Metals in Ambient Particulate Matter using Inductively Coupled Plasma (ICP) Spectroscopy”

Tools and materials required for hot acid extraction

Hot plate Model: SCPscience-Digi Prep Jr
Volumetric glassware
Test tube
Bottle, Polypropylene with leak proof caps, for storing sample
Nylon or Teflon 0.45 µm Syringe filter and syringe
Pipette
Ultra-pure Hydrochloric acid. Concentrated 36.5%-38%
Ultra-pure Nitric acid. Concentrated 70%
ASTM type I water (milli-Q water type I)

Extraction PUF substrates with Hot Acid Digestion

1) Cut the 1/3 PUF substrates to labeled 50 ml test tubes. Place the piece of PUF down into the lower portion of the tube to ensure acid volume will cover entire the substrate. The PUF substrates should be cut into a smallest piece as small as possible for easy digestion.
2) Prepare the extraction solution by adding in 500 ml of Type I Milli-Q water, 55.5 ml of concentrated HNO3, and 167.5 ml of concentrated HCl, dilute to one liter with Type I Milli-Q water.
3) Add 10 ml of extracting acid to the tube which contained P3 substrates

4) Add 15 ml of extracting acid to the tube which contained P2 substrates
5) Add 20 ml of extracting acid to the tube which contained P1 substrates
6) Place test tubes in the Hot Plate Device, contained in a fume hood. Do not allow sample to dry by adding milli-Q water while heating.
7) When all PUF was digested, remove test tubes from the hot- plate and allow cooling.
8) Transfer the extraction fluid to beaker.
9) Rinse the tube walls and wash with mill-Q water. Add the rinses to the beaker.
10) Using a nylon or Teflon syringe, pull-up a volume of sample from the beaker, place disc filter on syringe, and dispense into a pre-labeled Polypropylene bottle.
11) Add mill-Q water to the filtered fluid to have 30 ml in volume. This is the final extraction volume for all sizes of PUF
12) The PUF sample is now ready for analysis.

APPENDIX B

Calculation for Concentrations of PM, Ions and Metals

Appendix B-1: Calculation for quantity of PM.

From equation 3.1;

$$\text{Mass concentration of PM } (\mu g/m^3) = \frac{(w_f - w_i)*10^6}{V_{std}}$$

To find PM concentration, data from three sources was needed. The data used to ba an example here was record on 16th January 2006 at Yuparaj school

1) Field pressure data

ΔP orifice = 5.0 inch.H_2O

ΔP with respect to atmosphere = 90 inch.H_2O

2) Meteorological data

Average-24 hour temperature = 19.2 ºC

Average-24 hour air pressure = 29.82 inch.Hg

3) Laboratory data; used P1 PUF as the example

Wf = 2.17634 g

Wi = 2.14610g

From Flowmeter Calculation System;

After input data 1) and 2) the standard flow and actual flow were calculated

Standard flow rate = 741.5 SLPM

Actual flow rate = 752.8 ALPM

Standard flow used to find the standard volume of air for the sampling

$$\therefore \text{ Vstd} = 741.5*1.44 = 1067.76 \text{ m}^3/\text{day}$$

$$\text{Mass Concentration} = \frac{(2.17634 - 2.14610)}{1067.76}*10^6 = 28.32 \ \mu g/m^3$$

Appendix B-2: Calculation for quantity of ions.

From equation 3.2;

Ion concentration, (mg/g) $C = \left(\frac{(mg.ion/L)(V_f)(3) - F_m}{g.PM} \right)$

According to the extraction method, final volume of PUF is different by sizes which is P1 has final volume = 120 ml

P2 has final volume = 40 ml

P3 has final volume = 20 ml

For example; the calculation of NO_3^- ion extracted from P3 PUF on 20th June 2005, Yuparaj school

Ions concentration of the blank detected by IC device = 187.32 ppb

NO_3^- ion concentration of the samples detected by IC device = 6007.40 ppb

Amount of PM size fraction 1.0-2.5 (P3 PUF) = 0.0093 grams

$$\therefore \text{ Ions concentrations} = \left(\frac{(6.007)(0.02)(3) - (0.187)(0.02)(3)}{0.0093} \right)$$

$$= 37.55 \text{ mg. } NO_3^- \text{/g.PM}$$

Appendix B-3: Calculation for quantity of metals

From equation 3.3;

Metals concentration, (mg/g) $C = \left(\frac{(mg.ion/L)(V_f)(3) - F_m}{g.PM} \right)$

According to the extraction method, final volume of PUF is equal to 30 ml

For example; the calculation of Al metal extracted from P1 PUF on 19th August 2005,

Yuparaj school

Metal concentration of the blank detected by ICP-OES device = 0.9119 ppm

Concentration of the Al detected by ICP-OES device = 3.4475 ppm

Amount of PM size fraction > 10 micrometers (P1 PUF) = 0.0323 grams

$\therefore$ Metals concentrations = $\left(\frac{(3.4475)(0.03)(3) - (0.9119)(0.03)(3)}{0.0323} \right)$

= 7.065 mg. Al/g. PM

APPENDIX C

Meteorological Data, HVCI’s Pressure Losses, Flowrate, Air Volume and PUF Weighing for PM Concentrations

Table C-1 Meteorological data, pressure losses, flowrate and air volume

Date	**Temp. (°C)**	**Abs. pressure (inch.Hg)**	**ΔP w.r.t Atm. (inch.H_2O)**	**ΔP orifice (inch. H_2O)**	**Actual flow (LPM)**	**STD. flow (LPM)**	**Volume air (m^3/day)**
20/06/05	27.6	29.68	100	4.5	716.3	682.5	982.8
23/06/05	27.7	28.91	98	4.5	738.1	684.6	985.8
26/06/05	28.3	28.91	96	4.5	741.0	686.2	988.1
05/07/05	29.3	29.66	90	4.5	732.4	691.6	995.9
08/07/05	30.0	28.90	96	4.5	743.3	684.2	985.2
11/07/05	30.4	28.98	98	4.5	739.4	681.6	981.5
20/07/05	26.9	29.65	94	4.5	723.1	690.0	993.6
23/07/05	27.6	28.83	98	4.5	739.8	684.7	986.0
26/07/05	26.0	28.89	100	5.0	773.6	721.0	1038.8
04/08/05	26.6	29.65	93	5.0	763.1	728.8	1049.5
07/08/05	26.4	29.62	95	5.2	776.2	741.1	1067.2
10/08/05	27.1	29.82	110	4.8	723.7	694	999.4
19/08/05	25.7	30.55	110	4.9	723.9	702.8	1042.0
22/08/05	26.3	29.76	105	4.5	707.1	678.4	976.9
25/08/05	27.7	29.71	100	4.2	691.4	659.3	949.4
03/09/05	23.3	29.72	100	4.2	686.1	664.2	956.4
06/09/05	26.6	29.74	100	4.2	689.4	660.5	951.1
09/09/05	26.4	28.99	100	4.0	690.0	644.8	928.5
18/09/05	26.8	29.65	100	3.8	658.1	628.0	904.3
21/09/05	25.7	29.79	100	4.2	687.2	661.5	952.7
24/09/05	27.1	28.94	100	4.2	709.1	659.9	950.3
03/10/05	25.0	29.77	100	4.3	734.4	670.1	964.9
06/10/05	26.5	29.82	100	4.2	687.5	660.6	951.3
09/10/05	26.2	29.09	100	4.2	704.5	660.9	951.7
18/10/05	26.4	29.89	100	4.2	684.3	660.7	951.4
21/10/05	26.1	29.91	100	4.2	685.6	661.0	951.8
24/10/05	27.0	29.12	100	4.2	704.6	660.1	950.5

Table C-1 Meteorlogical data, pressure losses, flowrate and air volume(Cont.)

Date	Temp. (°C)	Abs. pressure (inch.Hg)	ΔP w.r.t Atm. (inch.H_2O)	ΔP orifice ((inch.H_2O)	Actual flow (LPM)	STD. flow (LPM)	Volume air (m^3/day)
02/11/05	25.4	29.82	100	4.2	686.2	661.8	953.0
05/11/05	25.3	29.86	100	4.2	685.2	661.9	953.1
08/11/05	26.2	29.10	100	4.2	704.2	660.9	951.7
17/11/05	26.6	29.86	100	4.2	686.5	660.7	951.4
20/11/05	24.8	29.96	100	4.2	682.3	662.5	954.0
23/11/05	22.1	29.17	100	4.2	697.6	655.9	943.9
02/12/05	23.2	29.88	100	4.2	682.3	664.3	956.6
05/12/05	25.2	29.83	105	4.6	711.8	687.2	989.6
08/12/05	22.8	29.11	100	4.2	700.0	664.7	957.2
17/12/05	22.0	30.01	108	4.7	707.8	694.9	1000.7
20/12/05	18.9	29.97	105	4.7	708.6	702.1	1011.2
23/12/05	18.9	29.14	97	4.9	753.9	726.2	1045.7
01/01/06	21.0	29.82	90	5.0	755.2	739.2	1064.4
04/01/06	20.3	29.84	105	4.6	705.7	692.9	997.8
07/01/06	24.2	29.10	105	4.8	744.1	703.2	1012.6
16/01/06	19.2	29.82	90	5.0	752.8	741.5	1067.8
19/01/06	20.7	29.80	100	4.8	728.3	713.2	1027.0
22/01/06	21.8	29.00	100	4.9	757.6	719.2	1035.6

Remark: The recommended air flowrate for the pump is 760±40 LPM. Since the pump cannot be controlled to get the recommended flow, 58% of flowrate not reached the recommended level.

Table C-2 The amount of precipitations (mm) during the study period

Amounts of rain (mm) during the study period								
Date	**Jun'48**	**July'48**	**Aug'48**	**Sep'48**	**Oct'48**	**Nov'48**	**Dec'48**	**Jan'49**
1	18.7	0	11.8	28.3	0	0	0	0
2	23.5	0.2	-	7.3	0	0	0	0
3	16.4	0	0	34.3	15.6	0	0	0
4	2.8	-	4.9	-	0	0	0	0
5	7.2	8.1	0	50	0	0	11.6	0
6	20.7	0	2.8	6.5	0	0	6.8	0
7	0.1	0	4.9	12.7	1	6	2.6	0
8	0.2	0	4.5	9.3	3.5	0	0	0
9	3.3	1.5	0.4	5.3	0	3.8	0	0
10	4.3	0	0	41	0	4.3	0	0
11	0	0	0.8	53.2	0	8.6	0	0
12	-	47.7	38.5	2.9	0	0	0	0
13	9.2	2.3	13.1	0	2.3	0	0	0
14	0	33.6	9.8	9.3	1.1	0	0	0
15	17.4	3.2	0.02	4.4	0	0	0	0
16	0.3	0.1	2.4	-	0	0	0	0
17	6.5	0	11.1	0.9	0	0	0	0
18	-	0	2.4	50	0	0.1	0	0
19	19.7	4.8	0.1	69.1	17.6	0	0	0
20	7.4	19.9	0.9	-	0	0	0	0
21	18.8	2	7.2	-	0	0	0	0
22	0	27.1	3.5	0	0	0	0	0
23	12.6	0	5	3.3	0	0	0	0
24	0	15.4	0	-	2.7	0	0	0
25	-	7.6	0.6	0	0	0	5.3	0
26	-	5.6	0	0	2.4	0	1.6	0
27	2	0	12.3	15.7	0.7	0	0	0
28	2.4	0	6.8	12.4	8.3	0	0	0
29	0	0	0	18.2	60.3	0	0	0
30	0	-	0.1	2.2	39.7	0	0	0
31	0	0	11.3	-	36.8	-	0	-

Figure C-2 Level of precipitation (mm) during the study period

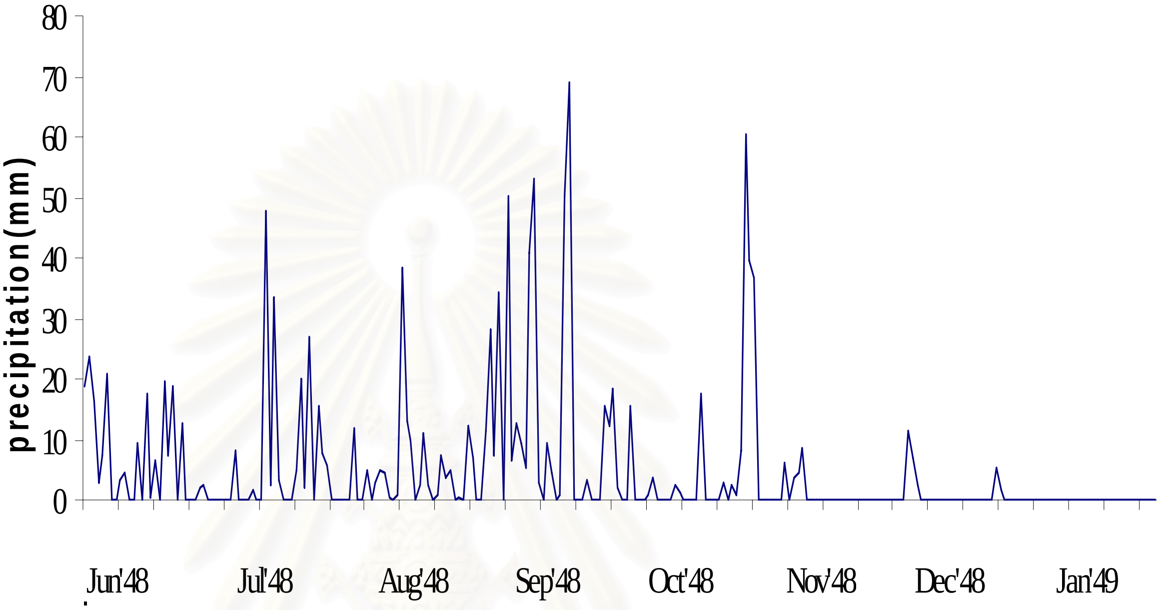

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram

Yuparaj	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
20-Jun-05	PM>10	52	24.5	2.16567	52	24.7	2.19144	0.02577	
	PM2.5-10	52	24.5	0.69725	52	24.7	0.71823	0.02098	
	PM1.0-2.5	53	24.7	0.35949	52	24.7	0.36879	0.0093	
	PM0.5-1.0	52	24.6	0.36209	52	24.7	0.36785	0.00576	
	PM0.1-0.5	51	24.6	0.36819	52	24.7	0.37242	0.00423	
	BlankP1	50	24.8	2.17422	50	24.8	2.17435	9.2E-05	**SD**
	BlankP2	51	24.8	0.53984	51	24.8	0.53985	7.1E-06	**SD**
	BlankP3	51	24.7	0.3657	51	24.8	0.36426	0.0010	**SD**
5-Jul-05									
	PM>10	51	24.8	2.13406	51	24.9	2.16004	0.02598	
	PM2.5-10	52	24.8	0.69973	51	24.8	0.72427	0.02454	
	PM1.0-2.5	52	24.8	0.36873	51	24.9	0.37844	0.00971	
	PM0.5-1.0	51	24.8	0.36328	52	24.9	0.36609	0.00281	
	PM0.1-0.5	52	24.7	0.36646	52	24.9	0.3705	0.00404	
	BlankP1	50	24.7	2.17525	45	24.7	2.17314	0.0015	**SD**
	BlankP2	51	24.7	0.53953	50	24.8	0.53964	7.8E-05	**SD**
	BlankP3	51	24.7	0.36376	48	24.8	0.36387	7.8E-05	**SD**
20-Jul-05									
	PM>10	51	25	2.12736	51	24.7	2.14343	0.01607	
	PM2.5-10	52	25	0.70371	51	24.7	0.71925	0.01554	
	PM1.0-2.5	51	25	0.37071	51	24.7	0.37657	0.00586	
	PM0.5-1.0	52	25	0.36166	51	24.8	0.3658	0.00414	
	PM0.1-0.5	51	24.9	0.36929	53	24.8	0.37333	0.00404	
	BlankP1	51	24.8	2.1749	50	24.6	2.1756	0.0005	**SD**
	BlankP2	51	24.8	0.53948	51	24.6	0.53953	3.5E-05	**SD**
	BlankP3	51	24.8	0.36418	51	24.6	0.36467	0.0003	**SD**
4-Aug-05									
	PM>10	52	24.7	2.17754	51	24.8	2.19514	0.0176	
	PM2.5-10	52	24.6	0.53341	52	24.8	0.55289	0.01948	
	PM1.0-2.5	50	24.7	0.34371	52	24.8	0.35391	0.0102	
	PM0.5-1.0	50	24.8	0.3624	52	24.7	0.36846	0.00606	
	PM0.1-0.5	50	24.8	0.36236	50	24.7	0.36679	0.00443	
	BlankP1	50	24.6	2.17557	50	24.6	2.1754	0.0001	**SD**
	BlankP2	50	24.8	0.68819	50	24.8	0.68838	0.0001	**SD**
	BlankP3	50	24.7	0.36508	50	24.8	0.36522	9.9E-05	**SD**

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Yuparaj	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
19-Aug-05	PM>10	52	24.8	2.14208	52	24.6	2.17438	0.0323	
	PM2.5-10	52	24.7	0.60928	52	24.6	0.63942	0.03014	
	PM1.0-2.5	52	24.7	0.36023	50	24.6	0.37291	0.01268	
	PM0.5-1.0	51	24.6	0.35953	52	24.8	0.36779	0.00826	
	PM0.1-0.5	51	24.6	0.36137	50	24.6	0.368	0.00663	
	BlankP1	50	24.8	2.17561	50	24.8	2.17558	2.1E-05	**SD**
	BlankP2	50	24.8	0.68835	50	24.8	0.68834	7.1E-06	**SD**
	BlankP3	50	24.8	0.36503	50	24.8	0.36512	6.4E-05	**SD**
3-Sep-05									
	PM>10	50	24.6	2.17648	51	24.8	2.19616	0.01968	
	PM2.5-10	51	24.6	0.68868	51	24.7	0.70594	0.01726	
	PM1.0-2.5	51	24.6	0.36516	51	24.7	0.37413	0.00897	
	PM0.5-1.0	52	24.6	0.37365	52	24.9	0.38042	0.00677	
	PM0.1-0.5	52	24.7	0.35663	51	24.8	0.36108	0.00445	
	BlankP1	50	24.6	2.12008	50	25	2.12014	4.2E-05	**SD**
	BlankP2	50	24.6	0.74637	50	25	0.7465	9.2E-05	**SD**
	BlankP3	50	24.8	0.37197	50	25	0.37203	4.2E-05	**SD**
18-Sep-05									
	PM>10	51	24.5	2.17443	51	24.8	2.18962	0.01519	
	PM2.5-10	51	24.6	0.67425	51	24.8	0.68774	0.01349	
	PM1.0-2.5	52	24.5	0.35733	52	24.7	0.36417	0.00684	
	PM0.5-1.0	51	24.4	0.36356	51	24.7	0.36885	0.00529	
	PM0.1-0.5	51	24.4	0.35781	51	24.7	0.36195	0.00414	
	BlankP1	50	24.7	2.12011	50	24.7	2.12045	0.0002	**SD**
	BlankP2	50	24.7	0.74636	50	24.7	0.74635	7.1E-06	**SD**
	BlankP3	50	24.6	0.37196	50	24.7	0.37198	1.4E-05	**SD**
3-Oct-05									
	PM>10	50	24.5	2.15193	50	24.7	2.17909	0.02716	
	PM2.5-10	50	24.5	0.63339	50	24.7	0.65773	0.02434	
	PM1.0-2.5	50	24.5	0.36914	50	24.7	0.37829	0.00915	
	PM0.5-1.0	51	24.6	0.3615	50	24.7	0.36781	0.00631	
	PM0.1-0.5	51	24.6	0.35686	50	24.6	0.36065	0.00379	
	BlankP1	50	24.6	2.16377	50	24.7	2.16389	8.5E-05	**SD**
	BlankP2	50	24.5	0.60123	50	24.6	0.60133	7.1E-05	**SD**
	BlankP3	50	24.5	0.36037	50	24.8	0.36012	0.0002	**SD**

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Yuparaj	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
18-Oct-05	PM>10	50	24.7	2.1548	50	24.5	2.17182	0.01702	
	PM2.5-10	50	24.5	0.69222	50	24.5	0.71536	0.02314	
	PM1.0-2.5	50	24.5	0.3516	50	24.5	0.36864	0.01704	
	PM0.5-1.0	50	24.7	0.35989	50	24.5	0.37232	0.01243	
	PM0.1-0.5	51	24.6	0.36465	50	24.5	0.37153	0.00688	
	BlankP1	50	24.5	2.16386	50	24.5	2.16377	6.4E-05	SD
	BlankP2	50	24.5	0.60114	50	24.5	0.60122	5.6E-05	SD
	BlankP3	50	24.5	0.36026	50	24.5	0.36027	7.1E-06	SD
2-Nov-05									
	PM>10	50	24.5	2.14143	51	24.8	2.17053	0.0291	
	PM2.5-10	51	24.5	0.66677	50	24.6	0.69678	0.03001	
	PM1.0-2.5	50	24.5	0.35306	50	24.6	0.36227	0.00921	
	PM0.5-1.0	50	24.6	0.34715	50	24.6	0.35403	0.00688	
	PM0.1-0.5	50	24.6	0.35201	50	24.7	0.3565	0.00449	
	BlankP1	50	24.5	2.14467	50	24.6	2.16386	0.0135	SD
	BlankP2	50	24.5	0.60118	50	24.6	0.60123	3.5E-05	SD
	BlankP3	50	24.5	0.3603	50	24.6	0.36031	7.1E-06	SD
17-Nov-05									
	PM>10	50	24.7	2.14033	50	24.8	2.18446	0.04413	
	PM2.5-10	50	24.6	0.66274	50	24.7	0.68602	0.02328	
	PM1.0-2.5	50	24.5	0.34799	50	24.7	0.36184	0.01385	
	PM0.5-1.0	50	24.5	0.35739	51	24.7	0.36922	0.01183	
	PM0.1-0.5	50	24.5	0.35638	51	24.7	0.36373	0.00735	
	BlankP1	50	24.5	2.14467	50	24.5	2.14428	0.0003	SD
	BlankP2	50	24.5	0.70623	50	24.8	0.70612	7.8E-05	SD
	BlankP3	50	24.5	0.35422	50	24.8	0.35419	2.1E-05	SD
2-Dec-05									
	PM>10	50	24.4	2.16704	51	24.6	2.19818	0.03114	
	PM2.5-10	50	24.3	0.68911	51	24.7	0.71695	0.02784	
	PM1.0-2.5	50	24.2	0.35323	50	24.6	0.36842	0.01519	
	PM0.5-1.0	50	24.5	0.35746	50	24.7	0.36717	0.00971	
	PM0.1-0.5	50	24.3	0.35494	50	24.6	0.36562	0.01068	
	BlankP1	50	24.3	2.14436	50	24.5	2.14475	0.0003	SD
	BlankP2	50	24.3	0.70632	50	24.5	0.70856	0.002	SD
	BlankP3	50	24.3	0.35419	50	24.5	0.35425	4.2E-05	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Yuparaj	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
17-Dec-05	PM>10	50	24.5	2.15605	50	24.2	2.19499	0.03894	
	PM2.5-10	50	24.8	0.62499	50	24.2	0.64457	0.01958	
	PM1.0-2.5	51	24.8	0.36085	50	24.2	0.37735	0.0165	
	PM0.5-1.0	50	24.4	0.36651	50	24.2	0.37869	0.01218	
	PM0.1-0.5	50	24.4	0.35312	50	23.3	0.35852	0.0054	
	BlankP1	50	24.5	2.14487	50	23.5	2.14477	7.1E-05	SD
	BlankP2	50	24.5	0.71264	50	23.2	0.71201	0.0004	SD
	BlankP3	50	24.5	0.35431	50	23.4	0.35424	5.0E-05	SD
1-Jan-06									
	PM>10	50	22.6	2.17591	50	24.4	2.18752	0.01161	
	PM2.5-10	50	22.9	0.70025	50	24.3	0.71481	0.01456	
	PM1.0-2.5	50	23.1	0.35341	50	24.2	0.36	0.00659	
	PM0.5-1.0	50	23	0.35895	50	24.1	0.36613	0.00718	
	PM0.1-0.5	50	23.1	0.35912	50	23.7	0.36462	0.0055	
	BlankP1	50	22.7	2.14565	50	23.5	2.14532	0.0002	SD
	BlankP2	50	22.7	0.71272	50	23.5	0.71255	0.0001	SD
	BlankP3	50	22.7	0.35444	50	23.5	0.35438	4.2E-05	SD
16-Jan-06									
	PM>10	50	23.6	2.1461	50	24.5	2.17634	0.03024	
	PM2.5-10	50	23.9	0.71296	50	24.4	0.75068	0.03772	
	PM1.0-2.5	50	24.2	0.35433	50	24.5	0.37011	0.01578	
	PM0.5-1.0	50	24.3	0.35885	50	24.5	0.37524	0.01639	
	PM0.1-0.5	50	24.4	0.36224	50	24.3	0.3771	0.01486	
	BlankP1	50	23.3	2.17314	50	24.1	2.17351	0.0003	SD
	BlankP2	50	23.5	0.85841	50	24.1	0.85804	0.0003	SD
	BlankP3	50	23.6	0.35729	50	24.3	0.35649	0.0006	SD
Hospital									
23-Jun-05	PM>10	52	24.8	2.17464	52	24.8	2.19958	0.02494	
	PM2.5-10	52	24.8	0.58708	52	24.8	0.60527	0.01819	
	PM1.0-2.5	52	24.7	0.35799	52	24.8	0.36391	0.00592	
	PM0.5-1.0	51	24.7	0.35714	52	24.7	0.36114	0.004	
	PM0.1-0.5	51	24.7	0.36583	52	24.7	0.36959	0.00376	
	BlankP1	50	24.8	2.17435	50	24.8	2.17497	0.0004	SD
	BlankP2	51	24.8	0.53985	50	24.8	0.53972	9.2E-05	SD
	BlankP3	51	24.8	0.36426	51	24.8	0.36444	0.0001	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Hospital	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
8-Jul-05	PM>10	50	24.9	2.17961	51	24.8	2.20586	0.02625	
	PM2.5-10	50	24.9	0.62024	52	24.7	0.63498	0.01474	
	PM1.0-2.5	50	24.8	0.36015	52	24.8	0.36735	0.0072	
	PM0.5-1.0	50	24.8	0.35995	51	24.8	0.36405	0.0041	
	PM0.1-0.5	48	24.8	0.35815	52	24.8	0.36303	0.00488	
	BlankP1	45	24.7	2.17314	51	24.8	2.1749	0.0012	SD
	BlankP2	50	24.8	0.53964	51	24.8	0.53948	0.0001	SD
	BlankP3	48	24.8	0.36387	51	24.8	0.36418	0.0002	SD
23-Jul-05									
	PM>10	51	24.8	2.13922	52	24.6	2.15887	0.01965	
	PM2.5-10	51	24.8	0.54257	52	24.7	0.55875	0.01618	
	PM1.0-2.5	52	24.7	0.36427	52	24.8	0.37076	0.00649	
	PM0.5-1.0	52	24.8	0.35707	52	24.8	0.3613	0.00423	
	PM0.1-0.5	52	24.8	0.35863	52	24.8	0.36217	0.00354	
	BlankP1	50	24.6	2.1756	50	24.7	2.17535	0.0002	SD
	BlankP2	51	24.6	0.53953	51	24.8	0.53947	4.2E-05	SD
	BlankP3	51	24.6	0.36467	51	24.7	0.36453	9.9E-05	SD
7-Aug-05									
	PM>10	51	24.7	2.1773	50	24.8	2.19724	0.01994	
	PM2.5-10	52	24.8	0.55812	51	24.8	0.58121	0.02309	
	PM1.0-2.5	52	24.7	0.36217	52	24.7	0.37343	0.01126	
	PM0.5-1.0	52	24.6	0.3575	52	24.8	0.36392	0.00642	
	PM0.1-0.5	52	24.7	0.36583	52	24.8	0.37099	0.00516	
	BlankP1	50	24.6	2.1754	50	24.7	2.17553	9.2E-05	SD
	BlankP2	50	24.8	0.68838	50	24.7	0.68822	0.0001	SD
	BlankP3	50	24.8	0.36522	50	24.7	0.36493	0.0002	SD
22-Aug-05									
	PM>10	52	24.6	2.14926	51	24.6	2.22015	0.07089	
	PM2.5-10	51	24.6	0.54812	51	24.7	0.61352	0.0654	
	PM1.0-2.5	51	24.6	0.35858	51	24.9	0.38146	0.02288	
	PM0.5-1.0	51	24.8	0.35334	52	24.8	0.36439	0.01105	
	PM0.1-0.5	51	24.7	0.35421	52	24.7	0.36215	0.00794	
	BlankP1	50	24.8	2.17558	50	24.7	2.17564	4.2E-05	SD
	BlankP2	50	24.8	0.68834	50	24.7	0.68828	4.2E-05	SD
	BlankP3	50	24.8	0.36512	50	24.7	0.36497	0.0001	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Hospital	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
6-Sep-05	PM>10	52	24.8	2.17193	51	24.7	2.19518	0.02325	
	PM2.5-10	52	24.5	0.66741	52	24.7	0.68942	0.02201	
	PM1.0-2.5	51	24.6	0.36324	51	24.5	0.37688	0.01364	
	PM0.5-1.0	50	24.5	0.34605	50	24.5	0.35788	0.01183	
	PM0.1-0.5	52	24.4	0.36303	50	24.5	0.36835	0.00532	
	BlankP1	50	25	2.12014	50	24.7	2.12034	0.0001	**SD**
	BlankP2	50	25	0.7465	50	24.7	0.74643	5.0E-05	**SD**
	BlankP3	50	25	0.37203	50	24.7	0.37201	1.4E-05	**SD**
21-Sep-05									
	PM>10	52	24.4	2.17195	50	24.6	2.1892	0.01725	
	PM2.5-10	52	24.5	0.62827	50	24.8	0.64898	0.02071	
	PM1.0-2.5	51	24.4	0.36301	50	24.7	0.37178	0.00877	
	PM0.5-1.0	50	24.4	0.35786	50	24.6	0.36394	0.00608	
	PM0.1-0.5	51	24.4	0.36566	51	24.7	0.37112	0.00546	
	BlankP1	50	24.7	2.12011	50	24.7	2.12052	0.0003	**SD**
	BlankP2	50	24.7	0.74636	50	24.7	0.74655	0.0001	**SD**
	BlankP3	50	24.6	0.37196	50	24.7	0.37208	8.5E-05	**SD**
6-Oct-05									
	PM>10	52	24.6	2.17881	51	24.7	2.22302	0.04421	
	PM2.5-10	50	24.7	0.58477	50	24.7	0.627	0.04223	
	PM1.0-2.5	51	24.7	0.36186	51	24.7	0.38196	0.0201	
	PM0.5-1.0	50	24.7	0.36278	50	24.7	0.37634	0.01356	
	PM0.1-0.5	50	25	0.3561	50	24.7	0.36349	0.00739	
	BlankP1	50	24.7	2.16389	50	24.5	2.16392	2.1E-05	**SD**
	BlankP2	50	24.6	0.60133	50	24.5	0.60136	2.1E-05	**SD**
	BlankP3	50	24.8	0.36012	50	24.5	0.3601	1.4E-05	**SD**
21-Oct-05									
	PM>10	50	24.7	2.19841	50	24.4	2.2285	0.03009	
	PM2.5-10	50	24.7	0.70928	50	24.4	0.73683	0.02755	
	PM1.0-2.5	50	24.7	0.36339	50	24.5	0.38463	0.02124	
	PM0.5-1.0	50	24.7	0.3585	50	24.5	0.37133	0.01283	
	PM0.1-0.5	50	24.7	0.35322	50	24.5	0.35871	0.00549	
	BlankP1	50	24.5	2.16381	50	24.5	2.16368	9.2E-05	**SD**
	BlankP2	50	24.5	0.60129	50	24.5	0.60116	9.2E-05	**SD**
	BlankP3	50	24.5	0.36023	50	24.5	0.36016	5.0E-05	**SD**

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Hospital	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
5-Nov-05	PM>10	50	24.4	2.18541	51	24.8	2.22984	0.04443	
	PM2.5-10	50	24.5	0.64139	50	24.7	0.67105	0.02966	
	PM1.0-2.5	50	24.5	0.35496	50	24.7	0.36672	0.01176	
	PM0.5-1.0	50	24.5	0.35618	50	24.7	0.36902	0.01284	
	PM0.1-0.5	50	24.6	0.35094	50	24.7	0.35958	0.00864	
	BlankP1	50	24.6	2.16386	50	24.8	2.16394	5.7E-05	SD
	BlankP2	50	24.6	0.60123	50	24.8	0.6014	0.0001	SD
	BlankP3	50	24.6	0.36031	50	24.8	0.36032	7.1E-06	SD
20-Nov-05									
	PM>10	50	24.5	2.17258	50	24.5	2.19561	0.02303	
	PM2.5-10	50	24.7	0.5955	50	24.5	0.61358	0.01808	
	PM1.0-2.5	51	24.9	0.35567	50	24.4	0.36439	0.00872	
	PM0.5-1.0	50	25	0.35288	50	24.4	0.36355	0.01067	
	PM0.1-0.5	50	24.7	0.35917	50	24.4	0.36422	0.00505	
	BlankP1	50	24.5	2.14428	50	24.5	2.14412	0.0001	SD
	BlankP2	50	24.8	0.70612	50	24.8	0.70626	9.9E-05	SD
	BlankP3	50	24.8	0.35419	50	24.6	0.35414	3.5E-05	SD
5-Dec-05									
	PM>10	51	24.4	2.21284	50	24.4	2.23181	0.01897	
	PM2.5-10	50	24.7	0.64814	50	24.7	0.66361	0.01547	
	PM1.0-2.5	50	24.5	0.35981	50	24.7	0.37049	0.01068	
	PM0.5-1.0	50	24.4	0.36277	50	24.7	0.37178	0.00901	
	PM0.1-0.5	50	24.8	0.35751	50	24.7	0.36415	0.00664	
	BlankP1	50	24.5	2.14472	50	24.5	2.14483	7.8E-05	SD
	BlankP2	50	24.5	0.70693	50	24.5	0.70722	0.0002	SD
	BlankP3	50	24.5	0.35416	50	24.5	0.35422	4.2E-05	SD
20-Dec-05									
	PM>10	50	24.6	2.16023	50	22.7	2.18475	0.02452	
	PM2.5-10	50	24.6	0.56953	50	22.6	0.59285	0.02332	
	PM1.0-2.5	50	24.7	0.36038	50	22.2	0.38953	0.02915	
	PM0.5-1.0	50	24.6	0.36392	50	22.3	0.38536	0.02144	
	PM0.1-0.5	50	24.7	0.35267	50	22.4	0.36633	0.01366	
	BlankP1	50	24.2	2.14475	50	22.4	2.14524	0.0003	SD
	BlankP2	50	24.4	0.71262	50	24.2	0.71273	7.8E-05	SD
	BlankP3	50	23.9	0.35414	50	24	0.35419	3.5E-05	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Hospital	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
4-Jan-06	PM>10	50	22.7	2.14353	50	24	2.16901	0.02548	
	PM2.5-10	50	22.7	0.65858	50	23.9	0.68798	0.0294	
	PM1.0-2.5	50	22.6	0.35524	50	23.8	0.36564	0.0104	
	PM0.5-1.0	50	22.6	0.36308	50	23.8	0.37191	0.00883	
	PM0.1-0.5	50	22.6	0.36042	50	23.6	0.36912	0.0087	
	BlankP1	50	22.8	2.14565	50	22.9	2.14553	8.5E-05	SD
	BlankP2	50	22.7	0.71272	50	23.1	0.71268	2.8E-05	SD
	BlankP3	50	22.7	0.35444	50	23	0.35451	5.0E-05	SD
19-Jan-06									
	PM>10	50	24	2.11602	50	23.2	2.1436	0.02758	
	PM2.5-10	50	23.9	0.69317	50	23	0.73153	0.03836	
	PM1.0-2.5	50	23.9	0.35719	50	23	0.37386	0.01667	
	PM0.5-1.0	50	24	0.36226	50	22.9	0.37892	0.01666	
	PM0.1-0.5	50	23.5	0.36712	50	22.9	0.38006	0.01294	
	BlankP1	50	23.3	2.17314	50	24.1	2.17351	0.0003	SD
	BlankP2	50	23.5	0.85841	50	24.1	0.85804	0.0003	SD
	BlankP3	50	23.6	0.35729	50	24.3	0.35649	0.0006	SD
Sarapee									
26-Jun-05	PM>10	52	24.8	2.16371	51	24.8	2.18508	0.02137	
	PM2.5-10	52	24.8	0.5862	52	24.8	0.60083	0.01463	
	PM1.0-2.5	52	24.8	0.35733	52	24.8	0.3653	0.00797	
	PM0.5-1.0	52	24.8	0.35624	52	24.8	0.36186	0.00562	
	PM0.1-0.5	52	24.8	0.36332	52	24.8	0.36785	0.00453	
	BlankP1	50	24.8	2.17497	50	24.7	2.17484	9.2E-05	SD
	BlankP2	50	24.8	0.53972	51	24.7	0.53955	0.0001	SD
	BlankP3	50	24.8	0.36444	51	24.7	0.36417	0.0002	SD
11-Jul-05									
	PM>10	49	24.7	2.13515	52	24.7	2.16025	0.0251	
	PM2.5-10	46	24.7	0.74571	52	24.7	0.77263	0.02692	
	PM1.0-2.5	51	24.7	0.36056	52	24.7	0.3739	0.01334	
	PM0.5-1.0	49	24.7	0.35133	51	24.7	0.3686	0.01727	
	PM0.1-0.5	50	24.7	0.37203	51	24.7	0.37952	0.00749	
	BlankP1	50	24.8	2.17621	51	24.8	2.1749	0.0010	SD
	BlankP2	50	24.8	0.54004	51	24.8	0.53948	0.0004	SD
	BlankP3	51	24.8	0.36442	51	24.8	0.36418	0.0002	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Sarapee	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
26-Jul-05	PM>10	52	24.8	2.21455	50	24.6	2.23471	0.02016	
	PM2.5-10	52	24.8	0.63396	50	24.6	0.65528	0.02132	
	PM1.0-2.5	52	24.7	0.36101	51	24.6	0.37171	0.0107	
	PM0.5-1.0	52	24.7	0.3574	50	24.7	0.3651	0.0077	
	PM0.1-0.5	52	24.6	0.3589	50	24.6	0.36418	0.00528	
	BlankP1	50	24.7	2.17535	50	24.7	2.17512	0.0002	SD
	BlankP2	51	24.8	0.53947	50	24.7	0.53964	0.0001	SD
	BlankP3	51	24.7	0.36453	50	24.7	0.36423	0.0002	SD
10-Aug-05									
	PM>10	51	24.8	2.17013	50	24.8	2.18974	0.01961	
	PM2.5-10	51	24.7	0.67222	51	24.8	0.68949	0.01727	
	PM1.0-2.5	50	24.7	0.35736	51	24.8	0.36629	0.00893	
	PM0.5-1.0	51	24.8	0.36016	50	24.8	0.36774	0.00758	
	PM0.1-0.5	51	24.9	0.36324	51	24.8	0.36926	0.00602	
	BlankP1	50	24.7	2.17553	50	24.7	2.17526	0.0002	SD
	BlankP2	50	24.7	0.68822	50	24.8	0.68815	5.0E-05	SD
	BlankP3	50	24.7	0.36493	50	24.8	0.36501	5.6E-05	SD
25-Aug-05									
	PM>10	51	24.6	2.17075	52	24.6	2.18853	0.01778	
	PM2.5-10	52	24.8	0.62694	52	24.7	0.64163	0.01469	
	PM1.0-2.5	50	24.5	0.36395	50	24.6	0.37242	0.00847	
	PM0.5-1.0	51	24.6	0.35644	51	24.6	0.36238	0.00594	
	PM0.1-0.5	50	24.5	0.35642	51	24.6	0.36038	0.00396	
	BlankP1	50	24.7	2.17564	50	24.7	2.17574	7.1E-05	SD
	BlankP2	50	24.7	0.68828	50	24.7	0.68842	9.9E-05	SD
	BlankP3	50	24.7	0.36497	50	24.7	0.36506	6.3E-05	SD
9-Sep-05									
	PM>10	51	24.8	2.20363	50	24.5	2.21409	0.01046	
	PM2.5-10	52	24.7	0.63943	50	24.5	0.64913	0.0097	
	PM1.0-2.5	51	24.8	0.36417	51	24.6	0.37322	0.00905	
	PM0.5-1.0	52	24.9	0.37045	51	24.6	0.37633	0.00588	
	PM0.1-0.5	51	24.7	0.35224	50	24.5	0.35612	0.00388	
	BlankP1	50	25	2.12014	50	24.7	2.12011	2.1E-05	SD
	BlankP2	50	25	0.7465	50	24.7	0.74636	9.9E-05	SD
	BlankP3	50	25	0.37203	50	24.7	0.37196	4.9E-05	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Sarapee	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
24-Sep-05	PM>10	52	24.7	2.16316	50	24.8	2.18116	0.018	
	PM2.5-10	52	24.7	0.66743	51	24.8	0.68273	0.0153	
	PM1.0-2.5	52	24.8	0.36423	50	24.7	0.37089	0.00666	
	PM0.5-1.0	50	24.6	0.35546	50	24.7	0.36169	0.00623	
	PM0.1-0.5	52	24.8	0.35793	50	24.6	0.36226	0.00433	
	BlankP1	50	24.7	2.12045	50	24.7	2.12012	0.0002	SD
	BlankP2	50	24.7	0.74635	50	24.7	0.7464	3.5E-05	SD
	BlankP3	50	24.7	0.37198	50	24.7	0.37207	6.3E-05	SD
9-Oct-05									
	PM>10	50	24.8	2.18904	51	24.6	2.20493	0.01589	
	PM2.5-10	50	24.8	0.63497	51	24.6	0.66992	0.03495	
	PM1.0-2.5	50	24.8	0.36281	50	24.7	0.37726	0.01445	
	PM0.5-1.0	50	24.8	0.35354	50	24.6	0.36379	0.01025	
	PM0.1-0.5	50	24.7	0.3651	50	24.8	0.37023	0.00513	
	BlankP1	50	24.7	2.16389	50	24.5	2.16378	7.8E-05	SD
	BlankP2	50	24.6	0.60133	50	24.5	0.60123	7.1E-05	SD
	BlankP3	50	24.8	0.36012	50	24.5	0.36007	3.5E-05	SD
24-Oct-05									
	PM>10	50	24.8	2.14446	50	24.7	2.16582	0.02136	
	PM2.5-10	50	24.6	0.60478	50	24.8	0.62636	0.02158	
	PM1.0-2.5	50	24.7	0.35589	50	24.6	0.38067	0.02478	
	PM0.5-1.0	50	24.7	0.35293	50	24.5	0.3669	0.01397	
	PM0.1-0.5	50	24.7	0.3517	50	24.5	0.35855	0.00685	
	BlankP1	50	24.5	2.16381	50	24.5	2.16386	3.5E-05	SD
	BlankP2	50	24.5	0.60129	50	24.5	0.60137	5.6E-05	SD
	BlankP3	50	24.5	0.36023	50	24.5	0.36029	4.2E-05	SD
8-Nov-05									
	PM>10	50	24.8	2.13004	50	24.8	2.16535	0.03531	
	PM2.5-10	50	24.8	0.62712	50	24.6	0.65852	0.0314	
	PM1.0-2.5	51	24.8	0.35433	50	24.8	0.36735	0.01302	
	PM0.5-1.0	50	24.8	0.36117	50	24.7	0.37364	0.01247	
	PM0.1-0.5	51	24.8	0.3478	50	24.7	0.35623	0.00843	
	BlankP1	50	24.9	2.16394	50	24.6	2.16467	0.0005	SD
	BlankP2	50	24.9	0.6014	50	24.6	0.60138	1.4E-05	SD
	BlankP3	50	24.8	0.36032	50	24.7	0.36047	0.0001	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Sarapee	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
23-Nov-05	PM>10	50	24.6	2.14976	50	23.9	2.17935	0.02959	
	PM2.5-10	50	24.7	0.62793	50	24.1	0.64736	0.01943	
	PM1.0-2.5	50	24.7	0.34657	50	24.9	0.36536	0.01879	
	PM0.5-1.0	50	24.6	0.35565	50	24.6	0.37257	0.01692	
	PM0.1-0.5	51	24.7	0.35804	50	24.4	0.36861	0.01057	
	BlankP1	50	24.5	2.14428	50	24.4	2.14452	0.0002	SD
	BlankP2	50	24.8	0.70612	50	24.3	0.71228	0.0043	SD
	BlankP3	50	24.8	0.35419	50	24.6	0.3542	7.1E-06	SD
8-Dec-05									
	PM>10	50	24.8	2.16629	50	24.6	2.2038	0.03751	
	PM2.5-10	50	24.8	0.70678	50	24.7	0.7403	0.03352	
	PM1.0-2.5	50	24.7	0.35569	50	24.4	0.37419	0.0185	
	PM0.5-1.0	50	24.8	0.35863	50	24.5	0.37652	0.01789	
	PM0.1-0.5	50	24.7	0.34929	50	24.6	0.36154	0.01225	
	BlankP1	50	24.5	2.14475	50	24.5	2.14487	8.5E-05	SD
	BlankP2	50	24.5	0.70856	50	24.6	0.71264	0.0029	SD
	BlankP3	50	24.5	0.35425	50	24.5	0.35431	4.2E-05	SD
23-Dec-05									
	PM>10	50	24.7	2.19382	50	24.3	2.21483	0.02101	
	PM2.5-10	50	24.7	0.6376	50	24.5	0.65981	0.02221	
	PM1.0-2.5	50	24.5	0.36039	50	24.6	0.39393	0.03354	
	PM0.5-1.0	50	24.4	0.35269	50	24.7	0.37746	0.02477	
	PM0.1-0.5	50	24.5	0.36363	50	24.3	0.37672	0.01309	
	BlankP1	50	24.2	2.14475	50	22.3	2.1454	0.0004	SD
	BlankP2	50	24.4	0.71262	50	22.8	0.71288	0.0002	SD
	BlankP3	50	23.9	0.35414	50	23.1	0.35445	0.0002	SD
7-Jan-06									
	PM>10	50	22.6	2.19805	50	24.3	2.23608	0.03803	
	PM2.5-10	50	22.8	0.66287	50	24.3	0.69784	0.03497	
	PM1.0-2.5	50	22.9	0.36038	50	24.4	0.37809	0.01771	
	PM0.5-1.0	50	23	0.36245	50	24.4	0.38295	0.0205	
	PM0.1-0.5	50	23.3	0.36375	50	24.5	0.37904	0.01529	
	BlankP1	50	22.8	2.14565	50	23.3	2.14555	7.1E-05	SD
	BlankP2	50	22.7	0.71272	50	22.9	0.71267	3.4E-05	SD
	BlankP3	50	22.7	0.35444	50	22.8	0.35443	7.1E-06	SD

Table C-3 Average PUF weighing before sampling (W_i) and after sampling (W_f) expressed in gram (Cont.)

Sarapee	PM size	Before sampling			After sampling			Wf –Wi (g)	Note
		%RH	Temp.	Wi (g)	%RH	Temp.	Wf (g)		
22-Jan-06	PM>10	50	23.6	2.17311	50	24.5	2.20504	0.03193	
	PM2.5-10	50	23.5	0.59552	50	24.4	0.62849	0.03297	
	PM1.0-2.5	50	24.2	0.36444	51	24.3	0.38948	0.02504	
	PM0.5-1.0	50	24.1	0.35057	50	24.4	0.37273	0.02216	
	PM0.1-0.5	50	24.2	0.37041	50	24.2	0.38648	0.01607	
	BlankP1	50	24.2	2.17354	50	24.6	2.17496	0.0010	SD
	BlankP2	50	24	0.85866	50	24.3	0.85883	0.0001	SD
	BlankP3	50	24	0.35698	50	24.6	0.35734	0.0002	SD

Remark: %RH = relative humid 50±5 % Temp. = Temperature 25±3 ºC

SD = standard deviation of weighing the pre-sampling blank and post-sampling blank

PUF were weighed for 5 times and reported only the average weight here.

APPENDIX D

Concentrations of Particulate Matter at Various Sizes Fractions at Chiang Mai: Effects of Sampling Sites and Durations on PM Concentrations.

Table D-1 Concentrations of PM (μg/m^3) at various sizes fractions across the study period defined as month compared by sampling sites

Month	NO. sample	Site	Average concentrations of PM (μg/m^3)					
			PM>10	PM2.5-10	PM1.0-2.5	PM0.5-1.0	PM0.1-0.5	total
June	1	Yuparaj	26.20	21.30	9.46	5.86	4.30	67.12
	1	Hospital	25.30	18.45	6.00	4.06	3.81	57.62
	1	Sarapee	21.63	14.80	8.06	5.69	4.58	54.76
July	2	Yuparaj	21.15	20.10	7.82	3.50	4.06	56.64
	2	Hospital	23.28	15.68	6.94	4.22	4.27	54.41
	2	Sarapee	22.49	23.98	11.94	12.50	6.36	77.27
August	2	Yuparaj	24.34	24.17	11.12	6.96	5.38	71.99
	2	Hospital	45.62	44.29	16.98	8.66	6.48	122.05
	2	Sarapee	19.175	16.38	8.93	6.92	5.10	56.50
September	2	Yuparaj	18.69	16.48	8.47	6.46	4.62	54.72
	2	Hospital	21.28	22.44	11.78	9.41	5.65	70.55
	2	Sarapee	15.10	13.28	8.38	6.44	4.37	47.56
October	2	Yuparaj	23.015	24.77	13.70	9.80	5.58	76.86
	2	Hospital	39.04	36.66	21.72	13.86	6.77	118.06
	2	Sarapee	19.58	29.71	20.64	12.74	6.30	88.96
November	2	Yuparaj	38.46	27.98	12.11	9.82	6.22	94.59
	2	Hospital	35.38	25.04	10.74	12.32	7.18	90.65
	2	Sarapee	34.22	26.79	16.80	15.51	10.03	103.35
December	2	Yuparaj	35.73	24.34	16.18	11.16	8.28	95.69
	2	Hospital	21.71	19.35	19.81	15.16	10.11	86.14
	2	Sarapee	29.64	28.13	25.70	21.19	12.65	117.31
January	2	Yuparaj	19.62	24.50	10.48	11.04	9.54	75.19
	2	Hospital	26.20	33.40	13.32	12.54	10.66	96.12
	2	Sarapee	38.38	34.78	18.41	19.46	13.95	124.98

Table D-2 Concentrations of PM (µg/m^3) at various sizes fractions across the study period defined as day during the week compared by sampling sites.

	Date	PM>10	PM2.5-10	PM1.0-2.5	PM0.5-1.0	PM0.1-0.5
Yuparaj						
Mon	20/6/05	26.20	21.30	9.46	5.86	4.30
	3/10/05	28.15	25.22	9.48	6.53	3.93
	16/01/06	28.32	35.33	14.78	15.35	13.92
Tue	5/7/05	26.10	24.60	9.75	2.82	4.06
	18/10/05	17.88	24.32	17.91	13.06	7.23
Wed	20/7/05	16.20	15.60	5.90	4.17	4.07
	2/11/05	30.54	31.49	9.66	7.22	4.71
Thurs	4/8/05	16.77	18.56	9.72	5.77	4.22
	17/11/05	46.38	24.47	14.56	12.43	7.72
Fri	19/8/05	31.92	29.78	12.53	8.16	6.55
	2/12/05	32.55	29.10	15.88	10.15	11.16
Sat	3/9/05	20.58	18.04	9.38	7.08	4.65
	17/12/05	38.91	19.57	16.49	12.17	5.40
Sun	18/9/05	16.80	14.92	7.56	5.85	4.58
	1/1/06	10.91	13.68	6.19	6.74	5.16
Hospital						
Mon	22/8/05	72.57	66.94	23.42	11.31	8.13
	5/12/05	19.17	15.63	10.79	9.1	6.71
Tues	6/9/05	24.44	23.14	14.34	12.44	5.59
	20/12/05	24.25	23.07	28.83	21.21	13.51
Wed	21/9/05	18.11	21.74	9.21	6.38	5.71
	4/1/06	25.54	29.46	10.42	8.85	8.72
Thurs	23/6/05	25.3	18.45	6.00	4.06	3.81
	6/10/05	46.48	44.39	21.13	14.25	7.77
	19/01/06	26.85	37.35	16.23	16.22	12.60

Table D-2 Concentrations of PM (µg/m^3) at various sizes fractions across the study period defined as day during the week compared by sampling sites. (Cont.)

	Date	PM>10	PM2.5-10	PM1.0-2.5	PM0.5-1.0	PM0.1-0.5
Hospital						
Fri	8/7/05	26.64	14.96	7.31	4.16	4.95
	21/10/05	31.61	28.94	22.31	13.48	5.77
Sat	23/7/05	19.93	16.41	6.58	4.29	3.59
	5/11/05	46.61	31.12	12.34	13.47	9.06
Sun	7/8/05	18.68	21.64	10.55	6.02	4.84
	20/11/05	24.14	18.95	9.14	11.18	5.29
Sarapee						
Mon	11/7/05	25.57	27.43	13.59	17.60	7.63
	24/10/05	22.47	22.70	26.10	14.70	7.20
Tues	26/7/05	19.41	20.52	10.3	7.41	5.08
	8/11/05	37.10	33.00	13.68	13.10	8.86
Wed	10/8/05	19.62	17.28	8.94	7.58	6.02
	23/11/05	31.35	20.58	19.91	17.92	11.20
Thu	25/8/05	18.73	15.47	8.92	6.26	4.17
	8/12/05	39.19	35.02	19.33	18.69	12.80
Fri	9/9/05	11.26	10.45	9.75	6.33	4.18
	23/12/05	20.09	21.24	32.07	23.69	12.50
Sat	24/9/05	18.94	16.10	7.00	6.55	4.56
	7/1/06	37.56	34.53	17.49	20.24	15.10
Sun	26/6/05	21.63	14.80	8.06	5.69	4.58
	9/10/05	16.70	36.72	15.18	10.77	5.39
	22/01/06	30.83	31.84	24.18	21.40	15.52

APPENDIX E

Compositions of PM at Various Sizes fractions in Chiang Mai’s Ambient Air

Table E-1 Ion Concentrations (milligram ion per gram PM)

Time/Date	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	NH_4^+	Mg^{2+}	K^+	Ca^{2+}
1/11200605	u	1.407	2.279	u	2.377	u	0.562	4.098	u
1/12200605	47.217	17.221	7.281	1.099	0.539	u	0.961	3.016	u
1/13200605	u	37.549	32.258	u	1.965	4.096	1.112	5.167	u
1/14200605	u	38.734	52.458	u	1.774	10.657	0.248	9.081	8.235
1/15200605	u	32.754	16.674	u	2.586	7.236	0.089	7.711	7.778
1/21230605	u	1.455	4.599	u	3.481	u	0.552	2.199	u
1/22230605	63.057	3.026	3.646	u	0.342	u	0.717	2.572	u
1/23230605	u	39.141	12.123	u	1.838	1.707	1.530	5.586	u
1/24230605	u	42.501	27.866	u	1.380	5.917	0.312	9.748	13.983
1/25230605	u	51.98	32.155	u	0.890	4.642	0.074	9.535	5.498
1/31260605	20.352	1.41	6.615	u	4.588	u	1.195	2.301	u
1/32260605	95.894	5.171	8.775	1.783	0.940	u	1.682	3.684	u
1/33260605	79.802	36.059	38.693	u	2.604	u	2.082	7.309	u
1/34260605	2.809	31.158	55.615	u	1.748	8.299	0.403	9.764	6.783
1/35260605	62.107	7.312	42.571	u	3.109	4.667	0.244	12.987	5.817
2/11050705	u	3.452	2.869	u	4.011	u	0.649	3.300	u
2/12050705	55.541	21.322	6.801	u	0.163	u	0.954	2.568	u
2/13050705	u	33.834	28.235	u	1.038	0.595	1.503	3.774	u
2/14050705	u	61.33	72.277	u	4.883	13.748	0.960	11.227	19.321
2/15050705	u	8.566	36.439	u	2.160	7.654	0.205	8.089	5.550
2/21080705	45.982	6.065	15.953	u	2.581	3.429	0.681	3.531	u
2/22080705	97.372	31.918	9.423	1.958	1.007	u	1.221	4.910	u
2/23080705	13.328	42.08	22.714	u	u	u	1.112	3.837	21.197
2/24080705	u	54.895	40.583	u	u	u	0.138	8.730	5.654
2/25080705	u	6.343	14.72	u	u	u	0.033	5.957	2.211
2/31110705	45.388	3.14	4.577	u	2.861	0.221	1.056	4.186	16.566
2/32110705	114.05	31.288	13.094	1.199	u	u	1.557	3.226	u
2/33110705	13.842	33.2	46.295	u	u	u	1.786	3.599	u
2/34110705	u	10.48	34.566	u	u	u	0.148	4.063	2.174
2/35110705	5.361	29.547	46.854	u	u	u	0.262	10.660	6.261
3/11200705	u	5.053	2.635	u	4.587	0.721	0.587	3.447	19.826
3/12200705	82.252	29.317	6.188	1.627	0.285	u	0.920	5.080	u
3/13200705	7.092	45.51	15.629	u	1.466	u	0.957	6.122	30.467
3/14200705	u	50.379	26.1	u	2.317	6.692	0.336	12.172	9.244

Table E-1 Ion Concentrations (milligram ion per gram PM) (Cont.)

Time/Date	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	NH_4^+	Mg^{2+}	K^+	Ca^{2+}
3/15200705	u	46.112	14.278	u	u	4.997	0.029	9.242	3.303
3/21230705	u	3.297	5.847	u	3.122	0.180	0.627	3.758	23.642
3/22230705	66.052	2.247	6.769	u	0.413	u	0.819	3.151	u
3/23230705	15.52	39.857	9.181	u	1.513	1.245	1.091	5.893	u
3/24230705	18.034	45.159	17.956	u	0.609	4.830	0.365	10.568	8.162
3/25230705	u	5.602	17.491	u	3.421	2.289	u	11.412	0.942
3/31260705	u	2.918	4.645	u	3.196	0.473	0.683	5.194	22.866
3/32260705	68.243	3.53	6.469	1.556	0.613	u	0.983	3.800	u
3/33260705	u	1.826	28.464	u	u	0.055	1.294	4.092	u
3/34260705	18.687	31.902	36.151	u	1.152	5.254	0.537	7.580	11.485
3/35260705	23.492	38.113	2.963	u	1.908	5.469	0.255	9.314	5.527
4/11040805	u	21.349	8.42	u	8.965	u	0.405	1.275	90.320
4/12040805	71.295	42.64	26.222	u	3.644	u	0.023	4.177	56.880
4/13040805	14.993	46.404	35.564	u	0.984	u	u	5.114	34.648
4/14040805	20.793	39.684	25.673	u	5.073	u	u	11.500	9.793
4/15040805	18.688	1.016	5.485	u	5.166	u	u	18.167	8.737
4/21070805	u	18.838	7.535	u	15.569	u	0.639	10.440	109.10
4/22070805	62.131	47.731	30.097	u	1.137	u	0.284	5.087	45.957
4/23070805	24.371	43.244	57.938	u	5.233	u	u	6.706	49.525
4/24070805	22.721	43.376	33.099	u	4.820	3.135	u	14.985	11.564
4/25070805	34.338	0.217	5.055	u	2.896	u	u	27.200	11.740
4/31100805	u	4.811	12.528	u	8.687	u	1.074	2.629	82.465
4/32100805	96.556	44.759	36.196	u	4.297	u	0.769	4.814	56.444
4/33100805	20.032	34.445	46.27	u	5.142	u	u	10.459	27.495
4/34100805	24.311	40.397	27.53	u	3.445	u	u	22.542	8.424
4/35100805	23.876	0.504	9.16	u	5.196	u	u	24.140	9.219
5/11190805	50.963	13.214	5.945	u	4.653	u	0.526	3.337	71.407
5/12190805	45.594	31.166	18.589	u	2.635	u	0.203	3.211	45.592
5/13190805	19.22	29.819	23.597	0.954	0.550	u	u	6.606	39.930
5/14190805	21.074	33.372	10.408	u	1.401	u	u	11.355	6.723
5/15190805	25.592	0.955	3.885	u	3.572	u	u	9.481	2.882
5/21220805	22.096	8.179	4.058	u	2.494	u	0.307	1.412	38.184
5/22220805	46.814	20.605	20.842	u	1.275	u	0.230	1.424	26.200
5/23220805	29.852	26.834	45.208	u	2.353	u	u	3.694	44.375
5/24220805	18.052	25.441	20.879	u	2.383	4.861	u	10.179	9.486

Table E-1 Ion Concentrations (milligram ion per gram PM) (Cont.)

Time/Date	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	NH_4^+	Mg^{2+}	K^+	Ca^{2+}
5/25220805	11.892	0.177	2.885	u	3.788	u	u	9.520	4.361
5/31250805	u	5.718	8.711	u	7.930	u	0.662	7.418	58.741
5/32250805	204.74	37.837	43.567	2.627	4.644	u	0.199	11.605	55.603
5/33250805	25.595	24.094	24.465	1.651	3.669	u	u	11.247	30.834
5/34250805	u	34.823	5.992	u	3.887	u	u	14.374	7.265
5/35250805	u	5.26	12.944	u	1.854	u	u	21.441	10.726
6/11030905	u	22.162	u	u	0.956	u	0.522	11.243	80.683
6/12030905	u	39.656	80.818	1.126	3.733	u	u	9.319	69.900
6/13030905	u	37.756	30.617	u	0.440	20.616	u	8.366	27.595
6/14030905	u	43.382	10.175	u	4.489	16.119	u	4.380	5.158
6/15030905	u	3.857	14.09	u	4.878	2.734	u	2.941	3.349
6/21060905	u	16.812	u	u	7.944	3.549	0.533	u	75.637
6/22060905	u	25.856	u	u	2.955	u	u	6.399	40.746
6/23060905	u	21.191	48.327	u	1.759	17.334	u	5.320	30.943
6/24060905	u	36.388	5.072	u	3.201	22.069	u	6.228	5.665
6/25060905	u	1.248	3.763	u	3.862	8.027	u	6.794	4.552
6/31090905	u	3.491	76.54	u	17.514	u	0.801	2.146	102.97
6/32090905	u	25.721	67.739	u	6.802	u	u	15.899	69.570
6/33090905	u	26.562	39.217	1.648	1.950	12.204	u	4.040	19.649
6/34090905	u	40.2	10.284	1.992	3.475	13.769	u	8.030	9.487
6/35090905	u	0.928	4.395	u	6.451	u	u	10.331	9.815
7/11180905	u	2.1	22.442	u	8.220	u	0.253	u	47.709
7/12180905	0.486	30.324	31.682	u	3.021	u	u	3.518	20.862
7/13180905	u	4.047	16.003	u	u	u	u	2.401	28.316
7/14180905	u	2.922	6.703	u	0.559	u	u	3.214	7.429
7/15180905	u	7.041	5.496	u	2.310	u	u	5.849	4.342
7/21210905	u	6.963	9.603	u	8.280	u	0.762	1.762	64.560
7/22210905	1.645	18.686	33.65	u	1.753	u	u	3.412	21.430
7/23210905	u	31.531	29.285	u	2.023	u	u	4.706	31.394
7/24210905	u	60.77	1.921	u	2.424	3.234	u	10.452	6.619
7/25210905	u	2.815	0.926	2.159	1.426	u	u	5.796	2.805
7/31240905	u	4.607	16.854	u	11.750	u	0.615	4.571	56.957
7/32240905	u	38.101	26.232	u	2.619	u	u	5.515	20.216

Table E-1 Ion Concentrations (milligram ion per gram PM) (Cont.)

Time/Date	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	NH_4^+	Mg^{2+}	K^+	Ca^{2+}
7/33240905	u	28.578	22.807	u	2.069	u	u	7.377	35.014
7/34240905	u	38.435	2.655	u	u	u	u	11.024	8.201
7/35240905	u	3.004	3.034	u	4.245	u	u	12.054	6.066
8/11031005	2.063	19.326	17.109	u	5.954	0.545	0.448	u	50.187
8/12031005	u	36.134	25.663	u	u	0.273	0.201	u	17.473
8/13031005	u	43.164	20.534	u	u	3.729	0.334	5.670	33.397
8/14031005	u	58.903	6.44	u	1.389	13.121	u	15.141	17.550
8/15031005	u	21.234	6.754	u	1.068	10.513	u	19.451	32.369
8/21061005	u	9.924	u	u	1.675	1.240	0.543	u	32.363
8/22061005	u	u	u	u	0.351	0.118	0.273	0.894	16.892
8/23061005	u	27.536	51.294	u	0.505	19.170	0.626	7.366	32.221
8/24061005	u	30.154	10.373	u	0.878	33.036	0.019	12.706	8.132
8/25061005	0.644	3.294	9.111	u	u	18.823	u	10.274	11.446
8/31091005	3.626	8.028	u	u	6.604	2.110	0.814	u	48.852
8/32091005	u	17.275	u	u	u	0.358	0.174	1.658	12.281
8/33091005	u	18.404	u	0.908	u	41.038	1.147	9.372	18.961
8/34091005	u	33.686	5.105	u	0.950	49.994	u	10.141	4.969
8/35091005	u	9.148	19.281	u	u	36.684	u	13.985	11.615
9/11181005	3.866	31.058	u	u	5.478	1.158	0.755	u	44.512
9/12181005	u	23.488	u	u	1.635	0.157	0.806	2.324	23.675
9/13181005	u	18.581	71.27	0.622	1.918	31.322	0.880	9.690	18.415
9/14181005	u	33.181	14.191	u	0.722	36.732	u	11.860	7.307
9/15181005	u	3.428	35.904	u	0.536	23.334	u	12.115	7.585
9/21211005	1.965	19.422	u	u	3.965	0.608	0.525	u	38.859
9/22211005	u	13.433	u	u	0.056	4.112	0.672	4.074	24.642
9/23211005	u	12.22	119.50	0.464	0.151	36.311	0.790	10.250	21.287
9/24211005	u	30.031	7.407	u	u	47.512	0.112	13.462	5.365
9/25211005	u	4.111	23.441	u	u	35.730	u	12.365	16.989
9/31241005	2.444	32.156	u	u	u	3.020	0.846	u	40.876
9/32241005	u	23.98	u	u	u	u	0.741	4.154	21.139
9/33241005	u	22.199	u	u	0.440	33.497	0.958	12.537	16.563
9/34241005	u	35.35	4.237	u	u	38.170	u	13.688	6.495
9/35241005	u	0.937	9.745	u	u	28.055	u	17.375	4.024

Table E-1 Ion Concentrations (milligram ion per gram PM) (Cont.)

Time/Date	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	NH_4^+	Mg^{2+}	K^+	Ca^{2+}
10/11021105	94.116	2.705	u	u	9.271	u	u	4.653	34.509
10/12021105	57.676	4.524	u	u	1.005	u	u	3.603	12.820
10/13021105	9.584	3.856	54.522	u	u	19.801	u	14.231	27.511
10/14021105	13.167	5.142	11.16	u	u	25.207	u	22.626	9.658
10/15021105	1.81	32.551	8.758	u	u	8.699	u	17.743	3.490
10/21051105	68.885	11.97	54.82	u	0.604	u	u	u	30.567
10/22051105	2.061	48.069	48.832	u	u	u	u	2.603	20.538
10/23051105	7.193	40.487	23.667	0.912	0.372	7.782	u	9.595	25.109
10/24051105	5.456	38.418	5.346	1.189	0.705	14.767	u	13.317	10.600
10/25051105	8.341	1.029	3.905	u	7.353	11.544	u	22.800	3.135
10/31081105	u	15.517	22.207	u	6.461	u	u	3.435	33.156
10/32081105	51.436	26.975	27.214	0.755	0.290	u	u	3.016	12.922
10/33081105	u	29.109	21.568	u	0.699	u	u	8.276	18.816
10/34081105	6.725	24.672	8.523	u	0.374	9.949	u	11.894	3.372
10/35081105	u	2.936	10.236	u	u	4.477	u	13.795	2.631
11/11171105	122.17	5.837	u	u	1.322	u	u	6.100	27.410
11/12171105	103.735	14.158	u	u	0.995	u	u	8.843	19.858
11/13171105	109.073	13.43	44.522	u	0.193	7.405	1.413	62.491	15.279
11/14171105	134.766	8.876	4.065	u	u	11.364	1.256	114.52	5.763
11/15171105	182.75	11.229	1.525	u	u	9.139	u	67.678	1.820
11/21201105	u	39.083	u	u	1.982	u	u	0.000	46.132
11/22201105	96.916	61.823	u	u	u	u	u	4.312	34.321
11/23201105	16.038	42.24	u	u	2.794	25.020	u	10.572	33.153
11/24201105	4.349	71.59	2.152	u	0.034	32.635	u	12.367	4.364
11/25201105	7.98	4.167	1.744	u	1.073	33.651	u	20.772	9.556
11/31231105	141.043	8.000	u	u	4.171	u	u	4.304	27.870
11/32231105	99.681	24.798	u	u	1.948	u	u	4.700	19.485
11/33231105	40.684	38.211	39.525	u	3.682	16.233	0.814	7.855	14.345
11/34231105	58.235	35.687	2.292	u	1.339	20.145	u	13.242	7.158
11/35231105	8.336	42.929	8.009	u	0.204	14.205	u	15.886	2.954
12/11021205	u	22.396	u	u	10.423	2.920	u	2.622	34.318
12/12021205	57.071	21.465	u	u	4.528	0.948	u	3.979	19.606
12/13021205	9.907	26.932	30.509	u	3.626	17.206	0.932	8.905	22.221
12/14021205	9.304	17.254	6.78	0.705	9.815	24.939	u	20.650	10.370
12/15021205	u	119.66	10.464	1.266	1.256	9.533	u	13.620	8.238

Table E-1 Ion Concentrations (milligram ion per gram PM) (Cont.)

Time/Date	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	NH_4^+	Mg^{2+}	K^+	Ca^{2+}
12/21051205	102.722	29.867	u	u	20.091	9.553	u	6.893	58.998
12/22051205	100.265	23.378	u	u	9.122	1.357	u	7.648	24.545
12/23051205	3.408	16.845	44.923	u	7.081	16.470	1.593	20.346	21.320
12/24051205	2.111	13.003	4.458	u	7.972	20.593	u	26.391	7.792
12/25051205	9.221	65.376	9.192	u	u	17.493	u	22.968	4.859
12/31081205	52.777	19.101	u	u	6.341	9.554	u	5.330	38.353
12/32081205	42.965	28.829	u	u	1.736	u	u	3.439	17.897
12/33081205	39.559	29.742	32.885	u	3.138	12.436	u	8.111	15.972
12/34081205	47.574	25.81	4.394	u	0.989	15.916	u	10.785	3.623
12/35081205	7.572	38.819	18.012	u	5.162	14.606	u	12.461	3.957
13/11171205	39.714	20.336	u	u	1.020	u	u	u	11.905
13/12171205	70.514	20.411	u	u	u	u	u	3.653	19.483
13/13171205	0.514	16.995	9.611	1.315	0.777	24.000	1.298	12.714	20.037
13/14171205	3.236	8.58	22.252	1.463	0.731	34.714	u	18.531	10.311
13/15171205	u	56.766	u	u	1.684	26.057	u	22.720	9.680
13/21201205	64.107	22.753	u	u	1.936	u	u	u	21.898
13/22201205	62.32	15.992	u	u	0.973	u	1.262	3.876	28.222
13/23201205	4.52	19.687	19.686	u	1.248	u	1.251	15.383	18.067
13/24201205	0.106	8.852	u	0.884	0.915	u	u	18.590	4.209
13/25201205	u	91.84	u	0.612	0.788	15.845	u	13.792	1.263
13/31231205	87.659	32.75	u	u	8.897	5.204	u	2.910	26.668
13/32231205	69.106	u	u	u	0.017	u	1.440	4.227	31.868
13/33231205	6.803	u	0.707	0.982	0.454	u	1.473	15.439	8.978
13/34231205	8.029	24.543	9.095	u	0.981	u	u	18.497	2.668
13/35231205	5.652	133.24	34.108	u	0.889	21.979	u	22.285	2.115
14/11010106	174.568	51.46	u	u	13.285	2.338	u	3.747	22.951
14/12010106	115.331	35.985	30.107	u	0.050	u	u	5.582	28.928
14/13010106	22.959	13.767	6.751	u	1.224	3.461	u	15.347	25.214
14/14010106	10.537	27.038	7.007	u	1.199	6.430	u	23.926	2.761
14/15010106	22.179	71.289	13.265	u	0.974	2.904	u	24.607	1.786

Table E-1 Ion Concentrations (milligram ion per gram PM) (Cont.)

Time/Date	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	NH_4^+	Mg^{2+}	K^+	Ca^{2+}
14/21040106	88.284	21.059	20.325	u	1.904	u	u	u	24.743
14/22040106	59.256	18.421	14.187	u	0.356	u	u	3.062	20.336
14/23040106	12.006	u	3.795	u	0.253	u	u	8.294	32.041
14/24040106	9.395	23.654	5.371	u	0.754	7.358	u	19.312	12.388
14/25040106	4.602	42.162	u	u	1.208	3.119	u	16.784	2.823
14/31070106	56.741	24.012	u	u	1.574	u	u	u	13.272
14/32070106	48.522	u	u	u	0.545	u	1.047	3.250	16.272
14/33070106	12.304	u	2.712	0.843	0.619	5.882	1.155	12.093	20.547
14/34070106	6.389	u	4.75	1.37	1.343	11.667	u	20.092	2.558
14/35070106	3.003	6.847	10.978	u	1.135	8.126	u	19.734	2.451
15/11160106	87.365	18.121	u	u	1.468	u	u	u	17.114
15/12160106	42.445	u	16.17	u	0.681	u	0.806	4.285	16.129
15/13160106	5.797	u	6.575	0.799	0.466	u	0.861	6.912	32.665
15/14160106	9.112	u	5.903	1.189	0.726	8.834	u	17.274	5.340
15/15160106	10.004	10.253	u	u	0.674	7.915	u	16.573	6.921
15/21190106	99.405	24.83	u	u	2.174	u	u	u	20.028
15/22190106	44.617	u	u	u	1.104	u	0.887	3.128	18.989
15/23190106	1.52	u	5.569	0.576	0.801	3.147	0.903	8.454	28.123
15/24190106	6.124	u	4.915	0.744	0.749	12.311	u	19.035	8.169
15/25190106	13.938	60.762	u	u	0.574	8.609	u	16.131	4.877
15/31220106	51.843	19.441	u	u	2.479	u	u	u	24.702
15/32220106	44.771	u	u	u	u	u	0.992	2.943	18.629
15/33220106	33.273	u	u	0.741	0.950	6.579	1.192	9.374	24.050
15/34220106	38.995	u	u	1.001	0.664	11.165	u	16.783	2.313
15/35220106	6.728	u	u	u	0.759	8.362	u	20.553	4.213

Remark: u = undetected concentrations by the devices which DL = 1µg/L

Time/Date = xx/yzddmmyy where xx = time of sampling at the site

y = site of sampling; 1= Yuparaj school 2= municipality hospital

3= the district office of Sarapee

z = stages of PUF; 1=PM-10, 2= PM-2.5, 3=PM-1.0, 4=PM-0.5, 5=PM-0.1

ddmmyy = date month year for example; 15/35220106 = the sample that taken at site 3, PUF size 5 on the date of 22nd January 2006. It was taken 15th times.

Table E-2 Metals Concentrations (milligram metal per gram PM)

Date/Time	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Pb	Sr	Ti	Zn
11190805	7.065	u	0.072	142.477	u	6.340	0.035	2.933	0.064	0.356	u	0.100	u	u
12190805	11.732	u	0.206	194.190	11.575	5.234	0.156	4.306	0.177	1.382	u	0.121	u	0.048
13190805	9.147	u	u	54.269	12.378	u	u	3.722	u	5.215	u	0.068	0.207	0.697
14190805	1.135	0.068	u	4.829	1.812	0.084	u	u	u	2.965	u	u	0.297	0.299
15190805	0.744	0.655	u	u	u	u	u	u	u	2.511	u	u	0.221	u
21220805	9.774	u	0.125	150.332	1.202	u	1.119	2.819	0.456	0.713	u	0.073	u	u
22220805	12.256	u	0.170	160.512	11.405	0.021	0.845	3.326	0.445	1.125	u	0.080	u	0.088
23220805	10.464	0.763	u	61.940	18.119	4.063	u	3.464	u	3.811	u	0.060	0.028	0.029
24220805	1.638	0.270	u	6.366	5.791	2.131	u	u	u	0.427	u	u	0.098	0.332
25220805	0.871	2.596	u	1.776	u	u	u	u	u	2.762	u	u	u	u
31110705	8.538	u	0.065	132.438	6.250	1.180	u	5.448	u	1.959	u	0.147	u	u
32110705	15.025	0.087	0.185	108.452	4.546	u	0.152	7.937	0.053	7.950	u	0.187	0.048	0.797
33110705	10.527	1.250	u	21.794	7.840	u	u	6.944	u	10.774	u	0.167	0.045	1.064
34110705	1.003	0.681	u	2.555	1.260	u	u	0.104	u	2.658	u	u	0.175	0.329
35110705	1.007	0.629	u	3.088	0.751	u	u	u	u	1.379	u	u	u	11.187
8/11031005	u	0.550	0.075	123.176	11.763	u	0.016	3.017	0.042	0.603	u	0.099	0.032	u
8/12031005	15.355	0.792	0.118	152.266	15.198	8.222	0.101	3.728	0.074	4.271	u	0.107	u	u
8/13031005	9.859	2.359	u	35.894	9.747	7.602	u	1.840	u	5.044	u	0.042	0.314	u
8/14031005	4.591	0.356	u	u	1.074	u	u	u	u	0.285	u	u	u	u
8/15031005	6.718	1.513	u	u	0.021	u	u	u	u	2.074	u	u	u	u

Table E-2 Metals Concentrations (milligram metal per gram PM) (Cont.)

Date/Time	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Pb	Sr	Ti	Zn
8/21061005	4.265	u	u	33.771	1.766	3.021	u	1.052	u	u	u	0.019	u	u
8/22061005	16.795	2.076	u	122.263	14.186	4.210	0.477	3.380	0.449	1.748	u	0.071	u	u
8/23061005	9.615	u	u	27.218	11.277	0.819	u	1.519	u	1.696	0.223	0.026	0.033	1.187
8/24061005	3.138	u	u	u	2.150	u	u	u	u	0.342	u	u	0.073	u
8/25061005	2.790	1.521	u	u	u	u	u	u	u	0.578	u	u	0.450	u
8/31091005	8.472	10.659	u	67.287	2.421	u	0.013	3.976	u	u	u	0.056	0.081	u
8/32091005	7.212	2.002	u	47.780	5.635	u	u	2.356	u	0.948	u	0.039	u	u
8/33091005	6.233	15.185	u	11.268	3.865	u	u	1.328	0.678	2.970	0.430	0.015	0.025	0.163
8/34091005	1.684	u	u	u	u	u	u	u	u	0.838	u	u	u	u
8/35091005	3.014	23.893	u	u	u	u	u	u	u	1.296	u	u	0.610	u
9/11181005	4.052	8.263	u	16.702	0.955	5.827	u	1.070	u	1.071	u	0.030	u	u
9/12181005	15.133	4.429	u	100.600	12.809	6.731	0.143	3.725	0.038	4.413	u	0.098	u	u
9/13181005	5.131	0.371	u	8.968	5.144	u	u	0.988	u	3.549	0.401	0.020	u	1.271
9/14181005	2.235	0.000	u	u	0.751	u	u	u	u	1.621	u	u	u	0.512
9/15181005	2.874	30.709	u	u	u	u	u	u	u	2.349	u	u	u	u
9/21211005	10.157	2.254	0.046	179.557	3.396	0.874	0.270	3.515	0.232	1.679	u	0.122	0.029	0.033
9/22211005	12.191	u	u	26.776	7.745	u	u	3.003	u	5.752	u	0.067	u	u
9/23211005	5.423	7.716	u	16.447	5.711	u	u	1.282	u	3.439	0.941	0.040	u	1.453
9/24211005	2.167	51.569	u	u	1.454	u	u	u	u	6.140	0.472	u	0.169	0.780
9/25211005	2.752	103.044	u	u	0.028	u	u	u	u	10.267	u	u	u	u

Table E-2 Metals Concentrations (milligram metal per gram PM) (Cont.)

Date/Time	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Pb	Sr	Ti	Zn
9/31241005	4.995	u	u	106.125	4.396	0.626	u	4.012	u	u	u	0.075	0.091	u
9/32241005	13.182	u	u	128.758	11.139	u	0.007	5.389	0.083	2.657	u	0.094	u	u
9/33241005	3.679	u	u	9.167	5.245	u	u	1.354	0.207	1.374	1.390	0.022	0.121	1.557
9/34241005	0.306	u	u	7.290	0.252	u	u	u	u	u	u	u	0.049	3.731
9/35241005	0.488	u	u	11.088	u	4.346	u	u	u	u	u	u	0.091	5.258
10/11021105	5.543	0.480	0.303	91.661	0.991	5.023	0.037	2.045	u	0.016	u	0.082	0.076	0.717
10/12021105	16.246	0.379	0.299	140.027	12.264	u	0.286	3.693	0.239	0.999	u	0.117	0.028	1.371
10/13021105	8.795	1.381	0.279	25.065	7.166	u	u	1.314	u	1.269	1.911	0.048	u	2.406
10/14021105	0.552	1.153	0.472	u	2.994	u	u	u	u	3.013	3.773	u	0.046	1.908
10/15021105	1.224	4.038	u	u	1.114	u	u	u	u	3.930	0.422	u	0.099	2.028
10/21051105	3.248	0.078	u	102.703	4.202	2.011	u	1.537	0.007	16.629	u	0.057	0.001	u
10/22051105	13.325	0.211	0.194	102.703	15.379	6.415	0.174	3.785	0.232	1.022	u	0.125	0.016	0.611
10/23051105	6.140	u	0.455	50.571	6.554	6.695	u	1.137	u	1.094	u	0.070	u	3.082
10/24051105	0.410	0.766	u	2.448	2.475	u	u	u	u	0.229	u	u	u	0.341
10/25051105	u	0.670	u	u	0.973	u	u	u	u	u	u	u	u	0.277
10/31081105	1.297	0.582	u	64.502	4.674	3.776	u	2.039	u	0.064	u	0.041	u	u
10/32081105	9.497	0.219	u	155.322	9.731	0.677	0.031	4.865	0.176	0.976	u	0.095	0.011	0.491
10/33081105	4.145	2.710	u	20.433	6.867	u	u	1.378	u	2.136	u	0.024	0.116	1.157
10/34081105	0.086	0.396	u	2.772	0.395	u	u	u	u	0.801	1.278	u	u	3.194
10/35081105	u	0.011	u	2.979	0.783	1.549	u	u	u	0.534	u	u	u	2.936

Table E-2 Metals Concentrations (milligram metal per gram PM) (Cont.)

Date/Time	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Pb	Sr	Ti	Zn
11/11171105	8.229	0.070	0.433	159.969	13.001	u	0.321	3.168	0.252	1.252	u	0.126	u	0.682
11/12171105	15.750	0.072	0.373	140.266	9.593	6.361	0.082	3.843	0.062	2.120	u	0.133	u	0.667
11/13171105	9.926	u	0.384	12.446	5.725	7.426	u	1.981	u	2.668	2.371	0.156	u	1.352
11/14171105	6.721	u	0.290	1.116	1.064	7.984	u	0.449	u	2.129	2.266	0.093	0.033	0.581
11/15171105	2.724	u	u	u	u	u	u	u	u	0.845	u	u	0.073	0.596
11/21201105	5.423	0.037	0.154	160.859	12.230	7.039	0.038	3.199	u	0.575	u	0.092	0.067	7.832
11/22201115	12.562	0.950	0.240	176.854	11.269	7.825	u	3.837	u	3.467	u	0.120	0.034	4.567
11/23201105	6.537	u	u	33.615	12.195	6.842	u	1.154	u	1.740	u	0.031	0.117	1.873
11/24201105	u	u	u	1.877	0.979	u	u	u	u	0.608	u	u	u	1.694
11/25201105	0.849	u	u	u	4.586	1.017	u	u	u	3.100	u	u	0.522	0.040
11/31231105	6.950	0.022	u	171.423	5.556	u	0.105	5.223	0.157	0.592	u	0.124	u	2.066
11/32231105	9.473	u	u	96.768	9.428	7.015	u	3.947	u	0.843	u	0.076	u	0.654
11/33231105	2.870	u	u	8.242	5.124	u	u	0.606	u	0.657	u	0.005	0.059	u
11/34231105	0.745	u	u	1.271	1.292	u	u	u	u	0.560	u	u	0.091	u
11/35231105	u	u	u	0.696	0.504	u	u	u	u	0.914	u	u	u	0.570
12/11021205	8.057	u	0.135	96.011	1.836	u	0.113	2.477	0.060	1.243	u	0.095	0.108	0.712
12/12021205	14.009	u	0.353	121.864	12.218	4.758	0.117	3.392	0.151	2.740	u	0.107	u	0.500
12/13021205	4.440	u	0.142	15.780	6.791	3.201	u	0.643	u	1.201	u	0.025	u	0.994
12/14021205	0.428	u	u	u	1.611	u	u	u	u	0.822	u	u	0.395	0.956
12/15021205	0.827	u	u	2.467	1.819	u	u	u	u	0.617	u	u	u	0.517

Table E-2 Metals Concentrations (milligram metal per gram PM) (Cont.)

Date/Time	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Pb	Sr	Ti	Zn
12/21051205	8.701	0.208	0.251	8.062	2.065	4.887	u	3.212	u	1.459	u	0.101	u	0.876
12/22051205	13.246	u	0.436	98.119	9.918	u	u	3.664	u	3.615	u	0.099	u	0.351
12/23051205	5.468	u	0.897	8.238	6.035	0.730	u	1.001	u	2.984	u	0.092	u	1.052
12/24051205	0.700	u	u	u	u	u	u	u	u	0.692	u	0.075	0.018	1.209
12/25051205	u	u	0.283	u	2.636	u	u	u	u	0.274	u	u	0.189	u
12/31081205	7.224	0.108	0.322	129.474	10.327	u	0.101	3.915	0.187	1.094	u	0.091	0.041	0.353
12/32081205	11.077	u	0.209	115.954	10.575	4.721	0.043	3.851	0.175	1.240	u	0.079	u	0.307
12/33081205	3.230	0.108	0.073	10.451	4.997	2.386	u	0.627	u	0.545	u	0.008	u	0.329
12/34081205	u	u	0.040	u	0.743	1.608	u	u	u	0.408	u	u	u	0.482
12/35081205	u	0.034	0.079	u	1.090	u	u	u	u	u	u	u	0.182	0.557
13/11171205	10.320	0.015	0.114	78.649	11.693	u	0.441	2.604	0.474	0.740	u	0.072	0.027	0.971
13/12171205	17.213	u	0.251	61.495	11.285	6.253	0.108	2.926	0.265	1.383	u	0.076	u	0.226
13/13171205	6.277	u	0.072	18.200	8.210	3.681	u	1.563	0.386	1.081	0.804	0.038	0.058	1.340
13/14171205	1.275	u	0.007	2.360	1.649	u	u	u	u	1.406	0.198	u	u	1.117
13/15171205	1.150	u	0.023	3.381	1.595	u	u	u	u	1.735	u	u	0.601	0.638
13/21201205	9.598	u	0.104	187.039	2.199	u	0.084	3.990	0.186	1.934	u	0.123	0.070	0.327
13/22201205	12.668	u	0.372	149.976	9.736	8.811	0.035	3.912	0.216	2.359	u	0.112	u	0.398
13/23201205	4.327	u	0.123	17.366	5.643	u	0.119	1.894	1.247	1.573	0.620	0.038	0.043	1.390
13/24201205	0.340	0.027	u	0.249	0.157	0.286	u	u	u	0.800	0.264	u	0.070	0.688
13/25201205	u	u	0.165	u	u	u	u	u	u	1.064	u	u	u	0.182

Table E-2 Metals Concentrations (milligram metal per gram PM) (Cont.)

Date/Time	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Pb	Sr	Ti	Zn
13/31231205	3.292	u	u	55.584	3.857	u	u	2.545	u	u	u	0.060	0.114	0.232
13/32231205	12.321	0.195	0.176	84.382	9.106	5.578	0.021	4.447	0.365	1.132	u	0.092	u	0.589
13/33231205	3.021	u	0.114	7.612	5.159	u	0.140	1.676	1.383	1.278	1.514	0.028	u	1.397
13/34231205	0.218	0.012	u	u	u	1.435	u	u	0.114	0.866	0.660	u	0.144	0.902
13/35231205	u	u	u	u	u	u	u	u	u	26.744	u	u	0.011	u
14/11010106	3.940	u	u	51.050	4.879	u	u	2.038	u	0.284	u	0.082	u	0.539
14/12010106	14.446	0.064	0.692	116.002	10.650	8.880	u	3.805	u	2.404	u	0.122	u	0.817
14/13010106	4.572	0.118	0.156	21.578	5.485	7.296	u	0.462	u	1.807	u	0.034	0.308	0.903
14/14010106	u	0.626	0.101	u	2.351	u	u	u	u	1.954	u	u	0.339	0.250
14/15010106	u	u	0.076	u	u	u	u	u	u	0.749	u	u	0.160	0.308
14/21040106	6.828	u	0.099	180.688	11.523	3.577	0.019	4.094	0.100	0.989	u	0.129	u	u
14/22040106	15.198	u	0.640	216.534	17.533	1.731	0.204	5.089	0.324	1.958	u	0.152	u	0.512
14/23040106	5.380	u	0.361	33.857	9.097	0.770	u	1.313	u	u	u	0.070	u	0.487
14/24040106	u	0.183	0.186	1.282	1.163	u	u	u	u	u	u	0.085	0.163	0.514
14/25040106	u	u	0.004	u	u	u	u	u	u	u	u	0.013	0.147	0.098
14/31070106	5.389	u	0.107	132.974	13.464	u	u	4.300	0.236	1.172	u	0.124	0.059	0.662
14/32070106	13.184	0.028	0.238	128.609	10.952	u	u	4.737	0.313	2.093	u	0.116	u	0.392
14/33070106	3.894	u	0.105	14.123	6.427	u	u	1.071	u	0.507	u	0.020	0.023	0.312
14/34070106	u	u	0.080	1.121	0.015	u	u	u	u	1.277	u	u	u	0.590
14/35070106	u	0.035	u	u	0.988	2.466	u	u	u	1.109	u	u	0.022	0.429

Table E-2 Metals Concentrations (milligram metal per gram PM) (Cont.)

Date/Time	Al	B	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Pb	Sr	Ti	Zn
15/11160106	7.554	u	u	95.648	0.336	3.734	0.123	2.499	0.126	0.838	u	0.074	0.091	0.733
15/12160106	13.243	u	0.063	105.706	5.610	4.194	0.260	2.835	0.262	1.132	u	0.081	0.000	0.268
15/13160106	5.255	u	u	18.533	4.379	2.041	u	0.836	u	0.596	u	0.019	0.013	0.277
15/14160106	0.585	u	u	2.126	0.323	1.848	u	u	u	0.876	u	u	0.071	0.135
15/15160106	u	u	u	0.978	u	u	u	u	u	0.787	u	u	u	0.049
15/21190106	4.983	u	u	122.367	11.854	u	u	2.705	0.040	1.226	u	0.080	u	0.834
15/22190106	13.107	0.035	0.061	147.575	9.526	1.575	0.270	3.869	0.319	2.031	u	0.099	u	0.672
15/23190106	4.724	u	u	16.739	6.356	u	u	0.985	u	1.665	u	0.014	u	0.506
15/24190106	1.023	u	u	4.732	2.113	0.834	u	u	u	0.859	u	u	0.046	0.755
15/25190106	u	u	u	0.652	u	u	u	u	u	1.090	u	u	0.085	0.781
15/31220106	3.429	u	u	42.750	u	u	u	1.835	u	0.079	u	0.038	0.021	u
15/32220106	11.722	u	u	79.667	8.654	0.101	0.042	3.608	0.101	0.814	u	0.072	u	0.330
15/33220106	4.100	u	u	12.463	6.659	u	u	1.285	u	0.457	u	0.019	u	0.273
15/34220106	u	0.019	u	u	1.336	u	u	u	u	0.432	u	u	0.008	0.077
15/35220106	u	u	u	u	u	u	u	u	u	0.636	u	u	u	0.185

Remark: u = undetected concentrations by the ICP-OES device which DL= 0.1 µg/L

Replicate number: 3 times for one sample

BIOGRAPHY

Miss Narumon Tiangviriya was born on October 19, 1981 in Bangkok, Thailand. She graduated from Wattanothai Payap School in Chiang Mai in 2000. She received her Bachelor’s Degree in Environmental Engineering from Chiang Mai University in 2004. She pursued her Master’s Degree study in the International Postgraduate Programs in Environmental and Hazardous Waste Management, Inter-Department of Environmental, Chulalongkorn University, Bangkok, Thailand in May 2004. She finished her Master’s Degree of Science in Environmental Management in October 2006.