METALLIC ELEMENT COMPOSITION AND POSSIBLE SOURCE OF PM2.5 IN THE DOWNTOWN AND UPTOWN AMBIENT AIR OF CHIANG MAI PROVINCE,THAILAND.

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จุฬาลงกรณ์มหาวิทยาลัย

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องค์ประกอบที่เป็นธาตุโลหะและแหล่งกำเนิดที่เป็นไปได้ของพีเอ็ม-2.5 ในอากาศเขตเมือง และเขตชานเมืองของจังหวัดเชียงใหม่ ประเทศไทย

นาย อนุวัตน์ แสงอ่อน

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)
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ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

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อนุวัตน์ แสงอ่อน : องค์ประกอบที่เป็นธาตุโลหะและแหล่งกำเนิดที่เป็นไปได้ของพีเอ็ม-2.5 ในอากาศเขตเมืองและเขตชานเมืองของจังหวัดเชียงใหม่ ประเทศไทย(METALLIC ELEMENT COMPOSITION AND POSSIBLE SOURCE OF $PM_{2.5}$ IN THE DOWNTOWN AND UPTOWN AMBIENT AIR OF CHIANG MAI PROVINCE, THAILAND.) อ. ที่ปรึกษา: อ. ดร. เพชร เพ็งชัย; 132 หน้า. ISBN 974-53-2161-3.

งานวิจัยนี้ได้วัดปริมาณพีเอ็ม-2.5 และองค์ประกอบที่เป็นธาตุโลหะจากจุดเก็บตัวอย่าง 2 จุดในจังหวัดเชียงใหม่โดยให้จุดเก็บตัวอย่างที่ 1 และจุดเก็บตัวอย่างที่ 2 เป็นตัวแทนของพื้นที่เขตเมืองและเขตชานเมือง ตามลำดับ ในการเก็บตัวอย่างพีเอ็ม-2.5 จะเก็บตัวอย่างละ 24 ชั่วโมงด้วยความถี่ 6 วันต่อสัปดาห์ โดยทำการเก็บตั้งแต่เดือนธันวาคม 2547 ถึงเดือนกุมภาพันธ์ 2548 สำหรับอุปกรณ์เก็บตัวอย่างพีเอ็ม-2.5 นั้นใช้เครื่องเก็บตัวอย่างฝุ่นไมโครโวล1100 จากผลการทดลองพบว่าค่าความเข้มข้นของพีเอ็ม-2.5 ณ จุดเก็บตัวอย่างที่ 1 และ 2 มีค่าอยู่ในช่วง 23-145 ไมโครกรัม/ลูกบาศก์เมตร และ 0-93 ไมโครกรัม/ลูกบาศก์เมตร ตามลำดับ ความเข้มข้นเฉลี่ยของพีเอ็ม-2.5 ณ จุดเก็บตัวอย่างที่ 1 และ 2 เท่ากับ 93 ไมโครกรัม/ลูกบาศก์เมตร และ 44 ไมโครกรัม/ลูกบาศก์เมตร ตามลำดับ ในช่วงที่ทำการศึกษาพบว่าพีเอ็ม-2.5มีแนวโน้มเพิ่มขึ้นตามระยะเวลาที่ผ่านไป ความเข้มข้นของพีเอ็ม-2.5 มีความสัมพันธ์เชิงบวกอย่างมีนัยสำคัญกับค่าอุณหภูมิเฉลี่ยและจำนวนชั่วโมงที่มีแสงแดด นอกจากนี้ยังพบว่าลำดับค่าความเข้มข้นเฉลี่ยของธาตุโลหะที่เป็นองค์ประกอบของพีเอ็ม-2.5 สำหรับจุดเก็บตัวอย่างที่ 1 คือ แคลเซียม> แมกนีเซียม> โปแตสเซียม> สังกะสี> แมงกานีส> เหล็ก> โครเมียม> ตะกั่ว> นิกเกิล> ทองแดง> แคดเมียม และสำหรับจุดเก็บตัวอย่างที่ 2 แคลเซียม> แมกนีเซียม> โปแตสเซียม> สังกะสี> เหล็ก>แมงกานีส > โครเมียม> ตะกั่ว> นิกเกิล> ทองแดง> แคดเมียม พบว่าที่จุดเก็บตัวอย่างที่ 1 และ 2 ความเข้มข้นของพีเอ็ม-2.5 สูงกว่าค่ามาตรฐาน 24 ชั่วโมงขององค์กรพิทักษ์สิ่งแวดล้อมของประเทศสหรัฐอเมริกา (65 ไมโครกรัม/ลูกบาศก์เมตร) ทั้งหมดจำนวน 27 วัน และ 6 วันตามลำดับ ผลการคำนวณโดยใช้ค่าความเข้มข้นเฉลี่ยของแคดเมียม ตะกั่ว โครเมียม และนิกเกิล พบว่าค่าความเสี่ยงต่อการเกิดโรคมะเร็งที่เพิ่มขึ้นเนื่องจากการสัมผัสกับบรรยากาศของจังหวัดเชียงใหม่ ณ จุดเก็บตัวอย่างที่ 1 และ 2 มีค่าเท่ากับ 1.6×10^{-3} และ 1.1×10^{-3} ตามลำดับ ผลการวิเคราะห์ด้วยวิธีตัวประกอบสำคัญ (Principal component analysis) สรุปได้ว่าแหล่งกำเนิดของพีเอ็ม-2.5 และเปอร์เซ็นต์ที่แต่ละตัวประกอบสามารถอธิบายความผันแปรของพีเอ็ม-2.5 เป็นดังนี้: การจราจร(50.7%), การเผาทางการเกษตร/ไฟป่า(16.7%), ดิน(10.8%) และการเผาในที่เปิดโล่ง(9.1%) กล่าวได้ว่าการจราจรเป็นแหล่งกำเนิดที่สำคัญของพีเอ็ม-2.5 ในอากาศทั้งเขตเมืองและเขตชานเมืองของจังหวัดเชียงใหม่ เป็นที่น่าสังเกตว่าค่าต่ำสุดและสูงสุดของคะแนนของตัวประกอบ (PC scores) สำหรับตัวอย่างในจุดเก็บตัวอย่างที่1 อยู่ในระดับเดียวกับกรณีจุดเก็บตัวอย่างที่2 กล่าวได้ว่าอิทธิพลของแหล่งกำเนิดแต่ละชนิดที่มีต่อพีเอ็ม-2.5 ณ จุดเก็บตัวอย่างทั้งสองจุดมีลักษณะคล้ายกัน นอกจากนี้ยังพบว่าการเผาทางการเกษตร/ไฟป่าสามารถจัดได้เป็นแหล่งกำเนิดมลพิษส่วนภูมิภาค (regional pollution source) เนื่องจากค่าคะแนนของตัวประกอบ (PC scores) ของการเผาทางการเกษตร/ไฟป่าที่คำนวณได้ในกรณีของจุดเก็บตัวอย่างที่ 1 และที่ 2 มีความสัมพันธ์กันอย่างชัดเจน

สาขาวิชาการจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต..

ปีการศึกษา 2547 ลายมือชื่ออาจารย์ที่ปรึกษา..

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม......................................

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จุฬาลงกรณ์มหาวิทยาลัย

##4689510120: MAJOR ENVIRONMENTAL MANAGEMENT
KEY WORD: $PM_{2.5}$/ METALLIC ELEMENT COMPOSITION /PRINCIPAL COMPONENT ANALYSIS/POSSIBLE SOURCES/CHIANG MAI

ANUWAT SANGON : METALLIC ELEMENT COMPOSITION AND POSSIBLE SOURCE OF $PM_{2.5}$ IN THE DOWNTOWN AND UPTOWN AMBIENT AIR OF CHIANG MAI PROVINCE, THAILAND. THESIS ADVISOR: PETCH PENGCHAI, Ph.D., 132 pp. ISBN 974-53-2161-3.

$PM_{2.5}$ and its metallic element compositions were measured at two different sites in Chiang Mai, site no.1 and site no.2 as the representatives of downtown and uptown area, from December 2004 to February 2005. Twenty-four-hour $PM_{2.5}$ samples were collected six days a week by MicroVol1100 particulate samplers. The concentrations of $PM_{2.5}$ at sites nos.1 and 2 varied from 23-145 $\mu g/std\ m^3$ and 0-93 $\mu g/std\ m^3$.The average $PM_{2.5}$ concentrations at sites nos.1 and 2 were 93 $\mu g/std\ m^3$ and 44 $\mu g/std\ m^3$, respectively. The increasing trends of $PM_{2.5}$ were observed at both sites during the study period. The significant positive correlations between the $PM_{2.5}$ concentrations and the daily average temperature and between the $PM_{2.5}$ concentrations and daily sunshine hour were observed at both sites. The average of metal elements were ordered as Ca> Mg> K> Zn> Mn> Fe> Cr> Pb> Ni> Cu> Cd for site no.1 and ordered as Ca> Mg> K> Zn> Fe> Mn> Cr > Pb> Ni> Cu> Cd for site no.2. There were 27 days for site no.1 and 6 days for site no.2 that the $PM_{2.5}$ concentrations were higher than the USEPA 24-h standard (65 $\mu g/std\ m^3$). Based on the average concentrations of Cd, Pb, Cr and Ni, the excess cancer risk resulting from exposure to Chiang Mai ambient air at sites nos.1 and 2 were $1.6x10^{-3}$ and $1.1x10^{-3}$, respectively. The principal component analysis (PCA) yielded 4 sources of $PM_{2.5}$ with the percentage of variance explained by each source as followings: traffic activity (50.7%), agricultural/forest fires (16.7%), soil (10.8%) and open burning (9.1%). Thus, traffic activity is considered as the major source of $PM_{2.5}$ in Chiang Mai ambient air. It was noticed that the maximum and minimum values of PC scores for samples collected from downtown appeared in the same level of those collected from uptown. This can be interpreted that the influence of each source type to $PM_{2.5}$ at the both sites are similar. Moreover, the agricultural/forest fires can be considered as the regional pollution source of $PM_{2.5}$ in Chiang Mai due to the high correlation coefficient between the PC scores of the second component for site no.1 and site no.2.

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Academic year 2004 Advisor’s signature………………………..
Co-advisor’s signature…………………….

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ABBREVIATIONS

AAS	Atomic absorption spectrometer
ATSDR	Agency for Toxic Substances and Disease Registry
AQI	Air quality index
HSDB	Hazardous Substances Data Bank
EPA	Environmental protection agency
IRIS	Integrated risk information system
NAAQS	National Ambient Air Quality Standard
PCA	Principal Component Analysis
PM	Particulate matter
RfC	Reference concentration
SPM	Suspended particulate matter
URE	Unit risk estimate

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CHAPTER I

INTRODUCTION

1.1 Motivation

Chiang Mai is located in the Northern part of Thailand surrounded with mountains and is recognized as one of the fastest growing province in this country. Because of its economic development, population growth, and urbanization, its environment is unavoidably contaminated.

Particle pollution is one of the major environmental problems in Chiang Mai. Recent concern about the health effects of air pollution has focused on particulate matter (PM), especially respirable particles. From epidemiological studies, some statistical associations between short-term increase in particulate matter concentration and daily mortality/morbidity have been found. In case of Chiang Mai one of the major causes of death is the diseases of respiratory system. There is also the report about the increasing of the cancer incidence rate and mortality in Chiang Mai where the lung cancer incidence rate is much higher than other places in Thailand. Particle pollution in Chiang Mai is present year-round, relatively high in wintertime, and there may be significant health implications associated with these high concentrations.

Even though there are the national ambient air quality standard and the monitoring system for the particle pollution, it only focuses on PM_{10} not including $PM_{2.5}$ that has been considered by the USEPA as the most pressing air quality problem in recent years. Moreover, the utilization of the PM data for the optimal determination of possible sources has remained limited. The importance and the need for source identification in Chiang Mai area has been recognized as important in order to obtain a better understanding of the ambient air quality for better solution in dealing with particle pollution.

Besides, some researches show that atmospheric mixing dominated over local particle sources in pollutant distribution of Chiang Mai so the difference between the downtown and uptown ambient air should be studied.

1.2 Objectives

The objectives of this study are:

1.2.1 To investigate $PM_{2.5}$ and its metallic element composition in the ambient air of Chiang Mai downtown and uptown.

1.2.2 To identify possible sources of $PM_{2.5}$ and its metallic element composition in Chiang Mai ambient air.

1.3 Scope of this work

1.3.1 This study will be performed during the winter season from December to February at two different locations in Chiang Mai. Site no.1 will be located in the center of Chiang Mai city as the representative of downtown area. Site no.2 will be located of about 6 kilometers southwest of site no.1 at Chiang Mai University (Mae Hea campus) as the representative of uptown area.

1.3.2 Metallic elements, for which will be analyzed in this study are these 11 elements: Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, and Zn.

1.3.3 In order to identify the possible sources, principal component analysis will be applied to the observed $PM_{2.5}$ metallic element composition data.

1.4 Benefits of this work

1.4.1 The results of this work might help increase government’s awareness and management on the particle pollution in Chiang Mai.

1.4.2 The knowledge from this study, the possible sources of $PM_{2.5}$, could be applied to provide the management of particle pollution.

1.4.3 The results of this work provide a database for the government to consider before developing National Ambient Air Quality Standards for $PM_{2.5}$.

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1.4.4 Better understanding the relationship between $PM_{2.5}$ in downtown and uptown area of Chiang Mai essential for the design of effective particle pollutant strategies for the protection of public health risk.

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CHAPTER II

LITERATURE REVIEW

2.1 Ambient air quality standards

Particulate matter (PM) is any system of solid particles or liquid droplets suspended in a gaseous medium. This particulate matter includes dust, ash, soot, lint, smoke, pollen, spores, algal cells, and many other suspended materials. Anthropogenic particulate emissions amount to about 362 million metric tons per year worldwide. Particulates often are the most apparent for of air pollution because they reduce visibility and leave dirty deposits on windows, painted surfaces, and textiles. Respirable particles smaller than 2.5 micrometers ($PM_{2.5}$) are among the most dangerous of this group because they can be drawn into the lungs, where they damage respiratory tissues. (USEPA, 2004; Cunningham *et al.*, 2003; Salvadors *et al.*, 2004).

USEPA has established a National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$, fine particulate matter, which the agency has determined to protect the public’s health since 1997. EPA first promulgated National Ambient Air Quality Standards (NAAQS) for total suspended particulate (TSP) in 1971. When the standards were revised in 1987, TSP was replaced by PM_{10}. EPA’s reason for adding $PM_{2.5}$ standards because fine particles are more closely associated with serious health effects. The NAAQS for PM_{10} and $PM_{2.5}$ include both short-term (24-hour) and long-term (annual) standards are shown in Table 2-1:

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Table 2-1 NAAQS for PM_{10} and $PM_{2.5}$

NAAQS	$PM_{2.5}$	PM_{10}
Short-term (24-hour average)	65 $\mu g/m^3$	150 $\mu g/m^3$
Long-term (annual average)	15 $\mu g/m^3$	50 $\mu g/m^3$

Source: USEPA, 2004.

Each PM standards carries a separate threshold for compliance. For the long-term standards for both PM_{10} and $PM_{2.5,}$ compliance is determined based on the average of three consecutive annual average values. Compliance with the short-term $PM_{2.5}$ standard is determined by the 3-year average of the annual 98th percentile of 24-hour concentrations. The short-term standard for $PM_{2.5}$ is not to be exceeded more than once per year, averaged over 3 years.

Thai standards for ambient air quality are shown in Table 2-2. These standards are similar to those recommended by the World Health Organization, and adopted in other countries such as the US, but adjusted for local socio-economic, technology, health and environmental concerns. Thai standards for 24 hour and annual average concentrations total suspended particulate (TSP) are 330 and 100 $\mu g/m^3$, respectively. For particulate matter less than 10 microns in aerodynamic diameter (PM_{10}), the 24-hour and annual average limits are 120 and 50 $\mu g/m^3$, respectively. Currently, there is no establishment of Thai official standard for $PM_{2.5}$ which is more harmful on health and environmental viewpoints and is a significant fraction of the suspended particulates in the urban air.

Table 2-2 Thai standards for ambient air quality

	1-hr average		8-hr average		24-hr average		Annual average	
	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm
CO	34.2	30	10.26	9	-	-	-	-
NO_2	0.32	0.17	-	-	-	-	-	-
SO_2	0.78	0.3	-	-	0.30	0.12	0.10*	0.04
TSP	-	-	-	-	0.33	-	0.10*	-
PM_{10}	-	-	-	-	0.12	-	0.05*	-
Ozone	0.20	0.1	-	-	-	-	0.10	0.04
Lead	-	-	-	-	-	-	0.0015**	-
* annual arithmetic mean **quarterly average								

Source: Pollution Control Department, 2005.

2.2 Geography and meteorology of Chiang Mai

Chiang Mai is located on the Northern part of Thailand (latitude 16^{o} N, latitude 99^{o} E) and about 310 m above mean sea level (MSL). It has a population of over 1.6 million inhabitants in an area of approximate 20,000 km^{2}. The area of Chiang Mai is generally forests and mountains. Residential areas are located on flat plains two side along the Mae Ping River on the center of the Province. The mountain area where its height is over 500 m above MSL covers approximately 80% of all the area.

The climate of Chiang Mai is quite cold through the year. The average temperature is about 25.4 ^{o}C. The maximum and the minimum temperature are 31.8 ^{o}C and 20.1 ^{o}C. The climate of Chiang Mai is influenced by two monsoons i.e. southwest monsoon and northeast monsoon. There are three seasons in Chiang Mai including rainy, winter and summer. Rainy season starts from Mid-May until October. Winter season begins in November and ends in February. Summer season is between March and Mid-May.

Table 2-3 shows meteorological observations from the Northern Meteorological Center between 1971 and 2000. From meteorological data table, it can be observed that there is a notable decrease in visibility and an increase in the number of days with observed haze during the winter months (particularly for the period from December to March). This correlates well with measured peak particulate concentrations. As wind speeds are typically low year round, these hazy conditions cannot be attributed solely to windblown dust. Instead, the increased haze, decreased visibility, and higher particulate levels are best explained by reduced dispersion and increased dust from road traffic and other anthropogenic sources during the dry months and winter fog episodes.

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Table 2-3 Chiang Mai Meteorological data for 30 years (1971-2000)

Climatological data for the period 30 years (1971-2000)

Station Chiang Mai Latitude 18.47 longitude 98.59 E Elevation of station above MSL 312 Meters

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pressure (Hectopascal)													
Mean	1013.63	1011.39	1009.06	1007.17	1006.07	1004.72	1004.80	1005.19	1007.62	1010.60	1013.25	1015.06	1009.1
Mean max.	1025.80	1023.68	1025.10	1018.50	1014.30	1012.20	1012.12	1014.50	1015.40	1020.40	1024.88	1025.78	1025.8
Mean min.	1002.85	1000.90	999.30	996.90	996.90	995.50	995.80	995.10	998.20	1001.00	1003.75	1003.90	995.1
Temteratur(Celsius)													
Mean	20.9	23.3	26.7	28.8	28.1	27.6	27.1	26.7	26.6	25.9	23.8	21.1	25.6
Mean max.	29.3	32.2	34.9	36.0	34.1	32.6	31.8	31.3	31.5	31.2	29.8	28.3	31.9
Mean min.	14.1	15.5	19.0	22.3	23.6	23.9	23.7	23.5	23.1	22.0	19.1	15.2	20.4
Ext. max.	34.1	37.7	39.2	41.4	40.1	39.3	37.5	36.5	36.1	37.9	34.5	33.4	41.4
Ext. min.	3.7	7.3	12.2	15.8	19.2	20.0	20.5	20.7	16.8	13.3	6.0	3.8	3.7
Relative Humidity(%)													
Mean	69	60	54	58	71	77	78	81	81	78	75	73	71.0
Mean max.	91	84	78	80	88	91	91	93	93	93	92	92	89.0
Mean min.	39	32	31	37	51	58	61	63	62	57	52	45	49.0
Ext. min.	3	5	3	11	22	21	40	41	34	29	10	12	3
Dew Point (Celsius)													
Mean	14.3	13.9	15.5	18.9	21.8	22.8	22.7	22.8	22.7	21.5	18.7	15.4	19.3
Evaporation (mm.)													
	108.1	128.7	171.7	189.4	178.6	143.7	129.6	126.3	128.8	129.0	106.8	98.3	1639.0
Cloudiness (0-10)													
Mean	2.2	2.0	2.2	3.7	6.2	7.7	8.4	8.5	7.5	5.9	4.5	3.2	5.2
Sunshine Duration (hr.)			**(Monthly totals)**										
	273.3	262.8	268.2	255.2	254.7	169.5	141.5	128.6	164.5	211.0	218.9	243.5	2591.7
Visibility (km.)													
Mean	8.2	8.0	7.2	8.9	11.5	12.2	12.0	11.8	11.3	10.5	9.9	9.1	10.1
Wind (Knots)													
Mean wind s	1.3	2.0	2.6	3.3	3.3	3.1	2.7	2.5	2.3	2.2	1.8	1.6	-
Prevailing wi	S	S	S	S	S	S,SW	S,SW	S	S	N	N	N	-
Max. wind s	39.0	54.0	55.0	60.0	64.0	43.0	50.0	56.0	41.0	40.0	45.0	43.0	64.0
Rainfall (mm.)													
Mean	7.7	9.2	17.3	54.5	155.4	119.4	157.6	224.4	202.4	116.6	51.4	18.1	1134.0
Mean rainy	1	1	2	6	15	16	19	21	17	12	5	2	116.1
Daily maxim	27.9	65.2	99.0	119.1	96.0	72.0	115.5	123.0	93.3	79.3	86.5	92.9	123.0
Number of days with													
Haze	26	27	30	21	2	0	0	0	2	5	10	17	141
Fog	1	0	0	0	0	0	0	0	0	1	2	3	8
Hail	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunderstor	0	0	2	7	11	6	5	8	10	6	1	0	57
Squall	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Northern Meteorological Center**,** 2005

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2.3 Anthropogenic and natural sources of $PM_{2.5}$

Airborne particulate matter can be of primary origin, i.e. emitted directly into the atmosphere or of secondary origin, i.e. formed in the atmosphere from gaseous species by either homogeneous or heterogeneous chemical reactions. Due to these different emission sources, particles have different chemical composition and size distributions. Depending on their size, particles have a different potential to be transported over either long or short distances (Prospero *et al.*, 1981).

2.3.1 Anthropogenic sources

2.3.1.1 Road transport

Particulate emissions from road transport arise as direct emissions from vehicle exhausts, tire and brake wear and resuspension of road dust. In general, diesel engine vehicles emit a greater mass of fine particulate matter, per vehicle, than petrol engines. Diesel emissions are mainly composed of soot particles, volatile hydrocarbons and some sulphate from the fuel sulphur. When hydrocarbons and sulphates are released by the car exhaust they condense on airborne particles, mainly on the freshly emitted carbon. The size distribution of these particles tends to be bimodal, with particles of 0.01 to 0.05 μm in the nucleation mode in the case of freshly emitted soot particles and, of some 0.05 to 2.5 μm in the accumulation mode in the case of older coagulated soot particles. The movement of vehicles on the street also results in resuspension of road dust (European Commission, 1997).

2.3.1.2 Industrial

Industrial emissions can be a significant source of particulate matter in urban areas. The contribution that this source makes to ambient particulate matter will vary depending on the location of the industry and the abatement technology adopted. Although many studies have been conducted to characterize emissions from large industrial sources, for example steel works, information on small urban emitters, for example metallurgical processes and small factories, is more limited. Particles emitted from industrial sources have been found to be in the size range 0.5 to some 100 μm, depending on the nature of the source. Composition will also depend on the nature of the source (European Commission, 1997).

2.3.1.3 Agricultural fire and open burning

Both direct emission from fires and ash resuspension from burnt soils could be an important source of airborne particulate matter. This pyrogenic material, which is composed of organic matter, black carbon and inorganic material, is to a large extent present in the size range below 10 μm and so can be resuspended by wind (Crutzen *et al*., 1990). Although the contribution to ambient aerosol from fire smoke will generally be episodic, in areas where there is a constant open burning, the particulate emission from this source could be significant. Agricultural fire emissions are mainly due to stubble burning. However, this source is episodic and has been banned in Chiang Mai.

2.3.1.4 Construction

Although data quantifying particulate emissions from construction and demolition work is scarce, some research carried out in USA gives an estimation for total suspended particle of 2.5 tones/hectare/month in zones where large construction work is in progress. The quantity of particles emitted from this source will depend on the type of construction in progress. These particles are mainly present in size fractions greater than 10 μm. However, some fraction of the total amount is likely to be present as $PM_{2.5}$ and smaller particles. Also, some of this dust will be resuspended either by traffic or wind (European Commission, 1997).

2.3.1.5 Cement plant and ceramic industry

It is difficult to assess the percentage of airborne particles emitted either from cement plants or from ceramic industries in urban aerosol, due to the similarity of their chemical composition to soil or construction dust. In the United Kingdom, cement and lime manufacture has been estimated to produce 4,456 tones of total particulate matter a year (European Commission, 1997).

2.3.2 Natural sources

2.3.2.1 Soil resuspension

Meteorological mechanisms such as wind, temperature changes and water produce soil dust by either rock or mineral weathering. This dust can be carried by wind and has a particle size distribution depending upon its original geological source (Warneck, 1988). The chemical composition of soil particles is similar to their geological origin as dolomite, gypsum quartz and clay minerals.

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Usually, an analysis showing enrichment in silicon, calcium, iron and aluminium in the aerosol indicates its geological origin.

The action of the wind on dry loose soil surfaces leads to particles blowing into the air. Factors favoring the suspension of soil dust particles into the atmosphere are an exposed dry surface of fine soil and a high wind speed. In towns and cities, the areas of exposed soil, particularly in town centers, are rather small. However, there are considerable quantities of dusts on road and pavement surfaces which arise from ingress of soil on vehicle tires and from the atmosphere, the erosion of the road surface itself and degradation of parts of the vehicle, especially the tires. Because these particles lie on a surface which readily dries and is subject to atmospheric turbulence induced by passing vehicles, this provides a ready source of particles for resuspension into the atmosphere. The amounts of dust resuspended in this process are extremely difficult to predict or measure, as they depend critically upon factors such as the dust loading of the surface, the preceding dry period and the speed of moving traffic. However, the size distribution and chemical composition of particles in the urban atmosphere give a clear indication that this source can contribute significantly to the airborne particle loading of our cities (European Commission, 1997)

2.3.2.2 Sea spray

Breaking waves on the sea cause the ejection of many tiny droplets of seawater into the atmosphere. These droplets dry by evaporation leaving sea salt particles suspended in the air. Particles are also directly emitted by the bursting of air bubbles on sea surface. Such particles are generally in the size range between 1 to 20 μm. (Blanchard *et al*., 1980). Whilst these particles are, in the main, rather coarse in size, a minor part of their mass is in particles small enough to have an appreciable atmospheric lifetime, which has been estimated as three days (Junge, 1972). Clearly, coastal areas will be the most affected, but sea salt is also measurable at inland locations.

Airborne sea salt shows a similar chemical composition to sea salt, with anions (chloride and sulphate), cations (sodium and magnesium) and organic phosphorus. Also, trace metals (cadmium, lead vanadium, and zinc) have been found in marine aerosol. This aerosol metal enrichment arises from bubbles of water scavenging before bursting.

2.4 Formation of $PM_{2.5}$

The mechanism of formation is crucial in influencing the size of particulate aerosol. Atmospheric aerosol shows evidence of several categories of sources in its size distribution. Typically three major components are recognized (Whitby, 1978). The first one, called nucleation mode, contains very large numbers of particles with a diameter of about 0.1 μm (100 nm). These fine particles can be formed as a result of combustion processes and evaporation from hot surfaces or from gas phase reactions in the free atmosphere to form involatile molecules. Nucleation particles have a short lifetime of a few hours because they coagulate with larger particles or act as condensation nuclei.

Particles with diameter between about 0.05 to 2.5 μm contained in the so-called accumulation mode are mainly formed by coagulation and generated from condensation processes. Particles in this size range or the so-called $PM_{2.5}$ can also be produced from secondary formation and natural sources such as sea spray or the resuspension of fine soil or dust, although less than 10% of mass concentration of $PM_{2.5}$ has a mineral origin. $PM_{2.5}$ is long lived in the atmosphere, since their removal mechanisms are least.

Some $PM_{2.5,}$ which is secondary aerosol, is produced by the oxidation of primary gases (sulphur dioxide, SO_2, nitrogen oxides, NO_x, and volatile organic compounds, VOCs,) to sulphuric and nitric acid, and organic vapours, followed by their gas-particle conversion (Calvert *et al*., 1985). Finally, some of these acidic gases can be neutralised by reaction with ammonia gas or calcium carbonate (calcite) forming secondary aerosol (ammonium sulphate, ammonium nitrate, calcium sulphate, calcium nitrate). In urban agglomerations the latter process will be predominant, due to the high anthropogenic emission of SO_2 and NO_x from domestic heating and traffic emissions. However, emissions of natural SO_2 and VOCs (terpenes) could play an important role in the formation of $PM_{2.5}$.

2.5 Health effects of $PM_{2.5}$

Health effects of air pollution vary based on the type of pollutants, length of exposure, and extent of interaction among pollutants. Fine particulate matter such as $PM_{2.5}$ poses a serious and direct threat to human health as the particles penetrate deep into lung tissue, conveying toxic substances. For Bangkok, the level of PM_{10} concentration and the number of outpatients with respiratory diseases peak during the dry season, from November until February is shown in Figure 2-1. There is a positive correlation with the number of outpatients with respiratory diseases for these months.

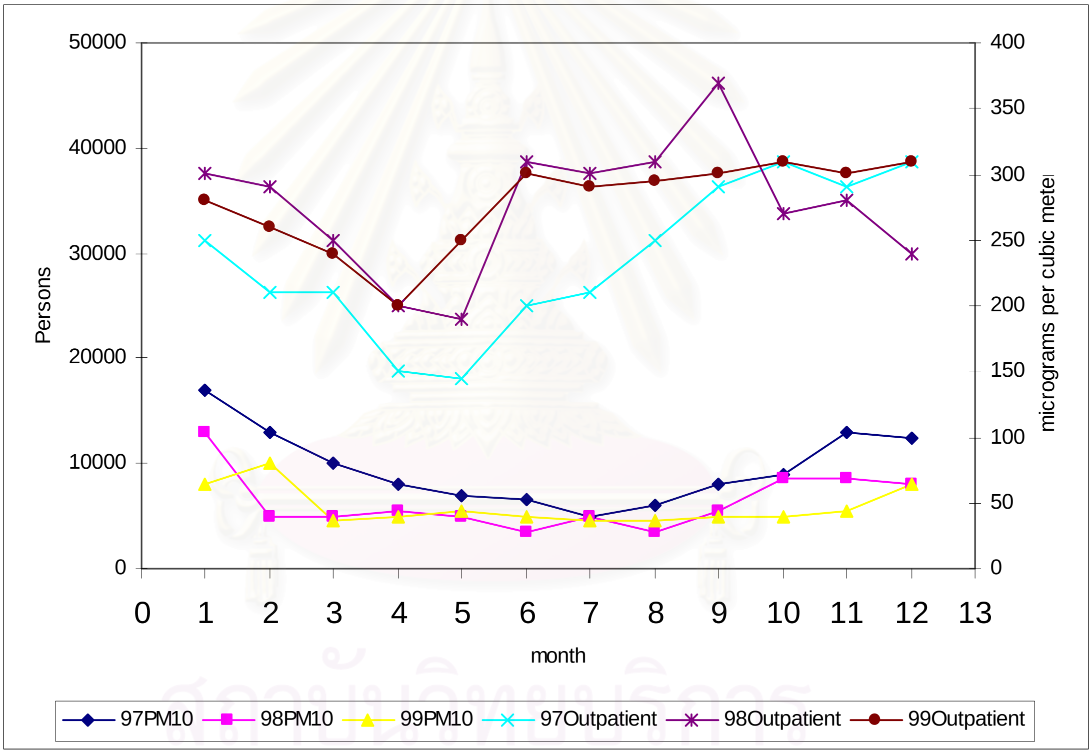

Figure 2-1 PM_{10} and respiratory outpatients (Pollution control department, 2004)

Moreover, numerous studies have attempted to estimate the health cost of PM_{10} emissions. Some of these have calculated costs on a value per ton basis, with figures ranging from US$20,000 per ton (for hospital costs only), to over US$500,000 per ton for total community costs in some high-income countries. Others have attempted to put a value on mortality and morbidity, especially declining respiratory functions and other cardiopulmonary diseases. An initial analysis of the cost of health

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impacts of PM_{10} in six major cities in Thailand-Bangkok, Chiang Mai, Nakhon Sawan, Khon Kaen, Nakhon Ratchasima, and Songkhla- was undertaken for this monitor and the resulted are shown in Table 2-4.

$PM_{2.5}$ particles are likely to penetrate deep into alveolar sacks of the lung. These particles can accumulate in the respiratory system and are associated with numerous negative health effects. A number of studies have shown that exposure to fine particulate matter is most closely associated with increased hospital admission and emergency room visits for heart and lung diseases (Wordley *et al*., 1997; Alkinson *et al*., 1999; Hong *et al*., 1999; Neas *et al*., 2000)

Recently, a WHO Working Group reported that there was strong evidence to conclude that fine particles or $PM_{2.5}$ are more hazardous than larger ones (coarse particles or PM_{10}) in terms of mortality and cardiovascular and respiratory endpoints in panel studies (WHO, 2003).

Table 2-4 Estimates of Health Impact and Costs by PM_{10} in 6 Cities for 2000

City	PM_{10} (µg/m^3)	Population (Million)	Mortality Rate	Excess deaths	Chronic Bronchitis	Cost in million US$
Bangkok	64	5.7	0.0065	1,092	4,550	424
Chiang Mai	57	1.6	0.00985	390	1,080	56.8
Nakhon Sawan	51	1.1	0.0058	134	630	26.1
Khon Kaen	66	1.8	0.006	324	1,476	59.2
Nakhon Ratchasima	51	2.6	0.0055	286	1,426	56.8
Songkhla	41	1.2	0.0061	104	464	1.3
Total		**14**		**2,330**	**9,626**	**644.2**

Source: Pollution Control Department**,** 2004**.**

2.6 Effects of $PM_{2.5}$ on vegetation and ecosystems

Particulate matter exerts most effects on vegetation and ecosystem by virtue of the mass loading of its chemical constituents. Deposition of particulate matter to vegetated surfaces depends on the size distribution of the particles and, to a lesser extent, on the chemistry. However, chemical loading of an ecosystem may be determined by the size distribution of the particles as different constituents dominate different size fractions. Coating with dust may cause abrasion and radiative heating, and may reduce the photosynthetically active photon flux reaching the photosynthetic tissues.

Acidic and alkaline materials may cause leaf surface injury while other materials may be taken up across the cuticle. A more likely route for metabolic uptake and impact on vegetation on vegetation and ecosystem is through the rhizosphere. PM deposited directly to the soil can influence nutrient cycling, especially that of nitrogen, through its effects on the rhizosphere bacteria and fungi. Alkaline cation and aluminium availability are dependent upon the pH of the soil that may be altered dramatically by deposition of various classes of particles. A regional effect of particles on ecosystems is linked to climate change. Increased particles may reduce radiation interception by plant canopies and may reduce precipitation through a variety of physical effects.

At the present time, evidence does not support large regional threats due to un-speciated particles; through site-specific and constituent-specific effects can be readily identified. Interactions of particles with other pollutants and with components of climate change remain important areas of research in assessment of challenges to ecosystem stability (Grantz *et al*., 2003).

2.7 Sources and atmospheric fate of metallic elements

2.7.1 Nickel (Ni)

Pure nickel is a hard, silvery-white metal, which has properties that make it very desirable for combining with other metals to form mixtures called alloys. Some of the metals that nickel can be alloyed with are iron, copper, chromium, and zinc. These alloys are used in making metal coins and jewelry and in industry for making items such as valves and heat exchangers. Most nickel is used to make stainless steel. There are also compounds consisting of nickel combined with many other elements, including chlorine, sulfur, and oxygen. Many of these nickel compounds are water soluble (dissolve fairly easily in water) and have a characteristic green color. Nickel and its compounds have no characteristic odor or taste. Nickel compounds are used for nickel plating, to color ceramics, to make some batteries, and as substances known as catalysts that increase the rate of chemical reactions.

Nickel combined with other elements occurs naturally in the earth's crust. It is found in all soil, and is also emitted from volcanoes. Nickel is the 24th most abundant element. In the environment, it is primarily found combined with oxygen or sulfur as oxides or sulfides. Nickel is also found in meteorites and on the ocean floor in lumps of minerals called sea floor nodules. An estimated $8x10^8$ tons of nickel are present in seabed nodules, which contain approximately 1% nickel. The earth's core is composed of 6% nickel. Approximately 0.009% of the earth's crust is nickel. Nickel is released into the atmosphere during nickel mining and by industries that make or use nickel, nickel alloys, or nickel compounds. These industries also might discharge nickel in waste water. The other economically-significant source of nickel is found in lateritic ores, in the form of oxides and silicates, which are found in regions that are, or which were once tropical or subtropical for extended periods. Nickel is also released into the atmosphere by oil-burning power plants, coal-burning power plants, and trash incinerators. Nickel plating is used for car bumpers and trim and other consumer products. Ni(II) is the most common oxidation state. Estimated worldwide atmospheric emissions of nickel from natural sources include (% of total emissions) windblown dust: 9.3%; volcanoes: 4.9% and vegetation: 1.6% (HSDB, 2005; ATSDR, 2005b).

2.7.2 Cadmium (Cd)

Cadmium is a relatively rare, naturally occurring element that is widely distributed in the earth's crust. It may enter the environment during the mining, ore processing and smelting of zinc and zinc-lead ores in which cadmium is found and during its recovery, refining, manufacture of cadmium compounds, use of cadmium metals, alloys and compounds, recycling, and disposal. Cadmium's initial route of entry is often via the atmosphere. Since it occurs naturally in the earth's crust, cadmium may also enter the atmosphere from the weathering of rocks, windblown soil, and volcanoes. However, these sources are minor compared with anthropogenic ones. When released to the atmosphere, cadmium will generally occur as particulate matter and be subject to dry and wet deposition. While anthropogenic releases are as small particles, most cadmium appears to be deposited relatively close to its source. Cadmium would be expected to be transformed to the oxide and carbonate in the atmosphere. The general population is exposed to cadmium from ambient air, especially in areas near industrial sources. However, the highest cadmium intake is from dietary sources. Exposure to cadmium in the workplace is generally via inhalation.

Cadmium released to the atmosphere will be in particulate matter and be returned to the earth by dry and wet deposition. For both rural and remote areas of the world, the estimated deposition rate for wet deposition of cadmium is almost twice that for dry deposition. Of the estimated 0.35 ng/cm^2-yr of cadmium deposited in the tropical North Pacific Ocean, approximately 30% is a result of dry deposition and 70% wet deposition. Cadmium is primarily associated with small particles such as are produced by combustion processes; its mass median diameter is fairly small, 0.84 μm. As a result of their small size, cadmium-containing particles can stay aloft long periods of time and travel long distances. Nevertheless, studies at a lead smelter using bulk deposition collectors indicate that cadmium from emission sources is primarily deposited close to (<5 km) the source. A study showing that the cadmium concentration in the upper 2 cm of lakes in the U.S. Arctic is similar to that in the pre-1900 sediment core suggests that there is no enrichment of the surface due to recent anthropogenic activity and that cadmium is not transported long distances from smelters and other emission sources to the Arctic. Recycled sea spray represents a significant but variable component of the deposition. The average annual scavenging ratio (concentration in precipitation (mg/L) to air concentration (μg/m^3)) for Cd in USA is 0.44x10^6. The mean ratio of wet to dry deposition of cadmium in southern, central and northern Ontario is 3.27, 1.91, and 6.35, respectively. For fine particles, this ratio is generally higher away from source areas. Wet and dry atmospheric deposition of cadmium measured at biweekly intervals between 9/92 and 9/93 at two sites on Massachusetts Bay averaged 405 μg/m^2-yr. Transformations of cadmium to the carbonate and oxide may be expected in the atmospheric environment (HSDB, 2005).

2.7.3 Chromium (Cr)

Chromium is a metallic element with oxidation states ranging from chromium(-2) to chromium(+6). The important valence states of chromium are III and VI. Chromium compounds are stable in the trivalent state and occur in nature in this state in ores, such as ferrochromite ($FeCr_2O_4$). The hexavalent (VI or chromate) is the second most stable state. Chromium compounds are released into the atmosphere mainly by anthropogenetic stationary point sources, including industrial, commercial, and residential fuel combustion, via the combustion of natural gas, oil, and coal. If released to air, chromium compounds will exist solely in the particulate phase in the ambient atmosphere. Other sources of chromium are cement-producing plants, Industrial cooling towers, busy roadways, and tobacco smoke (HSDB, 2005; ATSDR, 2005b).

2.7.4 Copper (Cu)

Copper is a reddish metal that occurs naturally in rock, soil, water, sediment, and, at low levels, air. Its average concentration in the earth's crust is about 50 parts copper per million parts soil (ppm) or, stated another way, 50 grams of copper per 1,000,000 grams of soil (1.8 ounces or 0.11 pounds of copper per 2,200 pounds of soil). Copper also occurs naturally in all plants and animals. It is an essential element for all known living organisms including humans and other animals at low levels of intake. At much higher levels, toxic effects can occur. The term copper in this profile not only refers to copper metal, but also to compounds of copper that may be in the environment.

Metallic copper can be easily molded or shaped. The reddish color of this element is most commonly seen in the U.S. penny, electrical wiring, and some water pipes. It is also found in many mixtures of metals, called alloys, such as brass and bronze. Many compounds (substances formed by joining two or more chemicals) of copper exist. These include naturally occurring minerals as well as manufactured chemicals. The most commonly used compound of copper is copper sulfate. Many copper compounds can be recognized by their blue-green color.

Copper is primarily used as the metal or alloy in the manufacture 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 (HSDB, 2005).

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2.7.5 Lead (Pb)

Lead is a naturally occurring bluish-gray metal found in small amounts in the earth's crust. It has no characteristic taste or smell. Metallic lead does not dissolve in water and does not burn. Lead can combine with other chemicals to form what are usually known as lead compounds or lead salts. Some lead salts dissolve in water better than others. Some natural and manufactured substances contain lead but do not look like lead in its metallic form. Some of these substances can burn, for example, organic lead compounds in some gasoline.

Lead has many different uses. Its most important use is in the production of some types of batteries. It is also used in the production of ammunition, in some kinds of metal products (such as sheet lead, solder, some brass and bronze products, and pipes), and in ceramic glazes. Some chemicals containing lead, such as tetraethyl lead and tetramethyl lead, were once used as gasoline additives to increase octane rating. However, lead gasoline was completely phased out in 1995. Other chemicals containing lead are used in paint. The amount of lead added to paints and ceramic products, caulking, gasoline, and solder has also been reduced in recent years to minimize lead's harmful effects on people and animals. Lead used in ammunition, which is the largest non-battery end-use, has remained fairly constant in recent years. Lead is used in a large variety of medical equipment (radiation shields for protection against X-rays, electronic ceramic parts of ultrasound machines, intravenous pumps, fetal monitors, and surgical equipment). Lead is also used in scientific equipment (circuit boards for computers and other electronic circuitry) and military equipment (jet turbine engine blades, military tracking systems).

Most lead used by industry comes from mined ores or from recycled scrap metal or batteries. Human activities (such as the former use of leaded gasoline) have spread lead and substances that contain lead to all parts of the environment. For example, lead is in air, drinking water, rivers, lakes, oceans, dust, and soil. Lead is also in plants and animals that people may eat.

Lead containing particles in ambient air have an aerodynamic diameter of approximately 0.1-1.0 μm, and the predicted deposition in the airway is about 35%. This is questionable for smaller particles (< 0.1 μm) which are mainly deposited by diffusion. Actual measurements of deposition in human volunteers gave results that differed considerably depending on the physical and chemical properties of the inhaled aerosol. A deposition of approximately 25% is observed after exposure to particles with a mass median aerodynamic diameter of 0.25 μm. A deposition in the respiratory tract of about 60% is observed in persons close to a motorway, where particles were about 0.03 μm in diameter. When volunteers inhaled lead particles near urban roads where the particle size was larger (0.2-2.0 μm), deposition was about 50%. Based on available data, it seems reasonable to conclude that the rate of deposition of airborne lead in the general population is approximately 30-50%, depending on particle size and ventilation rates (ATSDR, 2005b; HSDB, 2005).

2.7.6 Iron (Fe)

The major use of iron is in manufacture of iron, iron compound, and other sulfates. Moreover it can be found in iron electroplating baths, etching aluminum, water treatment and fertilizer producing. It also be used as food and feed supplement, writing ink, reducing agent in chemical processes, wood preservative, dye for leather, weed killer and other pesticides. The natural source of iron is the earth’s crust weathering (HSDB, 2005).

2.7.7 Magnesium (Mg)

Magnesium is an essential nutrient for humans, animals, and plants. Magnesium is approximately 2% of soil in the earth's crust, eighth in abundance, and widely distributed in the environment in a variety of rock and minerals, such as igneous (e.g., olivine), metamorphic (e.g., montmorillonite), and sedimentary rocks (e.g., magnesite, brucite, dolimite). Rocks and minerals contain a higher percentage of magnesium than do soils resulting from the loss of magnesium due to weathering. Magnesium salts, which make up 17% of sea salt, are released to the atmosphere as sea spray. The production and use of magnesium compounds as refractories (e.g., olivine), chemical intermediates, and in construction materials (e.g., magnesium oxide) may result in their release to the environment through various waste streams while the production and use of magnesium compounds in environmental applications (e.g., magnesium hydroxide), and agriculture (e.g., magnesium sulfate) result in their direct release to the environment. Magnesium compounds, as ionic salts, will exist solely in the particulate phase in the ambient atmosphere. Particulate-phase magnesium compounds may be removed from the air by wet and dry deposition. Occupational exposure to magnesium compounds may occur through inhalation and dermal contact with these compounds at workplaces where magnesium compounds are produced or used. Monitoring data indicate that the general population is exposed to magnesium compounds via inhalation of ambient air, ingestion of food and drinking water, and dermal contact with compounds and consumer products containing magnesium compounds. The average daily intake of magnesium for a 25-30 year man is 288 mg/day.

The atmospheric particulate concentration of magnesium at the South Pole between December 1974 and February 1975 ranged from 300 to 1,420 pg/m^3. The aerosol concentration of magnesium in Ponce, Puerto Rico, which is an industrial region, ranged from 0.389 to 1.252 μg/m^3 between 1983 and 1985. The concentration of magnesium in the atmosphere was measured in Hemsby, United Kingdom (March 1987 to March 1988, 247 ng/m^3); Ny Alesund, Norway (winter 1984, 55 ng/m^3; summer 1984, 18 ng/m^3); Ghent, Belgium (October to December 1986, 130 ng/m^3); Valladolid, Spain (Dec 1982-Jan 1984, 106.5 ng/m^3); Reading, PA (July to October 1982, 56.0 ng/m^3); Karachi, Pakistan (July 1985, 3,330 ng/m^3) (HSDB, 2005).

2.7.8 Manganese (Mn)

Manganese is a naturally occurring substance found in many types of rock. Manganese does not have a special taste or smell. Pure manganese is a silver-colored metal; however, it does not occur in the environment as a pure metal. Rather, it occurs combined with other substances such as oxygen, sulfur, and chlorine. These forms (called compounds) are solids that do not evaporate. However, small dust particles of the solid material can become suspended in air. Also, some manganese compounds can dissolve in water, and low levels of these compounds are normally present in lakes, streams, and the ocean. Manganese can change from one compound to another (either by natural processes or by human activity), but it does not break down or disappear in the environment.

Rocks with high levels of manganese compounds are mined and used to produce manganese metal. This manganese metal is mixed with iron to make various types of steel. Some manganese compounds are used in the production of batteries, in dietary supplements, and as ingredients in some ceramics, pesticides, and fertilizers.

Manganese is an essential trace element and is necessary for good health. The human body typically contains small quantities of manganese, and under normal circumstances, the body controls these amounts so that neither too little nor too much is present (ATSDR, 2005b).

2.7.9 Zinc (Zn)

Zinc is one of the most common elements in the earth's crust. Zinc is found in the air, soil, and water and is present in all foods. In its pure elemental (or metallic) form, zinc is a bluish-white, shiny metal. Powdered zinc is explosive and may burst into flames if stored in damp places. Metallic zinc has many uses in industry. A common use is to coat iron or other metals to prevent rust and corrosion. Metallic zinc is also mixed with other metals to form alloys such as brass and bronze. A zinc and copper alloy is used to make pennies in the United States. Metallic zinc is also used to make dry cell batteries.

Zinc can also combine with other elements, such as chlorine, oxygen, and sulfur, to form zinc compounds. Zinc compounds that may be found at hazardous waste sites are zinc chloride, zinc oxide, zinc sulfate, and zinc sulfide. Most zinc ore found naturally in the environment is in the form of zinc sulfide. Zinc compounds are widely used in industry. Zinc sulfide and zinc oxide are used to make white paints, ceramics, and other products. Zinc oxide is also used in producing rubber. Zinc compounds, such as zinc acetate, zinc chloride, and zinc sulfate, are used in preserving wood and in manufacturing and dyeing fabrics. Zinc chloride is also the major ingredient in smoke from smoke bombs. Zinc compounds are used by the drug industry as ingredients in some common products, such as vitamin supplements, sun blocks, diaper rash ointments, deodorants, athlete's foot preparations, acne and poison ivy preparations, and antidandruff shampoos.

Zinc enters the air, water, and soil as a result of both natural processes and human activities. Most zinc enters the environment as the result of mining, purifying of zinc, lead, and cadmium ores, steel production, coal burning, and burning of wastes. These activities can increase zinc levels in the atmosphere. Waste streams from zinc and other metal manufacturing and zinc chemical industries, domestic waste water, and run-off from soil containing zinc can discharge zinc into waterways. The level of zinc in soil increases mainly from disposal of zinc wastes from metal manufacturing industries and coal ash from electric utilities. In air, zinc is present mostly as fine dust particles. This dust eventually settles over land and water. Rain and snow aid in removing zinc from air. Most of the zinc in lakes or rivers settles on the bottom. However, a small amount may remain either dissolved in water or as fine suspended particles. The level of dissolved zinc in water may increase as the acidity of water increases. Fish can collect zinc in their bodies from water containing zinc.

Most of the zinc in soil is bound to the soil and does not dissolve in water. However, depending on the type of soil, some zinc may reach groundwater, and contamination of groundwater has occurred from hazardous waste sites. Zinc may be taken up by animals eating soil or drinking water containing zinc (ATSDR, 2005b).

2.7.10 Calcium (Ca)

Calcium is the fifth among elements and the third among metals in abundance in the earth's crust. Occurrence of calcium is very widespread; it is found in every major land area of the world. This element is essential to plant and animal life, and is present in bones, teeth, eggshell, coral, and many soils. Calcium chloride is present in seawater to the extent of 0.15%.

Calcium is an invariable constituent of all plants because it is essential for their growth. It is contained both as a structural constituent and as a physiological ion. The calcium ion is able to counteract the toxic effects of potassium, sodium, and magnesium ions. Calcium may also affect the growth of plants because its presence in soil affects the alkalinity of the latter.

Calcium is found in all animals in the soft tissues, in tissue fluid, and in the skeletal structures. The bones of vertebrates contain calcium as calcium fluoride, as calcium carbonate, and as calcium phosphate. In some lower animals, magnesium replaces either totally or partially the skeletal calcium. The importance of calcium in animals as a structural constituent is based on its abundance and on the low solubility of the three calcium salts just listed. Calcium is also essential in many biological functions of the vertebrates.

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2.7.11 Potassium (K)

Potassium is a lightweight, soft, low-melting, reactive metal. It is a very abundant element, ranking seventh among all the elements in the earth's crust, 2.59% of which is potassium in combined form. Only oxygen, silicon, aluminum, iron, calcium, and sodium are more abundant. Seawater contains 380 parts per million, making potassium the sixth most plentiful element in solution, exceeded by chlorine, sodium, manganese, sulfur, and calcium. Potassium chloride, KCl, is the most important potassium compound. It is not only the form in which potassium is often found in nature, but it is the form in which potash is used as a fertilizer.

Potassium chloride finds its main use in fertilizer mixtures. It also serves as the raw material for the manufacture of other potassium compounds. Potassium hydroxide is used in the manufacture of liquid soaps, and potassium carbonate in making soft soaps. Potassium carbonate is also an important raw material for the glass industry.

The comparison of metallic element composition of $PM_{2.5}$ studied in different places is provided in Table 2-5.

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Table 2-5 Comparison of metallic element composition of $PM_{2.5}$ (in unit of $\mu g/m^3$)

Species	**China**			**Japan**	**Portugal**	**UK**	**USA**	**Thailand**[h]	
	Taiwan[a]	**Shanghai**[b]	**Hong Kong**[c]	**Tokyo**[d]	**Lisbon**[e]	**Birmingham**[f]	**California**[g]	**Bangkhen**	**Klongha**
Ca	1.500	9.634	0.1723	0.650	0.269	0.0400	0.0972	0.199	0.439
Cd	0.010	0.0109	-	0.0018	-	-	-	-	-
Cr	0.020	0.0323	-	0.0059	-	-	-	-	-
Cu	0.250	0.171	0.013	0.0274	-	-	-	-	-
Fe	1.200	2.690	0.2116	0.763	0.128	0.114	0.194	0.107	0.279
K	0.800	3.331	1.2588	0.327	0.146	0.127	0.136	0.120	0.520
Mg	0.600	1.984	0.0397	0.193	-	-	-	-	-
Mn	0.070	0.186	0.0167	0.0303	0.0035	0.0099	0.0277	0.0039	0.0081
Ni	0.050	0.0139	0.0021	0.0048	-	-	-	-	-
Pb	0.090	0.515	0.1036	0.0644	-	-	-	-	-
Zn	0.380	1.409	0.1449	0.233	0.0528	0.297	0.112	0.0265	0.0702

[a] Wang *et al*., 1998, [b] Zheng *et al*., 2004, [c] Chao *et al*., 2002, [d] Iijima, 2001, [e] Freitas *et al*., 1995, [f] Harrison *et al*., 1997, [g] Chow *et al*., 1994, [h] Chueinta *et al*., 2000

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2.8 Health effects information of some metallic elements

Urban populations are exposed to metals in airborne particulate matter of which the concentrations are often above the natural background levels owing to anthropogenic processes. This can causes elevated metal concentrations in human body that will pose an important risk to human health (Antonio *et al*., 2001).

The USEPA has developed dose-response assessments for chronic exposure to many of the pollutants, including some heavy metals. These assessments give a reference concentration (RfC) to protect against effects other than cancer, and/or a unit risk estimate (URE) to estimate the probability of contracting cancer as a result of exposure to a pollutant. The RfCs and UREs for some heavy metals are shown in Tables 2-6 and 2-7.

The Agency for Toxic Substances and Disease Registry (ATSDR) also discussed with scientists within the Department of Health and Human Services (HHS) and the USEPA, ATSDR chose to adopt a practice similar to that of the EPA's Reference Dose (RfD) and Reference Concentration (RfC) for deriving substance specific health guidance levels for non neoplastic endpoints. A Minimal Risk Level (MRL) is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. The MRLs for some heavy metals are shown in Table 2-8.

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Table 2-6 Dose-Response Values for Cancer.

Pollutant	**Weight of evidence**[a]		**Unit Risk Estimate (per μg/m^3)**	**Source**[b]	**Confidence in URE**[c]
	EPA	**IARC**			
Cadmium	B1	1	1.8E-03	IRIS	Medium
Chromium	A	1	1.2E-02	IRIS	High
Lead	B2	2B	1.2E-05	CAL EPA	Low
Nickel	A	2B	4.8E-04	IRIS	High

[a] The EPA and International Agency for Research on Cancer (IARC) weight of evidence (WOE) categories characterize the extent to which available data support the hypothesis that a pollutant cause cancer in humans. The United State Environmental Protection Agency (USEPA) carcinogen categories are: Group A-known carcinogen; Group B1-probable carcinogen, based on incomplete human data; Group B2-probable carcinogen, based on adequate animal data; Group C-possible carcinogen; Group D-not classifiable; and Group E-evidence of non-carcinogenicity. The IARC categories are Group 1-carcinogenic in humans; Group 2A-probably carcinogenic; Group 2B-possibly carcinogenic; Group 3-not classifiable; and Group 4-probably not carcinogenic.

[b] IRIS-the USEPA Integrated Risk Information System. CAL EPA-California Environmental Protection Agency

[c] High-URE incorporate high-quality human data. Medium-URE considers human data of lower quality. Low-URE does not incorporate human data.

Source: USEPA, 1996b

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Table 2-7 Dose-Response Values for Effects Other Than Cancer.

Pollutant	**RfC[a] (mg/m^3)**	**Target organ for Chronic Critical Effect[b]**	**Severity of Critical Effect[c]**	**Target organ for Chronic Critical Effect**	**UF[d]**
Cadmium	2.0E-05	Kidney damage (proteinurea) in humans	Severe	Reduction in respiratory capacity in humans	30
Chromium	1.0E-04	Lung injury in rats	Medium	Immune system effects in rats	90
Lead	1.5E-03	Neurobehavioral effects (CNS) in humans	Severe	Blood, cardiovascular, and kidney effects in humans	1
Manganese	5.0E-05	Neurobehavioral effects (CNS) in humans	Medium	Cough, bronchitis in humans	1000
Nickel	2.0E-04	Respiratory tract inflammation in rats	Mild	Immune system effects in humans	30

[a] The RfC is an estimate of a concentration in air to which a human population might be exposed (including sensitive subgroups) that is likely to be without appreciable risks of deleterious effects during a lifetime.

[b] The critical effect is the adverse effect upon which the RfC or similar value is based.

[c] Severe-substantial AND irreversible. Medium-substantial OR irreversible. Mild-not substantial AND not irreversible.

[d] UF--uncertainty factor.

Source: USEPA, 1996b

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Table 2-8 Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) for heavy metals.

Name	**ATSDR Minimal Risk Levels (MRLs)** [a]			
	Route	Duration [b]	MRL	Uncertainty factor
Cadmium	oral	chronic	0.0002 mg/kg/day	10
Chromium(VI) (aerosol mists)	inhalation	intermediate	0.000005 mg/m^3	100
Chromium(VI) (particulates)	inhalation	intermediate	0.001 mg/m^3	30
Copper	oral	acute	0.01 mg/kg/day	3
		intermediate	0.01 mg/kg/day	3
Manganese	inhalation	chronic	0.00004 mg/m^3	500
Nickel	inhalation	intermediate	0.0002 mg/m^3	30
		chronic	0.00009 mg/m^3	30
Zinc	oral	intermediate	0.3 mg/kg/day	3
		chronic	0.3 mg/kg/day	3

[a] ATSDR uses the no observed adverse effect level/uncertainty factor (NOAEL/UF) approach to derive MRLs.

[b] Exposure durations: acute (1-14 days), intermediate (15-364 days), and chronic (365 days and longer).

Source: ATSDR, 2005a.

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2.9 Metallic elements and sources of $PM_{2.5}$

Louie *et al*. (2005) noted that Al, Si, K, Zn, Fe, and Ca were crustal elements and used as the indicators of $PM_{2.5}$ from soil.

Wang *et al*. (2003) noted that the metals contents in lubricant oil could play an important role on the emission of metals contents in the engine exhaust, particularly Ca and Zn.

Chueinta *et al*. (2000) suggested that the factor getting from factor analysis with high loading of Zn and Mn may contribute from motor vehicle, especially those of two-stroke engines such as motorcycle or motor scooter. Al, Ca and Fe come along with those from motor vehicle possibly suggesting contaminated road dust. For the factor with high factor loading of K as its only major constituent is then identified as charcoal or wood burning. If high loadings of Ca and Fe appeared in the factor were probably from the building construction. Chueinta *et al*. (2000) also noted that the factor consisting of Al, Ca, Fe, La, and Mn is possibly identified as soil; however, it also contains high value of K. therefore, this factor could represent local soil strongly contaminated by biological materials or wood ash.

Bortnick (2003) noted that vegetative burning and fireworks are major source of potassium. In case of road construction, the source profile is a mix of crustal components and diesel mobile. The source is stronger during weekdays and lasts for several months.

Ho *et al*. (2003) reported the high correlations were observed between mass concentration and traditional crustal elements (Si, Al, K, Ca, Ti, and Fe) in soil and dust samples in Hong Kong. Si, Al, K, Ca, Ti, and Fe are good indicators of soil and paved road dust, and Zn and Pb can be used as other indicators for paved road dust.

Senaratne *et al*. (2004) suggested that wood burning is the main source of K. Some of Fe and Zn may be found from this source. The elemental compositions of Diesel and Petrol with high loading are Fe, K, Zn, and Ca, while Fe, Ca and Mg are the main elemental composition of soil and road dust.

Watson *et al*. (2001) reported that in his study of the geological profiles, Al, K, Ca, and Fe have large abundances with low variability. The effect of motor vehicle contributions to paved road dust (e.g. brake and tire wear, oil drips, deposited exhaust) is evident in larger abundance of Pb. However, it is still difficult to distinguish paved road dust, unpaved road dust, and native soil compositions from each other.

Fang *et al*. (2003) studied the characteristics of particulate, metallic elements of the total suspended particulate, $PM_{2.5}$ and $PM_{2.5-10}$ aerosols at a farm sampling site in Taiwan. The results showed that the metallic elements Pb, Zn, Cr, and Ni were the largest abundance in the $PM_{2.5}$ fraction, while the metallic elements Fe and Cd were the largest composition in the $PM_{2.5-10}$ fraction.

Tables 2-9 and 2-10 show the metal element abundances of major source profile types studied by Chow *et al*. (1995) and Senaratne *et al*. (2004).

Table 2-9 Metal element abundances of major source profile types (Chow *et al*., 1995).

Source Type	**Metal element abundances in Percent Mass**		
	<0.1%	0.1 to 1%	1 to 10%
Vegetative burning	Ca, Mn, Fe, Zn, Pb	-	K
Construction	Cr, Mn, Zn	-	K, Ca, Fe
Natural soil	Cr, Mn, Zn	-	Mg, K, Ca, Fe
Vehicle exhaust	Cr, Ni	Mn, Fe, Zn, Pb	-
Incinerator	Mn, Cu	Zn	Pb, Fe, Ca
Agricultural soil	Cr, Zn	Mn	K, Ca, Fe
Residual oil combustion	Cr	Zn, Fe	Ni
Marine aerosol	Ni, Pb	K, Ca, Fe, Cu, Zn	-

Table 2-10 Metal element abundances of major source profile types (Senaratne *et al*., 2004).

Source Type	**Metal element abundances in Percent Mass**		
	<1%	1 to 10%	>10%
Sea spray	Sr	Mg, K, Ca	Na
Soil	Ni, Zn, Sr, K, Ba,Pb	Na, Mn	Mg, Ca, Fe
Road dust	Ni, Cu, Ba	Na, K, Ca, Mn,Pb	Mg, Al, Fe
Diesel emission	Mn, Ni, Pb	Mg, Cu, Zn	K, Ca, Fe, Zn
Petrol emission	Pb, Cu, Ni, Mn	Ca, Zn	Na, K, Fe
Wood combustion	Pb, Ca	Zn	K
Coal combustion	Ni, Cu	Ca, Pb	K, Fe, Zn

2.10 Source profiles of particulate matter studied in Thailand

In Thailand, there are a few inventories on source chemical compositions and concentrations. Japan International Cooperation Agency (JICA) investigated the air quality around Samut Prakarn industrial district for the air quality planning in that area in 1991. This study included the first data on chemical components contained in particulate matter present in ambient air of the area. The source profiles used at that time are shown in Table 2-11. In addition, the World Bank assisted the Royal Thai Government in 1996 in characterizing ambient suspended particulate matter problems and developing a cost-effective air pollution control strategy for the Bangkok Metropolitan Region (BMR). The compositions of emission sources and the average mobile source profiles of particulate matter for Bangkok, which are shown in Tables 2-12 and 2-13, were determined in this study.

Table 2-11 Source profiles of the emission sources in Samut Prakarn industrial district (μg/g).

Element	**Source type**							
	Sea salt	Soil	Diesel Auto.	Gasoline Auto.	Iron & Steel industry	Fuel oil combustion	Refuse incineration	Road dust
Ca	12000	1750	3250	0	47000	14500	13600	26000
Cd	NA	NA	NA	NA	NA	NA	NA	NA
Cr	0.001	27.5	45	21	4230	2760	570	33
Cu	NA	NA	NA	NA	NA	NA	NA	NA
Fe	0.29	12000	30700	4900	301000	28300	5900	18000
K	11000	31500	120	2000	11500	1300	10000	21000
Mg	NA	NA	NA	NA	NA	NA	NA	NA
Mn	0.058	365	77	51	27700	500	540	610
Ni	0.014	30	0	38	1700	21000	135	25
Pb	0.087	70	490	120000	10500	900	53400	130
Zn	0.029	17.5	1160	1400	26000	1700	794	130

NA = Not available

Source: JICA, 1991.

Table 2-12 Compositions of emission sources in Bangkok area (μg/g).

Element	**Source type**						
	Heavy duty truck	Light duty truck	Motorcy-cle	Soil	Road dusts	Steel mill	Power plant
Ca	2890	550	870	174500	202000	31330	620
Cd	NA	NA	NA	NA	NA	NA	NA
Cr	0	10	20	110	130	430	100
Cu	140	40	30	160	300	1060	20
Fe	3490	660	170	36850	35200	157000	1230
K	1060	10	90	15000	18270	4530	100
Mg	NA	NA	NA	NA	NA	NA	NA
Mn	10	10	10	780	750	6060	30
Ni	30	10	10	30	30	330	5480
Pb	270	30	110	120	240	4480	10
Zn	860	390	220	360	920	39130	30

NA = Not available

Source: Radian International LIC, 1998

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Table 2-13 Average mobile source profiles of particulate matter for Bangkok (µg/g).

Element	**Source type**		
	Motorcycle	Light duty diesel	Heavy duty diesel
Aluminium	270	165	730
Arsenic	20	9	ND
Barium	1370	ND	2170
Bromine	15	5	31
Calcium	856	377	1980
Chlorine	138	77	164
Chromium	79	7	ND
Copper	32	27	86
Iron	210	414	2190
Lead	111	60	182
Manganese	13	9	8.3
Nickel	13	12	21
Phosphorus	76	159	536
Potassium	94	85	706
Silicon	1220	2110	4100
Sulfer	1130	1960	1670
Titanium	22	31	305
Vanadium	31	14	44
Zinc	222	226	597

ND = Not detected

Source: Radian International LIC, 1998

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2.11 Source apportionment study

Salvador *et al.* (2004) performed a source apportionment study to characterize PM_{10} sources in the urban area of Madrid, Spain. They reported that the four major sources that contributed to most of the analyzed PM_{10} mass are road traffic (48%), crustal/mineral (26%), secondary (18%) and marine aerosol (3%) while 5% of the PM_{10} mass has been attributed to non-identified sources.

Kemp (2002) studied the trends and sources of heavy metals in urban atmosphere. The study discovered that the main sources of heavy metals were traffic, domestic heating and long-range transport. Using simple statistical methods to identify the main source of each metal, it was found that the main source of Cu, Cr and Zn was traffic.

Bilos *et al*. (2001) studied the sources, distribution and variability of airborne trace metals. Enrichment Factors (EFs) were calculated to evaluate anthropogenic versus natural element sources. The EFs of Pb, Zn, Cd and Cu were high reflecting the important of anthropogenic inputs. The comparison with EF calculated for high emitting vehicle particle emissions indicated that motor exhaust was the most important source of these elements in their study area. In contrast, the EFs of Mn, Cr, Ni, Ca and Mg were low suggesting chiefly natural sources.

Fang *et al*. (2003) studied the aerosol at a farm sampling site in Taiwan. According to the results of their principal component analysis (PCA), the major contributions of the PM_{10} fraction were soil, industry and traffic, respectively. As for the $PM_{2.5}$ fraction, the major sources were soil, traffic and industry, respectively.

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CHAPTER III

METHODOLOGY

3.1 Sampling sites

Samples of $PM_{2.5}$ were collected from December 2004 to February 2005 at two different outdoor sampling sites. A map of the city of Chiang Mai shows the locations of the sampling sites in Figure 3-1. Site no.1 is located outdoor on the balcony floor of the third floor of the third story building at the Nakhon Chiang Mai municipal office. The site is located in the downtown area and also the center of the city. Site no.2 is located outdoor in the agricultural meteorological station at the faculty of agriculture at Chiang Mai University (CMU), Mae Hea campus, which is about 6 km southwest of site no.1. This site is in a field, which is located at the foot of Doi Suthep Mountain and is about 1 km from traffic road (Highway 121). An overview of the methodology of this study is provided in Figure 3-2.

Figure 3-1 A map of Chiang Mai city shows the locations of the sampling sites

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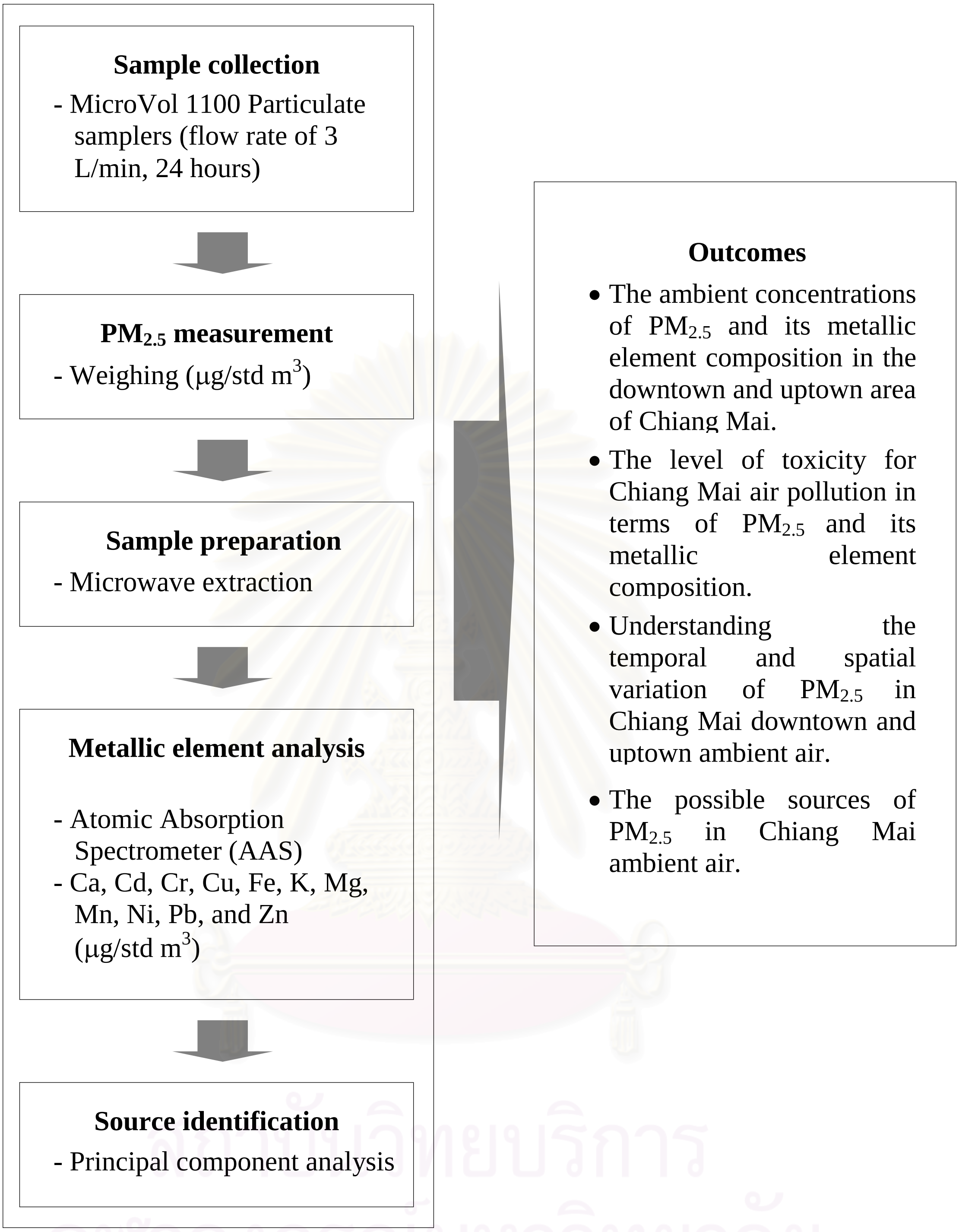

Figure 3-2 An overview of the methodology of the study

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3.2 Sample collection

Particle samples were collected on 47 mm Teflon membrane filters (MFS, 1.0 μm pore size, ADVANTEC MFS, Inc., 6691 Owens Drive, Pleasanton, CA 94588-3335, USA) using portable battery operated samplers (MicroVol1100

Particulate Samplers, Ecotech Pty Ltd. 12 Apollo Court, Blackburn, Victoria 3130, Australia, www.ecotech.com.au) (Figure 3-3). The installations of air particulate samplers are shown in Figures 3-4. The ambient air flow rate was adjusted to 3 L/min based on ambient temperatures and pressures for individual periods of 24 h. The samples are cylindrical in shape with a diameter of 17 cm and a height of 78.5 cm. They weigh about 8.15 kg, are battery operated and can run unattended for 24 consecutive hours. Filters and batteries were changed once per day in the field. Air first enters the sampler through an impactor with $PM_{2.5}$ Nozzle adaptor that was designed to pass particles that are 2.5 μm or less with 50% cut size as described by Reist, 1993.

Figure 3-3 MicroVol1100 Particulate Sampler

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a) Site no.1 **b) Site no.2**

Figure 3-4 Installations of air particulate samplers at site no.1 and site no.2

3.3 Filter preparation and $PM_{2.5}$ levels measurement

3.3.1 Pre-collection equilibration

3.3.1.1 Placed filters on a Petri dish, and labeled each dish with a filter number. The filters were equilibrated for at least 24 hours under precisely controlled temperature and relative humidity conditions:

Relative humidity was maintained at a constant level of 50%±10% with variability of less than 5% (Australian Standards 3580.9.6-1990).

Temperature was maintained at a constant level of 20-25°C (Australian standards 3580.9.6-1990).

3.3.1.2 Weighed each filter four times and recorded the average initial mass of each filter, W_i. The zero reading of the microbalance between each reading was checked constantly.

3.3.1.3 Immediately after weighing, each filter was placed into a Petri dish with a lid for traveling to the sampling site.

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3.3.1.4 Recorded the relative humidity, temperature, date and time of the initial weighing.

3.3.2 Filter exchange

3.3.2.1 Replaced a filter and recorded the time, date, sampling times and dates.

3.3.2.2 Recorded the sample volume and collected sample.

3.3.3 Post-collection equilibration

3.3.3.1 Carefully removed the filter elements from their holders.

3.3.3.2 Placed the filter element on its numbered Petri dish and put into a press –seal anti-static plastic bag.

3.3.3.3 Recorded the relative humidity, temperature, date and time of the post collection equilibration. The equilibration temperature and relative humidity were maintained as close as possible to the initial equilibration conditions.

3.3.3.4 Each filter was allowed to equilibrate for at least 24 hours.

3.3.4 Final weighing

3.3.4.1 Used the same microbalance that had been used in the initial weighing.

3.3.4.2 Weighed each filter four times and recorded the average initial mass of each filter, W_f. The zero reading of the microbalance between each reading was checked constantly.

3.3.4.3 Immediately after weighing, placed each filter into a Petri dish with lid and recorded the time and dates that the sample was taken.

3.3.4.4 Recorded the relative humidity, temperature, date and time of the final weighing.

3.3.5 PM$_{2.5}$ mass concentration calculation

Mass concentration (MC) was calculated using the formula:

$$MC = (W_f - W_i)/V$$

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where

W_f = Final mass of filter element

W_i = Initial mass of filter element

V = Sample volume

The units for the concentration were standard μg/m^3 referenced to standard temperature of 25^{o}C and standard pressure of 760 mmHg (USEPA, 1996a) when the corrected sample volume was used. The units for the concentration were μg/m^3 when the uncorrected sample volume was used.

3.4 Filter digestion

3.4.1 Placed a Teflon membrane filter into a TFM vessel of microwave equipment (Milestone ETHOS PLUS labstation with HPR-1000/10s high pressure segmented rotor, 2003 Milestone Inc., www.milestonesci.com) (USEPA, 1996a).

3.4.2 Introduced the TFM vessel into the HTC safety shield.

3.4.3 Added 3 mL H_2SO_4 96% and closed the vessel.

3.4.4 Introduced the TFM vessel into the rotor segment, and then tighten by using the torque wrench.

3.4.5 Inserted the segment into the microwave cavity and connected the temperature sensor.

3.4.6 Started the microwave program for first digestion as shown in Table 3-1 and Figure 3-5

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Table 3-1 Microwave program for first digestion

Step	Time	Temperature	Microwave power
1	10 minutes	200 ^{o}C	Up to 300 Watt
2	5 Minutes	200 ^{o}C	Up to 300 Watt

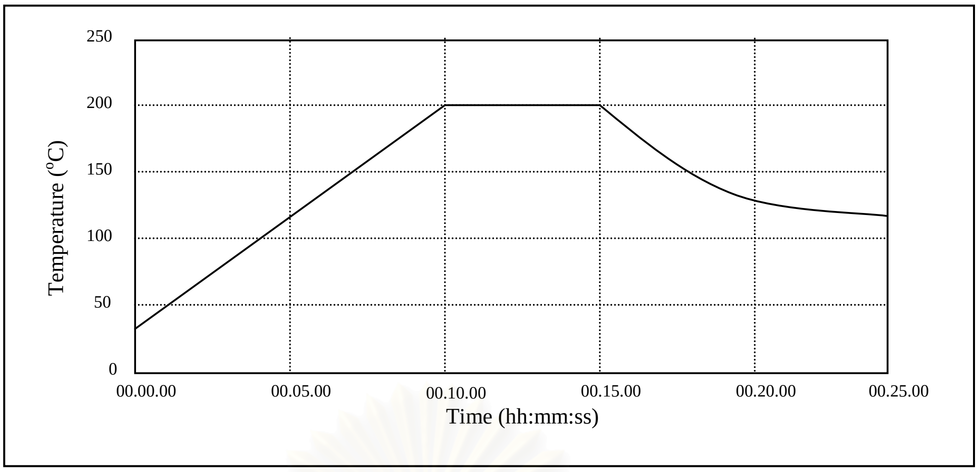

Figure 3-5 Microwave program plot

3.4.7 Cooled down, opened the vessels and, with care, added 5 mL of HNO_3 65%.

3.4.8 Leaved the vessels open for few minutes, then caped the vessels and closed them with torque wrench.

3.4.9 Inserted the segment into the microwave cavity and connected the temperature sensor.

3.4.10 Ran the microwave program for second digestion as shown in table 3-2 to completion.

Table 3-2 Microwave program for second digestion

Step	Time	Temperature	Microwave power
1	10 minutes	200 °C	Up to 1000 Watt
2	20 Minutes	200 °C	Up to 1000 Watt

3.4.11 Cooled the rotor by air until the solution reaches room temperature.

3.4.12 Opened the vessel and transferred the sample to a volumetric flask, the TFM vessels washed out with DI water and the flask volume made up to a final volume of 50 mL.

3.4.13 For each digestion, reagent blanks were obtained. The blanks were prepared in the same way as the samples.

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3.5 Metallic element analysis

3.5.1 Analyzed sample solutions based on the method described in compendium of methods for the determination of inorganic compounds in ambient air (USEPA, 1996a) by GF-AAS using the GBC-Avanta Σ Atomic Absorption Spectrometry with the System 3000 Graphite Furnace and the PAL 3000 auto-sampler and Flame Atomic Absorption Spectrometry.

3.5.2 The instrumental operating parameter and the wavelengths used for each kind of element were given in Table 3-3.

Table 3-3 Instrumental operating parameter and the wavelengths used for each kind of element analyzed by Atomic Absorption Spectrometry **(**Chow, 1995)

Element	**Wavelength (nm)**	**Minimum Detection Limit (ng/m^3) [a, b]**	**Remark**
Ag	328.1	0.005	GF-AAS [c]
Cd	228.8	0.003	GF-AAS [c]
Cr	357.9	0.01	GF-AAS [c]
Cu	324.7	0.02	GF-AAS [c]
Fe	248.3	0.02	GF-AAS [c]
Ni	232.0	0.1	GF-AAS [c]
Pb	217.0	0.05	GF-AAS [c]
Ca	422.7	1	FAAS [d]
K	766.5	2	FAAS [d]
Mg	285.2	0.3	FAAS [d]
Mn	279.5	1	FAAS [d]
Zn	213.9	1	FAAS [d]

[a] Minimum detection limit is three times the standard deviation of the blank for a filter of 1 mg/cm^2 area density.

[b] Concentration is based on the extraction of 1/2 of 47 mm filter in 15 ml of deionized water, with a nominal flow rate of 20 l/min for 24-hour samples

[c] GF-AAS = Graphite Furnace Atomic Absorption Spectrometry

[d] FAAS = Flame Atomic Absorption Spectrometry

3.6 Meteorological data

The most relevant meteorological data for Chiang Mai is from the Meteorological station located next to the Chiang Mai Airport. As the Chiang Mai residential area is relatively flat and small, the Meteorological station data should provide reliable and representative information for the greater Chiang Mai city. Figure 3-6 shows the location of the Meteorological station in relation to the sampling sites.

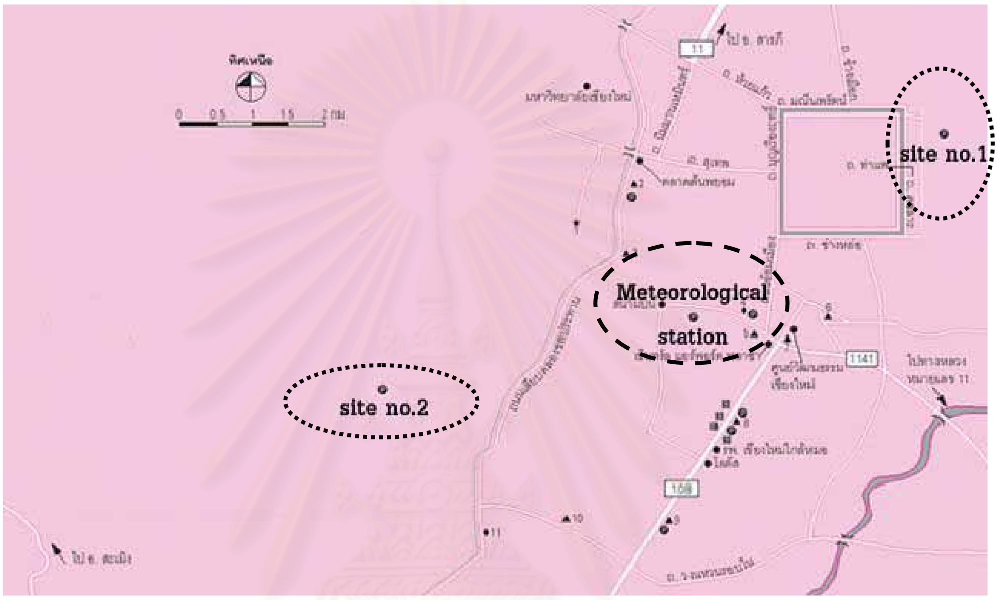

Figure 3-6 Location of the Meteorological station in relation to the sampling sites

3.7 Statistical analysis

3.7.1 Pearson correlation

Pearson correlation was used to illustrate the relation of two parameters without controlling other parameters (zero-order correlation). The Pearson correlation coefficient is a measure of linear association between two variables. The values of the correlation coefficient range from -1 to 1. The sign of the correlation coefficient indicates the direction of the relationship (positive or negative). The absolute value of the correlation coefficient indicates the strength, with larger absolute values indicating stronger relationships. The correlation coefficients on the main diagonal are always 1.0, because each variable has a perfect positive linear relationship with itself. The significance level is the probability of obtaining results as extreme as the one observed. If the significance level is very small (less than 0.05) then the correlation is significant and the two variables are linearly related. If the

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significance level is relatively large (for example, 0.50) the correlation is not significant and the two variables are not linearly related.

3.7.2 Principal component analysis (PCA)

Principal Component Analysis (PCA) was used to identify the possible sources of $PM_{2.5}$ in Chiang Mai ambient air. PCA is a multivariate statistical technique commonly used for source apportionment of particulate matter. PCA is basically a statistical technique, which can be applied to a set of variables in order to reduce their dimensionality. That is to replace a large set of intercorrelated variables with a smaller number of independent variables. These new variables, which are called as components are derived from the original variables, and are simply linear combinations of those variables. The PCA assumes that the total concentration of each element is made up of the sum of elemental contributions from each of the specific pollution source components.

The primary objective of applying PCA is to derive a small number of components, which explain a maximum of the variance in the data. Initially, the PCA results in as many principal components (PCs) as there are original variables. Usually, however, only a limited number of these uncorrelated PCs (e.g. five or six) are required to explain virtually all of the variance in a data set of original (intercorrelated) variables. In order for this reduction in the dimensionality to be useful, the new variables (components) must have simple substantive interpretations. For this reason, a limited number of components are usually subjected to rotation using a criterion such as varimax. After PCA rotation, the resulting components have been found to often be more representative of individual underlying sources of variation (Thurston *et al*., 1985).

The model of PCA can be expressed as following:

$$PC_1 = a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \ldots + a_{1m}X_m$$

$$PC_2 = a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + \ldots + a_{2m}X_m$$

$$\vdots$$

$$PC_m = a_{m1}X_1 + a_{m2}X_2 + a_{m3}X_3 + \ldots + a_{mm}X_m$$

Where the following assumptions are made:

1. $X_1, X_2, \ldots, X_m$ are the original variables.
2. $PC_1, PC_2, \ldots, PC_m$ are the principal components. These components are assumed to have zero means and unit variances.

3. m is the number of principal components (this number is equal to the number of original variables).
4. a_{ij} is the coefficient of X_j in the linear combination describing PC_i. This term is called the loading of the jth variable on the ith principal component.

Coefficients of these linear combinations are chosen to satisfy the following three requirements:

1. Variance PC_1 > Variance PC_2 > … > Variance PC_m
2. The values of any two principal components are incorrelated.
3. For any principal component the sum of the squares of the coefficients is one.

In other words, PC_1 is the linear combination with the largest variance. Subject to the condition that it is uncorrelated with PC_1, PC_2 is the linear combination with the largest variance. Similarly, PC_3 has the largest variance subject to the condition that it is uncorrelated with PC_1 and PC_2; etc. The variances PC_i are the eigenvalues. All of these variances add up to the original total variance. The total variance is simply the number of variables, and the propotion explained by each principal component is the corresponding eigenvalue divided by m.

When a satisfactory solution had been derived, each principal component was attempted to assign some meaning to it. Before interpretation, a minimum acceptable level of significance for a principal component loading was selected at above 0.500. Significant loadings were then compared to the percentages of those variable contents in the real source samples. If the types of high loading variables in one component are the same as those in one source samples, the component will be named after that source.

Further, the score for each component, which can be calculated from the model above, implied the influence of one source to the collected air samples. For example, if the plot between PC_1 and PC_2 of samples from site no.1 located separately from those of site no.2, it can be said that the comparative influence of source PC_1 and PC_2 in site no. 1 are clearly different from the case of site no. 2. Additionally, if the plot between PC_1 of samples from site no.1 and site no.2 shows significant correlation, then it can be concluded that the contribution process of source PC_1 in site no. 1 is related to the contribution process of that source in site no. 1.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Ambient $PM_{2.5}$ concentrations in downtown and uptown area of Chiang Mai city

Ambient $PM_{2.5}$ concentrations observed at the two different sites (site no.1 and site no.2 as the representatives of downtown and uptown area, respectively) from December 2004 to February 2005 are as shown in Table 4-1, Figure 4-1, Figure 4-2 and Figure 4-3.

From Table 4-1, the average concentrations of $PM_{2.5}$ at site no.1 and site no. 2 were 93 μg/std m^3 and 44 μg/std m^3, respectively. It was found that the average concentration of $PM_{2.5}$ at site no.1 was about 2 times of the average concentration of $PM_{2.5}$ at site no. 2. This result is similar to that of the studies performed by Zee *et al.* (1998) and Hoek *et al.* (1997), which reported about the higher average concentrations of particle in the urban areas than in the corresponding non-urban areas. Moreover, from December 2004 to February 2005, the 24-h ambient concentrations of $PM_{2.5}$ at sites nos.1 and 2 varied from 23 to 145 and 0 to 93 μg/std m^3, respectively (Table 4-1). The peak $PM_{2.5}$ 24-h ambient concentrations at sites nos. 1 and 2 were 145 and 93 μg/std m^3 and took place at February 2 and January 11, respectively. At the both two sites during the study period there was not any day that $PM_{2.5}$ 24-h ambient concentration of above 150 μg/std m^3 (defined by USEPA as the very unhealthy concentration of $PM_{2.5}$). During the study period there were 27 days (from the data of 33 days) that $PM_{2.5}$ were higher than 65 μg/std m^3 (USEPA standard for 24-h average concentration of $PM_{2.5}$) at site no. 1 and there were 6 days (from the data of 36 days) above 65 μg/std m^3 at site no. 2. These results show the severity of particle pollution in the downtown area of Chiang Mai, which represented by site no.1. Comparison of the result in this study to the study of particle pollutions in urban areas of Chiang Mai performed by Vinitketkumnuen *et al.* (2002), which performed her study in 1998-1999, the $PM_{2.5}$ concentrations are almost at the same level (93 μg/std m^3 and 90.17 μg/std m^3 for this study and Vinitketkumnuen's study, respectively).

Table 4-1 Summary of 24-hour $PM_{2.5}$ concentration in Chiang Mai downtown and uptown area during December 2004 to February 2005

	$PM_{2.5}$ concentration (μg/ std m^3)	
	Downtown (site no.1)	Uptown (site no. 2)
Maximum	145	93
Minimum	23	0
Average	93	44
Standard Deviation	28	21
Number of samples	33	36
NAAQS[a]	65	65
Number of sample exceed the NAAQS	27	6

[a] NAAQS = National Ambient Air Quality Standards, USEPA (2004)

According to Figure 4-1, the increasing trend of $PM_{2.5}$ level in winter time was observed at both sites from December 2004 to February 2005. The similar increasing trend was also found in the report of Vinitketkumnuen *et al*. (2002) as shown in Table 4-2.

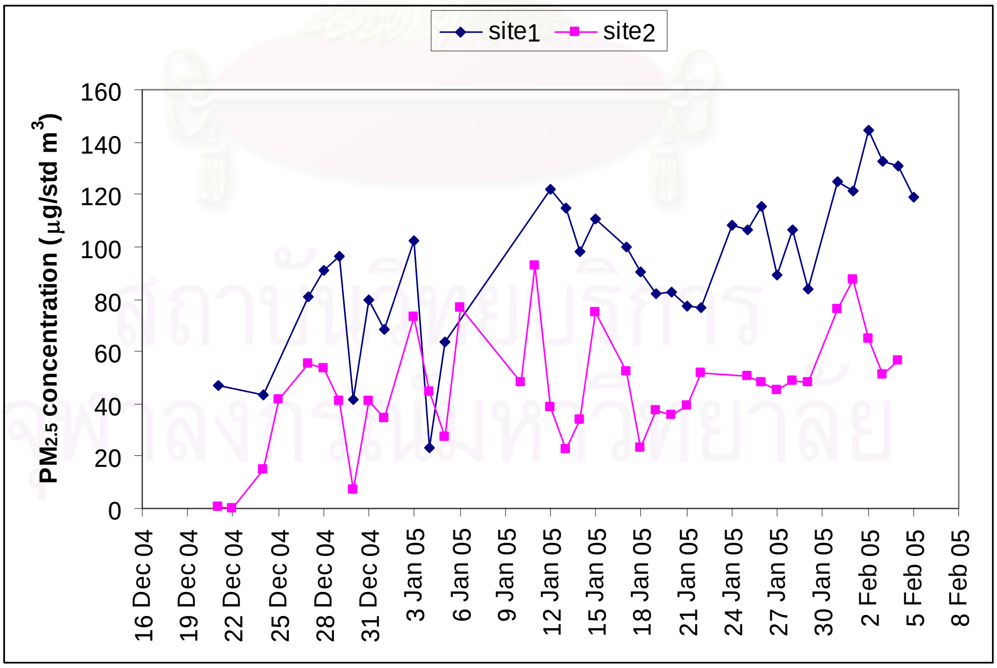

Figure 4-1 Time series of 24-hour $PM_{2.5}$ concentrations in Chiang Mai ambient air at sampling site nos. 1 and 2 during December 2004 to February 2005 (n=33 for site no.1 and n=36 for site no.2)

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Table 4-2 Monthly average of $PM_{2.5}$ concentrations in Chiang Mai ambient air from March 1998 to October 1999 (Vinitketkumnuen *et al*., 2002).

Month	**$PM_{2.5}$ concentration (μg/m^3)**	
	Mean ± S.D.	**Range of 24 h values**
March 1998	138.31 ± 66.5	57-324
April 1998	67.33 ± 31.4	30-142
May 1998	34.16 ± 2.7	21-69
June 1998	18.59 ±7.8	9-39
July 1998	17.33 ± 6.8	7-37
August 1998	15.39 ± 7.1	1.3-41
September 1998	31.44 ± 5.6	9-75
December 1998	77.34 ± 26.4	39-138
January 1999	90.17 ± 34.2	32-173
February 1999	120.67 ± 49.5	28-208
March 1999	119.54 ± 34.4	73-174
June 1999	30.95 ± 14.1	16-71
July 1999	24.10 ± 9.1	12-43
August 1999	26.40 ± 14.5	7-76
September 1999	32.57 ± 13.2	10-61
October 1999	32.62 ± 10	9-58

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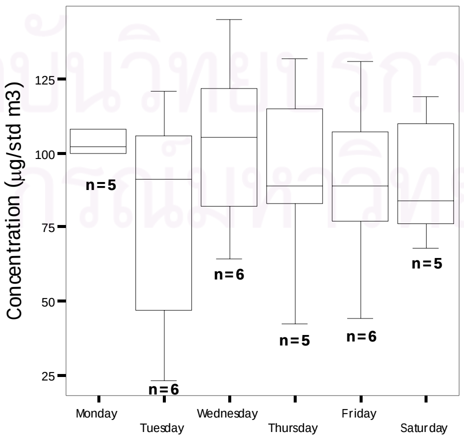

Figure 4-2 Daily variation of $PM_{2.5}$ concentrations observed at site no.1 during December 2004 to February 2005.

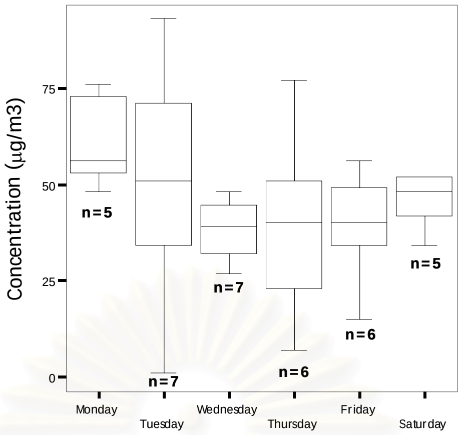

Figure 4-3 Daily variation of $PM_{2.5}$ concentrations observed at site no.2 during December 2004 to February 2005.

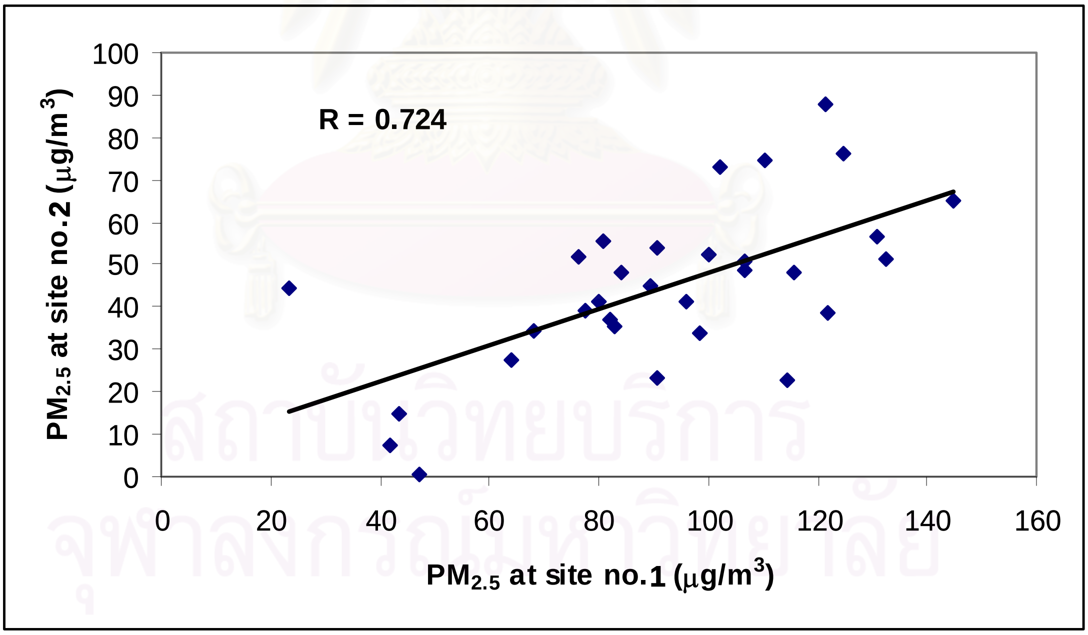

Figure 4-4 $PM_{2.5}$ concentrations observed plot between site no.1 and site no.2.

The correlation coefficient between the ambient $PM_{2.5}$ concentrations at site no.1 and site no.2 is of 0.724 at the 0.01 significance level as shown in Figure 4-4. This relatively high correlation coefficient in Figure 4-4 and the increasingly trends in

Figure 4-1 may be explained by the characteristics of Chiang Mai meteorology. Chiang Mai is in a valley and given the generally lower ventilation in the winter than the summer month. Namely, $PM_{2.5}$ in Chiang Mai ambient air are likely to be stored in a small mixing air volume in winter and disperse over bigger air volume in summer. For example, during the winter months the average wind speed in Chiang Mai (Northern Meteorological Center, 2005) was 14.6 km/hr, while in the summer month it was 22.9 km/hr. The average high temperature during the months of winter is in the range of 26.1 – 36.0 ^{o}C, and average lows are on the order of 15 ^{o}C, while in the summer month it was 36 ^{o}C. All of these meteorological data agree with the temperature balloon soundings taken at the Chiang Mai airport which indicate that much stronger ground-based inversions develop during the winter than in the summer months. Estimated mid-day mixing heights during the winter are on the order of 900 m, while from April to October they are of about 1400 m (Vinitketkumnuen *et al*., 2002). Thus, the increasing of $PM_{2.5}$ concentration in winter is consider to be found normally in many sampling sites of Chiang Mai province.

Besides, $PM_{2.5}$ concentrations and daily average temperature in the winter season were analyzed for their relation. The result as shown in Table 4-3 shows that they have a positive correlation (0.447 at a significance level of 0.01). Moreover, the correlation coefficient between $PM_{2.5}$ concentrations and daily sunshine hour show the positive correlation (0.389 at a significance level of 0.01). These results suggested the influence of the atmospheric stability on the distribution of $PM_{2.5}$ in Chiang Mai ambient air in winter season. The atmospheric stability causes the distribution of pollutants to be more or less. Unstable conditions cause a pollutants to expand more and stable conditions cause a pollutant to expand less (LaGrega *et al*., 2001). In generally, the meteorological conditions affect the atmospheric stability are wind speed, temperature, and the rate of solar heating. During the winter, the wind speed of Chiang Mai is slow and does not have significant variation. This agrees with the result that there is no significant correlation between $PM_{2.5}$ concentration and the average wind speed. It can be said that the meteorological conditions which significantly affect the distribution of pollutants are the daily average temperature and sunshine hour.

Table 4-3 Correlation between $PM_{2.5}$ concentrations and meteorological data during December 2004 to February 2005

	Pearson correlation coefficient			
	$PM_{2.5}$ concentration	Average wind speed	Average temperature	Sunshine hours
$PM_{2.5}$ concentration		0.222	0.410*	0.341*
Average wind speed	0.222			
Average temperature	0.410*			
Sunshine hours	0.341*			

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

4.2 Metallic element composition of downtown and uptown $PM_{2.5}$ in Chiang Mai ambient air

The average concentrations of metallic element composition of $PM_{2.5}$ in the downtown and uptown area of Chiang Mai city are shown in Table 4-4, Table 4-5 , Figure 4-5, Figure 4-6 and Figure 4-7. From Tables 4-4 and 4-5 the concentrations of metallic element composition based on grams of $PM_{2.5}$ were found to be higher for site no.2 than site no.1, even though the $PM_{2.5}$ levels of site no.1 were higher than site no.2 for all sampling days. The difference occurred when the comparison of metallic element composition was done based on the volume of air. This difference suggested that some particles at site no.1 were not the carrier of metallic elements or there might be other compounds that were dominantly carried by the particle at site no.1. Current knowledge indicates that $PM_{2.5}$ is not a single pollutant, but a mixture of many chemical species such as sulfate (SO_4^{2-}), ammonium (NH_4^+), nitrate ions (NO_3^-), metallic elements, organic material, water and crustal components (Artinano *et al.*, 2003). Figure 4-5, Figure 4-6 and Figure 4-7 showed that the averaged $PM_{2.5}$ composition order as Ca> Mg> K> Zn> Mn> Fe> Cr> Pb> Ni> Cu> Cd for downtown area and the averaged $PM_{2.5}$ composition order as Ca> Mg> K> Zn> Fe> Mn> Cr > Pb> Ni> Cu> Cd for uptown area.

The daily variations of metallic element composition at site no.1 and site no.2 are shown in Figure 4-8 and Figure 4-9. Ca, Mg, Zn and K were the most enriched

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elements and the second group was Fe, Mn, Pb, and Cr for both sites. Ni, Cu and Cd were found in relatively small amounts for both sites.

The percentages of averaged elemental composition in $PM_{2.5}$ for downtown and uptown area of Chiang Mai were shown in Figures 4-10 and 4-11. Some assumptions about $PM_{2.5}$ sources were made based on the figures. Firstly, the similar elemental compositions of $PM_{2.5}$ in the ambient air of sites nos. 1 and 2. imply the similarity of $PM_{2.5}$ source types at both site. Secondly, since Ca is usually identified as the indication of soil and construction source, high concentration of Ca for both sites suggest the influence of the soil on $PM_{2.5}$ concentration in the ambient air of Chiang Mai. Chiang Mai soil composition analyzed by Inthasan *et al*. (2002) as shown in Figure 4-12 also supports the above assumption. In fact, numbers of construction sites in Chiang Mai were observed during the sampling campaign. This resulted from the rapidly development for Chiang Mai to be the center of northern region.

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Table 4-4 Average concentrations (µg/std m^3) of metallic element composition of $PM_{2.5}$ in the downtown and uptown area of Chiang Mai city

Element	Downtown (site no.1)			Uptown (site no.2)		
	Mean±S.D.	Maximum	Minimum	Mean±S.D.	Maximum	Minimum
Pb	0.1280± 0.1040	0.3430	0.0000	0.1070± 0.1210	0.7150	0.0000
Cd	0.0053± 0.0052	0.0151	0.0000	0.0040± 0.0041	0.0098	0.0000
Ni	0.0402± 0.0343	0.1410	0.0000	0.0217± 0.0186	0.0585	0.0000
Cu	0.0357± 0.0719	0.2830	0.0000	0.0221± 0.0553	0.2780	0.0000
Cr	0.1280± 0.0529	0.3010	0.0173	0.0908± 0.0373	0.2400	0.0098
Fe	0.2410± 0.1380	0.5930	0.0142	0.1690± 0.1200	0.4290	0.0000
K	0.841± 0.759	2.420	0.000	0.775± 0.633	2.200	0.000
Zn	0.803± 0.265	1.640	0.358	0.552± 0.150	1.020	0.312
Mg	1.040± 0.980	3.890	0.043	1.050± 1.610	6.760	0.000
Ca	3.880± 2.980	11.100	0.077	2.490± 2.470	8.360	0.000
Mn	0.269± 0.091	0.521	0.130	0.169± 0.046	0.260	0.091

Table 4-5 Average concentrations (mg/g) of metallic element composition of $PM_{2.5}$ in the downtown and uptown area of Chiang Mai city

Element	Downtown (site no.1)			Uptown (site no.2)		
	Mean±S.D.	Maximum	Minimum	Mean±S.D.	Maximum	Minimum
Pb	1.220± 0.913	2.830	0.000	2.520± 3.270	14.900	0.000
Cd	0.054± 0.059	0.236	0.000	0.117± 0.220	1.240	0.000
Ni	0.426± 0.393	1.810	0.000	0.541± 0.589	2.520	0.000
Cu	0.326± 0.610	2.380	0.000	0.442± 0.980	4.150	0.000
Cr	1.390± 0.871	5.410	0.362	2.360± 2.190	13.100	0.657
Fe	2.900± 2.640	14.50	0.107	5.270± 8.250	49.700	0.000
K	10.40± 12.90	50.10	0.00	20.40± 29.70	147.00	0.00
Zn	8.84± 4.69	29.30	2.10	14.10± 9.46	45.10	5.13
Mg	14.50± 18.40	73.30	0.37	28.20± 44.00	207.00	0.00
Ca	40.40± 38.00	220.00	0.97	60.40± 69.80	250.00	0.00
Mn	2.96± 1.31	6.29	0.51	4.55± 5.15	33.20	1.28

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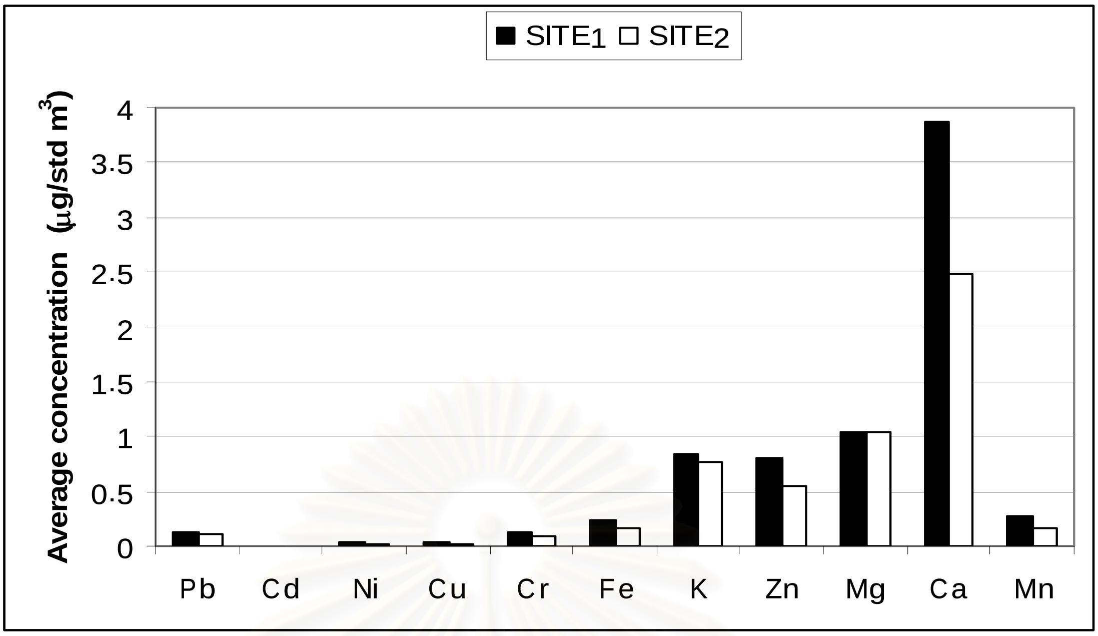

Figure 4-5 Comparison of each metal element in $PM_{2.5}$ between sites nos.1 and 2

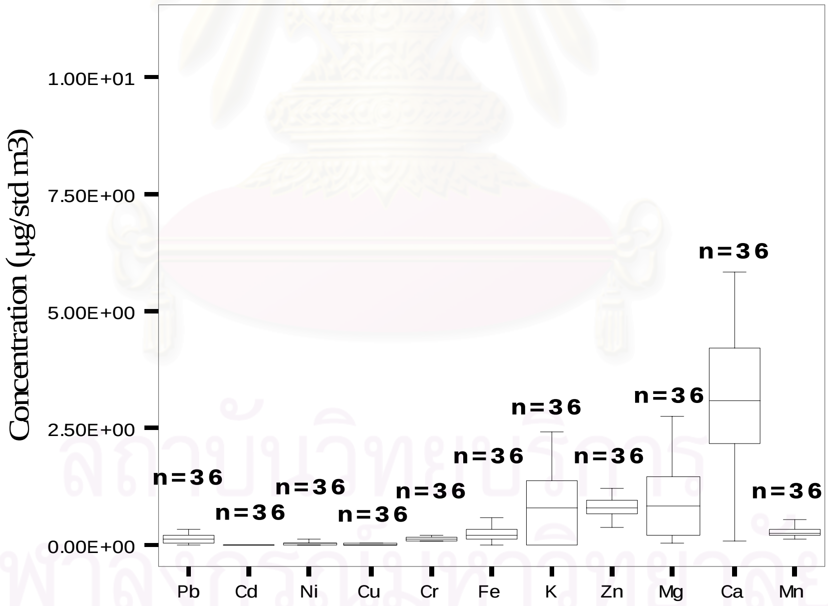

Figure 4-6 Average concentrations (µg/std m^3) of metal element composition at site no.1

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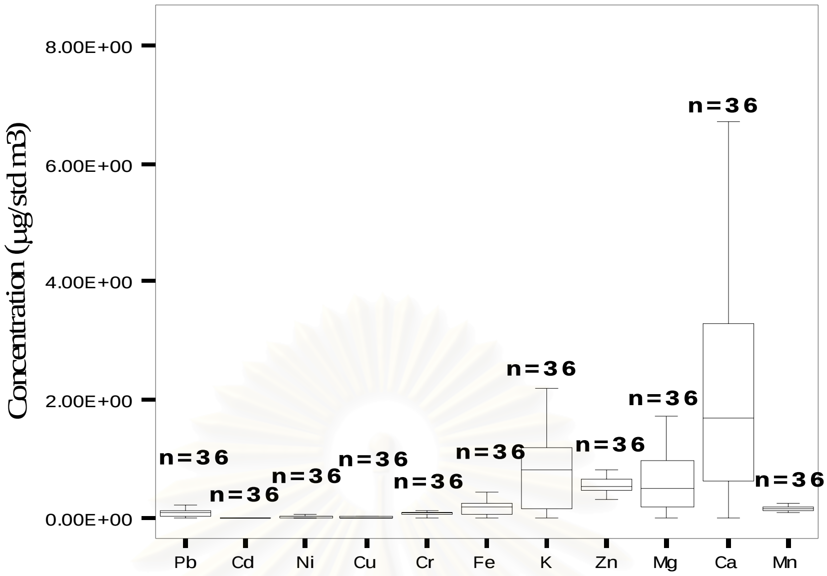

Figure 4-7 Average concentrations (µg/std m^3) of metal element composition at site no.2

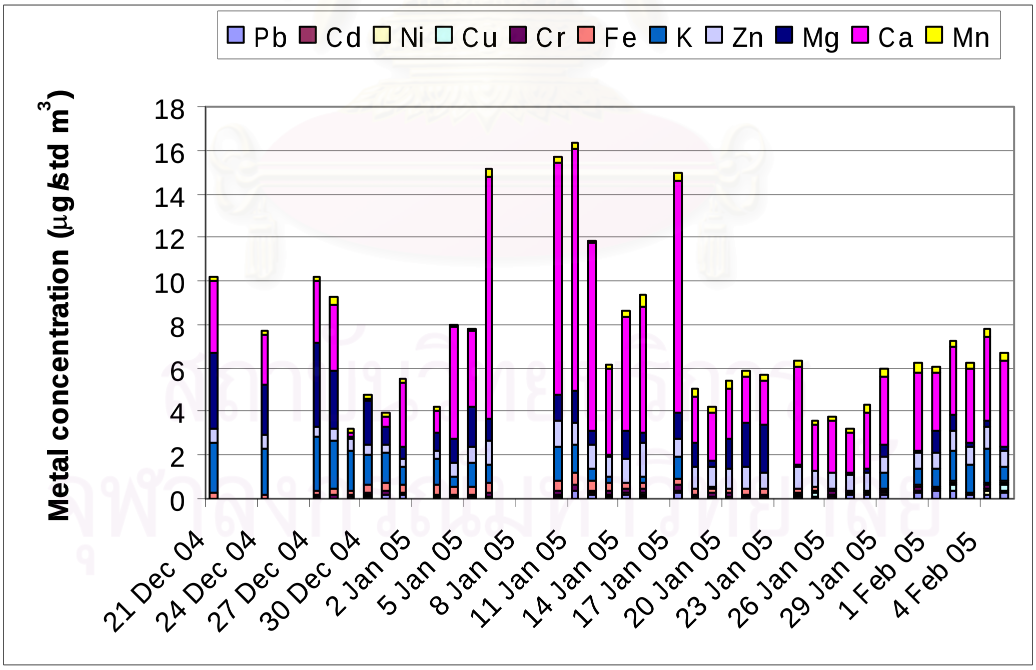

Figure 4-8 Metallic element compositions for PM$_{2.5}$ during December 2004 to February 2005 at site no.1

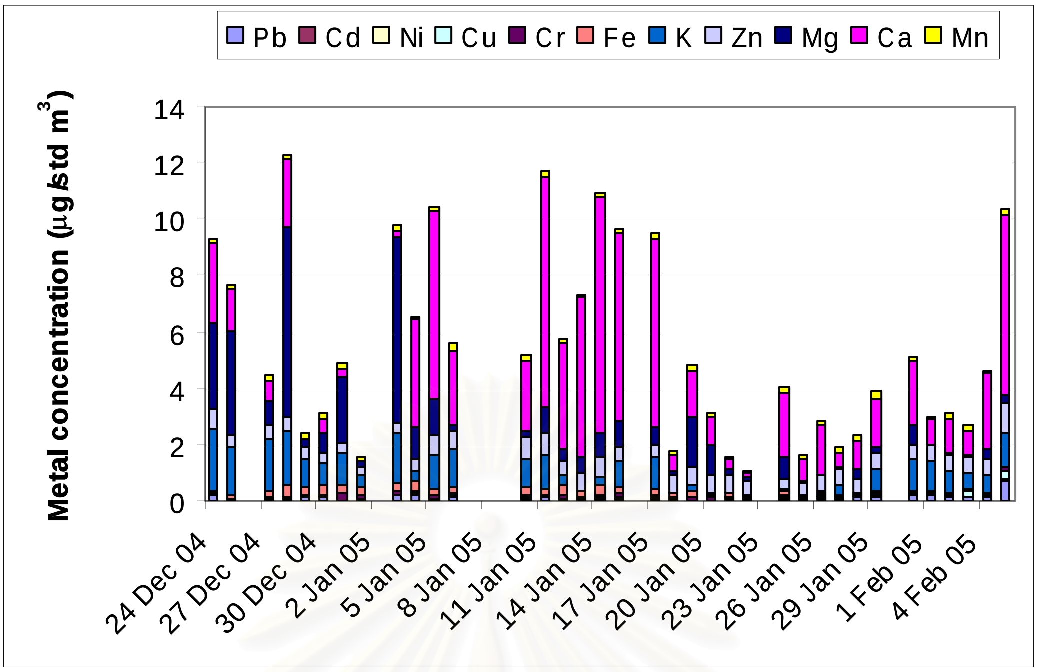

Figure 4-9 Metallic element compositions for $PM_{2.5}$ during December 2004 to February 2005 at site no.2

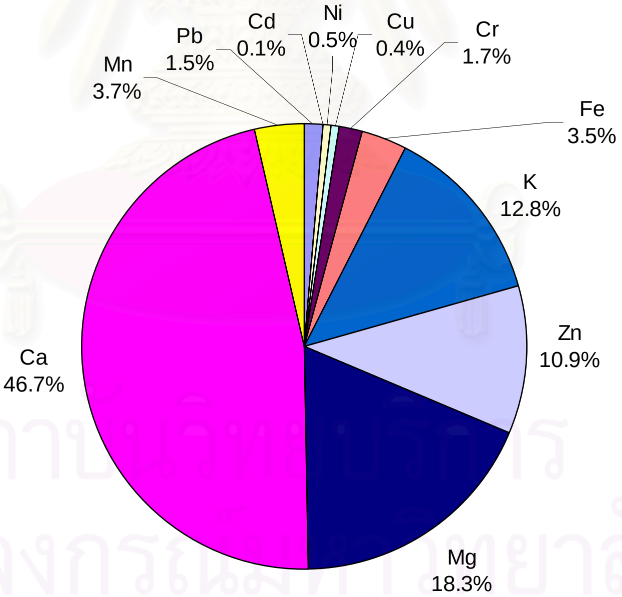

Figure 4-10 Percentages of average metallic element composition in $PM_{2.5}$ for downtown area of Chiang Mai

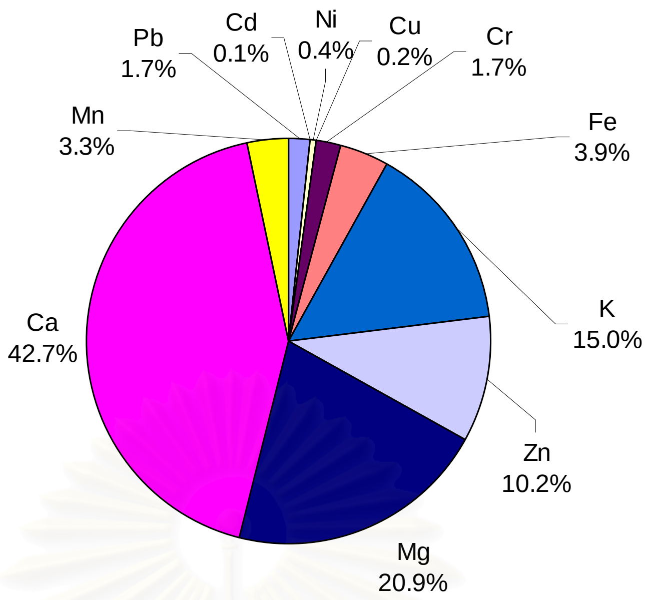

Figure 4-11 Percentages of average metallic element composition in $PM_{2.5}$ for uptown area of Chiang Mai

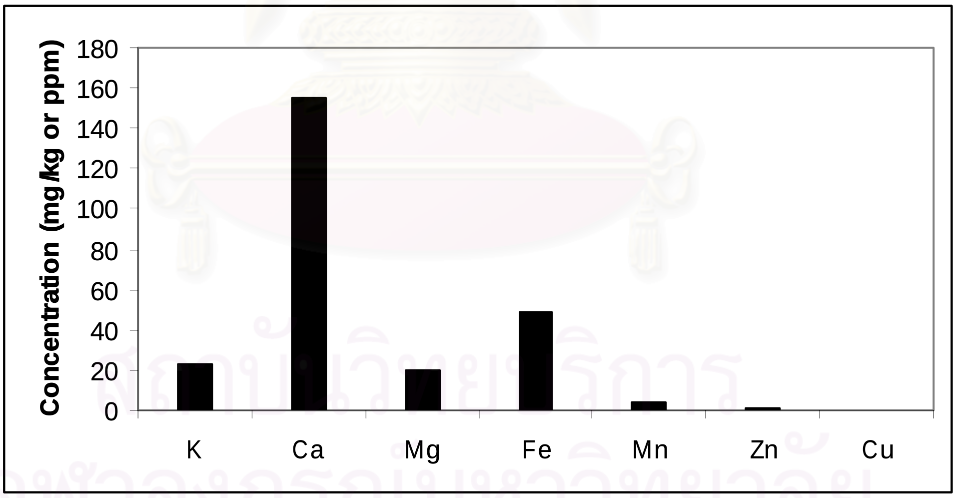

Figure 4-12 Concentrations of metallic element composition in Chiang Mai soil (Inthasan *et al*., 2002)

The result of statistical analysis of metallic element composition for all data set is shown in Table 4-6. The metallic elements can be classified into three groups by consideration their correlation coefficients (>0.9 = strong correlation, between 0.8 and 0.9 = moderately strong correlation and <0.8 = moderate and weak correlation). The

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group of elements which has strong correlation between each element consists of Fe, Cd, Cr and Mn (0.911 for Mn and Fe, 0.907 for Fe and Cd, 0.904 for Fe and Cr, and 0.882 for Cd and Cr at the significance level of 0.01). These metal elements are identified as anthropogenic origin (Wang *et al.*, 2003; Odabasi *et al.*, 2002; Bilos *et al.*, 2001; Salvador *et al.*, 2004). The group of elements which has moderately strong correlation coefficient between each element consists of K and Mg (0.830 for K and Mg at the significant level of 0.01). These metal elements are identified as natural origin. The Pb, Ni, Cu, Zn, and Ca have moderate and weak correlation coefficient between each others so they can be classified into the other group.

Table 4-6 The correlation coefficients between metal elements

	Pb	**Cd**	**Ni**	**Cu**	**Cr**	**Fe**	**K**	**Zn**	**Mg**	**Ca**	**Mn**
Pb	1.000										
Cd	.520	1.000									
Ni	.211	.032	1.000								
Cu	.407	-.109	.178	1.000							
Cr	.436	.882	.113	-.110	1.000						
Fe	.536	.907	.083	-.125	.904	1.000					
K	.658	.452	.235	.134	.392	.594	1.000				
Zn	.527	.524	.487	.192	.623	.669	.625	1.000			
Mg	.400	.240	.310	.049	.271	.455	.830	.567	1.000		
Ca	.192	.311	.457	.121	.318	.304	.292	.607	.322	1.000	
Mn	.669	.809	.080	.001	.819	.911	.654	.693	.454	.160	1.000

4.2.1 Lead (Pb)

Lead concentrations were in the range of 0-0.3430 μg/std m^3 and the range of 0-0.7150 μg/std m^3 at sites nos.1 and 2, respectively. The average concentration of lead at site no.1 was about 1.2 times higher than that at site no.2. The maximum lead concentration at site no.1 was 0.5 times the maximum lead concentration at site no.2. The high concentrations of lead usually occurs in weekdays, which may be suggested that their source related to anthropogenic especially traffic activity. Even though lead gasoline has already been phased out, the study of Wang *et*

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al. (2000) reported the average lead concentration in the particles from unleaded gasoline of about 450 μg/g.

4.2.2 Cadmium (Cd)

Cadmium was found to be lower in concentration compared to the other metal elements in this study. These low concentrations agreed with reported in other studies (Zheng *et al*., 2004, Iijima, 2001, Wang *et al*., 1998). Cadmium concentrations were in the range of 0-0.0151 μg/std m^3 and the range of 0-0.0098 μg/std m^3 at sites nos.1 and 2, respectively. The average concentration of cadmium at site no.1 was 1.3 times higher than that at site no.2. The maximum cadmium concentration at site no.1 was 1.5 times the maximum cadmium concentration at site no.2. These low concentrations were below the reference concentration of cadmium compound (0.020 μg/std m^3) provided by California Environmental Protection Agency (USEPA, 1996b).

4.2.3 Nickel (Ni)

The average concentrations of nickel measured at both sites have remained within the range of those reported in other studies (0.0048-0.0500 μg/m^3) (Wang *et al*., 1998, Zheng *et al*., 2004, Chao *et al*., 2002, Iijima, 2001). The average nickel concentration of site no.1 was found to be 0.0402 μg/std m^3. The average concentration of nickel at site no.2 was found to be 0.0217 μg/std m^3. The average concentration of nickel at site no.1 was 1.8 times higher than that at site no.2. The highest concentration of nickel was found at site no.1 (0.1410 μg/std m^3). This value was 2.4 times higher than the maximum concentration of nickel (0.0585 μg/std m^3) at site no.2. These concentrations were below the reference concentration of nickel compound (0.200 μg/std m^3) provided by Agency for Toxic Substances and Disease Registry (USEPA, 1996b).

4.2.4 Copper (Cu)

In this study, the highest copper concentration (0.2830 μg/std m^3) was found at site no.1. The average concentration was found to be 0.0357 μg/std m^3 at site no.1 and 0.0221 μg/std m^3 at site no.2. The average concentration of copper at site no.1 was about 1.6 times higher than that at site no.2. The maximum copper concentration at site no.1 was almost equal to the maximum copper concentration at site no.2.

4.2.5 Chromium (Cr)

The average concentrations of chromium measured at both sites have remained within the range of those reported in other studies (0.0059-0.0323 μg/m^3) (Zheng *et al.*, 2004, Iijima, 2001, Wang *et al.*, 1998). The average concentration of chromium at site no.1 was about 1.4 times higher than that at site no.2. The maximum chromium concentration at site no.1 was 1.3 times the maximum chromium concentration at site no.2. The highest chromium concentrations (0.3010 and 0.2400 μg/std m^3 at sites nos.1 and 2) were about 3 and 2.4 times higher than the reference concentration of chromium compound provided by Integrated Risk Information System (0.1 μg/std m^3) (USEPA, 1996b).The high concentrations of chromium usually occurs in weekdays as lead, which may be suggested that their source related to anthropogenic especially traffic activity.

4.2.6 Iron (Fe)

The average iron concentrations were determined to be 0.2410 and 0.1690 μg/std m^3 at sites nos.1 and 2, respectively. These values have remained within the iron concentrations reported by Chueinta *et al.* (2000) (0.1070-0.2790 μg/m^3). The average concentration of iron at site no.1 was 1.4 times higher than that at site no.2. The highest concentration of iron was found at site no.1 (0.5630 μg/std m^3). This value was 1.4 times higher than the maximum concentration of iron (0.3990 μg/std m^3) at site no.2.

4.2.7 Potassium (K)

The average concentrations of potassium at sites nos.1 and 2 were found to be almost the same (0.841 and 0.775 μg/std m^3 for sites nos.1 and 2, respectively). Potassium concentrations were in the range of 0-2.420 μg/std m^3 and the range of 0-2.200 μg/std m^3 at sites nos.1 and 2, respectively.

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4.2.8 Zinc (Zn)

In this study, zinc concentrations were in the range of 0.358-1.640 μg/std m^3 and the range of 0.312-0.821 μg/std m^3 at sites nos.1 and 2, respectively. The average concentration of zinc at site no.1 was about 1.4 times higher than that at site no.2 and the maximum concentration at site no.1 was about two times higher than that at site no.2.

4.2.9 Magnesium (Mg)

The average concentrations of magnesium measured at both sites have remained within the range of those reported in other studies (0.040-1.984 μg/m^3) (Wang *et al*., 1998, Zheng *et al*., 2004, Chao *et al*., 2002, Iijima, 2001). The average magnesium concentration of site no.1 was found to be 1.040 μg/std m^3. The average concentration of magnesium at site no.2 was found to be 1.050 μg/std m^3.

4.2.10 Calcium (Ca)

According to results of metal elements at both sites, calcium concentrations were the highest. The average concentrations of calcium were determined to be 3.880 and 2.490 μg/std m^3 at site nos.1 and 2, respectively. The maximum concentration of calcium at site no.1 was 1.3 times higher than site no.2.

4.2.11 Manganese (Mn)

The concentrations of manganese were in the range of 0.130-0.521 μg/std m^3 and the range of 0.091-0.260 μg/std m^3 at site nos.1 and 2, respectively. The average concentration of manganese at site no.1 was about 1.6 times higher than that at site no.2. From their relatively high ratio ranged from 1.6 to 2.1 for the average concentrations and 2.0 to 2.6 for the maximum concentrations, manganese, nickel and copper can be grouped together. The highest manganese concentrations (0.521 and 0.260 μg/std m^3 at site nos.1 and 2) were about 10 and 5 times higher than the reference concentration of nickel compound provided by Integrated Risk Information System ((0.05 μg/std m^3) (USEPA, 1996b).

4.3 The level of toxicity for Chiang Mai air pollution in terms of $PM_{2.5}$ and its metallic element composition

From the Air Quality Index (AQI) for $PM_{2.5}$ level provided by USEPA (USEPA, 2004), $PM_{2.5}$ concentrations in 27 days at site no.1 and 6 days at site no.2 are in the zone of unhealthy for sensitive groups (Figure 4-13). These results are the same as which were reported by Vinitketkumnuen *et al*. (2002). The USEPA standard for $PM_{2.5}$ is 65 μg/std m^3 for a 24-h-period. This is a statistical standard and is based on the 98th percentile sample out of a 3-year-period, with 24-hour samples being taken once every 6 days. Basically this means the third highest sample from this 3-year-period cannot exceed the standard (Vinitketkumnuen *et al*., 2002). It was found in this study that there are significant exposures to fine particles and these exposures go on for weeks.

According to the unit risk estimate (URE) established by USEPA as shown in Table 4-7 (USEPA, 1996b), the excess cancer risk (calculation is provided in Appendix D) resulting from exposure to Chiang Mai ambient air at site no.1 based on the average concentrations of Cd, Pb, Cr, and Ni was about 1.6×10^{-3}. At site no.2 the excess cancer risk resulting from exposure to the ambient air based on the average concentrations of Cd, Pb, Cr, and Ni was about 1.1×10^{-3}.

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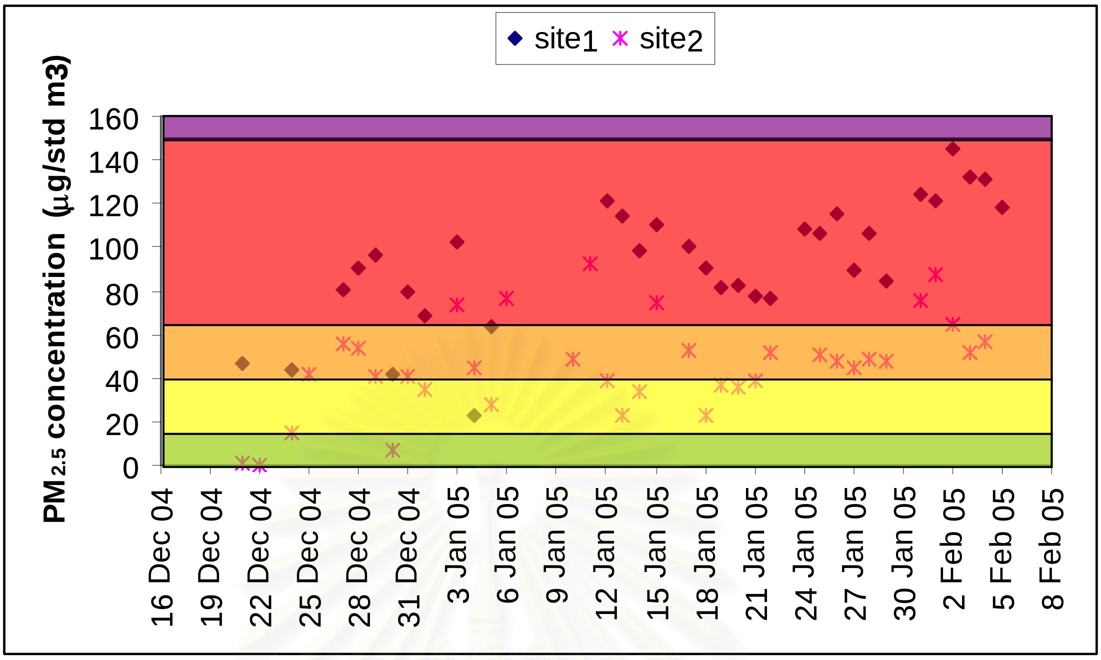

AQI	$PM_{2.5}$ (µg/m^3)	Air Quality Descriptor
0-50	0.0-15.4	Good
51-100	15.5-40.4	Moderate
101-150	40.5-65.4	Unhealthy for Sensitive Groups
151-200	65.5-150.4	Unhealthy
201-300	150.5-250.4	Very Unhealthy

Figure 4-13 Chiang Mai $PM_{2.5}$ concentrations and Air Quality Index (AQI)

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Table 4-7 Excess Cancer Risk estimation

Pollutant	Weight of evidence		Unit Risk Estimate (per µg/m^3)	Average concentration of PM$_{2.5}$ at site no.1 (µg/m^3)	Average concentration of PM$_{2.5}$ at site no.2 (µg/m^3)
	EPA	IARC[a]			
Cadmium	B1[b]	1[c]	1.8E-03	0.0053	0.0040
Chromium	A[b]	1[c]	1.2E-02	0.128	0.091
Lead	B2[b]	2B[c]	1.2E-05	0.128	0.107
Nickel	A[b]	2B[c]	4.8E-04	0.0402	0.022
Total Risk				1.6E-03	1.1E-03

[a] IARC: International Agency for Research on Cancer

[b] Group A: known carcinogen, Group B1: probable carcinogen, based on incomplete human data, Group B2: probable carcinogen, based on adequate animal data

[c] Group 1: carcinogenic in humans, Group 2A: probably carcinogenic, Group 2B: possibly carcinogenic

Source: USEPA, 1996b

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4.4 Source identification using principal component analysis (PCA)

The PCA was performed with the elements: Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Pb, and Zn in the $PM_{2.5}$ at sites nos.1 and 2 (n=72) to identify the possible sources of $PM_{2.5}$ for the whole Chiang Mai city. The results of the PCA with varimax rotation for Chiang Mai city are shown in Table 4-8. The analysis yielded 4 principal components with eigenvalues of more than 1 and they accounted for 87.3% of the total variance. Names of the principal components were mostly identified by comparing high loading coefficients of each principal component to the composition of each possible particulate source shown in Table 4-9.

Table 4-8 Rotated component matrix for the combined data of the $PM_{2.5}$ metallic element composition at sites nos.1 and 2 (factor loadings > 0.5 are shown in bold; factor loadings < 0.2 are omitted)

Element	PC1	PC2	PC3	PC4	Communality
Ca	0.217		**0.846**		0.767
Cd	**0.947**				0.912
Cr	**0.937**				0.918
Cu				**0.931**	0.906
Fe	**0.923**	0.310			0.961
K	0.357	**0.866**			0.928
Mg		**0.917**	0.251		0.923
Mn	**0.866**	0.394			0.924
Ni			**0.807**		0.704
Pb	0.499	0.420		**0.632**	0.826
Zn	**0.538**	0.400	**0.596**		0.839
% variance	50.7	16.7	10.8	9.1	
Cumulative %	50.7	67.4	78.2	87.3	
Source	traffic activity	agricultural/ forest fires	soil	open burning	

Extraction method: Principal component analysis; Rotation method: Varimax with Kaiser Normalization.

Table 4-9 Elemental composition of potential particulate sources as a percentage of the 9 selected metal element concentrations (data of Cd and Mg are not available)

Element[a]	**Source type**					
	Motorcycle[b]	Light duty truck[b]	Heavy duty truck[b]	Soil[b]	Road dusts[b]	Refuse burning[c]
Ca	56.863	32.164	33.029	**76.565**	**78.343**	16.011
Cr	**1.307**	0.585	0.000	0.048	0.050	0.671
Cu	1.961	**2.339**	1.600	0.070	0.116	NA
Fe	11.111	**38.596**	**39.886**	16.169	13.652	6.946
K	5.882	0.585	12.114	6.582	7.086	11.773
Mn	**0.654**	0.585	0.114	0.342	0.291	0.636
Ni	**0.654**	0.585	0.343	0.013	0.012	0.159
Pb	7.190	1.754	3.086	0.053	0.093	**62.869**
Zn	14.379	**22.807**	9.829	0.158	0.357	0.935

[a] If the percentage of an element is the highest in a particular source, and that element is absent or present in very low percentages in the other sources, then that element is chosen as a reference element for that source and shown in bold.

[b] Data available from the compositions of emission sources in Bangkok area (Radian International LIC, 1998)

[c] Data available from the source profiles of the emission sources in Samut Prakarn industrial district (JICA, 1991)

NA = Not available

4.4.1 Traffic activity

This principal component was indicated as traffic activity based on high loadings of Cd, Cr, Fe, Mn, Zn, and Pb. From Table 4-9, Cr, Fe, Mn, and Zn are the reference elements of traffic activity. Cr and Mn are related to the emission from motorcycle. This result agree with the high number of motorcycle in Chiang Mai reported by the Department of Land Transport in 2004 (the number of motorcycle in Chiang Mai is 700,000). Chueinta *et al.* (2000) also suggested that Zn and Mn are contributed from motor vehicles, especially those of two-stroke engines such as motorcycle/motor scooter. Wang *et al.* (2003) reported that the top four abundant elements for the anthropogenic elements in emissions from a diesel vehicle engine are

Zn, Cr, Mo, and Ti. In Weckwerth's (2001) study, it was found that the top absolute abundant metals in diesel-soot were Zn and Cr.

Fe and Mn can be also produced by brake-drum abrasion (Harrison *et al*., 1996). Even though lead gasoline has already been phased out, the study of Wang *et al*. (2000) reported the average Pb concentration in the particles from unleaded gasoline of about 450 μg/g.

4.4.2 Agricultural/forest fires

Although no available source composition data is found for the forest fires in Thailand, this principal component was named as agricultural/forest fires due to the presence of K in high loading. From the study of Manandhar (2003) and Tipayarom (2004), they reported that the emissions from open biomass burning and open rice-straw burning in Thailand had the high concentration of K. Bortnick (2003) noted that vegetative burning emits a significant amount of K. Chueinta *et al*. (2001) and Watson *et al*. (2001) also noted that wood burning and forest fires are the main sources of K.

During the winter months, farmers in Chiang Mai burn their fields and grass. Views from commercial air flights coming into and leaving Chiang Mai during this season provide direct visual evidence of huge smoke plumes and a haze that hangs over the fields and forests (Vinitketkumnuen *et al*., 2002).

Watson *et al*. (2001) reported the presence of Mg in a significant amount in $PM_{2.5}$ mass emitted from forest fires. From the study of Sutton *et al*. (2002) soils and grass in areas of natural forest in Kenya had significantly high concentrations of K, Mg, and P.

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4.4.3 Soil

Very high loading of Ca indicates that this principal component as soil. This agrees with the study of Inthasan *et al*. (2002) which reported the high concentration of Ca in Chiang Mai soil. This also agrees with the reference element of soil profile in Table 4-9.

Arditsoglou *et al*. (2005) noted that Ni as one of the elements that are primarily of crustal origin. Moreover, Ni and Zn, which appear as high loadings in this principal component, possibly suggest the contamination of road dust (Chueinta *et al*. 2000).

4.4.4 Open burning

This principal component was considered as open burning such as the burning of domestic waste. Refer to Table 4-9, Pb is the reference element for refuse burning source. Even though the data on Cu concentration from refuse burning is not available in Table 4-9, Hien *et al*. (1999) reported the principal component with high loadings of Cl, Cu, K, Pb, and Sb as the representative of solid waste burning emissions. Moreover, data on the heavy metal composition of outlets from incinerators show highest concentration of Zn (1020 mg/kg), Cu (620 mg/kg) and Pb (370 mg/kg) (Riber, 2005). In fact, Chiang Mai has confronted with the problem of solid waste removal. Open burning of solid waste has been performed in hiding, even though government officer notices that activity is illegal (Regional Environment Office 1, 2005). Therefore, having this open burning as one of the principal components for $PM_{2.5}$ in Chiang Mai ambient air is a reasonable thing.

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4.5 Sources of $PM_{2.5}$ in Downtown and Uptown ambient air of Chiang Mai

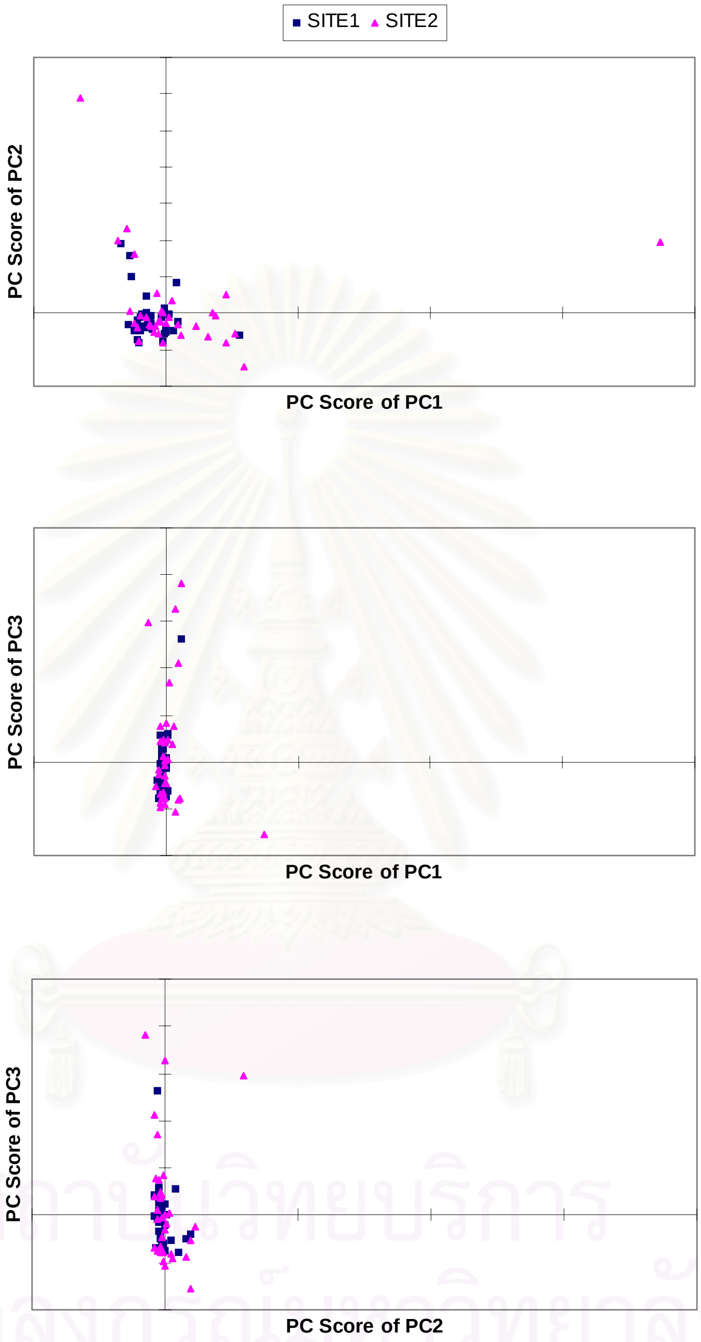

Figure 4-14 Distribution of principal component score of sites nos.1 and 2

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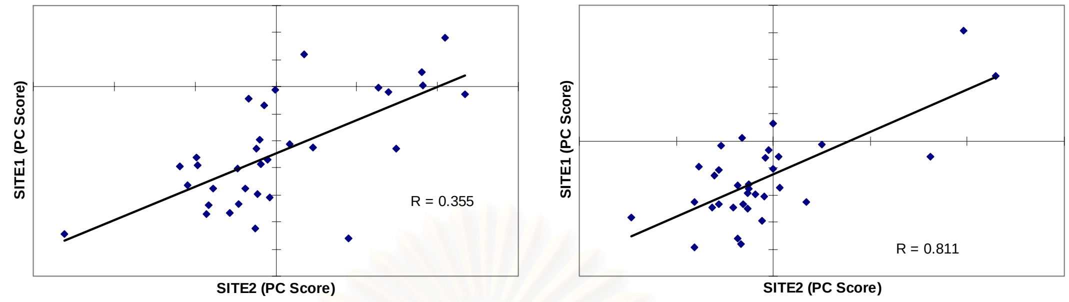
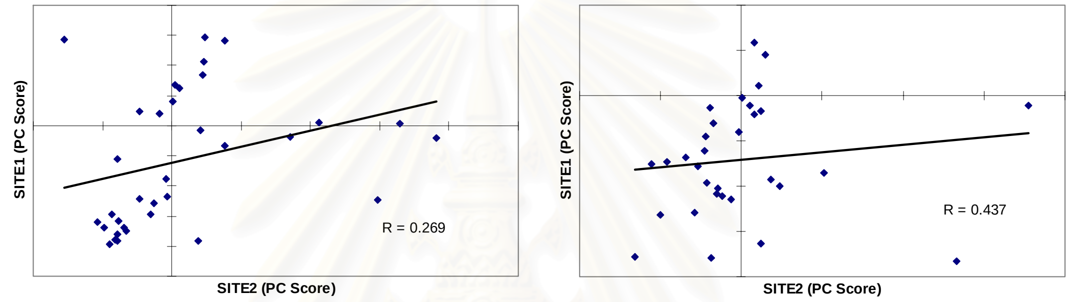
From the concept of principal component analysis explained in chapter 3, the principal component scores of sites nos.1 and 2 were plotted as shown Figure 4-14. Since the plot of samples collected from site no.1 almost located in the same area of those collected from site no.2, it can be interpreted that the influence of each $PM_{2.5}$ source type for the both sites are similar.



a) PC1 (traffic activity) b) PC2 (agricultural/forest fires)



c) PC3 (soil) d) PC4 (open burning)

Figure 4-15 Principal component score plot between site no.1 and site no.2 (exclude outliers)

To observe the relationship between the same source type of $PM_{2.5}$ in site no.1 and site no.2, principal component scores were plotted as shown in Figure 4-15. Moreover, the correlation analysis of these components is performed as shown in Table 4-8. The results show that only the second component of the two sites has relatively high correlation coefficient of 0.811 at the significance level of 0.01. This suggests the strong correlation between the agricultural/forest fires source of $PM_{2.5}$ in downtown and uptown ambient air. Furthermore, the ratio of potassium concentrations, which is the indicator of agricultural/forest fires, in the $PM_{2.5}$ collected at site no.1 to those collected at site no.2 is almost equal to 1. These results can be interpreted that the contribution amount of agricultural/forest fires to $PM_{2.5}$ in both sampling sites are related to each other. Therefore, the agricultural/forest fires are considered as the certain regional pollution source of $PM_{2.5}$ in Chiang Mai. From the report of the Regional Environment Office 1, the number of forest fires occurred in 2004 in Chiang Mai was reported as 2,397 (Regional Environment Office 1, 2005).

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On the other hand, the rest 3 sources: traffic activity, soil and open burning are considered as the local pollution sources due to the low correlation coefficients in Table 4-10. To put the matter simply, it can be said that the contribution amounts of soil (as well as traffic activity and open burning) to $PM_{2.5}$ at site no.1 are not related to those at site no.2. The difference in terms of daily contribution processes between 2 sites can be raised up as the reason for that phenomenon.

Table 4-10 Correlation coefficients of the principal components of site no.1 and site no.2

Site 1 Site 2	Component 1	Component 2	Component 3	Component 4
Component 1	0.355			
Component 2		0.811		
Component 3			0.269	
Component 4				0.437

4.6 Management of particle pollution in Chiang Mai

One of the great challenges in managing air quality is that there are so many contributing sources and variables, and things are constantly changing. From this study, the concentration of $PM_{2.5}$ was found at high level. The monitoring system for $PM_{2.5}$ should be established and the effects of $PM_{2.5}$ on the quality of life in Chiang Mai should be study to provide the information for researching to establish the National Ambient Air Quality Standard.

From the results of PCA, traffic activity is the major source of $PM_{2.5}$ in Chiang Mai. However, cars and motorcycle are an important part of people’s lives and trucks are an essential element of many businesses. This results in hardly to get a handle on the $PM_{2.5}$ from traffic activity. The government should motivate automobile consumer and business to use cleaner technologies and cleaner fuel. The government should also emphasize the importance of making improvements to the planning and public transport systems. This will reduce the reliance on personal cars.

Emissions from agricultural/forest fires and open burning are one of the biggest challenges in the air pollution management. To address this problem the

Government should pay more attention to educate, enforce and incentive to encourage people in reducing particle pollution from those sources.

Soil resuspension by wind or by other mechanism such as traffic activity is thought be the origin of particulate matter emitted from soil source. The management of $PM_{2.5}$ from this source should focus on how to prevent soil resuspension. The most commonly recommended soil management technique for erosion prevention is cover crops. Cover crops improve soil physical properties and soil filth and reduce soil erosion. Road dust also is one of the sources of $PM_{2.5}$ from soil source. Cleaning road surface routinely should be performed to reduce this source of $PM_{2.5}$.

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CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

5.1.1 Ambient $PM_{2.5}$ concentrations in downtown and uptown area of Chiang Mai

- The average concentrations of $PM_{2.5}$ at downtown and uptown sites were 93 μg/std m^3 and 44 μg/std m^3, respectively.
- The increasing trends were observed at both sites during the study period. This can be explained by characteristics of Chiang Mai meteorology
- The significant positive correlations between the $PM_{2.5}$ concentrations and the daily average temperature and between the $PM_{2.5}$ concentrations and daily sunshine hour were observed at both sites. It can be said that the meteorological conditions which significantly affect the distribution of pollutants are the daily average temperature and sunshine hour.

5.1.2 Metallic element composition of downtown and uptown $PM_{2.5}$ in Chiang Mai ambient air

- The order of the average metal concentrations (g metal/g $PM_{2.5}$) in $PM_{2.5}$ is Ca(46.7%)> Mg(18.3%)> K(12.8%)> Zn(10.9%)> Mn(3.7%)> Fe(3.5%)> Cr(1.7%)> Pb(1.5%)> Ni(0.5%)> Cu(0.4%)> Cd(0.1%) for downtown area.
- The order of the percentages of average metal concentrations (g metal/g $PM_{2.5}$) in $PM_{2.5}$ is Ca(42.7%)> Mg(20.9%)> K(15.0%)> Zn(10.2%)> Fe(3.9%)> Mn(3.3%)> Cr (1.7%)> Pb(1.7%)> Ni(0.4%)> Cu(0.2%)> Cd(0.1%) for uptown area.

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5.1.3 The level of toxicity for Chiang Mai air pollution in terms of $PM_{2.5}$ and its metallic element composition

- There were 27 days for site no.1 and 6 days for site no.2 that the $PM_{2.5}$ concentrations were higher than the USEPA 24-h standard.
- Based on the average concentrations of Cd, Pb, Cr and Ni, the excess cancer risk resulting from exposure to Chiang Mai ambient air at site no.1 was $1.6x10^{-3}$.
- Based on the average concentrations of Cd, Pb, Cr and Ni, the excess cancer risk resulting from exposure to Chiang Mai ambient air at site no.2 was $1.1x10^{-3}$.
- The highest manganese concentrations (0.521 and 0.260 μg/std m^3 at site nos.1 and 2) were 10 and 5 times higher than the reference concentration of manganese compound provided by Integrated Risk Information System (0.05μg/std m^3) (USEPA, 1996b).

5.1.4 Source identification using principal component analysis (PCA)

- The PCA analysis yielded 4 principal components with the percentage of variance explained by each component: traffic activity (50.7%), agricultural/forest fires (16.7%), soil (10.8%) and open burning (9.1%). Thus, the main sources of $PM_{2.5}$ in Chiang Mai ambient air are considered to be the above 4 sources. Consequently, the environmental strategies made towards the traffic activity and agricultural/forest fires will reduce more than 50% of $PM_{2.5}$ in Chiang Mai ambient air.
- The range of PC scores for samples collected from downtown almost in the same level of those collected from site no.2. This can be interpreted that the influence of each source type to $PM_{2.5}$ at the both sites are similar.
- The strong correlation between the agricultural/forest fires source of $PM_{2.5}$ in the ambient air of site no.1 and site no.2 was observed. To put it plainly, the contribution amounts of agricultural/forest fires to $PM_{2.5}$ in both sampling sites was found to be related to each other. Hence, the agricultural/forest fires are considered as

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the regional pollution source of $PM_{2.5}$ in Chiang Mai. On the other hand, the rest 3 sources: traffic activity, soil and open burning are considered as the local pollution sources due to their low correlation coefficients.

5.2 Recommendation for further study

Now the problem about particle pollution becomes more of concern in the area of Chiang Mai-Lumphun. This study is just the first step that tries to understand the basic characteristic of $PM_{2.5}$ and to identify the possible sources of $PM_{2.5}$. There might be other compounds such as organic carbon or polycyclic aromatic hydrocarbons (PAHs), that were dominantly carried by the particle; therefore, the further study should be conducted in more details of $PM_{2.5}$ composition for better understanding in its characteristic and source.

Moreover, the relationship between $PM_{2.5}$ and PM_{10} should be studied for better understanding about them. The toxicity of particle pollution should be separately studied on each possible source of particle to define the exact toxicity of them. The study of the characteristic of each particle source should also be performed.

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APPENDICES

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APPENDIX A

METEOROLOGICAL DATA

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Table A-1 Chiang Mai meteorological data for December 2004

Date	Pressure (Pascal)			Temperature (^{o}C)			Humidity (%)			Rain (mm)	Sunshine (hour)	Average wind	
	Max	Min	Average	Max	Min	Average	Max	Min	Average			Direction	Speed (km/hr)
1	1017.3	1012.2	1015.2	29.6	18.4	23.2	89	50	73	0.0	3.4	NE	19
2	1019.0	1013.0	1016.2	30.0	16.0	21.9	99	42	75	0.0	3.8	E	13
3	1018.4	1011.0	1015.0	30.1	15.1	21.2	97	42	75	0.0	3.5	N	22
4	1017.4	1011.9	1014.9	29.9	15.1	21.3	97	40	73	0.0	4.0	NE	28
5	1016.6	1010.7	1014.4	29.6	13.9	20.8	96	43	72	0.0	3.3	NE	17
6	1018.1	1013.5	1015.9	28.1	16.4	22.0	91	48	73	0.0	3.9	S	15
7	1021.0	1016.8	1018.9	26.6	15.7	21.4	90	56	72	0.0	1.4	NE	20
8	1021.5	1013.6	1018.2	26.7	12.2	18.9	98	44	74	0.0	3.0	NE	20
9	1019.0	1012.4	1016.5	27.4	11.3	18.2	97	37	73	0.0	2.7	E	9
10	1019.6	1013.5	1017.3	27.4	12.4	18.7	97	46	75	0.0	2.5	E	13
11	1019.9	1014.2	1017.7	27.7	12.7	19.0	98	45	75	0.0	3.7	NE	19
12	1022.2	1015.7	1019.0	27.8	12.6	19.2	98	44	77	0.0	2.7	E	15
13	1020.3	1013.0	1017.1	28.1	12.0	18.3	98	40	71	0.0	2.1	N	11
14	1016.5	1010.0	1013.8	26.7	12.3	18.6	96	43	75	0.0	3.9	S	9
15	1015.9	1010.2	1013.5	28.2	13.0	19.5	97	40	73	0.0	2.5	NE	13

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Table A-1 (Cont.) Chiang Mai meteorological data for December 2004

Date	Pressure (Pascal)			Temperature (^oC)			Humidity (%)			Rain (mm)	Sunshine (hour)	Average wind	
	Max	Min	Average	Max	Min	Average	Max	Min	Average			Direction	Speed (km/hr)
16	1016.7	1011.1	1014.2	28.1	13.3	19.5	95	39	71	0.0	3.6	S	15
17	1018.2	1011.4	1015.0	28.5	12.5	18.7	97	38	74	0.0	2.5	NE	11
18	1017.6	1010.4	1014.3	28.7	12.6	18.8	96	40	75	0.0	3.8	N	11
19	1015.7	1009.6	1013.2	28.4	12.0	18.6	98	32	74	0.0	2.0	SW	9
20	1015.3	1008.3	1012.3	27.7	11.4	18.3	98	38	74	0.0	2.2	N	9
21	1014.6	1008.4	1011.8	27.7	11.9	18.8	98	46	76	0.0	3.6	NE	11
22	1014.4	1007.9	1011.4	29.4	12.8	19.0	98	41	76	0.0	3.0	SE	7
23	1015.3	1008.9	1012.0	29.2	12.9	19.3	98	44	77	0.0	1.7	SE	11
24	1016.1	1010.3	1013.3	29.8	13.3	20.2	97	38	76	0.0	2.7	NE	11
25	1016.6	1009.7	1013.4	29.2	14.1	20.4	98	46	77	0.0	2.4	N	9
26	1014.5	1007.6	1011.4	29.6	14.4	20.5	97	44	75	0.0	3.5	W	13
27	1014.9	1009.2	1012.1	29.2	15.1	20.9	97	47	78	0.0	2.2	SW	13
28	1016.3	1009.9	1013.1	29.6	15.0	20.6	98	44	78	0.0	2.4	N	9
29	1015.5	1008.9	1012.7	28.6	14.5	20.5	97	45	77	0.0	2.8	S	9
30	1015.1	1009.0	1012.4	29.2	13.1	20.1	98	32	73	0.0	3.1	S	11
31	1018.3	1012.0	1014.8	28.1	13.8	20.4	97	46	74	0.0	2.8	SW	17

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Table A-2 Chiang Mai meteorological data for January 2005

Date	Pressure (Pascal)			Temperature (^oC)			Humidity (%)			Rain (mm)	Sunshine (hour)	Average wind	
	Max	Min	Average	Max	Min	Average	Max	Min	Average			Direction	Speed (km/hr)
1	1018.9	1012.9	1015.8	26.2	15.1	20.1	94	46	73	0.0	3.19	W	13
2	1018.2	1011.0	1014.7	27.0	12.9	19.0	96	45	75	0.0	3.10	N	11
3	1015.5	1009.7	1012.9	28.5	12.3	19.1	99	46	77	0.0	2.63	S	13
4	1017.3	1010.6	1014.0	31.1	13.3	20.4	99	38	74	0.0	4.11	NE	13
5	1017.6	1010.4	1013.9	29.0	13.5	20.1	97	43	75	0.0	1.86	W	9
6	1017.7	1010.2	1014.3	30.0	14.1	20.6	97	36	75	0.0	2.12	W	13
7	1016.2	1009.5	1013.6	30.5	14.3	20.9	97	42	75	0.0	2.78	S	17
8	1016.0	1009.4	1013.0	29.4	14.8	21.4	97	45	75	0.0	2.52	W	11
9	1015.4	1008.2	1011.8	29.1	16.3	22.7	94	49	70	0.0	3.36	S	17
10	1013.7	1007.8	1011.0	29.3	16.1	22.3	93	45	70	0.0	2.76	W	13
11	1015.5	1009.6	1012.6	29.3	16.1	21.9	90	47	72	0.0	3.20	S	13
12	1016.1	1008.4	1012.7	30.5	15.4	21.9	96	32	67	0.0	2.80	SW	19
13	1013.6	1006.5	1010.9	30.1	11.8	20.5	90	31	63	0.0	4.59	W	11
14	1014.3	1007.2	1011.0	29.1	11.5	19.7	93	33	65	0.0	3.58	W	17
15	1015.2	1008.6	1012.0	27.6	12.8	19.9	95	51	75	0.0	2.28	SW	13

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Table A-2 (Cont.) Chiang Mai meteorological data for January 2005

Date	Pressure (Pascal)			Temperature (^{o}C)			Humidity (%)			Rain (mm)	Sunshine (hour)	Average wind	
	Max	Min	Average	Max	Min	Average	Max	Min	Average			Direction	Speed (km/hr)
16	1016.8	1010.4	1013.8	26.1	15.1	20.2	93	57	79	0.0	2.57	S	15
17	1015.6	1010.0	1013.3	28.4	14.5	20.7	99	51	78	0.0	2.40	SW	17
18	1016.6	1009.3	1013.1	30.6	15.2	22.2	99	43	73	0.0	3.25	W	13
19	1016.1	1009.1	1012.9	32.0	15.5	22.7	96	40	72	0.0	3.58	SW	15
20	1016.7	1010.1	1013.7	31.9	16.3	23.6	96	42	73	0.0	4.76	SW	17
21	1018.3	1010.7	1014.8	32.1	17.1	23.9	94	43	74	0.0	2.05	SW	15
22	1017.8	1010.8	1014.4	31.6	16.8	24.0	93	45	70	0.0	4.45	NE	11
23	1016.0	1008.9	1013.0	32.1	15.8	23.9	95	38	67	0.0	4.68	SW	11
24	1015.5	1008.7	1012.5	32.9	16.5	24.0	91	37	66	0.0	3.97	W	24
25	1013.2	1005.5	1010.0	31.5	15.3	22.9	90	37	65	0.0	3.35	S	13
26	1010.8	1004.3	1007.7	31.8	14.5	22.2	93	37	66	0.0	3.84	NE	13
27	1010.7	1004.4	1007.9	32.4	14.2	22.3	91	32	63	0.0	3.66	S	9
28	1010.8	1004.3	1008.1	32.8	14.7	22.6	90	34	66	0.0	4.10	NE	15
29	1011.0	1004.6	1008.2	34.7	14.7	23.9	93	34	65	0.0	3.84	S	11
30	1012.4	1006.8	1009.8	34.3	16.4	24.0	90	32	62	0.0	4.09	NW	13
31	1013.9	1007.3	1010.8	34.6	16.3	23.7	88	34	65	0.0	3.75	NE	11

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Table A-3 Chiang Mai meteorological data for February 2005

Date	Pressure (Pascal)			Temperature (^{o}C)			Humidity (%)			Rain (mm)	Sunshine (hour)	Average wind	
	Max	Min	Average	Max	Min	Average	Max	Min	Average			Direction	Speed (km/hr)
1	1012.8	1005.9	1010.0	33.7	16.4	24.1	91	36	67	0.0	8.8	E	9
2	1012.1	1005.4	1009.2	34.0	16.5	24.8	93	36	66	0.0	8.8	W	15
3	1013.0	1006.5	1010.0	34.8	18.8	25.7	87	38	62	0.0	9.1	SW	13
4	1013.8	1006.9	1010.4	34.2	16.0	25.0	90	32	60	0.0	9.4	NE	15
5	1013.1	1005.4	1009.7	34.4	18.0	26.0	87	37	61	0.0	9.1	W	15
6	1013.4	1006.8	1010.3	34.4	18.5	26.3	88	36	58	0.0	9.4	S	19
7	1016.8	1009.7	1013.1	33.4	18.3	24.9	79	30	58	0.0	9.3	SE	11
8	1016.9	1009.5	1013.2	34.1	16.0	24.4	86	23	54	0.0	9.4	SW	15
9	1016.2	1009.3	1012.8	34.3	16.1	23.9	76	22	52	0.0	9.2	NW	17
10	1016.9	1010.5	1013.6	34.6	14.6	23.3	81	27	56	0.0	9.0	NE	17
11	1017.0	1009.0	1013.3	33.4	15.9	23.8	83	41	63	0.0	7.7	W	13
12	1015.6	1007.5	1011.8	34.3	19.3	26.5	90	33	60	0.0	8.4	W	22
13	1013.3	1005.3	1009.9	34.6	15.3	24.1	93	24	56	0.0	9.1	S	22
14	1012.6	1005.1	1009.1	34.6	15.8	25.0	79	22	47	0.0	9.3	SW	24
15	1011.3	1004.4	1008.7	35.4	17.0	26.2	78	23	47	0.0	9.3	NW	24

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Table A-3 (Cont.) Chiang Mai meteorological data for February 2005

Date	Pressure (Pascal)			Temperature (^{o}C)			Humidity (%)			Rain (mm)	Sunshine (hour)	Average wind	
	Max	Min	Average	Max	Min	Average	Max	Min	Average			Direction	Speed (km/hr)
16	1010.7	1004.1	1008.4	33.9	16.8	25.6	75	27	47	0.0	9.1	NW	26
17	1011.6	1005.0	1008.6	35.8	16.8	26.5	73	33	45	0.0	9.1	NW	26
18	1012.7	1006.0	1009.5	35.6	16.2	25.7	78	26	50	0.0	9.4	W	15
19	1013.7	1006.0	1010.2	36.0	16.2	24.8	73	18	49	0.0	9.4	SW	13
20	1014.1	1006.5	1010.8	34.7	15.4	24.8	75	26	52	0.0	9.3	SW	15
21	1014.5	1006.9	1011.1	34.3	17.7	26.0	92	33	60	0.0	8.9	SW	20
22	1016.0	1008.9	1012.1	34.2	17.1	25.4	84	30	56	0.0	9.6	N	13
23	1013.0	1005.5	1010.2	35.2	17.3	26.0	76	23	48	0.0	9.5	S	19
24	1011.8	1004.7	1009.1	33.9	15.6	24.2	71	25	49	0.0	9.6	E	15
25	1011.1	1004.4	1008.1	34.4	14.7	23.6	81	23	52	0.0	9.4	S	15
26	1012.1	1005.7	1009.0	35.2	15.8	24.6	76	20	50	0.0	9.5	SW	13
27	1012.1	1005.6	1008.9	34.7	17.6	25.1	73	28	52	0.0	9.2	SW	13
28	1011.2	1005.0	1008.5	35.6	16.3	25.4	80	25	53	0.0	9.5	S	13

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APPENDIX B

EXPERIMENTAL DATA

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Table B-1 $PM_{2.5}$ collecting data at site no.1

Date	Total corrected volume (Liter)	Filter weighing before use (g)		Filter weighing after use (g)		Weight gain (g)	$PM_{2.5}$ (µg/std. m^3)
		Mean	Standard deviation	Mean	Standard deviation		
20/12/04	-	-	-	-	-	-	-
21/12/04	4185	0.06716	0.00001	0.06735	0.00000	0.00020	47
22/12/04	-	-	-	-	-	-	-
23/12/04	-	-	-	-	-	-	-
24/12/04	4184	0.06913	0.00001	0.06931	0.00002	0.00018	44
25/12/04	-	-	-	-	-	-	-
26/12/04	-	-	-	-	-	-	-
27/12/04	4185	0.07019	0.00003	0.07052	0.00000	0.00034	81
28/12/04	4182	0.06923	0.00008	0.06961	0.00002	0.00038	91
29/12/04	4184	0.06890	0.00007	0.06931	0.00001	0.00040	96
30/12/04	4190	0.06938	0.00009	0.06955	0.00001	0.00018	42
31/12/04	4193	0.07046	0.00002	0.07079	0.00004	0.00033	80
1/1/05	4212	0.06862	0.00005	0.06891	0.00001	0.00029	68
2/1/05	-	-	-	-	-	-	-
3/1/05	4232	0.06850	0.00001	0.06893	0.00001	0.00043	102
4/1/05	4197	0.06929	0.00007	0.06939	0.00002	0.00010	23
5/1/05	4193	0.06916	0.00002	0.06943	0.00001	0.00027	64
6/1/05	-	-	-	-	-	-	-
7/1/05	-	-	-	-	-	-	-
8/1/05	-	-	-	-	-	-	-

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Table B-1 (Cont.) $PM_{2.5}$ collecting data at site no.1

Date	Total corrected volume (Liter)	Filter weighing before use (g)		Filter weighing after use (g)		Weight gain (g)	$PM_{2.5}$ (μg/std. m^3)
		Mean	Standard deviation	Mean	Standard deviation		
9/1/05	-	-	-	-	-	-	-
10/1/05	-	-	-	-	-	-	-
11/1/05	-	-	-	-	-	-	-
12/1/05	2794	0.06774	0.00000	0.06808	0.00004	0.00034	122
13/1/05	2792	0.06924	0.00001	0.06956	0.00004	0.00032	115
14/1/05	2797	0.06729	0.00003	0.06756	0.00002	0.00027	98
15/1/05	2806	0.06925	0.00001	0.06956	0.00002	0.00031	110
16/1/05	-	-	-	-	-	-	-
17/1/05	2798	0.06811	0.00002	0.06839	0.00003	0.00028	100
18/1/05	2789	0.06665	0.00002	0.06691	0.00004	0.00025	91
19/1/05	2778	0.06889	0.00004	0.06912	0.00001	0.00023	82
20/1/05	2777	0.06751	0.00002	0.06774	0.00003	0.00023	83
21/1/05	2778	0.06820	0.00003	0.06842	0.00002	0.00022	77
22/1/05	2779	0.06883	0.00002	0.06904	0.00002	0.00021	76
23/1/05	-	-	-	-	-	-	-
24/1/05	2778	0.06737	0.00001	0.06767	0.00001	0.00030	108
25/1/05	2770	0.06752	0.00005	0.06782	0.00001	0.00030	106
26/1/05	2771	0.06769	0.00001	0.06801	0.00001	0.00032	115
27/1/05	2771	0.06816	0.00001	0.06841	0.00001	0.00025	89
28/1/05	2767	0.06811	0.00002	0.06841	0.00002	0.00030	107

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Table B-1 (Cont.) $PM_{2.5}$ collecting data at site no.1

Date	Total corrected volume (Liter)	Filter weighing before use (g)		Filter weighing after use (g)		Weight gain (g)	$PM_{2.5}$ (µg/std. m^3)
		Mean	Standard deviation	Mean	Standard deviation		
29/1/05	2767	0.06956	0.00001	0.06979	0.00001	0.00023	84
30/1/05	-	-	-	-	-	-	-
31/1/05	2767	0.06834	0.00003	0.06869	0.00002	0.00034	125
1/2/05	2760	0.07035	0.00002	0.07068	0.00001	0.00034	121
2/2/05	2746	0.06761	0.00003	0.06801	0.00001	0.00040	145
3/2/05	2756	0.06846	0.00002	0.06882	0.00003	0.00037	132
4/2/05	2753	0.06794	0.00006	0.06830	0.00002	0.00036	131
5/2/05	2758	0.06808	0.00003	0.06841	0.00001	0.00033	119

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Table B-2 PM$_{2.5}$ collecting data at site no.2

Date	Total corrected volume (Liter)	Filter weighing before use (g)		Filter weighing after use (g)		Weight gain (g)	PM$_{2.5}$ (µg/std. m^3)
		Mean	Standard deviation	Mean	Standard deviation		
20/12/04	-	-	-	-	-	-	-
21/12/04	4186	0.06880	0.00001	0.06880	0.00001	0.00000	1
22/12/04	4188	0.06777	0.00000	0.06777	0.00001	0.00000	0
23/12/04	-	-	-	-	-	-	-
24/12/04	4185	0.06947	0.00001	0.06953	0.00002	0.00006	15
25/12/04	4186	0.06793	0.00006	0.06811	0.00001	0.00017	42
26/12/04	-	-	-	-	-	-	-
27/12/04	4188	0.06785	0.00007	0.06808	0.00001	0.00023	56
28/12/04	4189	0.06658	0.00008	0.06681	0.00002	0.00022	54
29/12/04	4192	0.06750	0.00007	0.06768	0.00003	0.00017	41
30/12/04	4194	0.06972	0.00009	0.06975	0.00002	0.00003	7
31/12/04	4198	0.06831	0.00003	0.06848	0.00002	0.00017	41
1/1/05	4217	0.06781	0.00002	0.06796	0.00001	0.00014	34
2/1/05	-	-	-	-	-	-	-
3/1/05	4244	0.06778	0.00002	0.06809	0.00002	0.00031	73
4/1/05	4201	0.06744	0.00004	0.06763	0.00002	0.00019	45
5/1/05	4203	0.06696	0.00008	0.06707	0.00001	0.00012	27
6/1/05	4194	0.06828	0.00003	0.06860	0.00002	0.00032	77
7/1/05	-	-	-	-	-	-	-
8/1/05	-	-	-	-	-	-	-

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Table B-2 (Cont.) $PM_{2.5}$ collecting data at site no.2

Date	Total corrected volume (Liter)	Filter weighing before use (g)		Filter weighing after use (g)		Weight gain (g)	$PM_{2.5}$ (µg/std. m^3)
		Mean	Standard deviation	Mean	Standard deviation		
9/1/05	-	-	-	-	-	-	-
10/1/05	4184	0.06845	0.00009	0.06865	0.00001	0.00020	48
11/1/05	4179	0.06985	0.00002	0.07024	0.00002	0.00039	93
12/1/05	4197	0.06880	0.00001	0.06896	0.00004	0.00016	39
13/1/05	4200	0.06918	0.00002	0.06927	0.00002	0.00009	23
14/1/05	4197	0.06782	0.00008	0.06796	0.00002	0.00014	34
15/1/05	4209	0.06887	0.00001	0.06919	0.00002	0.00031	75
16/1/05	-	-	-	-	-	-	-
17/1/05	4187	0.06707	0.00005	0.06729	0.00003	0.00022	53
18/1/05	4179	0.06958	0.00003	0.06968	0.00003	0.00010	23
19/1/05	4163	0.06697	0.00003	0.06712	0.00001	0.00016	37
20/1/05	4161	0.06713	0.00001	0.06727	0.00002	0.00015	35
21/1/05	4163	0.06866	0.00004	0.06882	0.00001	0.00016	39
22/1/05	4164	0.06617	0.00001	0.06638	0.00003	0.00022	52
23/1/05	-	-	-	-	-	-	-
24/1/05	-	-	-	-	-	-	-
25/1/05	4153	0.06791	0.00003	0.06812	0.00002	0.00021	51
26/1/05	4156	0.06984	0.00003	0.07004	0.00002	0.00020	48
27/1/05	4151	0.06873	0.00003	0.06892	0.00002	0.00019	45
28/1/05	4143	0.06853	0.00002	0.06874	0.00001	0.00020	49

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Table B-2 (Cont.) $PM_{2.5}$ collecting data at site no.2

Date	Total corrected volume (Liter)	Filter weighing before use (g)		Filter weighing after use (g)		Weight gain (g)	$PM_{2.5}$ (µg/std. m^3)
		Mean	Standard deviation	Mean	Standard deviation		
29/1/05	4150	0.06817	0.00002	0.06837	0.00002	0.00020	48
30/1/05	-	-	-	-	-	-	-
31/1/05	4146	0.06918	0.00002	0.06949	0.00000	0.00031	76
1/2/05	4132	0.06856	0.00003	0.06893	0.00002	0.00036	88
2/2/05	4118	0.06942	0.00002	0.06969	0.00002	0.00027	65
3/2/05	4132	0.06847	0.00003	0.06868	0.00004	0.00021	51
4/2/05	4115	0.06775	0.00004	0.06798	0.00001	0.00023	56
5/2/05	-	-	-	-	-	-	-

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Table B-3 Metal element concentration data at site no.1 (based on the standard air volume)

Date	Metal element concentration (µg/std. m^3)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
20/12/04	-	-	-	-	-	-	-	-	-	-	-
21/12/04	0.0178	0.0000	0.0000	0.0000	0.0173	0.2138	2.366	0.611	3.459	3.331	0.202
22/12/04	-	-	-	-	-	-	-	-	-	-	-
23/12/04	-	-	-	-	-	-	-	-	-	-	-
24/12/04	0.0148	0.0000	0.0002	0.0000	0.0186	0.1741	2.070	0.645	2.298	2.282	0.202
25/12/04	-	-	-	-	-	-	-	-	-	-	-
26/12/04	-	-	-	-	-	-	-	-	-	-	-
27/12/04	0.0492	0.0000	0.0000	0.0000	0.1067	0.2497	2.420	0.464	3.892	2.788	0.187
28/12/04	0.0000	0.0033	0.0221	0.0007	0.1327	0.3335	2.126	0.564	2.728	3.017	0.319
29/12/04	0.0238	0.0088	0.0397	0.0000	0.1113	0.2210	1.801	0.508	0.179	0.093	0.243
30/12/04	0.1155	0.0099	0.0758	0.0000	0.1016	0.3415	1.382	0.429	2.015	0.077	0.237
31/12/04	0.1394	0.0105	0.0275	0.0012	0.1462	0.3727	1.428	0.358	0.814	0.482	0.177
1/1/05	0.1784	0.0084	0.0099	0.0000	0.1111	0.3605	0.836	0.366	0.519	2.916	0.191
2/1/05	-	-	-	-	-	-	-	-	-	-	-
3/1/05	0.0452	0.0082	0.0400	0.0000	0.1138	0.3988	1.204	0.370	0.865	0.990	0.155
4/1/05	0.0001	0.0038	0.0196	0.0314	0.1257	0.3358	0.490	0.681	1.072	5.101	0.146
5/1/05	0.0371	0.0078	0.0224	0.0094	0.1064	0.3471	1.096	0.760	1.803	3.489	0.162
6/1/05	0.0000	0.0151	0.0289	0.0037	0.1961	0.4896	0.864	1.042	1.079	11.094	0.330
7/1/05	-	-	-	-	-	-	-	-	-	-	-

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Table B-3 (Cont.) Metal element concentration data at site no.1 (based on the standard air volume)

Date	Metal element concentration (μg/std. m^3)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
8/1/05	-	-	-	-	-	-	-	-	-	-	-
9/1/05	-	-	-	-	-	-	-	-	-	-	-
10/1/05	0.0717	0.0132	0.0441	0.0375	0.2062	0.4266	1.597	1.198	1.181	10.663	0.290
11/1/05	0.3431	0.0151	0.0217	0.0211	0.1988	0.5931	1.300	0.968	1.531	11.092	0.266
12/1/05	0.2250	0.0146	0.0129	0.0004	0.1568	0.3869	0.584	1.088	0.623	8.645	0.136
13/1/05	0.1313	0.0136	0.0598	0.0063	0.1619	0.3688	0.294	0.910	0.072	3.933	0.243
14/1/05	0.2054	0.0095	0.0363	0.0227	0.1657	0.2812	0.000	1.115	1.278	5.256	0.235
15/1/05	0.0753	0.0092	0.0715	0.1552	0.1543	0.3060	0.196	1.641	0.410	5.835	0.521
16/1/05	-	-	-	-	-	-	-	-	-	-	-
17/1/05	0.2832	0.0048	0.0618	0.0128	0.3010	0.2634	0.980	0.843	1.202	10.657	0.340
18/1/05	0.0132	0.0000	0.0479	0.0088	0.1237	0.2807	0.000	0.968	1.127	2.097	0.364
19/1/05	0.0360	0.0000	0.0674	0.0137	0.1268	0.2206	0.060	0.953	0.241	2.202	0.335
20/1/05	0.0447	0.0000	0.0603	0.0088	0.1257	0.1932	0.000	0.925	1.367	2.299	0.351
21/1/05	0.0483	0.0000	0.0569	0.0105	0.1033	0.2022	0.000	1.023	2.020	2.154	0.259
22/1/05	0.0619	0.0000	0.0281	0.0090	0.1065	0.2263	0.000	0.797	2.163	2.057	0.244
23/1/05	-	-	-	-	-	-	-	-	-	-	-
24/1/05	0.0864	0.0000	0.1103	0.0000	0.1108	0.1390	0.000	1.028	0.086	4.495	0.259
25/1/05	0.1195	0.0000	0.0000	0.1886	0.1000	0.1383	0.000	0.696	0.069	2.112	0.130
26/1/05	0.1238	0.0000	0.0462	0.0299	0.1260	0.1102	0.000	0.715	0.043	2.377	0.214

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Table B-3 (Cont.) Metal element concentration data at site no.1 (based on the standard air volume)

Date	Metal element concentration (μg/std. m^3)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
27/1/05	0.1749	0.0000	0.0000	0.0050	0.1248	0.0566	0.000	0.776	0.055	1.799	0.191
28/1/05	0.1751	0.0022	0.0301	0.0027	0.0926	0.0828	0.000	0.768	0.215	2.622	0.321
29/1/05	0.2223	0.0025	0.0139	0.0065	0.1049	0.0797	0.724	0.744	0.556	3.109	0.421
30/1/05	-	-	-	-	-	-	-	-	-	-	-
31/1/05	0.2377	0.0017	0.1127	0.0151	0.1579	0.1106	0.763	0.720	0.072	3.598	0.421
1/2/05	0.3309	0.0030	0.0253	0.0359	0.1003	0.0560	0.803	0.741	1.041	2.653	0.253
2/2/05	0.3270	0.0030	0.0135	0.2762	0.0864	0.1611	1.358	0.878	0.729	3.157	0.301
3/2/05	0.1506	0.0024	0.0125	0.0326	0.0712	0.0142	1.259	0.856	0.172	3.390	0.292
4/2/05	0.2173	0.0086	0.1405	0.0579	0.2275	0.0914	1.558	1.018	0.278	3.814	0.392
5/2/05	0.2741	0.0107	0.0865	0.2827	0.1016	0.0346	0.688	0.728	0.214	3.906	0.353

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Table B-4 Metal element concentration data at site no.1 (based on $PM_{2.5}$ mass)

Date	Metal element concentration (mg element/g $PM_{2.5}$)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
20/12/04	-	-	-	-	-	-	-	-	-	-	-
21/12/04	0.376	0.000	0.000	0.000	0.366	4.529	50.13	12.93	73.27	70.56	4.29
22/12/04	-	-	-	-	-	-	-	-	-	-	-
23/12/04	-	-	-	-	-	-	-	-	-	-	-
24/12/04	0.339	0.000	0.005	0.000	0.426	3.991	47.46	14.79	52.68	52.32	4.64
25/12/04	-	-	-	-	-	-	-	-	-	-	-
26/12/04	-	-	-	-	-	-	-	-	-	-	-
27/12/04	0.610	0.000	0.000	0.000	1.323	3.096	30.00	5.75	48.25	34.56	2.32
28/12/04	0.000	0.037	0.243	0.008	1.462	3.672	23.40	6.21	30.04	33.22	3.51
29/12/04	0.248	0.091	0.413	0.000	1.157	2.297	18.72	5.28	1.86	0.97	2.52
30/12/04	2.764	0.236	1.814	0.000	2.433	8.176	33.09	10.28	48.25	1.85	5.68
31/12/04	1.745	0.132	0.344	0.015	1.830	4.664	17.87	4.48	10.18	6.03	2.21
1/1/05	2.613	0.124	0.146	0.000	1.628	5.282	12.25	5.36	7.61	42.72	2.80
2/1/05	-	-	-	-	-	-	-	-	-	-	-
3/1/05	0.442	0.080	0.391	0.000	1.114	3.902	11.78	3.62	8.47	9.69	1.52
4/1/05	0.003	0.165	0.843	1.350	5.411	14.454	21.10	29.29	46.16	219.56	6.29
5/1/05	0.581	0.122	0.351	0.147	1.667	5.441	17.17	11.91	28.26	54.69	2.53
6/1/05	0.000	0.112	0.215	0.027	1.461	3.649	6.44	7.77	8.04	82.68	2.46
7/1/05	-	-	-	-	-	-	-	-	-	-	-

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Table B-4 (Cont.) Metal element concentration data at site no.1 (based on $PM_{2.5}$ mass)

Date	Metal element concentration (mg element/g $PM_{2.5}$)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
8/1/05	-	-	-	-	-	-	-	-	-	-	-
9/1/05	-	-	-	-	-	-	-	-	-	-	-
10/1/05	0.126	0.023	0.077	0.066	0.362	0.749	2.80	2.10	2.07	18.73	0.51
11/1/05	1.615	0.071	0.102	0.099	0.936	2.792	6.12	4.55	7.21	52.21	1.25
12/1/05	1.848	0.120	0.106	0.004	1.288	3.179	4.80	8.94	5.12	71.03	1.12
13/1/05	1.146	0.118	0.522	0.055	1.412	3.218	2.57	7.94	0.63	34.31	2.12
14/1/05	2.090	0.097	0.370	0.231	1.685	2.860	0.00	11.34	12.99	53.45	2.39
15/1/05	0.682	0.083	0.648	1.405	1.397	2.770	1.77	14.86	3.71	52.82	4.71
16/1/05	-	-	-	-	-	-	-	-	-	-	-
17/1/05	2.829	0.048	0.617	0.128	3.008	2.632	9.80	8.42	12.01	106.48	3.40
18/1/05	0.145	0.000	0.530	0.098	1.367	3.101	0.00	10.69	12.45	23.17	4.02
19/1/05	0.440	0.000	0.823	0.167	1.549	2.694	0.73	11.63	2.94	26.89	4.09
20/1/05	0.539	0.000	0.728	0.106	1.518	2.333	0.00	11.16	16.51	27.76	4.23
21/1/05	0.624	0.000	0.735	0.136	1.334	2.613	0.00	13.22	26.10	27.83	3.35
22/1/05	0.809	0.000	0.368	0.118	1.392	2.960	0.00	10.42	28.29	26.90	3.19
23/1/05	-	-	-	-	-	-	-	-	-	-	-
24/1/05	0.800	0.000	1.021	0.000	1.026	1.287	0.00	9.52	0.80	41.62	2.40
25/1/05	1.123	0.000	0.000	1.771	0.939	1.299	0.00	6.54	0.65	19.83	1.22
26/1/05	1.072	0.000	0.400	0.259	1.091	0.954	0.00	6.19	0.37	20.58	1.85

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Table B-4 (Cont.) Metal element concentration data at site no.1 (based on $PM_{2.5}$ mass)

Date	Metal element concentration (mg element/g $PM_{2.5}$)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
27/1/05	1.958	0.000	0.000	0.056	1.397	0.634	0.00	8.69	0.61	20.14	2.14
28/1/05	1.642	0.020	0.282	0.025	0.868	0.776	0.00	7.20	2.02	24.59	3.01
29/1/05	2.646	0.030	0.166	0.078	1.248	0.948	8.62	8.85	6.62	36.99	5.01
30/1/05	-	-	-	-	-	-	-	-	-	-	-
31/1/05	1.907	0.014	0.904	0.121	1.266	0.887	6.12	5.78	0.58	28.86	3.37
1/2/05	2.726	0.025	0.209	0.296	0.826	0.462	6.62	6.11	8.58	21.86	2.08
2/2/05	2.259	0.021	0.093	1.908	0.597	1.113	9.38	6.06	5.04	21.81	2.08
3/2/05	1.138	0.018	0.095	0.246	0.538	0.107	9.51	6.46	1.30	25.60	2.20
4/2/05	1.662	0.065	1.075	0.443	1.740	0.699	11.92	7.79	2.13	29.17	3.00
5/2/05	2.308	0.090	0.728	2.381	0.856	0.291	5.79	6.13	1.80	32.90	2.97

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Table B-5 Metal element concentration data at site no.2 (based on the standard air volume)

Date	Metal element concentration (µg/std. m^3)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
20/12/04	-	-	-	-	-	-	-	-	-	-	-
21/12/04	-	-	-	-	-	-	-	-	-	-	-
22/12/04	-	-	-	-	-	-	-	-	-	-	-
23/12/04	-	-	-	-	-	-	-	-	-	-	-
24/12/04	0.1796	0.0000	0.0376	0.0368	0.0098	0.1225	2.201	0.673	3.088	2.834	0.147
25/12/04	0.0000	0.0000	0.0087	0.0000	0.0500	0.1236	1.708	0.433	3.727	1.461	0.177
26/12/04	-	-	-	-	-	-	-	-	-	-	-
27/12/04	0.0645	0.0000	0.0042	0.0000	0.0931	0.2189	1.799	0.523	0.868	0.686	0.243
28/12/04	0.0132	0.0035	0.0223	0.0000	0.1022	0.4285	1.923	0.457	6.760	2.426	0.167
29/12/04	0.1070	0.0082	0.0017	0.0000	0.1245	0.2727	0.999	0.417	0.256	0.000	0.202
30/12/04	0.1066	0.0089	0.0000	0.0000	0.0934	0.3552	0.815	0.312	0.706	0.481	0.237
31/12/04	0.0141	0.0082	0.0048	0.0000	0.2398	0.2806	1.130	0.367	2.339	0.279	0.237
1/1/05	0.0421	0.0096	0.0081	0.0000	0.1313	0.2994	0.399	0.313	0.217	0.000	0.161
2/1/05	-	-	-	-	-	-	-	-	-	-	-
3/1/05	0.1839	0.0081	0.0268	0.0008	0.1022	0.2875	1.798	0.375	6.569	0.230	0.194
4/1/05	0.2157	0.0026	0.0528	0.0000	0.1155	0.3129	0.401	0.373	1.141	3.848	0.106
5/1/05	0.0359	0.0071	0.0406	0.0003	0.1285	0.2466	1.177	0.730	1.267	6.687	0.101
6/1/05	0.1103	0.0086	0.0177	0.0442	0.1031	0.2349	1.322	0.665	0.171	2.667	0.257
7/1/05	-	-	-	-	-	-	-	-	-	-	-

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Table B-5 (Cont.) Metal element concentration data at site no.2 (based on the standard air volume)

Date	Metal element concentration (μg/std. m^3)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
8/1/05	-	-	-	-	-	-	-	-	-	-	-
9/1/05	-	-	-	-	-	-	-	-	-	-	-
10/1/05	0.0710	0.0098	0.0309	0.0034	0.1268	0.2568	0.964	0.821	0.221	2.494	0.157
11/1/05	0.1068	0.0094	0.0071	0.0000	0.1013	0.2006	1.243	0.772	0.870	8.215	0.208
12/1/05	0.0586	0.0079	0.0279	0.0000	0.1058	0.3682	0.350	0.509	0.410	3.752	0.146
13/1/05	0.0000	0.0096	0.0365	0.0000	0.1013	0.1914	0.000	0.668	0.585	5.647	0.091
14/1/05	0.0882	0.0089	0.0185	0.0079	0.0974	0.3282	0.312	0.677	0.881	8.363	0.177
15/1/05	0.1038	0.0095	0.0483	0.0086	0.1048	0.1997	0.947	0.502	0.917	6.696	0.146
16/1/05	-	-	-	-	-	-	-	-	-	-	-
17/1/05	0.0909	0.0083	0.0167	0.0069	0.1005	0.2118	1.097	0.470	0.630	6.712	0.167
18/1/05	0.0122	0.0000	0.0428	0.0057	0.0772	0.1687	0.000	0.599	0.137	0.593	0.137
19/1/05	0.0146	0.0000	0.0099	0.0024	0.0924	0.2335	0.210	0.677	1.730	1.678	0.198
20/1/05	0.0193	0.0000	0.0104	0.0052	0.0808	0.1159	0.066	0.661	1.049	1.007	0.132
21/1/05	0.0283	0.0000	0.0237	0.0365	0.0745	0.1059	0.000	0.639	0.238	0.344	0.107
22/1/05	0.0488	0.0000	0.0000	0.0014	0.0628	0.0880	0.000	0.513	0.140	0.109	0.091
23/1/05	-	-	-	-	-	-	-	-	-	-	-
24/1/05	0.0686	0.0000	0.0585	0.0370	0.0799	0.0925	0.102	0.368	0.729	2.321	0.169
25/1/05	0.0607	0.0000	0.0040	0.0044	0.0530	0.0660	0.000	0.474	0.039	0.818	0.143
26/1/05	0.0831	0.0020	0.0210	0.0228	0.0754	0.0582	0.106	0.527	0.000	1.810	0.158

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Table B-5 (Cont.) Metal element concentration data at site no.2 (based on the standard air volume)

Date	Metal element concentration (μg/std. m^3)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
27/1/05	0.0926	0.0000	0.0000	0.0114	0.0608	0.0438	0.367	0.565	0.045	0.534	0.178
28/1/05	0.1218	0.0000	0.0145	0.0011	0.0816	0.0364	0.000	0.506	0.405	0.995	0.215
29/1/05	0.1685	0.0005	0.0217	0.0037	0.0678	0.0683	0.824	0.578	0.198	1.716	0.260
30/1/05	-	-	-	-	-	-	-	-	-	-	-
31/1/05	0.1922	0.0016	0.0523	0.0164	0.0581	0.0127	1.169	0.456	0.777	2.205	0.168
1/2/05	0.2200	0.0014	0.0000	0.0170	0.0644	0.0312	1.100	0.552	0.036	0.886	0.113
2/2/05	0.1629	0.0003	0.0034	0.0169	0.0570	0.0250	0.793	0.601	0.032	1.227	0.190
3/2/05	0.1372	0.0005	0.0038	0.1965	0.0523	0.0104	0.626	0.561	0.043	0.886	0.174
4/2/05	0.1083	0.0016	0.0537	0.0303	0.0697	0.0000	0.692	0.526	0.350	2.685	0.134
5/2/05	0.7146	0.0062	0.0509	0.2783	0.1312	0.0000	1.264	1.018	0.329	6.346	0.203

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Table B-6 Metal element concentration data at site no.2 (based on $PM_{2.5}$ mass)

Date	Metal element concentration (mg element/g $PM_{2.5}$)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
20/12/04	-	-	-	-	-	-	-	-	-	-	-
21/12/04	-	-	-	-	-	-	-	-	-	-	-
22/12/04	-	-	-	-	-	-	-	-	-	-	-
23/12/04	-	-	-	-	-	-	-	-	-	-	-
24/12/04	12.034	0.000	2.516	2.463	0.657	8.206	147.46	45.07	206.94	189.90	9.82
25/12/04	0.000	0.000	0.208	0.000	1.196	2.958	40.87	10.35	89.18	34.95	4.23
26/12/04	-	-	-	-	-	-	-	-	-	-	-
27/12/04	1.163	0.000	0.075	0.000	1.677	3.943	32.40	9.41	15.63	12.35	4.37
28/12/04	0.245	0.065	0.416	0.000	1.903	7.978	35.80	8.51	125.86	45.16	3.10
29/12/04	2.599	0.199	0.042	0.000	3.025	6.627	24.28	10.13	6.22	0.00	4.91
30/12/04	14.908	1.243	0.000	0.000	13.055	49.661	113.97	43.57	98.69	67.30	33.16
31/12/04	0.343	0.199	0.118	0.000	5.836	6.828	27.51	8.93	56.92	6.78	5.77
1/1/05	1.224	0.279	0.234	0.000	3.819	8.708	11.62	9.10	6.30	0.00	4.67
2/1/05	-	-	-	-	-	-	-	-	-	-	-
3/1/05	2.518	0.111	0.367	0.011	1.399	3.937	24.61	5.13	89.93	3.14	2.66
4/1/05	4.833	0.058	1.184	0.000	2.588	7.012	8.98	8.35	25.56	86.21	2.37
5/1/05	1.312	0.261	1.485	0.009	4.696	9.012	43.01	26.66	46.30	244.41	3.68
6/1/05	1.435	0.112	0.230	0.575	1.341	3.054	17.19	8.65	2.23	34.68	3.35
7/1/05	-	-	-	-	-	-	-	-	-	-	-

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Table B-6 (Cont.) Metal element concentration data at site no.2 (based on $PM_{2.5}$ mass)

Date	Metal element concentration (mg element/g $PM_{2.5}$)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
8/1/05	-	-	-	-	-	-	-	-	-	-	-
9/1/05	-	-	-	-	-	-	-	-	-	-	-
10/1/05	1.466	0.202	0.638	0.070	2.619	5.306	19.93	16.97	4.57	51.52	3.24
11/1/05	1.152	0.101	0.077	0.000	1.093	2.163	13.41	8.32	9.39	88.60	2.24
12/1/05	1.514	0.205	0.721	0.000	2.733	9.510	9.05	13.15	10.59	96.89	3.78
13/1/05	0.000	0.424	1.613	0.000	4.477	8.464	0.00	29.51	25.88	249.63	4.01
14/1/05	2.598	0.262	0.544	0.234	2.868	9.664	9.18	19.95	25.93	246.27	5.20
15/1/05	1.387	0.127	0.646	0.115	1.401	2.667	12.65	6.70	12.25	89.46	1.95
16/1/05	-	-	-	-	-	-	-	-	-	-	-
17/1/05	1.731	0.157	0.318	0.132	1.912	4.032	20.88	8.94	11.98	127.76	3.17
18/1/05	0.524	0.000	1.833	0.244	3.307	7.232	0.00	25.66	5.89	25.41	5.86
19/1/05	0.391	0.000	0.266	0.064	2.481	6.271	5.65	18.17	46.45	45.07	5.33
20/1/05	0.544	0.000	0.294	0.148	2.280	3.268	1.87	18.65	29.59	28.41	3.73
21/1/05	0.726	0.000	0.606	0.935	1.909	2.713	0.00	16.37	6.09	8.81	2.73
22/1/05	0.946	0.000	0.000	0.027	1.217	1.704	0.00	9.94	2.71	2.11	1.77
23/1/05	-	-	-	-	-	-	-	-	-	-	-
24/1/05	1.475	0.000	1.258	0.795	1.719	1.990	2.20	7.91	15.68	49.92	3.63
25/1/05	1.200	0.000	0.079	0.088	1.049	1.306	0.00	9.37	0.77	16.18	2.82
26/1/05	1.727	0.042	0.437	0.474	1.566	1.209	2.20	10.94	0.00	37.62	3.28

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Table B-6 (Cont.) Metal element concentration data at site no.2 (based on $PM_{2.5}$ mass)

Date	Metal element concentration (mg element/g $PM_{2.5}$)										
	Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
27/1/05	2.050	0.001	0.000	0.252	1.347	0.969	8.13	12.51	0.99	11.82	3.95
28/1/05	2.492	0.000	0.297	0.023	1.670	0.745	0.00	10.36	8.29	20.37	4.39
29/1/05	3.496	0.010	0.451	0.077	1.407	1.418	17.09	11.99	4.11	35.60	5.40
30/1/05	-	-	-	-	-	-	-	-	-	-	-
31/1/05	2.530	0.022	0.689	0.216	0.765	0.167	15.38	6.00	10.22	29.02	2.22
1/2/05	2.507	0.016	0.000	0.194	0.734	0.355	12.53	6.29	0.41	10.10	1.28
2/2/05	2.508	0.005	0.052	0.261	0.878	0.385	12.20	9.26	0.49	18.88	2.93
3/2/05	2.668	0.009	0.074	3.820	1.016	0.202	12.17	10.91	0.85	17.23	3.39
4/2/05	1.917	0.029	0.951	0.536	1.233	0.000	12.25	9.30	6.20	47.51	2.37
5/2/05	10.653	0.092	0.759	4.148	1.956	0.000	18.84	15.17	4.90	94.61	3.02

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APPENDIX C

CALIBRATION DATA AND CURVES

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Table C-1 Calibration data and curve of lead (Pb)

STD	CONC(Y),μg/L	ABS(x)	CONC$_{calc}$,μg/L	ERROR	(ERROR)^2	VARIATION
STD1	5.000	0.0849	5.4114	0.4114	0.169263	1604.587196
STD2	10.000	0.1377	9.1321	0.8679	0.753222	1229.014207
STD3	15.000	0.2030	14.1723	0.8277	0.685127	903.441218
STD4	20.000	0.2808	20.9173	0.9173	0.841364	627.868229
STD5	25.000	0.3225	24.9184	0.0816	0.006658	402.295240
STD6	30.000	0.3794	30.8846	0.8846	0.782515	226.722250
STD7	35.000	0.4138	34.8119	0.1881	0.035397	101.149261
STD8	40.000	0.4603	40.5580	0.5580	0.311349	25.576272
STD9	45.000	0.4897	44.4806	0.5194	0.269800	0.003283
STD10	50.000	0.5252	49.5523	0.4477	0.200408	24.430294
SUM	**225.0000**	**2.7721**	**225.2865**	**5.2560**	**3.854693**	**5120.657156**

R^2 = 0.999

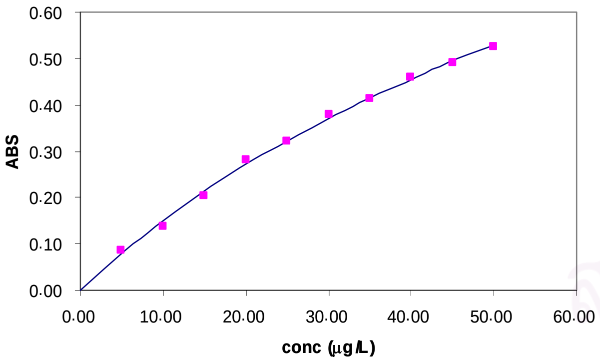

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Table C-2 Calibration data and curve of cadmium (Cd)

STD	CONC(Y),µg/L	ABS(x)	CONC$_{calc}$,µg/L	ERROR	(ERROR)^2	VARIATION
STD1	0.500	0.0438	0.5304	0.0304	0.000925	2.957471
STD2	1.000	0.0824	1.0251	0.0251	0.000630	1.487741
STD3	1.500	0.1187	1.5156	0.0156	0.000244	0.518011
STD4	2.000	0.1463	1.9062	0.0938	0.008795	0.048281
STD5	2.500	0.1754	2.3357	0.1643	0.026982	0.078551
STD6	3.000	0.2101	2.8733	0.1267	0.016046	0.608821
STD7	3.500	0.2421	3.3955	0.1045	0.010929	1.639092
STD8	4.000	0.2721	3.9098	0.0902	0.008145	3.169362
STD9	4.500	0.3158	4.7057	0.2057	0.042310	5.199632
STD10	5.000	0.3483	5.3369	0.3369	0.113531	7.729902
SUM	**22.5000**	**1.6067**	**22.1973**	**0.8563**	**0.115006**	**15.706962**

R^2 = 0.993

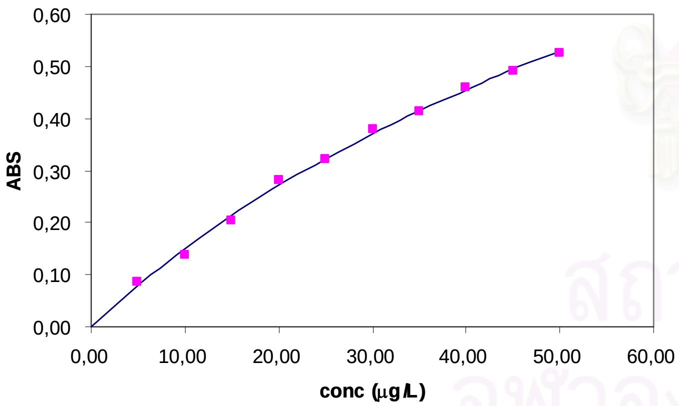

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Table C-3 Calibration data and curve of nickel (Ni)

STD	CONC(Y),μg/L	ABS(x)	CONC$_{calc}$,μg/L	ERROR	(ERROR)^2	VARIATION
STD1	2,000	0,0500	2,1806	0,1806	0,032626	45,450509
STD2	4,000	0,0800	3,9793	0,0207	0,000430	22,483712
STD3	6,000	0,1030	5,7419	0,2581	0,066637	7,516915
STD4	8,000	0,1260	7,9885	0,0115	0,000132	0,550118
STD5	10,000	0,1400	9,6857	0,3143	0,098800	1,583321
STD6	12,000	0,1520	11,4077	0,5923	0,350840	10,616524
STD7	14,000	0,1650	13,6361	0,3639	0,132402	27,649727
STD8	16,000	0,1740	15,4629	0,5371	0,288449	52,682929
STD9	18,000	0,1820	17,3343	0,6657	0,443127	85,716132
STD10	20,000	0,1890	19,2068	0,7932	0,629106	126,749335
SUM	**90,0000**	**1,172**	**87,4170**	**2,9443**	**1,413443**	**254,249887**

R^2 = 0,994

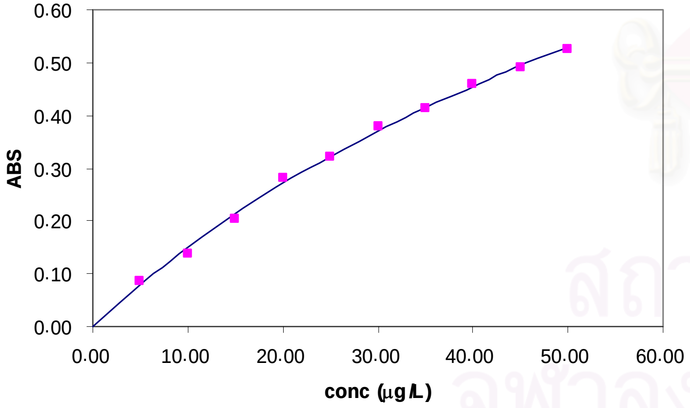

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Table C-4 Calibration data and curve of copper (Cu)

STD	CONC(Y),μg/L	ABS(x)	CONC$_{calc}$,μg/L	ERROR	(ERROR)^2	VARIATION
STD1	2.000	0.0568	2.0514	0.0514	0.002639	48.325485
STD2	4.000	0.1129	4.1307	0.1307	0.017071	24.518872
STD3	6.000	0.1576	5.8267	0.1733	0.030049	8.712258
STD4	8.000	0.2095	7.8411	0.1589	0.025253	0.905644
STD5	10.000	0.2568	9.7208	0.2792	0.077956	1.099031
STD6	12.000	0.3135	12.0312	0.0312	0.000975	9.292417
STD7	14.000	0.3523	13.6494	0.3506	0.122898	25.485803
STD8	16.000	0.4109	16.1529	0.1529	0.023382	49.679190
STD9	18.000	0.4556	18.1124	0.1124	0.012636	81.872576
STD10	20.000	0.5088	20.5030	0.5030	0.253004	122.065962
SUM	**90.0000**	**2.3259**	**89.5165**	**1.4406**	**0.312859**	**249.891275**

R^2 = 0.999

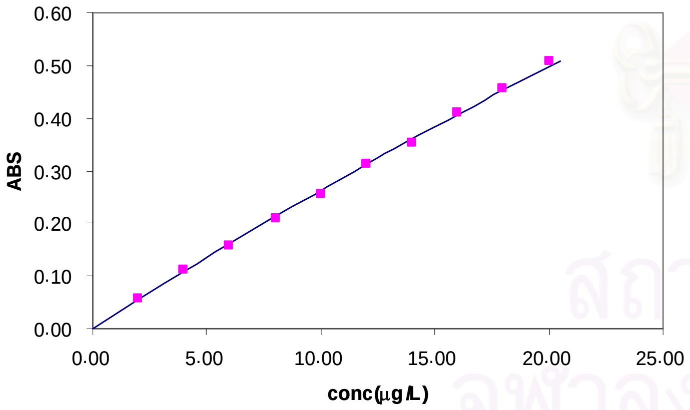

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Table C-5 Calibration data and curve of iron (Fe)

STD	CONC(Y),μg/L	ABS(x)	$CONC_{calc}$,μg/L	ERROR	$(ERROR)^2$	VARIATION
STD1	5.000	0.1114	4.7150	0.2850	0.081229	309.669007
STD2	10.000	0.2262	10.4302	0.4302	0.185102	158.694859
STD3	15.000	0.3049	14.9775	0.0225	0.000504	57.720711
STD4	20.000	0.3904	20.6425	0.6425	0.412826	6.746564
STD5	25.000	0.4645	26.3019	1.3019	1.694878	5.772416
STD6	30.000	0.5118	30.3539	0.3539	0.125241	54.798268
STD7	35.000	0.5565	34.5528	0.4472	0.199999	153.824120
STD8	40.000	0.6029	39.3493	0.6507	0.423454	302.849973
STD9	45.000	0.6492	44.6510	0.3490	0.121778	501.875825
STD10	50.000	0.6720	47.4772	2.5228	6.364479	750.901677
SUM	**225.0000**	**3.8178**	**225.9741**	**4.4829**	**3.245010**	**1551.951742**

R^2 = 0.998

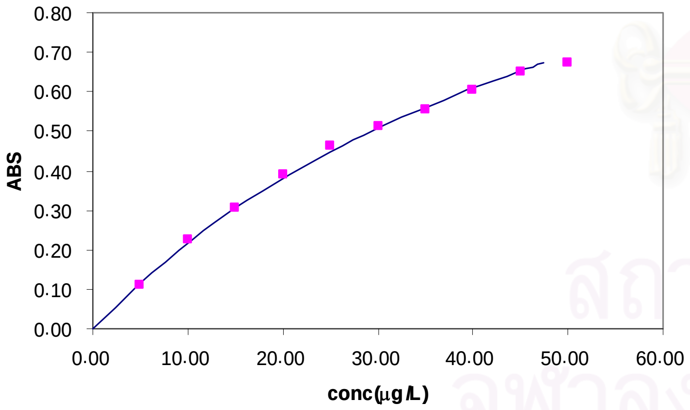

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Table C-6 Calibration data and curve of chromium (Cr)

STD	CONC(Y),μg/L	ABS(x)	$\text{CONC}_{\text{calc}}$,μg/L	ERROR	$(\text{ERROR})^2$	VARIATION
STD1	1.000	0.0484	1.1378	0.1378	0.018976	11.869924
STD2	2.000	0.0827	1.9775	0.0225	0.000506	5.979373
STD3	3.000	0.1140	2.7694	0.2306	0.053167	2.088822
STD4	4.000	0.1520	3.7655	0.2345	0.055000	0.198270
STD5	5.000	0.1945	4.9271	0.0729	0.005307	0.307719
STD6	6.000	0.2200	5.6497	0.3503	0.122723	2.417168
STD7	7.000	0.2680	7.0650	0.0650	0.004228	6.526616
STD8	8.000	0.2949	7.8916	0.1084	0.011759	12.636065
STD9	9.000	0.3380	9.2692	0.2692	0.072460	20.745514
STD10	10.000	0.3770	10.5760	0.5760	0.331758	30.854963
SUM	**45.0000**	**1.7125**	**44.4528**	**1.4912**	**0.344127**	**62.769472**

R^2 = 0.995

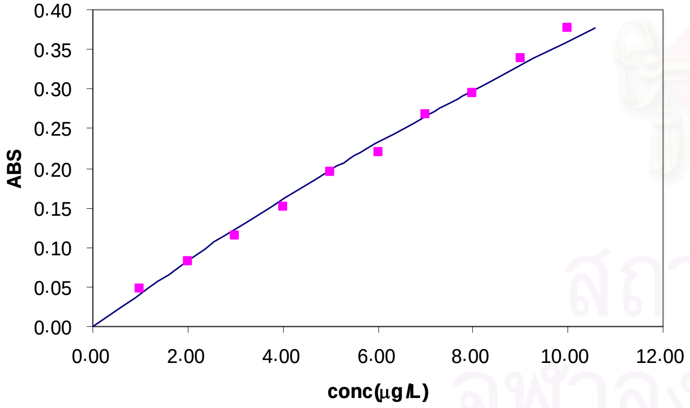

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Table C-7 Calibration data and curve of potassium (K)

STD	CONC(Y),mg/L	ABS(x)	$\text{CONC}_{\text{calc}}$,mg/L	ERROR	$(\text{ERROR})^2$	VARIATION
STD1	0.100	0.0087	0.0941	0.0059	0.000035	0.040061
STD2	0.200	0.0211	0.2141	0.0141	0.000199	0.010031
STD3	0.300	0.0309	0.2990	0.0010	0.000001	0.000000
STD4	0.400	0.045	0.4081	0.0081	0.000066	0.009969
STD5	0.500	0.0562	0.4855	0.0145	0.000210	0.039939
SUM	**1.5000**	**0.1619**	**1.5008**	**0.0436**	**0.0005**	**0.1000**

R^2 = 0.995

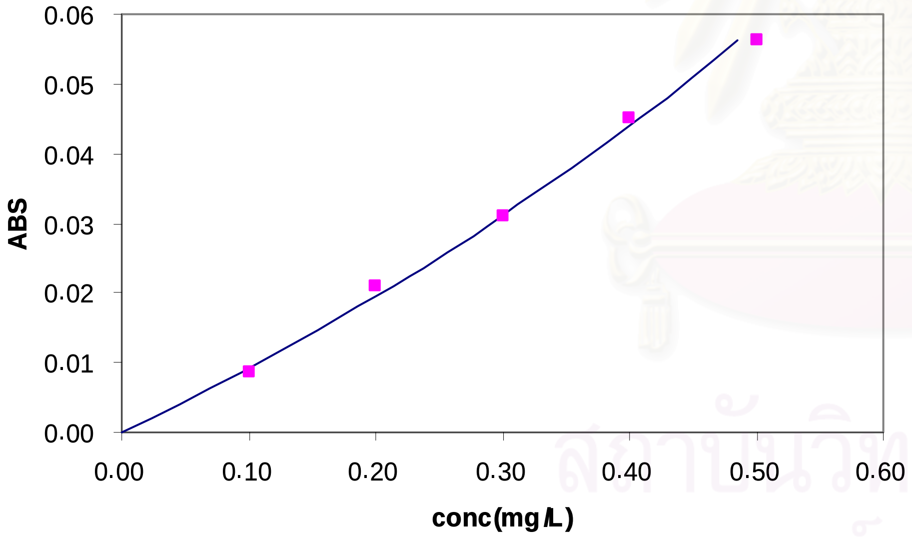

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Table C-8 Calibration data and curve of zinc (Zn)

STD	CONC(Y),mg/L	ABS(x)	CONC$_{calc}$,mg/L	ERROR	(ERROR)^2	VARIATION
STD1	0.2000	0.0781	0.1993	0.0007	0.000000	0.159962
STD2	0.4000	0.1500	0.4040	0.0040	0.000016	0.039981
STD3	0.6000	0.2103	0.5940	0.0060	0.000036	0.000000
STD4	0.8000	0.2707	0.8037	0.0037	0.000014	0.040019
STD5	1.0000	0.3218	0.9987	0.0013	0.000002	0.160038
SUM	**3.0000**	**1.0309**	**2.9998**	**0.0157**	**0.0001**	**0.4000**

R^2 = 1.000

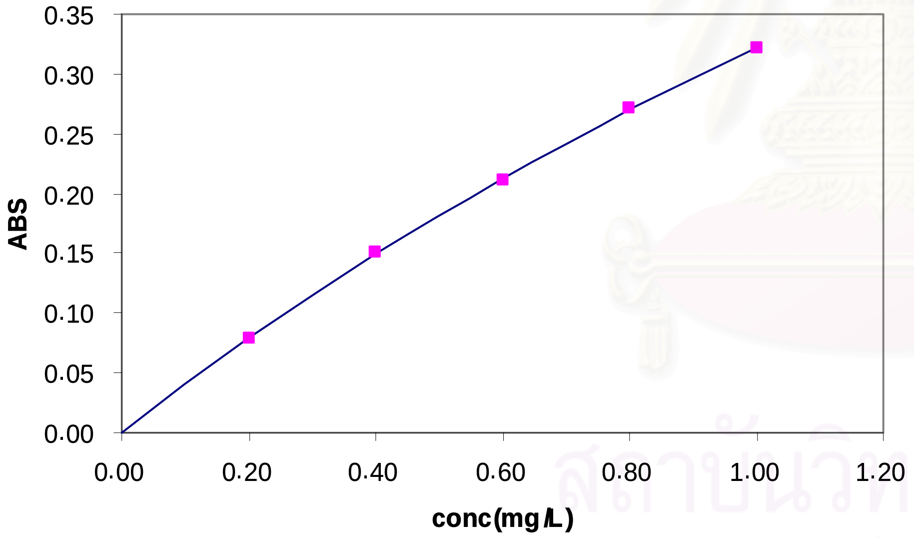

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Table C-9 Calibration data and curve of magnesium (Mg)

STD	CONC(Y),mg/L	ABS(x)	CONC$_{calc}$,mg/L	ERROR	(ERROR)^2	VARIATION
STD1	0.1000	0.2035	0.0990	0.0010	0.000001	0.039965
STD2	0.2000	0.3942	0.2051	0.0051	0.000026	0.009983
STD3	0.3000	0.5383	0.2956	0.0044	0.000019	0.000000
STD4	0.4000	0.6847	0.3985	0.0015	0.000002	0.010017
STD5	0.5000	0.8156	0.5014	0.0014	0.000002	0.040035
SUM	**1.5000**	**2.6363**	**1.4996**	**0.0134**	**0.0001**	**0.1000**

R^2 = 0.999

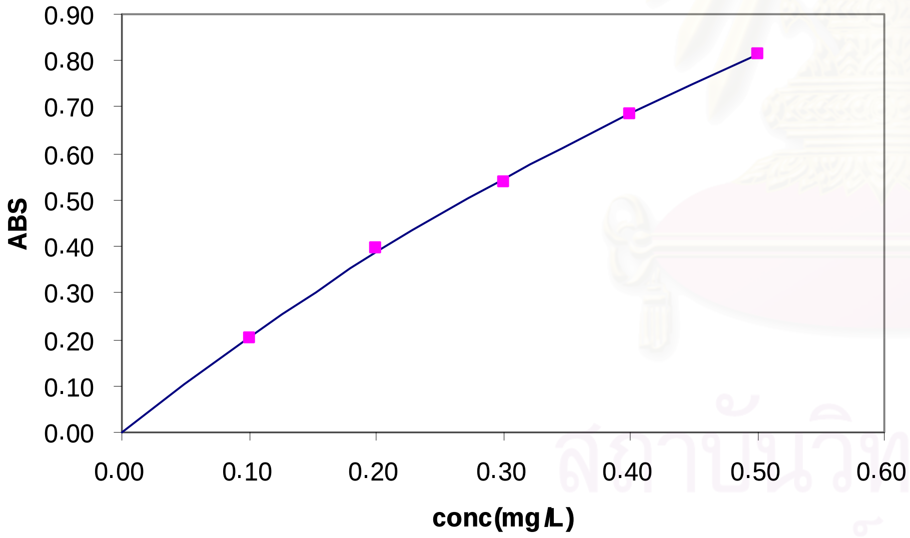

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Table C-10 Calibration data and curve of calcium (Ca)

STD	CONC(Y),mg/L	ABS(x)	CONC$_{calc}$,mg/L	ERROR	(ERROR)^2	VARIATION
STD1	0.5000	0.0384	0.5169	0.0169	0.000286	1.001259
STD2	1.0000	0.0690	0.9783	0.0217	0.000473	0.250630
STD3	1.5000	0.0955	1.4194	0.0806	0.006499	0.000000
STD4	2.0000	0.1303	2.0678	0.0678	0.004600	0.249371
STD5	2.5000	0.1521	2.5208	0.0208	0.000432	0.998741
SUM	**7.5000**	**0.4853**	**7.5031**	**0.2079**	**0.0123**	**2.5000**

R^2 = 0.995

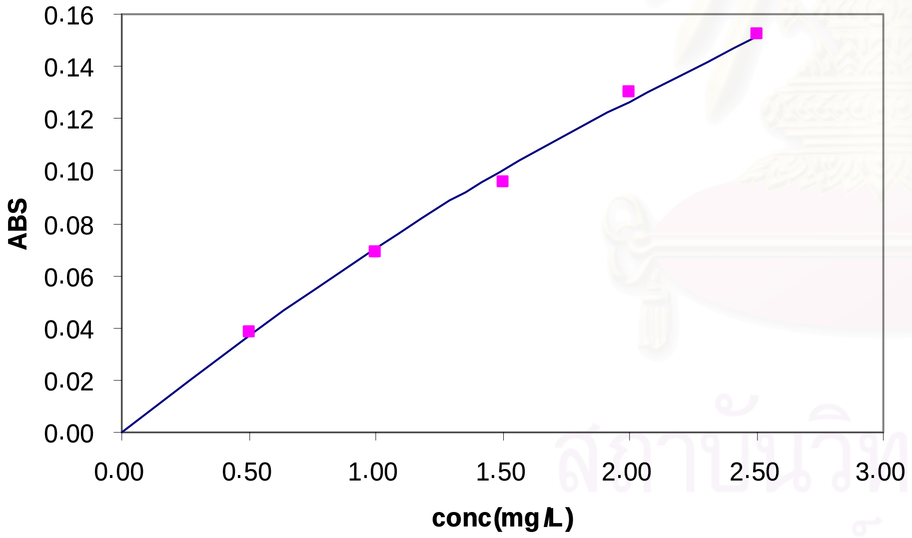

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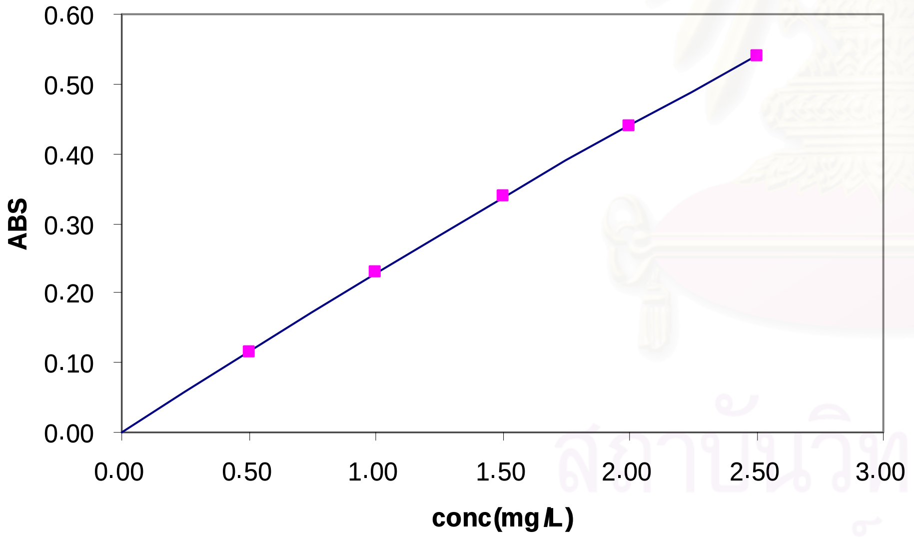
Table C-11 Calibration data and curve of manganese (Mn)

STD	CONC(Y),mg/L	ABS(x)	CONC$_{calc}$,mg/L	ERROR	(ERROR)^2	VARIATION
STD1	0.5000	0.1154	0.4965	0.0035	0.000012	0.999660
STD2	1.0000	0.2296	1.0064	0.0064	0.000041	0.249830
STD3	1.5000	0.3385	1.5107	0.0107	0.000115	0.000000
STD4	2.0000	0.4388	1.9917	0.0083	0.000069	0.250170
STD5	2.5000	0.5400	2.4938	0.0062	0.000038	1.000340
SUM	**7.5000**	**1.6623**	**7.4992**	**0.0351**	**0.0003**	**2.5000**

R^2 = 1.000



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APPENDIX D

EXCESS CANCER RISK CALCULATION

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Table D-1 Dose-Response Values for Cancer

Pollutant	Weight of evidence		Unit Risk Estimate (per $\mu g/m^3$)	Source	Confidence in URE
	EPA	IARC[a]			
Cadmium	B1[b]	1[c]	1.8E-03	IRIS	Medium
Chromium	A[b]	1[c]	1.2E-02	IRIS	High
Lead	B2[b]	2B[c]	1.2E-05	CAL EPA	Low
Nickel	A[b]	2B[c]	4.8E-04	IRIS	High

[a] IARC: International Agency fro Research on Cancer

[b] Group A: known carcinogen, Group B1: probable carcinogen, based on incomplete human data, Group B2: probable carcinogen, based on adequate animal data

[c] Group 1: carcinogenic in humans, Group 2A: probably carcinogenic, Group 2B: possibly carcinogenic

Calculation

Excess Cancer Risk for site no.1 = Σ Excess Cancer Risk of each pollutant

= (average concentration of Cd)$(\mathrm{URE})_{\mathrm{Cd}}$ + (average concentration of Cr)$(\mathrm{URE})_{\mathrm{Cr}}$ + (average concentration of Pb)$(\mathrm{URE})_{\mathrm{Pb}}$ + (average concentration of Ni)$(\mathrm{URE})_{\mathrm{Ni}}$

= (0.0053)(1.8E-03) + (0.128)(1.2E-02) + (0.128)(1.2E-05) + (0.0402)(4.8E-04)

= 1.6E-0.3

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Excess Cancer Risk for site no.2 = Σ Excess Cancer Risk of each pollutant

= (average concentration of Cd)$(\mathrm{URE})_{\mathrm{Cd}}$ + (average concentration of Cr)$(\mathrm{URE})_{\mathrm{Cr}}$ + (average concentration of Pb)$(\mathrm{URE})_{\mathrm{Pb}}$ + (average concentration of Ni)$(\mathrm{URE})_{\mathrm{Ni}}$

= (0.0040)(1.8E-03) + (0.091)(1.2E-02) + (0.107)(1.2E-05) + (0.022)(4.8E-04)

= 1.1E-0.3

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APPENDIX E

PRINCIPAL COMPONENT ANALYSIS

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Table E-1 Correlation coefficients and their significance level (1-tailed)

		Pb	Cd	Ni	Cu	Cr	Fe	K	Zn	Mg	Ca	Mn
Correlation	Pb	1.000	0.520	0.211	0.407	0.436	0.536	0.658	0.527	0.400	0.192	0.669
	Cd	0.520	1.000	0.032	-0.109	0.882	0.907	0.452	0.524	0.240	0.311	0.809
	Ni	0.211	0.032	1.000	0.178	0.113	0.083	0.235	0.487	0.310	0.457	0.080
	Cu	0.407	-0.109	0.178	1.000	-0.110	-0.125	0.134	0.192	0.049	0.121	0.001
	Cr	0.436	0.882	0.113	-0.110	1.000	0.904	0.392	0.623	0.271	0.318	0.819
	Fe	0.536	0.907	0.083	-0.125	0.904	1.000	0.594	0.669	0.455	0.304	0.911
	K	0.658	0.452	0.235	0.134	0.392	0.594	1.000	0.625	0.830	0.292	0.654
	Zn	0.527	0.524	0.487	0.192	0.623	0.669	0.625	1.000	0.567	0.607	0.693
	Mg	0.400	0.240	0.310	0.049	0.271	0.455	0.830	0.567	1.000	0.322	0.454
	Ca	0.192	0.311	0.457	0.121	0.318	0.304	0.292	0.607	0.322	1.000	0.160
	Mn	0.669	0.809	0.080	0.001	0.819	0.911	0.654	0.693	0.454	0.160	1.000
Sig. (1-tailed)	Pb		0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.000
	Cd	0.000		0.396	0.182	0.000	0.000	0.000	0.000	0.021	0.004	0.000
	Ni	0.038	0.396		0.067	0.173	0.243	0.023	0.000	0.004	0.000	0.253
	Cu	0.000	0.182	0.067		0.179	0.147	0.131	0.053	0.343	0.156	0.497
	Cr	0.000	0.000	0.173	0.179		0.000	0.000	0.000	0.011	0.003	0.000
	Fe	0.000	0.000	0.243	0.147	0.000		0.000	0.000	0.000	0.005	0.000
	K	0.000	0.000	0.023	0.131	0.000	0.000		0.000	0.000	0.006	0.000
	Zn	0.000	0.000	0.000	0.053	0.000	0.000	0.000		0.000	0.000	0.000
	Mg	0.000	0.021	0.004	0.343	0.011	0.000	0.000	0.000		0.003	0.000
	Ca	0.053	0.004	0.000	0.156	0.003	0.005	0.006	0.000	0.003		0.090
	Mn	0.000	0.000	0.253	0.497	0.000	0.000	0.000	0.000	0.000	0.090	

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Table E-2 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.779
Bartlett's Test of Sphericity	Approx. Chi-Square	770.093
	df	55
	Sig.	0.000

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Table E-3 Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.581	50.733	50.733	5.581	50.733	50.733	4.131	37.551	37.551
2	1.830	16.639	67.372	1.830	16.639	67.372	2.225	20.230	57.781
3	1.193	10.842	78.214	1.193	10.842	78.214	1.876	17.056	74.837
4	1.004	9.127	87.341	1.004	9.127	87.341	1.375	12.504	87.341
5	0.537	4.878	92.218						
6	0.338	3.070	95.288						
7	0.233	2.122	97.410						
8	0.116	1.058	98.468						
9	7.357E-02	0.669	99.137						
10	5.937E-02	0.540	99.677						
11	3.556E-02	0.323	100.000						

Extraction Method: Principal Component Analysis.

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Table E-4 Component Matrix

	Component			
	1	2	3	4
Fe	0.912	-0.356		
Mn	0.903	-0.280	0.171	
Zn	0.845	0.290	-0.192	
Cr	0.826	-0.402	-0.183	0.202
Cd	0.820	-0.440		0.198
K	0.782	0.256	0.282	-0.415
Pb	0.718	0.175	0.490	0.198
Mg	0.637	0.375		-0.607
Ni	0.315	0.653	-0.413	
Cu		0.582	0.509	0.547
Ca	0.476	0.428	-0.571	0.179

Extraction Method: Principal Component Analysis.

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Table E-5 Rotated Component Matrix

	Component			
	1	2	3	4
Cd	0.947			
Cr	0.937		0.182	
Fe	0.923	0.310	0.110	
Mn	0.866	0.394		0.141
Mg	0.137	0.917	0.251	
K	0.357	0.866	0.131	0.182
Ca	0.217		0.846	
Ni		0.179	0.807	0.131
Zn	0.538	0.400	0.596	0.187
Cu	-0.134		0.145	0.931
Pb	0.499	0.420		0.632

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

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Table E-6 Component Score Coefficient Matrix

	Component			
	1	2	3	4
Pb	0.079	0.079	-0.145	0.447
Cd	0.303	-0.175	-0.016	-0.012
Ni	-0.111	-0.027	0.495	-0.002
Cu	-0.043	-0.155	0.015	0.745
Cr	0.298	-0.197	0.057	-0.056
Fe	0.240	-0.002	-0.035	-0.089
K	-0.085	0.496	-0.114	-0.004
Zn	0.059	0.024	0.272	0.034
Mg	-0.182	0.596	-0.010	-0.195
Ca	0.009	-0.162	0.538	-0.086
Mn	0.209	0.062	-0.139	0.059

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

BIOGRAPHY

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