Asia-Pacific Network for Global Change Research

# Investigation on the Impacts of Urban-Rural Air Pollution on Air Quality and Climate in Southeast Asia

**Final report for APN project: ARCP2007-07CMY-Oanh**


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# INVESTIGATION ON THE IMPACTS OF URBAN-RURAL AIR POLLUTION ON AIR QUALITY AND CLIMATE IN SOUTHEAST ASIA

**Project Reference Number:** ARCP2007-07CMY-Oanh

## Final Report submitted to APN

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## Overview of project work and outcomes

### Non-technical summary

This research project was designed to investigate the influences of various emission sources, typically present in rural and urban areas, on the air pollution levels and atmospheric climate-related properties. The goal of this project is to initiate the measurements of the climate change relevant properties of airborne particles in selected cities that can be further expanded to other countries in Asia. The monitoring activities were conducted in two selected Metropolitan Regions in Southeast Asia, which are Bangkok of Thailand and Hanoi of Vietnam. The research focused on airborne particles (PM), particle compositions and key gaseous pollutants emitted from typical sources in the region such as traffic and open biomass burning. During the first one year (2007), sampling activities were completed in Hanoi with over 400 PM samples and 200 gaseous measurements. In the second year (2007- 2008), PM sampling were deployed in Bangkok including 137 pairs (274 single) of PM2.5 and PM10-2.5 samples. In parallel, measurements of climate change relevant species of particles (i.e. EC/BC and OC), CO and meteorology were conducted continuously using RCAST automatic equipments since March 2007, which generated thousands of data points.

For capacity building and networking, one AIT student was sent to Research Center for Advanced Science and Technology (RCAST) at Tokyo University for training on the OC/EC monitoring. Several scientist visits were made among the three project partners. The RCAST researchers gave two trainings at AIT for the RCAST equipment installation and operation. One Vietnamese research fellow from Hanoi University of Science (HUS) spent three months for data analysis at AIT. The launching workshop, organized at AIT in April 2007, was attended by 50 participants and included members from the partner institutions, local experts and graduate students. The AIT project principal investigator (PI) also visited Hanoi in December 2007 to discuss the HUS workplan for 2008. APN workshop in Vietnam was organized in October 2008. The regional dissemination workshop was held as a special event at Best Air Quality (BAQ) 2008 in Bangkok (13 Nov. 2008), which was attended by 29 participants. The APN project "Investigation on the impacts of urban-rural air pollution on air quality and climate in Southeast Asia" sponsored 5 experts from Vietnam, Lao, Cambodia, Thailand and Japan.

**Objectives**

The main objectives of the project are:

- To characterize ambient air pollution important for climate change and health hazards
- To identify the major sources of selected pollutants in the urban area
- To build capacity of the research partners in developing countries
- To disseminate the results among policy makers, scientists and publics

**Amount received and number years supported**

The Grant amounts awarded to this project were:

- 2006-2007: USD 30,000
- 2007-2008: USD 30,000

**Activity undertaken**

Measurements for air pollution levels and climate related properties were conducted in the two Metropolitan Regions, Bangkok (BMR) and Hanoi. The parameters monitored were airborne particles (mass and compositions), CO, and meteorology. The activities during the 2 years according to the project objectives are listed below.

*(1) Characterization of the ambient air pollutants in two Metropolitan Regions*

In Hanoi, 400 samples including PM2.5, PM10-2.5 and PM10 samples were collected for both 24-h (routine sampling) and 4-h sampling interval (intensive sampling) in November 2006 - January 2007 at a mixed urban site in the city. All PM samples were analyzed for the mass and chemical compositions including water soluble ions, elements, OC, EC and BC. Simultaneously, measurements of CO and hourly meteorological conditions were also undertaken.

In Bangkok Metropolitan Region (BMR), sampling of PM2.5 and PM10 (24-h, filter based) using dichotomous samplers was conducted from May 2007 to February 2008 in Environmental Engineering and Management (EEM) ambient lab at AIT. These samples were analyzed for similar parameters as for the samples collected in Hanoi. Since March 2007, a continuous monitoring station of CO, OC/EC (Sunset analyzer) and meteorological parameters was set up in the Ambient Laboratory at AIT. Other on-line measurement of black carbon (BC) was also operated in August 2007 using a Continuous Soot Monitoring System (COSMOS). The equipment was developed by the RCAST-UT group. Comparison between on-line EC results provided by Sunset analyzer and BC by COSMOS analyzer (prototype) was made in order to access the performance of each technique.

*(2) Source apportionment study*

The PM data collected in both Hanoi and BMR were analyzed by PMF receptor modeling to identify major sources contributing to the air pollution at the selected sites during the monitoring period. The results show that traffic, biomass burning, industry and secondary particles (sulfate and nitrate) are the major contributors to PM2.5 and PM10 in the cities. Addition of PM composition data such as online OC/EC, water soluble organic carbon, inorganic soluble ions, and CO will be used to better identify the PM sources.

*(3) Capacity building and networking*

- RCAST experts conducted hands-on trainings at AIT for operation of OC/EC and COSMOS equipment.
- One AIT student was sent to RCAST for training on the OC/EC monitoring method in 2007.
- One HUS (Vietnamese) researcher received a research fellowship from the project for 3 months (Aug to Oct 2007) to do data analysis and training for OC/EC operation at AIT.
- Several scientist visits to collaborating institutions were made: AIT PI visited RCAST-TU and HUS to discuss about the project activities, RCAST team and HUS team visited AIT.

*(4) Results dissemination*

The project launching workshop "Interaction between Air Pollution and Climate: Aerosol and Climate" was organized at the Asian Institute of Technology, Pathumthani, Thailand in April 2007. This workshop aimed at setting a framework for the collaboration within 3 research partners of this project (Asian Institute of Technology, The University of Tokyo and Hanoi University of Science). The three partners met and discussed in detail the activities and work-plans. In addition, a one-day regional workshop was conducted on 2 April 2007 which served as a forum to disseminate the innovative project ideas to potential collaborating data users in the region including participants from universities in Thailand. The workshop included over 30 participants from RCAST, Vietnam (HUS), AIT as well as the participants from other institutions such as UNEP and Thai universities (Chulalongkorn and JGEES) and about 20 AIT graduate students.

- A workshop in Hanoi, Vietnam organized by HUS in December 2007 was held to discuss the data and plan for 2008 activities of the project. The workshop was attended by 15 local participants and AIT PI.
- A data analysis workshop was organized in Ha Long, Vietnam during 11-12 October 2008 for dissemination and capacity building for Vietnam researchers. There were totally 10 participants from 5 institutions participating in the workshop.

The regional dissemination workshop on "Black Carbon: Air Quality and Climate Change Issue" was organized by the project team as a special session in the "Better Air Quality Workshop 2008" on 12 November 2008, Bangkok, Thailand. The ultimate objective of this workshop is to disseminate the findings among policy makers, scientists and the public who are actively involved in research and management of urban air quality, with specific consideration for climate co-benefit. There are 29 people including policy makers and academics from Asia and beyond participating in the workshop. Specifically, there are 5 participants sponsored by the APN project from different countries, i.e. Japan, Vietnam, Laos, Cambodia, and Thailand. Four presentations on preliminary finding of APN projects were made at the workshop followed by a discussion.

- Two AIT Master students graduated with the research topics "Particulate matter air pollution in Hanoi with a focus on source apportionment study by receptor modeling" and "Characterization of atmospheric particles for source apportionment" related to APN project activities in 2007 and 2008.

- Journal papers one paper was published and a few others are in preparation.

**Results**

*Hanoi*

The monitoring in Hanoi shows that 24-h PM10 mass concentrations during the study period were 60-157 $\mu g/m^3$ and only one measurement exceeded the Vietnam 24-h PM10 AAQS of 150 $\mu g/m^3$. However, all 24-h PM2.5 mass concentrations ranged within 42-134 $\mu g/m^3$ which exceeded the currently US EPA AAQS of 35 $\mu g/m^3$ and WHO guideline of 25 $\mu g/m^3$. The PM2.5/PM10 ratio was above 0.7 for all samples and the temporal trends of PM2.5 and PM10 were quite similar. All hourly CO measurements were below 1-h VN AAQS of 30 $mg/m^3$. In general, the levels of CO and PM were higher in the morning and evening hours (6-10 am and 6-10 pm), when more road traffic and residential cooking activities occurred. EC and OC were the major components of PM2.5 with the 24-h average range within 1.48- 4.89 $\mu g/m^3$ and 9.75-39.14 $\mu g/m^3$, respectively. The fine fraction (PM2.5) mainly contained low concentrations (< 0.5 $\mu g/m^3$) of elements such as Zn, Si, Pb, Sr, Ti, V, Be, Cd, Cr, Cu, Li, Mn. The major elements in coarse fraction were Ca, Si and Fe. The highest concentration was Ca (2 $\mu g/m^3$) that may be a result of contributions from road dust and construction activities. Results of receptor modeling indicated that the secondary particles and diesel exhaust were the major sources of PM2.5 in Hanoi, contributing about 40%, respectively. For PM10, the major sources were diesel exhaust (41%) and construction/soil (40%).

*BMR*

Measurements in BMR shown significant levels of daily EC and OC in PM2.5, i.e. EC varied within 0.6 – 13.7 $\mu g/m^3$ (average of 3.8 $\mu g/m^3$) and OC varied within 2 – 32.4 $\mu g/m^3$ (average of 8.3 $\mu g/m^3$) (Lalicha, 2008). High EC concentrations were mostly found during the morning (6-7 am) and early evening (7-10 pm) and at low wind speed (<0.5 m/s). This suggests a significant contribution from traffic on the highway nearby, which commonly peaked during the rush hours. By contrast, there was no significant peak for diurnal OC concentration except for some high levels recorded from 10 am to 10 pm during dry days, which may be due to the highly intensive photochemistry as well as open biomass burning that normally took place during this period. In addition, high OC concentrations were generally associated with strong wind (> 2m/s) that links to the regional transport of OC from surrounding rice fields (within 10-20 km radius) to the site. A good correlation between BC concentration measured by 34D Smoke Stain Reflectometer and EC concentration measured by Sunset OCEC analyzer was also observed.

Water soluble organic carbon (WSOC) in ambient PM2.5 was monitored by Mini-Vol samplers at AIT during May 2007- Feb 2008. The data show a fluctuation of WSOC between 2 - 25 $\mu gC/m^3$ with an average of10 $\mu gC/m^3$. Higher levels were observed during the dry season. More intensive biomass open burning, stable atmosphere and higher photochemistry intensity may be the reason for higher WSOC, OC and PM2.5 mass during the dry season.

**Relevance to APN's Science Agenda and Objectives**

- **Relationship to the APN's Second Strategic Plan (2005-2010)**

In Southeast Asia, drastic environment changes are expected due to the rapid industrialization and urbanization. Various air pollution sources in the region such as traffic and biomass burning have been recognized to play an important role for atmospheric environment over Asia and Western Pacific. Because of relatively short residence-time of BC aerosols in the air, their impacts on the air and climate are expected to be much stronger near the sources; this is quite different from influences of greenhouse-gases which are uniformly distributed over the globe. The results of measurements in the two selected countries (Vietnam and Thailand) in Southeast Asia would help to elucidate the relationship between emission sources in the urban-rural areas and air pollution, as well as their impact on climate. The method developed in this project can be used for other countries in the region. Understanding on aerosol emissions and behavior would improve our understanding of the regional issues of air pollution and climate. Consequently, this study will greatly contribute to the APN's 2nd strategy (APN, 2008).

- **Science Agenda**

The new data on the climate change properties of regional aerosols generated by the project directly contributed to two (2) scientific agenda of APN, namely 1) climate and 2) change in the atmospheric composition. Further, the incorporation of climate change properties in the current air pollution monitoring activities would help to promote co-benefit opportunities in Asia. The data can be further used for modeling to assess the climate-forcing effects of current air pollution levels in Asia-Pacific.

- **Policy Agenda**

The new and more comprehensive particle composition data generated by the proposed APN project will help to improve the quantification of contributing sources to PM and EC by receptor modeling. The often-overlooked open biomass burning sources can now be adequately quantified, which will be useful for policy formulation in identifying priority sources for abatement.

- **Institutional Agenda**

Each country partner in the project interacts directly with the national agencies/government to inform them about the project activities and findings using both existing and newly established networks. The partners actively promote the APN in their respective countries and beyond. AIT with its strong international connections is especially relevant for this purpose. In addition, the project organized a workshop at BAQ 2008 which was attended by a wide audience of scientists and policy makers. This provided a good opportunity to discuss the project findings.

**Self-evaluation**

All activities in the project progressed well in accordance to the project plan. The samplings in both Hanoi and BMR were completed. Substantial amount of data has been generated to achieve the project objectives. The PM source identification study

has completed. The data are presented in 2 published Master theses of AIT students. A paper has been published in a international peer-review journal. Several scientific manuscripts are being prepared based on the data collected by the project in both Hanoi and Bangkok. Two dissemination workshops were successfully organized in Ha Long and Bangkok for capacity building and data dissemination, to achieve the 2nd and 3rd project objectives. The capacity building is also done through AIT student involvement in the project (2 students) and research staff (2 staff) as well as research exchange from Vietnam to AIT (1 researcher) and from AIT to Tokyo university and vice versa (6 research visits).

**Potential for further work**

Long-term measurements for PM, OC, EC are still necessary to present a complete picture of the impact of emission sources in the region on air quality and climate which will be useful for the policy making to integrate air quality and climate change policies for co-benefit.

**Publications**


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**Technical Report**

## Preface

This report presents the major findings of the project entitled "Investigation on the impacts of urban-rural air pollution on air quality and climate in Southeast Asia" which is supported by the Asia-Pacific Network for Global Change Research (APN). The focus is on the assessment of particulate matter levels and the chemical compositions relevant to air pollution and climate forcing properties, in two selected metropolitan regions: Bangkok (Thailand) and Hanoi (Vietnam). The report was prepared by the project team from the Asian Institute of Technology (AIT) in collaboration with two partners, the Research Center for Advanced Science and Technology (RCAST), University of Tokyo, Japan and the Faculty of Environment Sciences, Hanoi University of Science (HUS), Vietnam.

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# 1 Introduction

Air pollution is an important environmental problem that needs to be addressed to achieve sustainable development. Ambient air pollution in an urban area is a dynamic mixture of pollutants emitted from numerous sources including traffic, industry, residential and commercial combustion as well as neighboring rural sources such as agro-residue open burning. The impacts of air pollution are directly related to human health, food production, ecosystem, and climate. In Southeast Asia, air pollution, which is linked to unsustainable economic developments, has increasingly presented itself as a serious problem that must be addressed by proper control strategies.

Atmospheric particulate matter (PM) or aerosol is among the types of air pollutants that has the most significant negative impact on public health and climate. These aerosols interact directly and/or indirectly with the Earth radiation energy balance and can subsequently affect global climate (IPCC, 2001). The Asian brown cloud, which causes multiple effects on regional air quality and climate originated from anthropogenic activities including biomass burning (UNEP & $C^4$, 2002). The types and the degree of potential effects of particles depend on their chemical and physical properties. For example, element carbon (EC or BC) and organic carbon (OC) contents of particles are found to be also important for regional climate in Asia. The global warming potential of BC and OC is found to be 2000 and 250 times higher, respectively, than that of $CO_2$, on the mass basis, for 20 years time span (Bond et al., 2004). The important data on particulate air pollution, especially the particle physical-chemical properties, is still scarce in Asian developing countries.

Therefore, it is important to conduct systematic measurements to characterize and evaluate anthropogenic emission sources to understand behavior of key chemical species and aerosols, especially in the rural-urban interface where a mixture of sources such as biomass burning and traffic is present. These physical-chemical properties of aerosols are the basis for study of effects on human health and climate change. The data generated can be analyzed by receptor modeling to quantify the contributions of various air pollution sources to the ambient air quality. Such measurements are largely missing in Southeast Asia, which is a cause for the scarcity of data needed for analysis. Therefore, this project has started measurements of selected important species (OC/EC aerosols, CO, etc.) to provide reliable data to assess current ambient air pollution status and climate forcing strength of ambient aerosols in Southeast Asia.

# 2 Methodology

The research project was designed to measure the mass concentration and their chemical compositions of particles ($PM_{2.5}$ and $PM_{10}$) and source apportionment of those PM fractions using receptor modeling. Two regions were selected which are Bangkok Metropolitan Region (BMR), Thailand and Hanoi Metropolitan Region, Vietnam.

## *2.1 Study area*

- **Hanoi**

Hanoi, estimated population 6.232.940 (2008), is the capital and the second-largest

city of Vietnam. Hanoi is located at 21°2’N and 105°51’E in the northern part of Vietnam. Since 1 August 2008, Ha Tay province, Vinh Phuc's Me Linh district and 4 communes of Luong Son district, Hoa Binh has merged into the metropolitan area of Hanoi. Hanoi's total area increased to 334,470 hectares divided into 29 subdivisions with the new population being 6,232,940 hectares. Motorbikes remain the most common transport mean with a share of 94% of the fleet.

The selected sampling area was located in the Thanh Xuan district surrounded by traffic, traffic, industry and institutes/universities. The monitoring site was setup in the Hanoi University of Science

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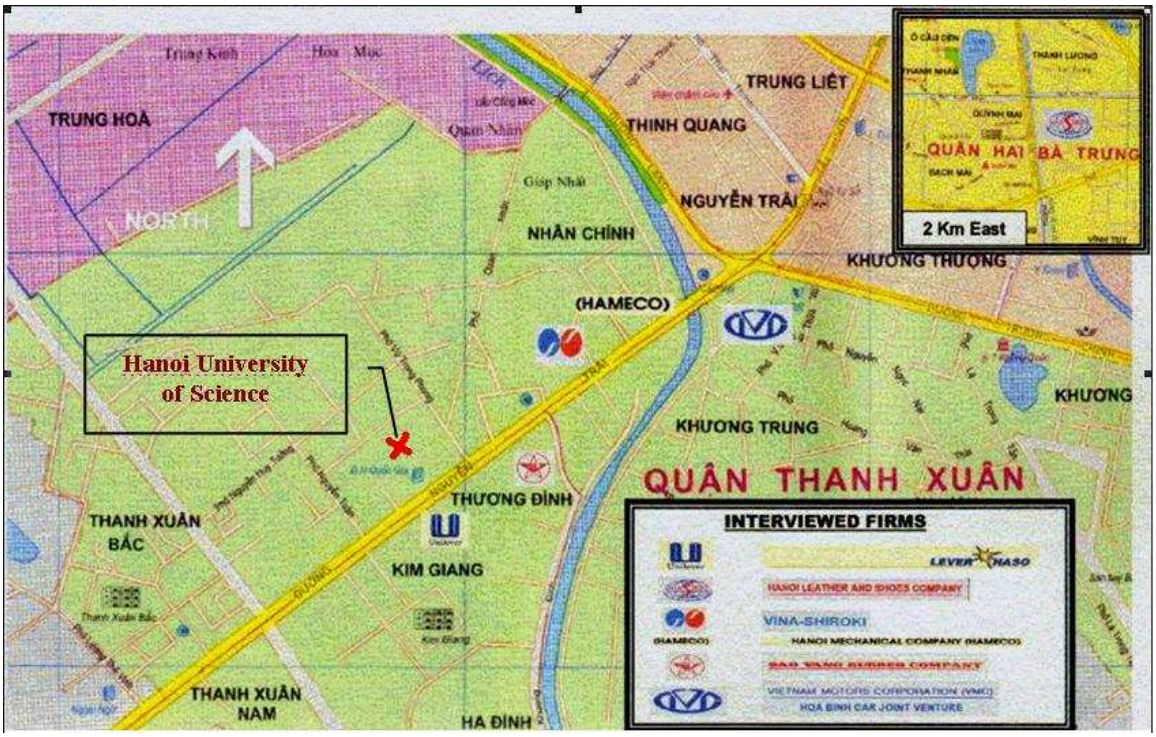



Figure 1) in Thuong Dinh, Thanh Xuan district. During the dry season from December 2006 to February 2007 a strong influence of the Northeast monsoon was presented. The samplers were placed on the rooftop of the C4 building in Hanoi University of Science (HUS) at a height of 15m from the ground and a distance of 100m far away from Nguyen Trai Street.

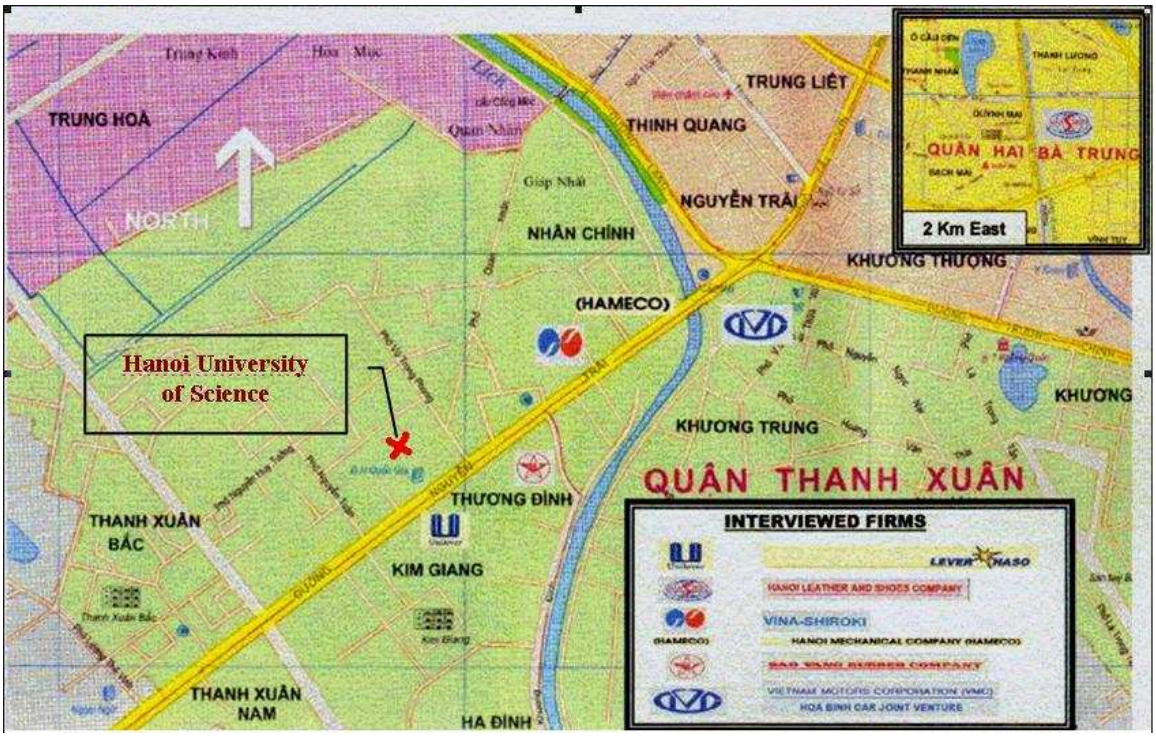



Figure 1. Location of the HUS sampling site in Hanoi

- **BMR**

Bangkok Metropolitan Area (BMR) includes Bangkok and 6 surrounding provinces of Thailand (Figure 2). It is located in the central part of Thailand and extends approximately 18 km from East to West and 16 km from North to South (Latitude 13°45′N, longitude 100°29′E). BMR covers an area of 7,761.50 km² and has a registered population of 11,971,000 (as of January 1, 2008), with a population density of 1,301 people per km². The city is congested with a large number of motor vehicles including both public and private transportation. It is estimated that more than 5.4 million vehicles circulating the city roads. Construction of highways and buildings takes place continuously throughout the city. Many small scale factories are also located in the area. As a result of these contributing sources, air pollution is currently a serious problem in Bangkok.

The sampling site was located at AIT, i.e. in an open area at the suburb of BMR. The monitoring equipments were setup on a rooftop of the Ambient Laboratory at Asian Institute of Technology which is about 8.5 m from the ground and approximately 1 km from the Paholyothin highway.

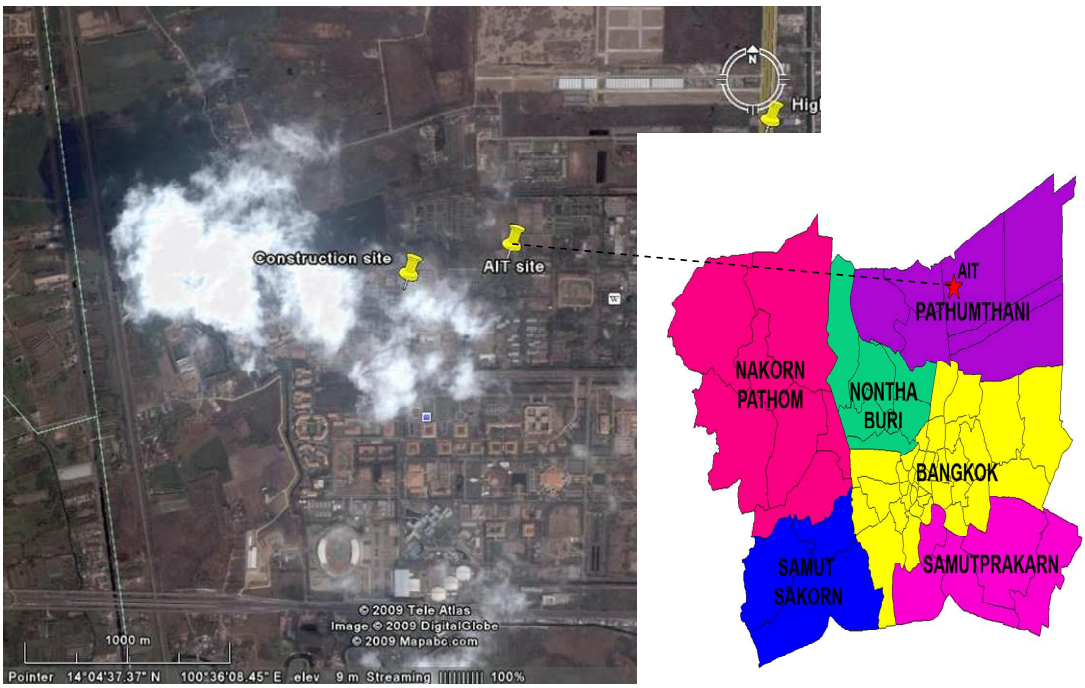



Figure 2. Location of sampling site in BMR

### *2.2 Sampling Methods*

- **Hanoi**

An Andersen dichotomous sampler, two MiniVol Portable Air Samplers and a Sibata 30L were used for both routine (every 24 hour) and intensive (every 4 hour) PM sampling in Hanoi (2006-2007). A CO portable equipment was used only for intensive sampling.

- **BMR**

Two co-located Anderson dichotomous samplers were used for 24-h PM2.5 and PM10-2.5 sample collection at AIT (2007-2008). In addition, on-line measurements of carbon monoxide (CO) and meteorological parameters (e.g. wind speed, wind direction, temperature, humidity, rainfall and pressure) were also conducted during sampling period. Moreover, BC was measured on-time at the AIT site using an aethalometer, namely a Continuous Soot Monitoring System (COSMOS). Element Carbon (EC) and Organic Carbon (OC) portions were also monitored using the Sunset Laboratory Semi-Continuous Carbon Aerosol Analyzer. The BC and EC data measured by these methods were then compared in order to assess the performance of each instrument.

Sampling methods and the equipments were used in Hanoi and BMR are summarized in Table 1. Photos of the sites are shown in

Figure 3 and Figure 4, respectively.

Table 1 Sampling Methods used in Hanoi and BMR

| Items | **Hanoi (Vietnam)** | | **BMR (Thailand)** | | |
|---|---|---|---|---|---|
| | Intensive sampling | Routine (24-h) | 24-h sampling | On-line | |
| Equipment | 1 dichot sampler for $PM_{2.5}$ & $PM_{10-2.5}$ | 1 dichot sampler for $PM_{2.5}$ & $PM_{10-2.5}$ | 2 Dichot sampler for: $PM_{2.5}$ & $PM_{10-2.5}$ | COSMOS for BC | OCEC analyzer for OC & EC |
| | 2 MiniVol samplers for $PM_{10}$ and $PM_{2.5}$ | 1 Shibata 30L for $PM_{10}$ | | | |
| Filter | Quartz filters (Ø 47 mm & 1.2 µm pore size) for dichot sampler | Quartz filters (Ø 37 mm & 1.2 µm pore size) for dichot sampler | Quartz & Mixed cellulose filters (Ø 37 mm, 1.2 and 0.8 µm pore size, respectively) | | |
| | Mixed cellulose (Ø 37 mm, 0.8 µm pore size) for MiniVol | Mixed cellulose (Ø 47 mm, 0.8 µm pore size) for Shibata 30L | | | |
| Sampling period | 12 – 20/01/07 to 05 – 11/02/07 | 23/12/06 to 07/01/07 | 15/05/2007 to 29/02/ 2008 | 23/08/2007 to 29/02/2008 | 15/05/2007 to 29/02/2008 |
| Avg.time | 4 hours | 24 hours | 24 hours | 1 min | 1 hour |
| No. of samples | 116 pairs (quartz and mixed cellulose) | 15 pairs (quartz and mixed cellulose) | 137 pairs (quartz and mixed cellulose) | | |
| Other par. | CO portable analyzer | | CO (online CO analyzer) and Meteorological data (Vaisala Weather Transmitter) | | |

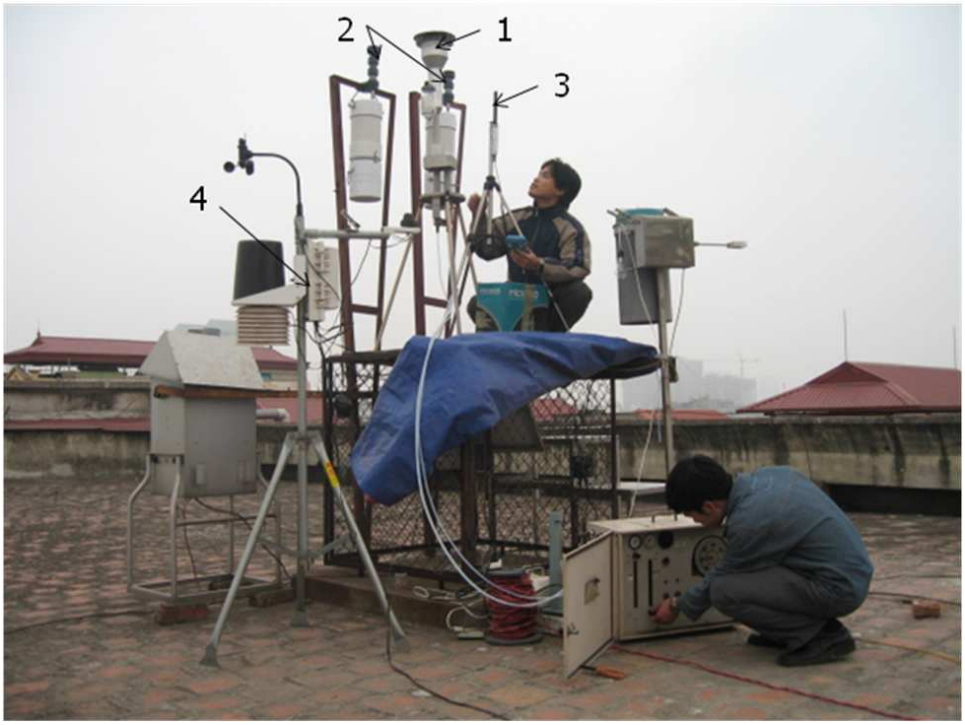



Figure 3. Monitoring equipments at HUS, 2006-2007. (1) Dichotomous sampler; (2) Minivol samplers (3) Shibata 30L; (4) Meterometer

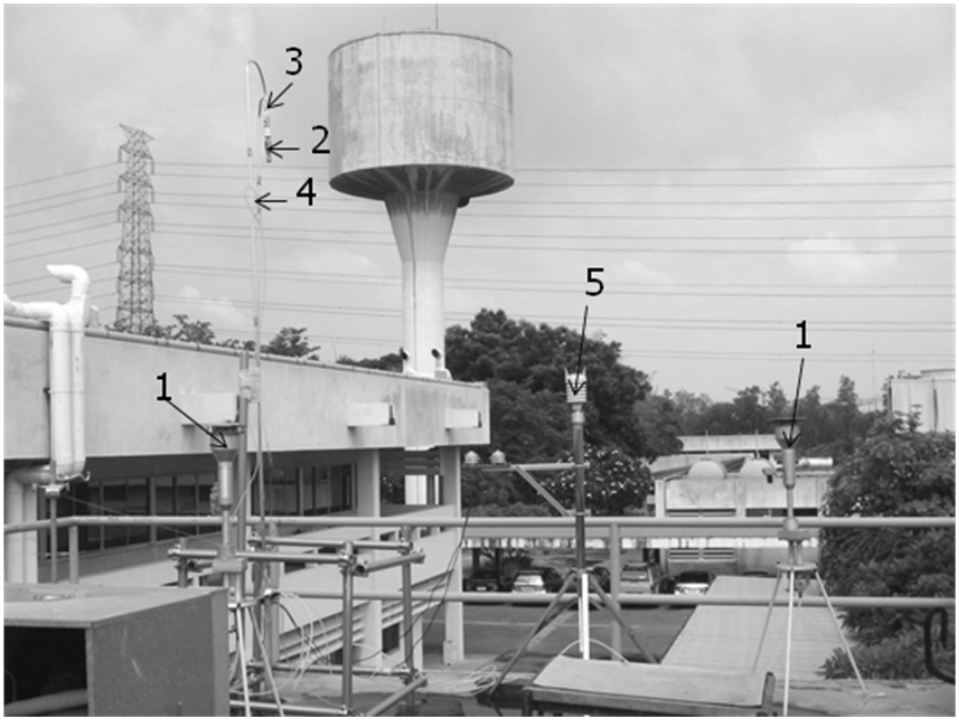



Figure 4. Monitoring equipments at AIT, 2007-2008. (1) Dichotomous samplers; (2) Sunset Laboratory Semi-Continuous Carbon Aerosol Analyzer inlet; (3) Continuous Soot Monitoring System (COSMOS) inlet; (4) On-line CO analyzer Inlet; (5) Meterometer

### *2.3 Sample preservation and transport*

After sampling each filter sample for Hanoi was placed into a petri-dish inside an individual air-tight plastic bag, kept in an isolated box and then transported to AIT laboratory for chemical analysis. The filters exposed at AIT site were kept in the petri-dishes and brought directly back to this laboratory.

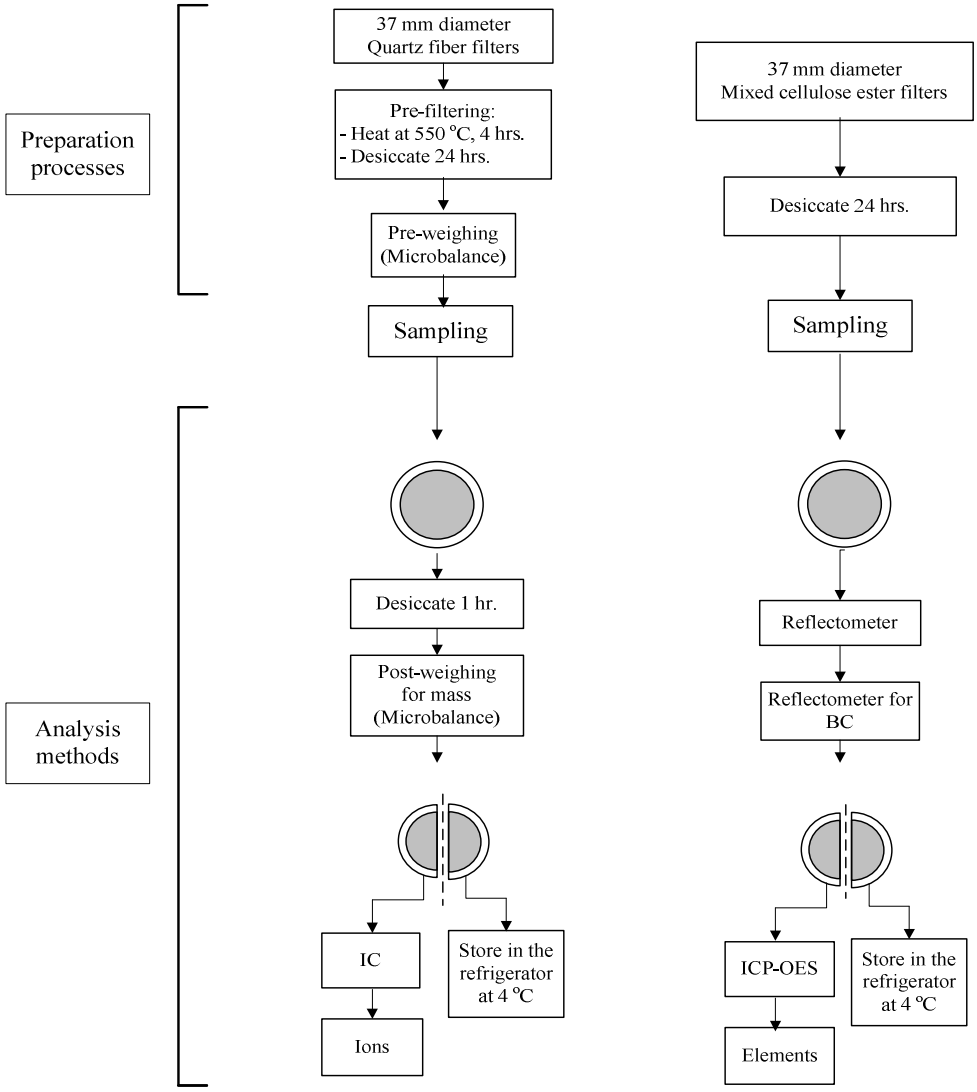



Figure 5. Filter sample preparation and analysis

### *2.4 Analysis Methods*

When the filter samples were delivered to AIT lab, quartz fiber filters were conditioned again in a desiccator under 42±5% humidity and at 22±2°C (conditioning time was 1 h for AIT samples and overnight for Hanoi samples) then were weighed and cut into half. The first half of each filter was put into a plastic bottle and soaked with miliQ (MQ) water for ion analysis; the second half was preserved at 4°C for further analysis. Samples collected in mixed cellulose ester filters were kept in desiccators for 24 hours before measured for BC, and also cut into half. The first half was soaked in 4% $HNO_3$ for elemental analysis, and the second was kept for further analysis. All extracted

solutions were preserved at 4°C to avoid loss of $NH_4^+$ and $NO_3^-$ by volatilization until the next analysis. The detail of sample preparation and analysis is presented in Figure 5. The parameters (mass concentration, ionic species, elements, OC and BC) and analytical methods for each type of filter are shown in Table 2. For CO measurement, absorption method (24-h sampling) was applied during the campaign period in Hanoi whereas an on-line CO measurement (recorded every 10 minutes for 24-h sampling) was used at AIT site.

Table 2. Summary of filter types used and analytical methods

| **Type of Filter** | **Parameters Determination** | **Analytical Method** |
|---|---|---|
| Quartz fiber filter | - Mass concentrations ($PM_{2.5}$, $PM_{10}$) | - Microbalance |
| | - OC/EC | - Sunset OC/EC instrument<br>(online measurement) |
| Mixed cellulose filter | - Ionic species:<br>Cations ($Na^+$, $K^+$, $Ca^{2+}$, $NH4^+$, $Mg^{2+}$ )<br>Anions ($Cl^-$, $NO_3^-$, $NO_2^-$, $SO_4^{2-}$) | - DIONEX Ion Chromatography |
| | - Black carbon (BC) | - 34D Smoke Stain Reflectometer |
| | - Elements<br>(Fe, Ni, Pb, Sr, Ti, V, Zn, Si, Al, Be, Ca, Cd, Co, Cr, Cu, Li, Mg, Mn, Mo, Tl ) | - Perkin Elmer ICP-OES |

Note: IC: Ion Chromatography

ICP-OES: Inductively Coupled Plasma – Optical Emission Spectrometer

### *2.5 Quality Assurance and Quality Control (QA/QC)*

In order to minimize uncertainties which might occur through processes such as transportation, sample handling or analysis, QA/QC measures were carried out during all stages including flowrate calibration, filter blanks, lab blanks and daily standard injection.

**Blank for IC and ICP/OES analysis:** One blank filter was analyzed for every 10 actual samples. This blank, which had no air drawn through, is subjected to the same handling manipulations as the actual samples.

**Blank for filter weighing**: QA/QC filters were used for pre- and post-weighing of the sample filters. These filters were conditioned and weighed in a conditioned room at a relative humidity RH of 42 ± 5 % and at 22 ± 2°C (Wilson et al., 2002). QA/QC filter was re–weighted after every 10 sample filters. These readings were used in

calculation PM mass to compensate for minor variability due to changing of temperature and humidity conditions. In the case where the reading of a QA/QC filter from microbalance deviate by more than 30 µg from normal values (due to high humidity in rainy day), the filter weighting that day was not performed. Each filter was weighted at least 3 times confirm the consistency of the microbalance.

**Checking performance of IC and ICP/OES**: A five-point calibration curve of each parameter was prepared using the standard solutions. The correlation coefficient ($R^2$) was considered acceptable when the calculated value is greater than 0.95. A mid-point standard was injected daily before the sample batch. A bias of approximately 10% from the corresponding standard was accepted for IC and ICP (US EPA, 1999a and b). In case where the bias is outside of the reference value, the data was rejected and an inspection of instrument was done.

**Sampler calibration:** for Dichotomous, MiniVol and Sibata samplers, a flowrate calibration was done before the sampling campaign, as well as after major maintenance. A monthly calibration was also applied for OC/EC analyzer. The procedures for sampler operation and calibration in this study were conducted following previously established sampling protocols (US EPA, 1997 and AirMetrics).

### *2.6 Receptor modeling*

The ambient concentrations of mass and chemical compositions of $PM_{10-2.5}$ and $PM_{2.5}$ were inputted into the Positive Matrix Factorization (PMF) receptor model to determine the source contributions to the ambient PM for both monitoring sites in Hanoi and BMR.

The fundamental calculation formula in mathematical receptor models is shown in Equation (1). In this equation, a measured concentration $x_{ij}$ of $j$ different chemical components in $i$ samples can be expressed as a sum of contributions from a small number of sources with a constant composition $p$.

$$x_{ij} = \sum_{k=1}^{p} f_{ik} . g_{kj}$$

Equation (1)

where $x_{ij}$ is the $i^{th}$ elemental concentration measured in the $j^{th}$ sample, $f_{ik}$ is the gravimetric concentration (fraction) of the $i^{th}$ element in material from the $k^{th}$ source, and $g_{kj}$ is the airborne mass concentration (weigh/volume) of material from the $k^{th}$ source contributing to the $j^{th}$ sample.

**The structure of PMF input and output files**

In the PMF model, two types of input variables are required, which are presented as a matrix with the rows being $i^{th}$ samples and the columns being $j^{th}$ species and its uncertainties. As a multivariate model, the PMF requires a large number of samples ($i^{th}$).

The following variables needed to be adjusted for each model running.

- Number of factors/sources
- F-peak (rotation)

**PMF run and output data processing**

- Input files: In the PMF model, two input file types are needed.

  1. Ambient data file

  2. Uncertainty file
- Output files

  1. Source contribution: data of sample and number of sources (such as biomass, diesel, etc.)

  2. Source profile: number of sources and species (such as ions, elements, mass, etc.)

# 3 Results & Discussion

## *3.1 Results of Monitoring in Hanoi*

The mass concentrations of PM10 and PM2.5 and their chemical compositions were determined for both intensive and routine sampling periods. Totally, 186 pairs of PM2.5 and PM10/PM10-2.5 samples were collected during intensive sampling period for every 4 hour (starting from 6 am to 6 am of the next day, i.e. 6 samples/day), and 15 pairs of 24-h PM2.5 and PM10-2.5 samples were collected during the routine sampling period. PM10 concentrations determined by dichotomous samplers in this study were calculated by summation of fine fraction (PM2.5) and coarse fraction (PM10-2.5).

**Meteorological conditions**

The monitoring program was divided into three periods (i.e. from 23 Dec 2006 - 7 Jan 2007, 12 - 20 Jan 2007; and 5 - 11 February 2007) during the dry season in Hanoi. All meteorology parameters were simultaneously recorded for every 30 minutes but were merged to hourly data for reporting.

The weather during the sampling periods (Dec. 2006 to Feb. 2007) was mainly influenced by the Northeast monsoon. However, a high variation of wind direction was observed in the first period. In the second period, the wind direction was mostly Northwesterly then it was turned to Southeasterly in the third period. Average temperature was around 15±5°C. The period was considered as dry but some fine drizzling rain was observed on last two days of the second period (19 and 20 Jan. 2007).

**PM10 and PM2.5 concentration during dry season in Hanoi**

A variation of 24-h PM concentrations was observed with the ranges of 60-157 $\mu g/m^3$ for PM10 and 42-134 $\mu g/m^3$ for PM2.5 in Hanoi (Figure 6). Only one PM10 measurement on 12 Jan. 2007 (a Saturday) exceeded the Vietnam 24-h PM10 AAQS of 150 $\mu g/m^3$. Particularly, all 24-h PM2.5 mass concentrations exceeded the currently proposed US EPA standard of 35 $\mu g/m^3$. The variation trend of PM2.5 and PM10 were almost similar. The mass concentration of PM10 and PM2.5 of the first five days were higher than the remaining days. It was observed that the wind on those days was

mainly from Northwest (not from Southeast). This high concentration probably related to construction activities in the North and emissions from industries located in the area.

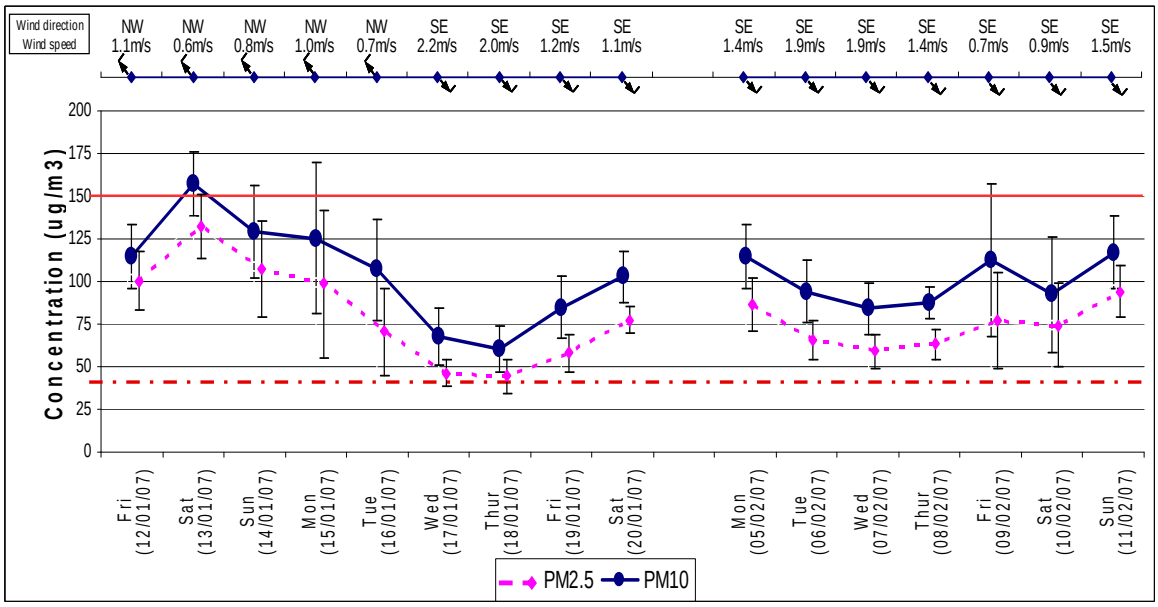



Figure 6. 24-h PM10 and PM2.5 in the intensive sampling periods in Hanoi (whiskers represent one standard deviation, SD of the daily mass concentration data series)

Diurnal variations of PM10 and PM2.5 show somewhat different patterns of the concentrations between weekdays and weekend (Saturday and Sunday) (Figure 7 and

Figure 8). The PM concentrations on weekend appear to be higher than those on weekday. Two peaks, which are during 6-10 am and 6-10 pm, are presented in Figure 7 and 8. These may be caused by higher traffic density during rush hours in the morning and evening. In addition, residential cooking, construction activities and vehicles transporting construction materials during early evening time may also contribute to high PM concentration in the area. The peak of PM concentration at 6-10 pm on Sunday may be related to the high traffic and residential fuel combustion around the site that was visually observed on that time.

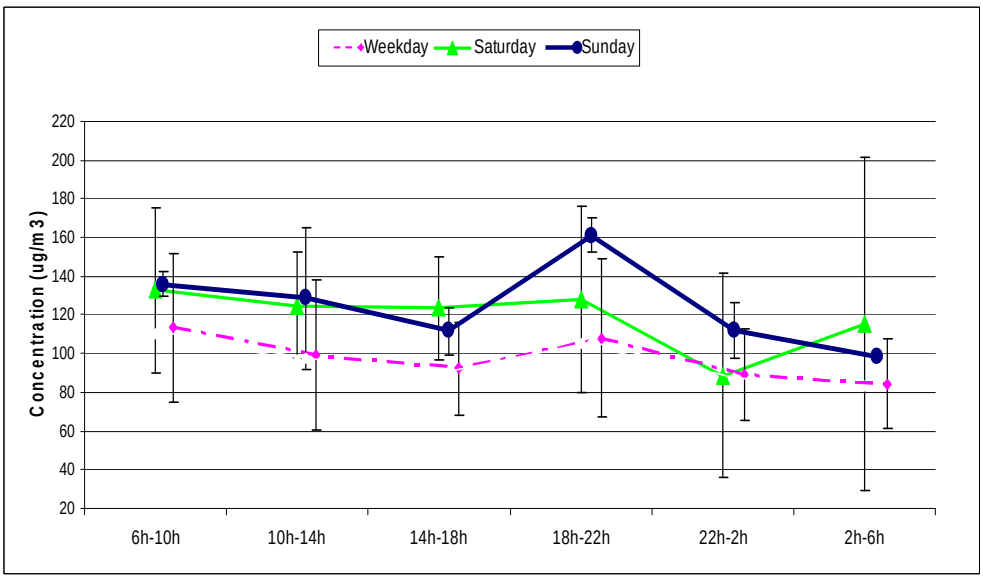



Figure 7. Variation of 4-h PM10 concentrations on weekday and weekend in Hanoi (whiskers represent one standard deviation, SD of 4-h average PM10 data series)

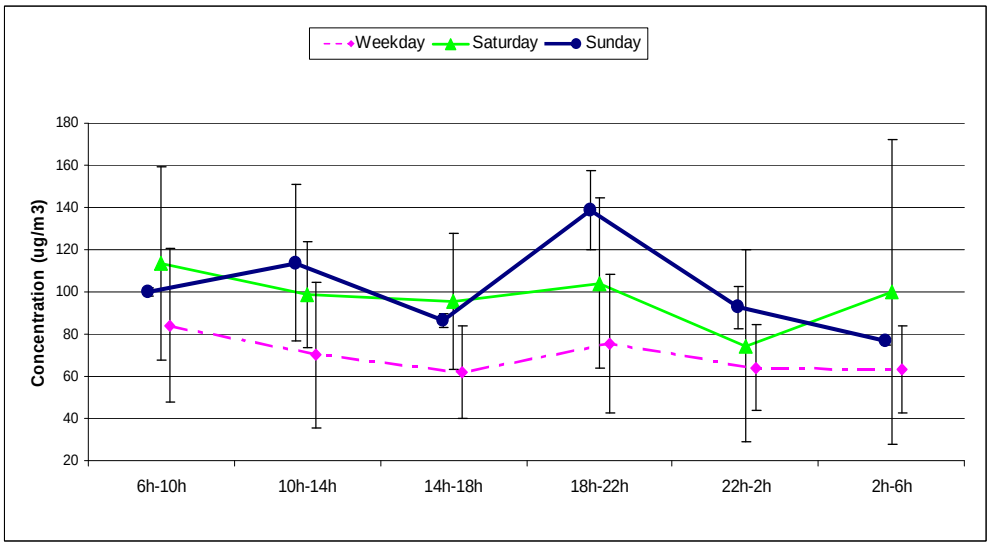



Figure 8. Variation of 4-h PM2.5 on weekday and weekend in Hanoi (whiskers represent one standard deviation of the 4-h average PM2.5)

High correlation between PM10 and PM2.5 was observed in Hanoi with $R^2$ = 0.92 (Figure 9). The PM2.5/PM10 ratio was high (>0.7) especially during the NE wind. This ratio would depend upon the contributing sources, especially those contributing to the coarse particles (Kim Oanh, et al,. 2006) and would need further experiments to clarify.

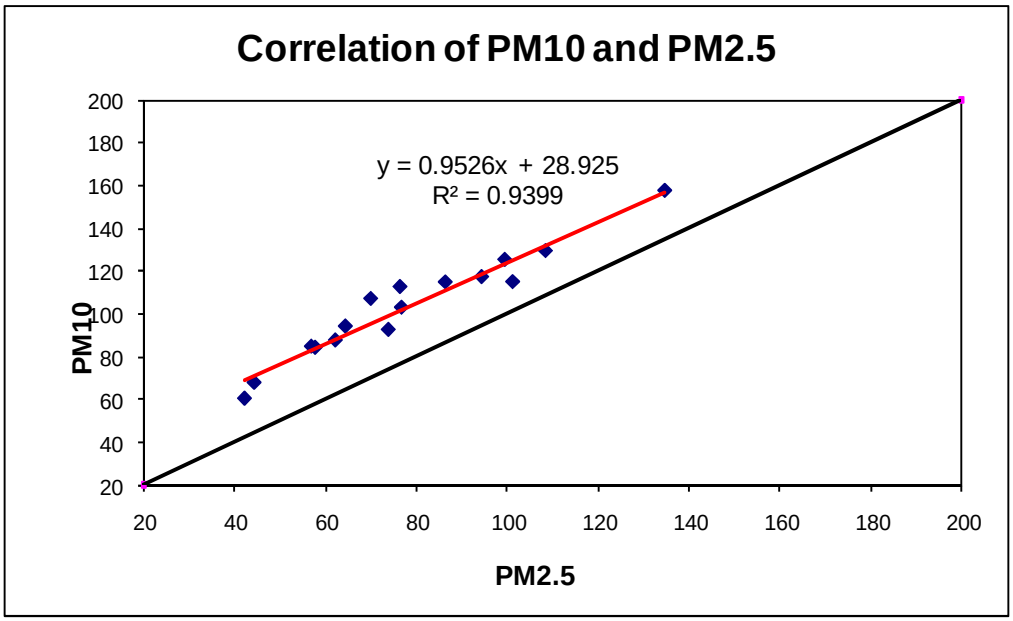



Figure 9. Correlation between PM10 and PM2.5 in Hanoi

**CO Concentration**

During the PM sampling period, CO concentrations were simultaneously measured. The hourly CO results ranged between 1.63–2.51 ppm for weekdays and 1.40–2.29 ppm for weekends, which were much lower than the 1-h Vietnam AAQS of 26 ppm. Variation of hourly CO and PM2.5 concentrations during weekday and weekend is presented in Figure 10. Higher CO concentration was observed during morning (6-8 am) and evening rush hours (7-8 pm), when a higher traffic density was observed. However, CO concentrations on weekend were lower than those on weekdays, which is opposite to PM2.5 variation trend mentioned earlier. The correlation between 4-h PM2.5 and CO in Hanoi was not clear.

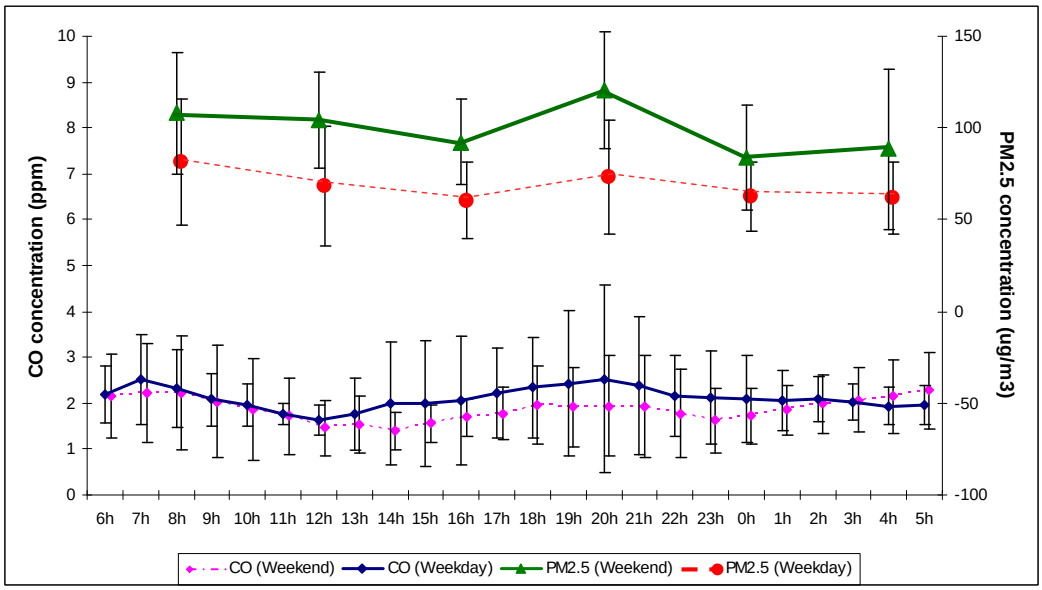



Figure 10. 1-h CO and 1-h PM2.5 concentrations in weekday and weekend in Hanoi (whiskers represent one standard deviation of the 1-h CO and PM2.5 data series)

**Chemical composition of PM2.5 and PM10-2.5**

- Black Carbon (BC)

The BC levels found in PM2.5 and PM 10 were in the range of 12-25 μg/m$^3$ and were the major component of fine fraction. As shown in Figure 11, the 4-h average BC concentrations during weekend and weekdays presented a peak during traffic morning and evening rush hours (6-10 am and 6-8 pm), which was similar to the PM2.5 concentration pattern.

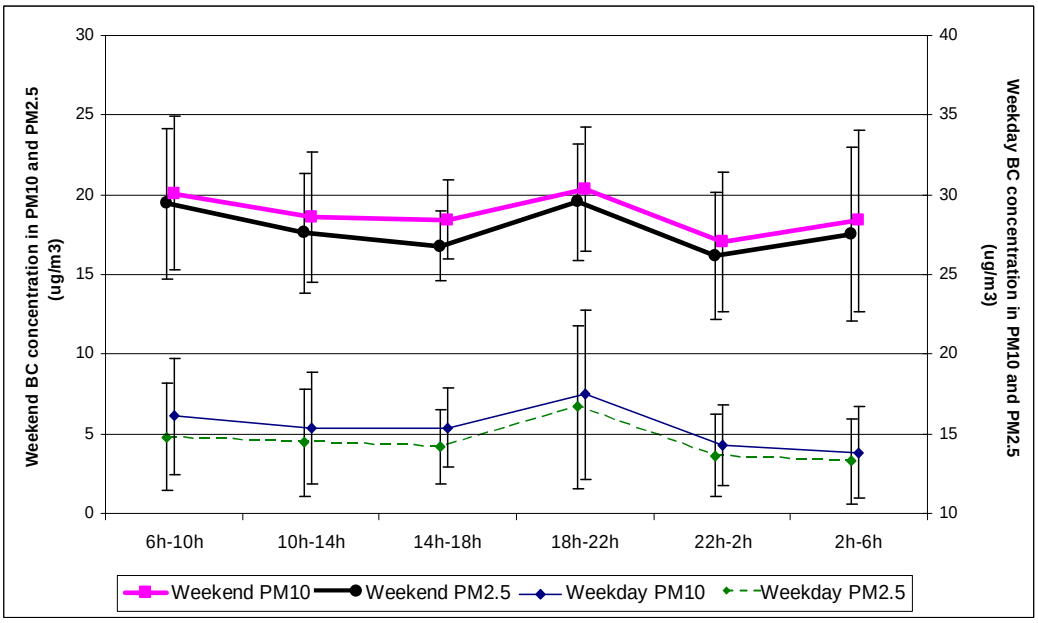
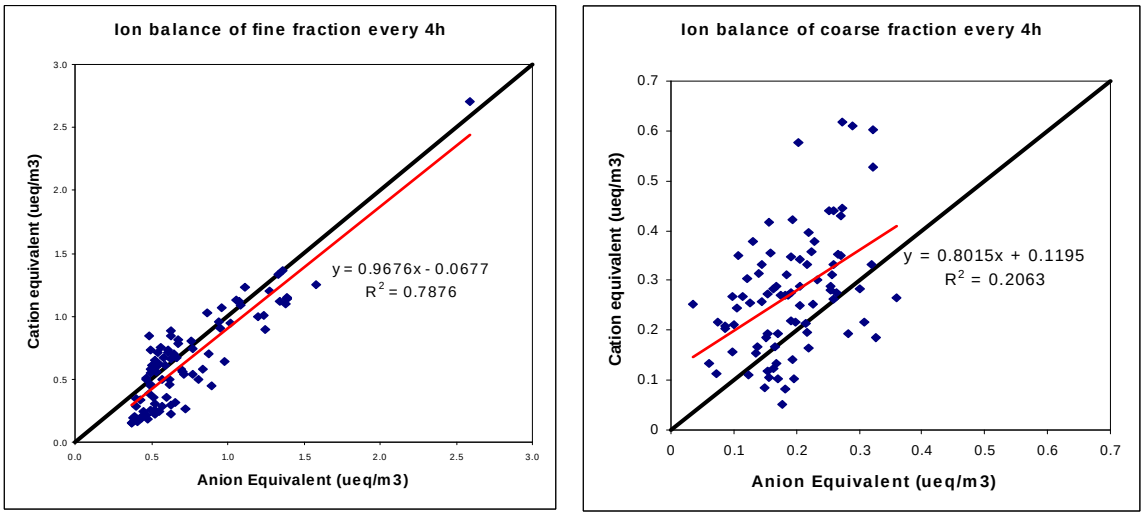



Figure 11. Fluctuation of 4–h BC concentration in PM2.5 and PM10 on weekend and weekday in Hanoi (whiskers represent one standard deviation of the 4-h BC)

- Ionic species

Among three anions ($Cl^-$, $NO_3^-$ and $SO_4^{2-}$) and five cations ($Na^+$, $NH_4^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$) measured, the results show that $SO_4^{2-}$, $NH_4^+$ and $NO_3^-$ are the major ionic components in PM2.5 whereas those in the coarse fraction were low. A relative equal ion balance (slope ~ 1.0) between cation and anions was obtained for fine fraction with a correlation of 0.8 (Figure 12a) while for coarse fraction the cations were slightly higher than the anions (Figure 12b).




a) b)

Figure 12. Ion balance of 4h-average fine fraction and coarse PM fraction

- Trace elements

Twenty elements (Fe, Ni, Pb, Sr, Ti, V, Zn, Si, Al, Be, Ca, Cd, Co, Cr, Cu, Li, Mg, Mn, Mo, Tl) were analyzed using the Inductively-coupled plasma optical emission spectroscopy (ICP-OES) at AIT. The results show that the fine fraction (PM2.5) mainly contained Zn, Si, Ca, Pb, Cr and Mn, whereas the major components of coarse fraction were Ca, Si, Mg and Fe. Nevertheless, all 24-h Pb concentrations in both coarse and fine particles were below the VN AAQS of 1.5 $\mu g/m^3$.

### *3.2 Source contribution to PM10 and PM2.5 in Hanoi*

The PM composition data sets were input into the PMF model to analyze for source contributions to PM2.5 and PM10 levels. Eight preliminary contributing sources to PM10 were identified in this study, namely diesel vehicle, oil combustion, industry I, industry II, construction, secondary particles, biomass burning, and aged sea spray. Diesel vehicles account for the highest contribution to PM10 (41%), whereas construction and soil together account for 28% of the mass (Figure 13).

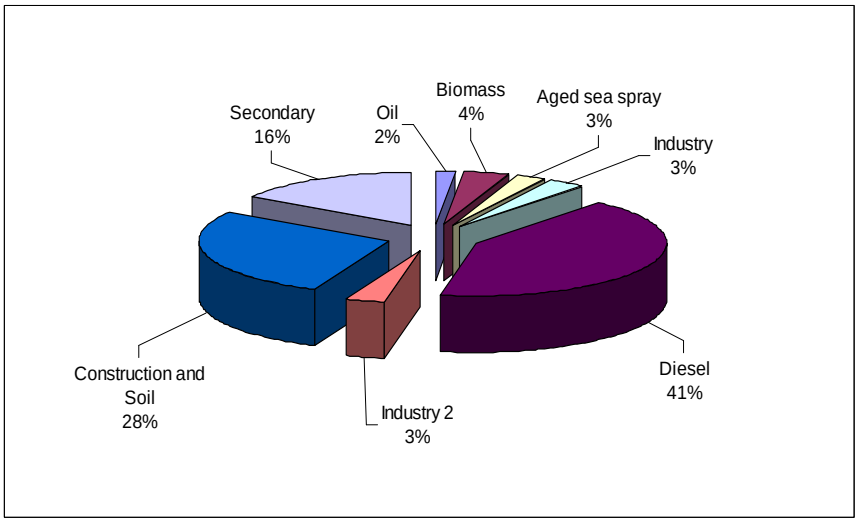



Figure 13. Source contributions for 24-h PM10 in Hanoi

Seven sources, which included diesel, oil, industry, construction, secondary, biomass and aged sea salt spray were determined by PMF model for PM2.5 source contribution (Figure 14). Diesel vehicles (40%) and secondary particles (40%) are the major contributors to PM2.5. Relative high correlation between the calculated mass and the measured mass was obtained (slope ~ 1.02; $R^2$ = 0.72).

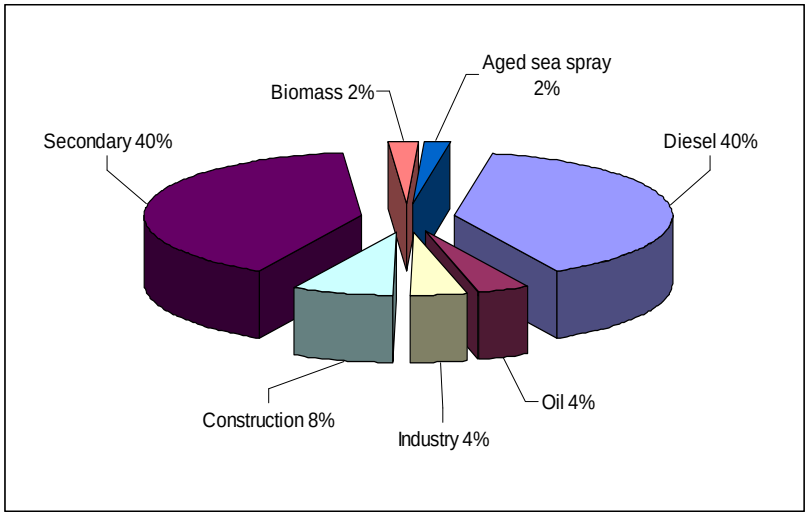



Figure 14. Source contributions for 24-h PM2.5 in Hanoi

Variations of source contributions with time during the sampling periods are shown in Figure 15. Diesel sources, for example, had rather constant contributions but some peaks are seen during the morning rush hours. Other sources have fluctuating contributions. Further data analysis including local sources and long-range transport contributions would be necessary to produce a better source apportionment for PM in Hanoi.

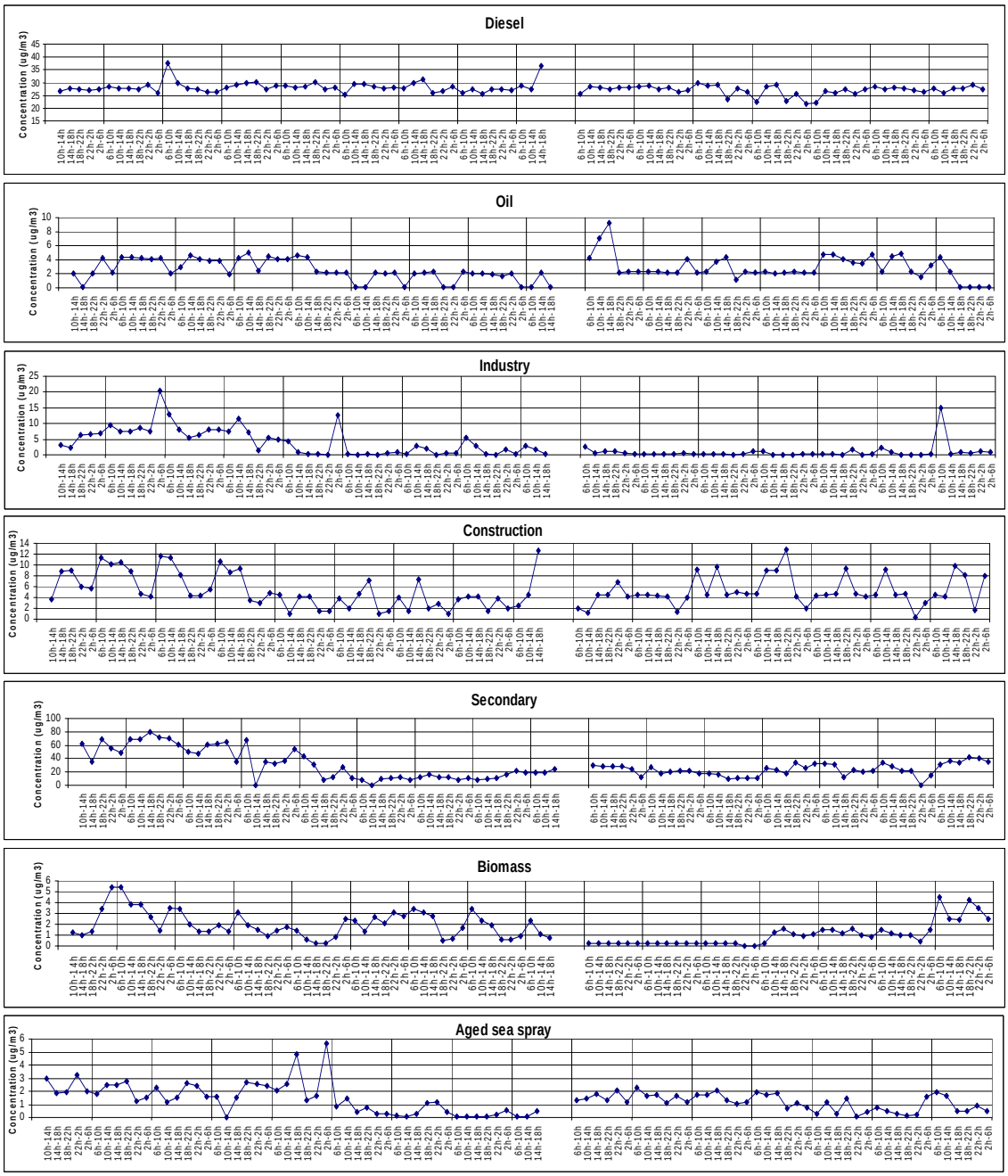



Figure 15. Temporal variations of source contributions to PM2.5 in Hanoi

### *3.3 Results of Monitoring in Bangkok Metropolitan Region (BMR)*

In BMR, a total of 137 pairs of 24h-PM2.5 and PM10-2.5 were collected during wet and dry season (15 May 2007 to 29 Feb. 2008) using two co-located dichotomous samplers. The sampling was carried out every 1-2 days for the whole study period. However, some equipment problems caused interruption during the period from 18 July to 17 September 2007. Like the Hanoi samples, the PM10 concentrations determined by dichotomous sampler in BMR were calculated by summation of fine fraction (PM2.5) and coarse fraction (PM10-2.5) and the mass concentrations of PM2.5 and PM10-2.5 along with their chemical compositions were also analyzed.

**Meteorological conditions**

Sampling campaign included 2 periods: May to October 2007, which represents the wet season, and November 2007 to February 2008, which represents the dry season.

During the wet season, highly intense and frequent rain was observed due to the influence of the southwest wind. October was the wettest month during the sampling period. Temperature in the wet period ranged from 23.5-30.2°C (Figure 16), which reached the highest value of 30.2°C on 13th August 2007. In the dry period, the temperature decreased as expected as the season transitioned from summer to winter. In this time the atmospheric pressure was higher due to an influence from high pressure over China. The temperature was in a range of 22.0-29.3°C with the lowest on 3rd February 2008 (22.0°C), while the temperature was highest on 18th December 2007 (29.3°C) in dry season. The average temperature and wind speed during sampling period is presented in Figure 16 and Figure 17.

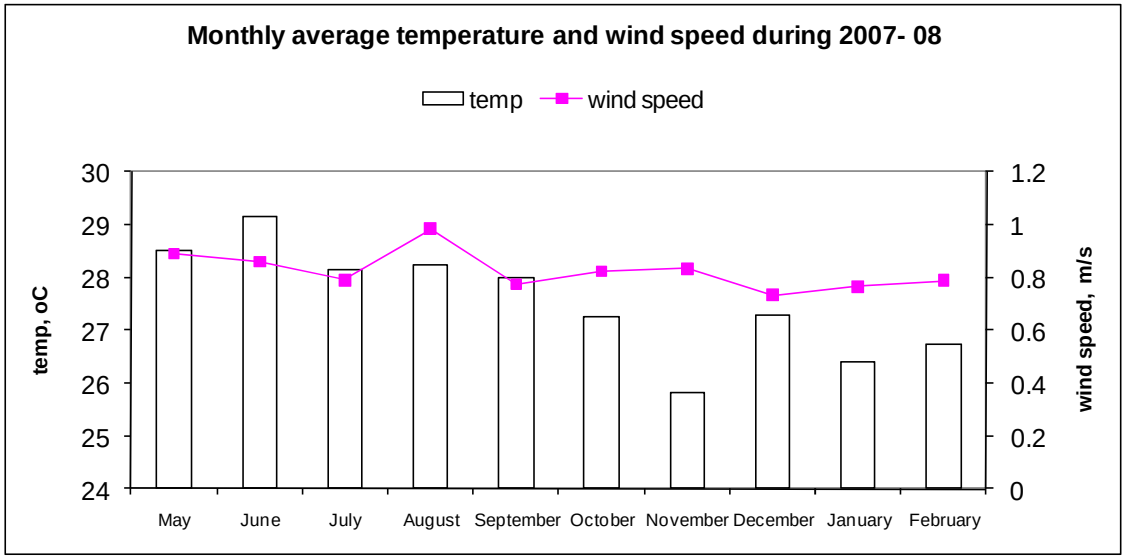



Figure 16. Monthly average temperature and wind speed during Jul 2007 to Feb 2008

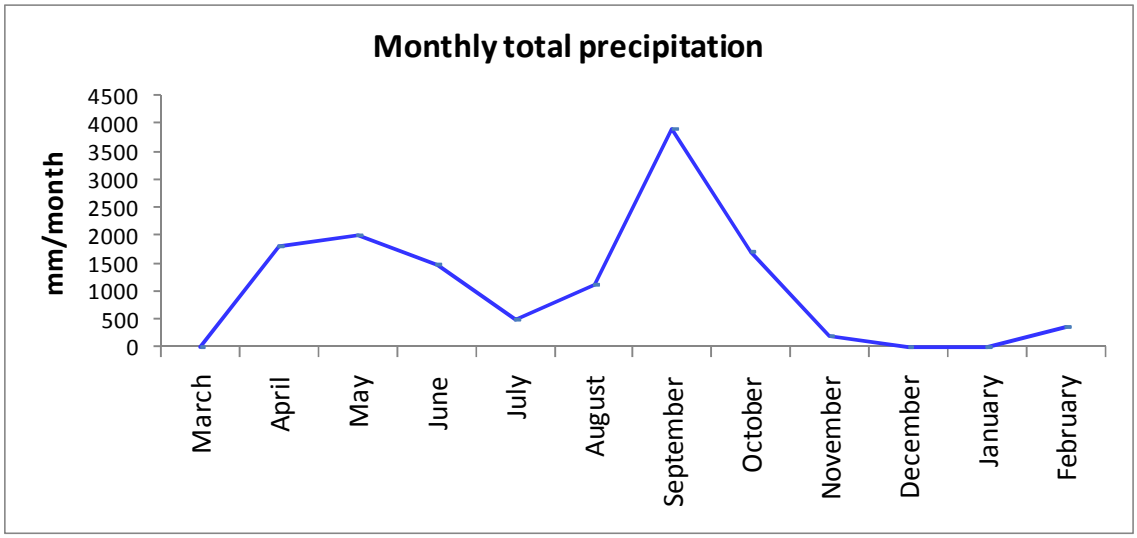



Figure 17. Monthly average precipitation during Jul 2007 to Feb 2008

**PM10 and PM2.5 concentration in BMR**

- Wet season

During the first sampling period, heavy rain was observed from May to the end of October 2007. Due to the rain, airborne particles were partly removed by wet removal process, and the particulate matter concentrations in this period were lower than those collected in dry season. In the wet season, the lowest 24-h average concentration of PM2.5 was 5 μg/m$^3$ (observed on 16th May 2007) and that of PM10 was 10 μg/m$^3$ (observed on 30th June 2007). As mentioned previously, the lowest 24-h average concentration of PM2.5 (19 μg/m$^3$ on 1th February 2008) and PM10 (40 μg/m$^3$ on 29th October 2007) in dry season was higher than those for the wet season.

- Dry season

During November 2007 to February 2008, the high atmospheric pressure areas, which brought a stagnant air condition, were presented. Activities such as biomass burning, high traffic congestion and firework for Chinese New Year celebration were observed for this period. As a result of these activities, the highest 24-h average concentration of both PM2.5 and PM10 were 85 μg/m$^3$ and 119 μg/m$^3$, respectively. There was no PM10 measurement exceeded the AAQS for 24-h average PM10 (120 μg/m$^3$) in both wet and dry season. There were 2 days in the wet season and 37 days in the dry season in which 24-h average PM2.5 exceeded the US EPA AAQS (35 μg/m$^3$). A comparison between PM10, PM2.5 concentration during the wet season and those during the dry season is shown in Figure 18.

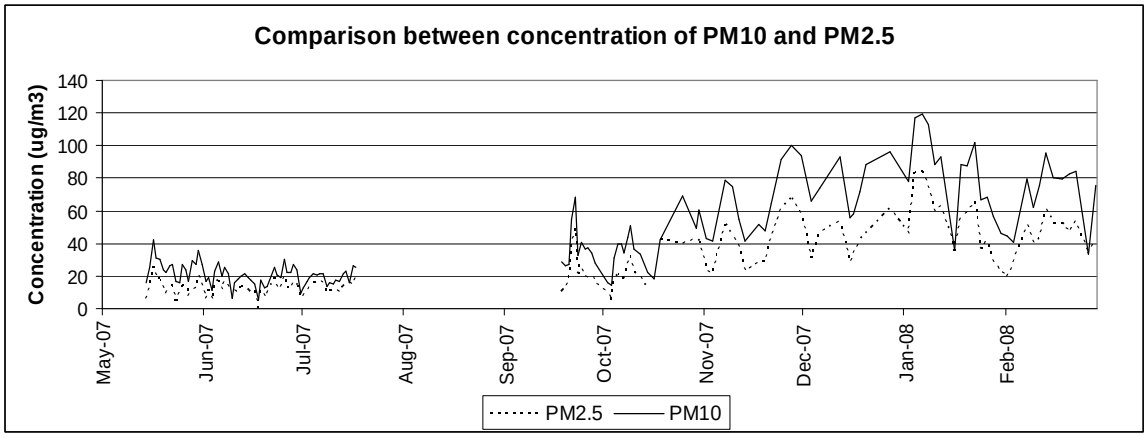



Figure 18.Comparison between 24-h average mass concentration of PM2.5 and PM10 in BMR

The ratio between PM2.5 to PM10 shown in Figure 19 was 0.71 with $R^2$ = 0.96.

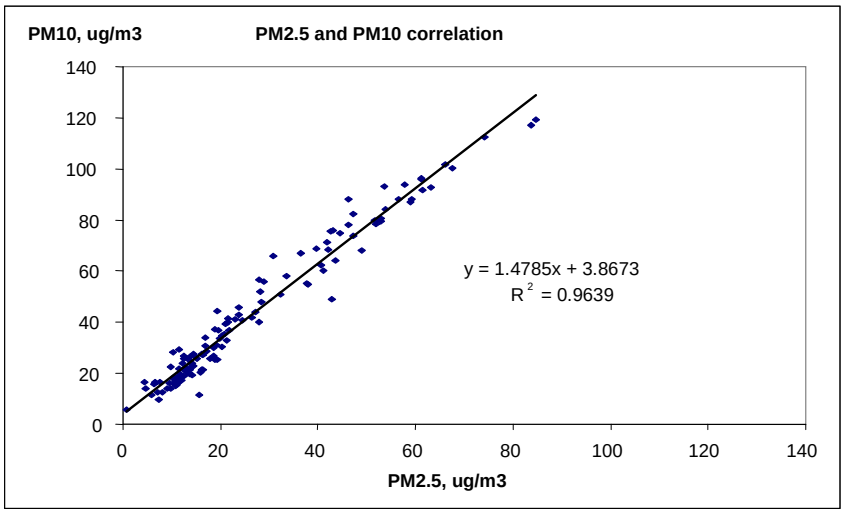
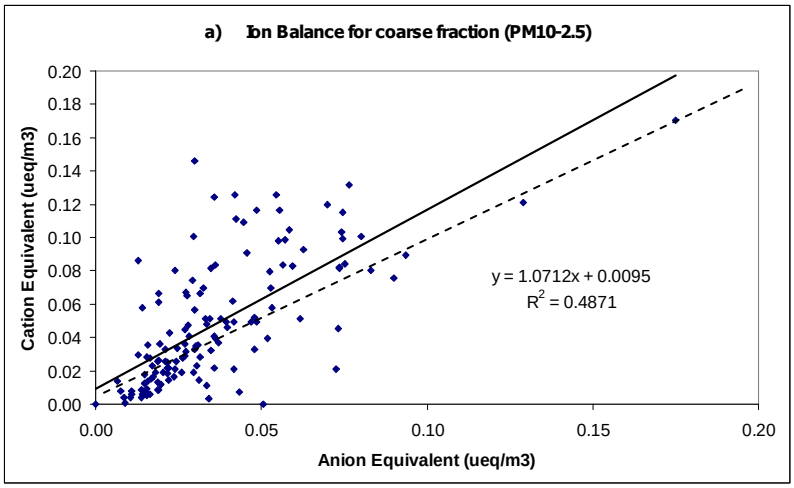



Figure 19.The relationship between $PM_{2.5}$ and $PM_{10}$ concentration

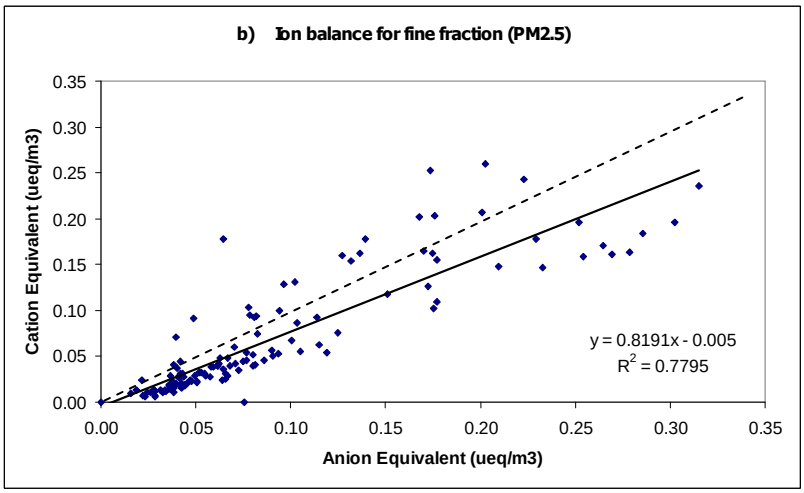
**Chemical composition of PM10-2.5 and PM2.5**

Ionic species consisting of seven anions ($F^-$, $Cl^-$, $NO_3^-$, $Br^-$, $NO_2^-$, $PO_4^{2-}$ and $SO_4^{2-}$) and six cations ($Li^+$, $Na^+$, $NH_4^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$) were analyzed by Dionex-1000 and Dionex-600 Ion Chromatography, respectively. Due to very low levels of $Li^+$ and $Br^-$, only eleven ionic species were reported.

In both wet and dry season, the most abundant species of PM2.5 was $SO_4^{2-}$ with the average concentrations of 2.16 and 5.57 μg/$m^3$, respectively. Secondary sulfate particles can also be formed from the chemical reactions, e.g. $(NH_4)_2SO_4$ is formed in the reaction between ammonia vapor and sulfuric acid. In addition, $NO_3^-$ and $NH_4^+$ also constituted a significant portion in PM2.5. The primary source of $NH_4^+$ might be from the agriculture activities surrounding the sampling site. In PM10-2.5, the most abundant was $NO_3^-$ in wet season with the average concentration of 1.0 μg/$m^3$ while in dry season was $Ca^{2+}$ (1.4 μg/$m^3$). The average concentrations of $NO_3^-$ , $SO_4^{2-}$ and $NH_4^+$ in the fine fraction were higher than those in the coarse fraction, whereas $Mg^{2+}$ and $Ca^{2+}$ concentration in the coarse fraction were higher than those in the fine fraction. Average concentrations of $NO_2^-$ were almost equal in both fine and coarse fraction. The Ion balance showing a correlation between sum of anions and cations equivalent for all PM10-2.5 and PM2.5 samples (137 pairs of quartz filter) as seen in Figure 20a and b.




a)




b)

Figure 20. Anion and Cation concentration balance for $PM_{10-2.5}$ (a) and $PM_{2.5}$ (b) at AIT

Higher correlation coefficient between anion and cation of PM2.5 ($R^2$ = 0.75) was observed than that for PM10-2.5 ($R^2$=0.49). The result of ion balance in PM10-2.5 shows that the concentration of cationic species are slightly higher than anionic species (Figure 20a). However, higher anions (acidic) were present for fine samples (Figure 20b). In coarse particles, the anion shortage might have been caused by unanalyzed carbonate ions from soil, while lower cation contribution in fine particles was probably caused by hydrogen ions. The results also suggest that the coarse particles in most samples were neutral or alkaline, where the fine particles in most samples were neutral or acidic due to high observed concentrations of $NO_3^-$ , $Cl^-$ and $SO_4^{2-}$ in fine particles.

**Element compositions**

Mixed cellulose ester filters with a low matrix blank were used to collect PM2.5 and

PM10-2.5 samples for elements analyzes. The trace elements were determined by using PerkinElmer ICP-OES, with which twenty elements (Fe, Ni, Pb, Sr, Ti, V, Zn, Si, Al, Be, Ca, Cd, Co, Cr, Cu, Li, Mg, Mn, Mo, Tl) were analyzed. The elements, whose concentration was higher in coarse fraction than in the fine fraction, included Ca (1,055 and 174 ng/m3, respectively), Al (179 and 66 ng/$m^3$, respectively), Si (164 and 105 ng/$m^3$, respectively), Fe (149 and 102 ng/$m^3$, respectively) and Mg (97 and 34 ng/$m^3$), respectively. The elements of V, Zn, Mn and Tl were found higher in fine fraction than the coarse fraction.

**EC, OC concentration in PM2.5 in BMR**

The time series of daily EC, OC and OC/EC ratio in PM2.5 during one year campaign in BMR (2007-08) is show in Figure 21. In the wet season (Apr – Oct), daily OC and EC ranged from 2 – 16.3 ug/$m^3$ (avg. 8.7 ug/$m^3$) and 0.6 – 7.5 ug/$m^3$ (avg. 4.9 ug/$m^3$), respectively, and measured 4.8 – 32.4 ug/$m^3$ (avg. 20.1 ug/$m^3$) and 1.7 – 13.7 ug/$m^3$ (avg. 9.1 ug/$m^3$) in the dry season (Nov - Mar). OC maybe directly emitted from biomass burning and fluctuated highly in the dry season. The OC/EC ratios were almost similar in both wet and dry season, which are 3.2 and 3.5, respectively. Several abnormal high OC/EC ratios were observed when biomass burning smoke was observed at the areas surrounding the sampling.

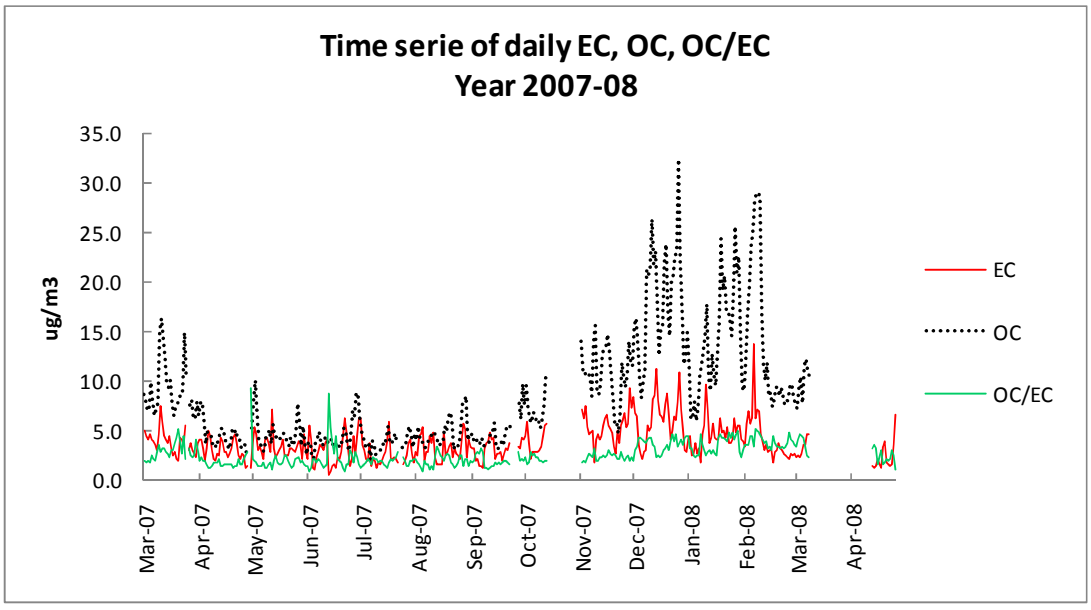



Figure 21. Time series of daily EC, OC and OC/EC in PM2.5 at BMR site during 2007-08

Monthly variations of OC and EC during one year (2007-08) are presented in Figure 22, show that, in general, both the EC and OC concentrations were lower from April to October (wet season) and increased from November to March (dry season). However, OC levels during the dry season increased significantly, while EC levels were slightly higher than wet season. In the wet season, the EC concentrations ranged between 2.7 – 4.1 μg/$m^3$ with the average of 3.3 μg/$m^3$. For OC concentration, the variation was from 3.9 – 11.3 μg/$m^3$ with the average of 5.9 μg/$m^3$. The EC and OC results for the dry season were 4.0 – 5.7 μg/$m^3$ (average 4.8 μg/$m^3$) and 7.7 – 17.2 μg/$m^3$ (average 12 μg/$m^3$), respectively.

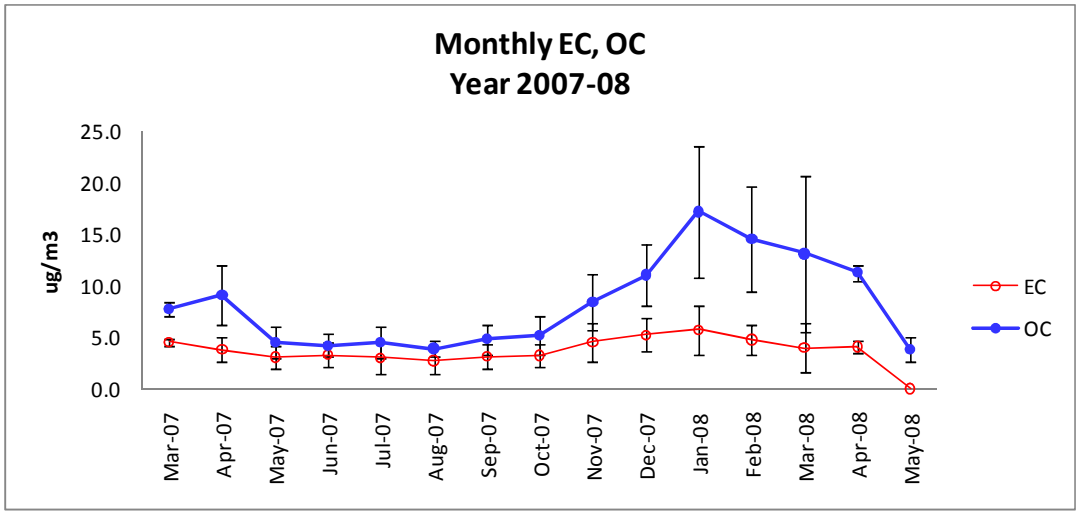



Figure 22. Monthly variations of EC and OC during one year 2007-08

A summary of seasonal EC, OC and OC/EC during the monitoring period is stated in Table 3.

Table 3. Seasonal data of EC, OC and OC/EC ratio year 2007-08

| **Wet season (April-October)** | | | |
|---|---|---|---|
| | **EC** | **OC** | **OC/EC** |
| Min | 2.7 | 3.9 | 1.7 |
| Max | 4.1 | 11.3 | 3.2 |
| Average | 3.3 | 5.9 | 2.3 |
| STDEV | 0.4 | 2.7 | 0.5 |
| **Dry season (November-March)** | | | |
| Min | 4.0 | 7.7 | 1.9 |
| Max | 5.7 | 17.2 | 3.9 |
| Average | 4.8 | 12.0 | 2.9 |
| STDEV | 0.6 | 3.6 | 0.9 |

Average diurnal variations of EC concentrations along the year in BMR are presented in Figure 23. In both wet and dry seasons, a high EC concentration was generally found during the morning (6-8 am) and evening hours (7-10 pm). High vehicle density in rush hours and heavy duty trucks permitted to enter the city after 9 pm may be the cause of EC peaks during these periods. EC levels were within 1.6 – 5.3 $\mu g/m^3$ (avg. 3.2 $\mu g/m^3$) in the wet season while those were 2.3 – 8.2 $\mu g/m^3$ (avg. 4.9 $\mu g/m^3$) in the dry season.

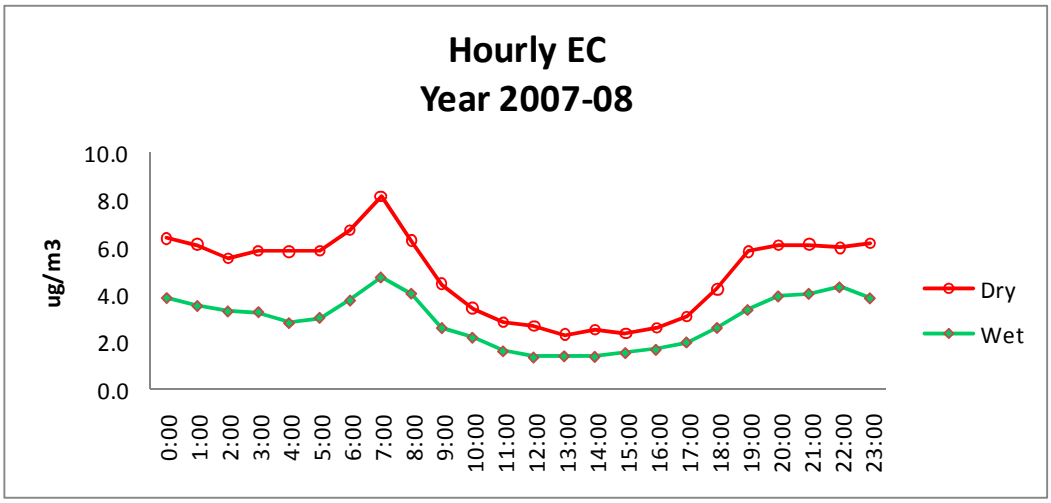



Figure 23. Diurnal variations of hourly EC concentrations

The diurnal OC concentrations for wet and dry seasons were different from those for EC as shown in Figure 24. During wet season, low and relatively constant OC concentration was observed, which were from 4.3 – 6.9 μg/m$^3$. The OC concentrations were higher during dry season (9.4 – 17.1 μg/m$^3$). In addition, concentrations tended to elevate from the evening (after 6 pm) until next morning (7 am) since open biomass burning (rice straw, grass) normally took place around the area at this time of the day. Open biomass burning of agro-residue occurs during afternoon time and early evening when the soil was drier.

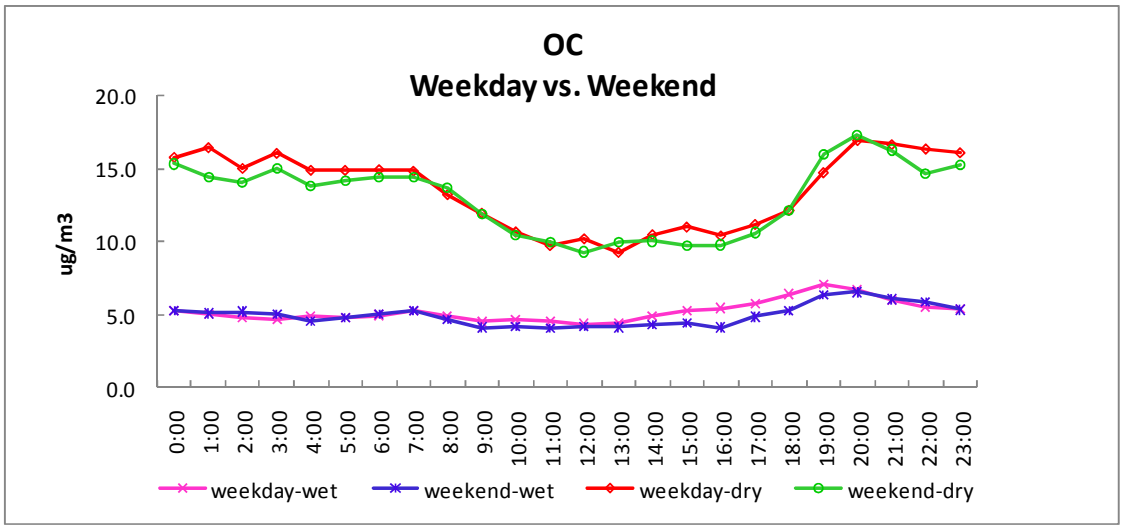



Figure 24. Diurnal variations of hourly OC concentrations

Some light rains were observed during the dry season sampling period and produced interesting effect on EC and OC concentrations. Figure 25 and Figure 26 show diurnal OC and EC concentrations on the rainy days as compared to the dry days. On the dry days (without rain), higher OC concentrations were observed during afternoon time and early evening. This may link to more photochemical reactions leading to the formation of the secondary OC on dry days. Also, there may be more open biomass burning during dry days. This together may bring about higher OC concentration in

dry weather. For EC, there was no significant difference in EC concentration between the rainy days and dry days. This suggests that the major source of EC could be traffic, which does not change much with weather conditions especially when light rains were reported.

It was also observed that high OC concentrations were generally associated with stronger wind (> 2m/s), whereas high EC concentrations were normally observed with low wind speed (<0.5 m/s). Thus, high OC may be brought in from the open burning located at some distance (10-20 km in radius) from the monitoring site, while EC may be emitted from the traffic over the highway nearby (0.6 km).

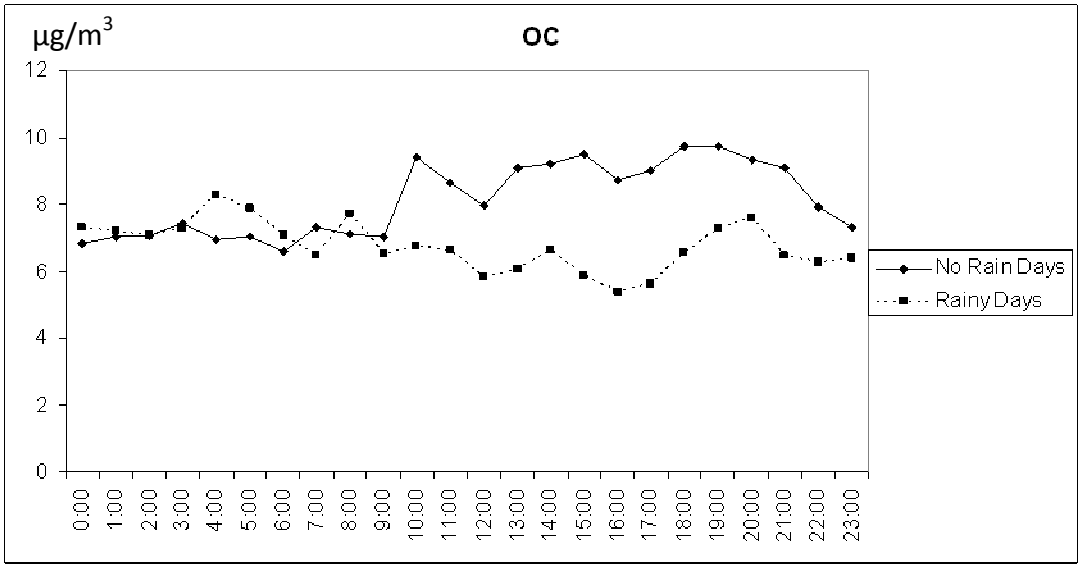



Figure 25. Diurnal OC concentration on the rainy day and dry days during the dry season in BMR

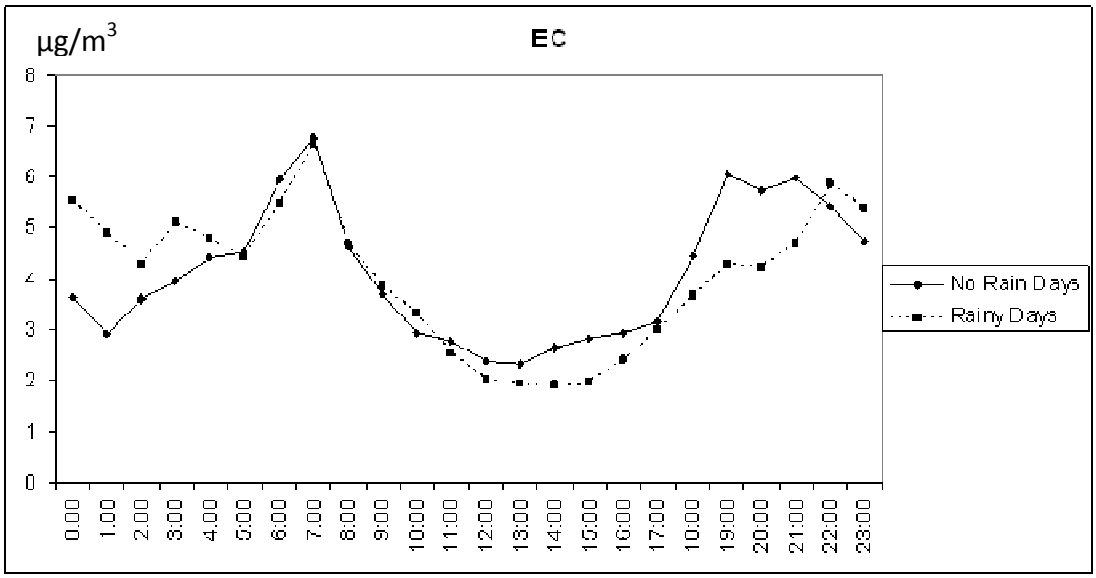



Figure 26. Diurnal EC concentration on the rainy days and dry days during the dry season in BMR

**Comparison between COSMOS and OC/EC analyzer**

A comparison between BC concentrations measured by COSMOS (prototype by RCAST-UT) and EC concentrations by OC/EC analyzer (Sunset lab) showed a good agreement between the measurements with a slope of 0.996 and $R^2$ of 0.96 (Figure 27).

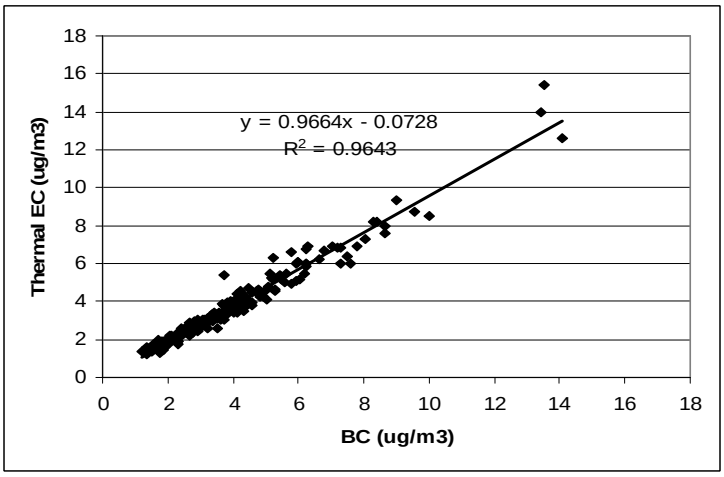



Figure 27. Correlation between BC by COSMOS and EC by OCEC analyzer

**CO concentration**

Diurnal variation of CO concentration in BMR is presented in Figure 28. The morning hour (6-8 am) peak is not visible in CO, due to elevated background caused by transportation and extensive biomass burning, with other features similar to OC.

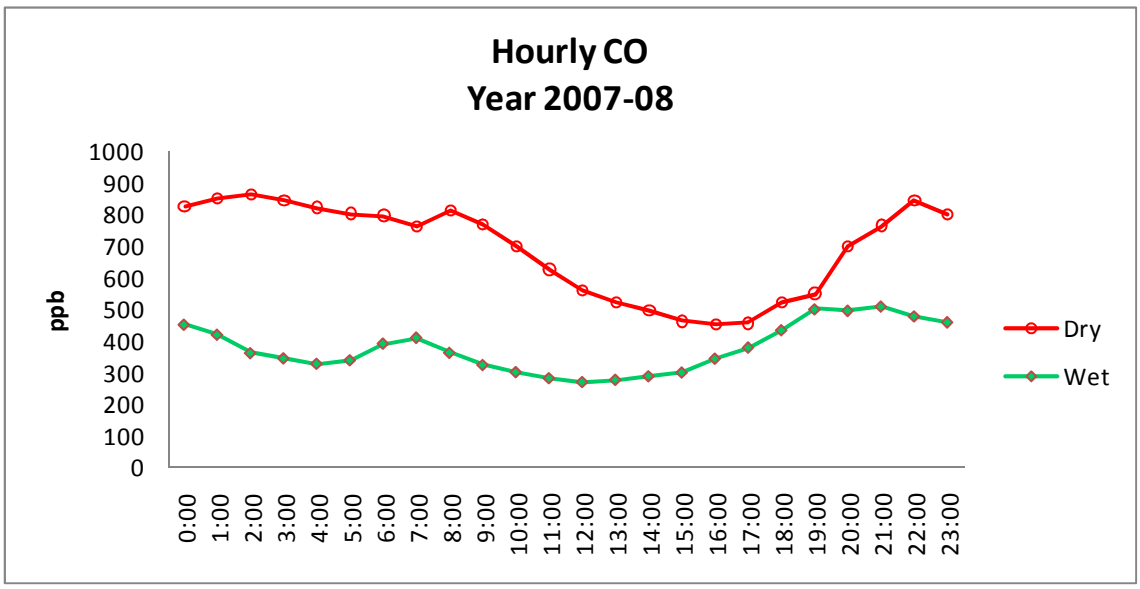



Figure 28. Diurnal variation of CO concentration in BMR

Similar to the diurnal variations, EC, OC and CO concentrations during weekday and weekend (Figure 29- Figure 31) in dry season were also higher than the wet season. In general, there was no significant difference between weekday and weekend EC, OC and CO concentrations. This suggests that the intensity was same from impacts of

traffic emission, as well as fossil fuel and biomass burning during weekdays and weekend.

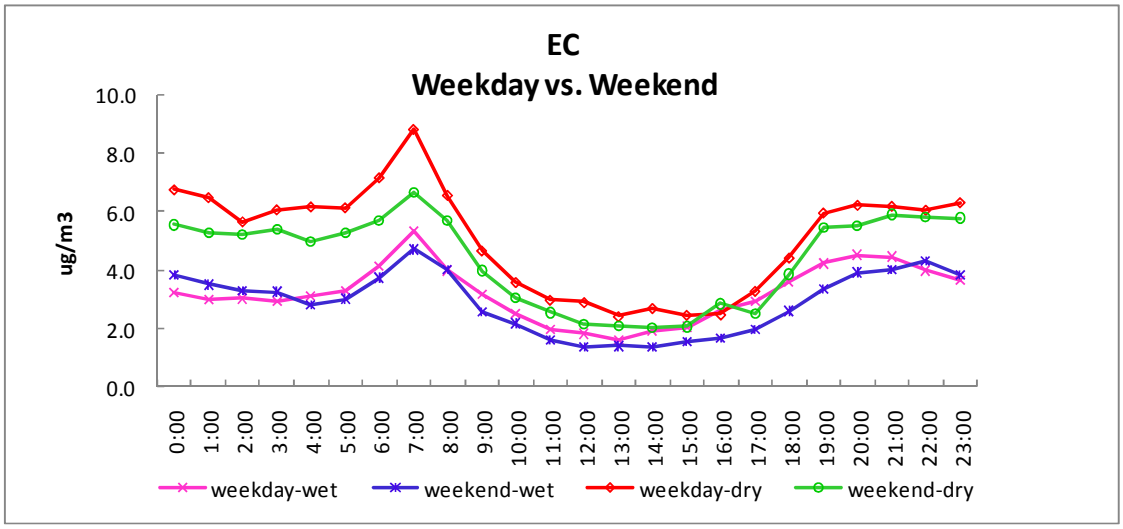



Figure 29. EC variation during weekday and weekend, dry versus wet season

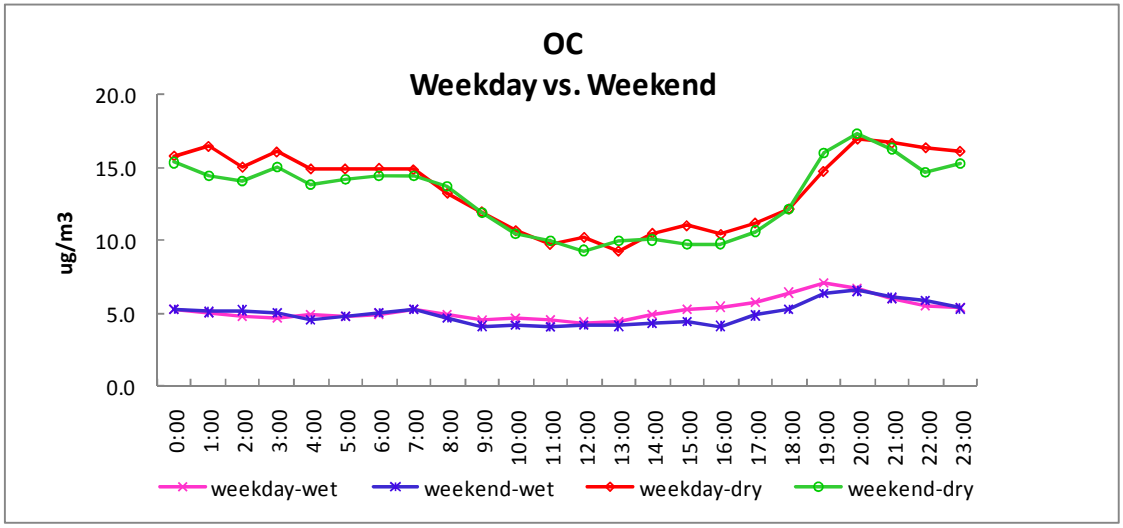



Figure 30. OC variation during weekday and weekend, dry versus wet season

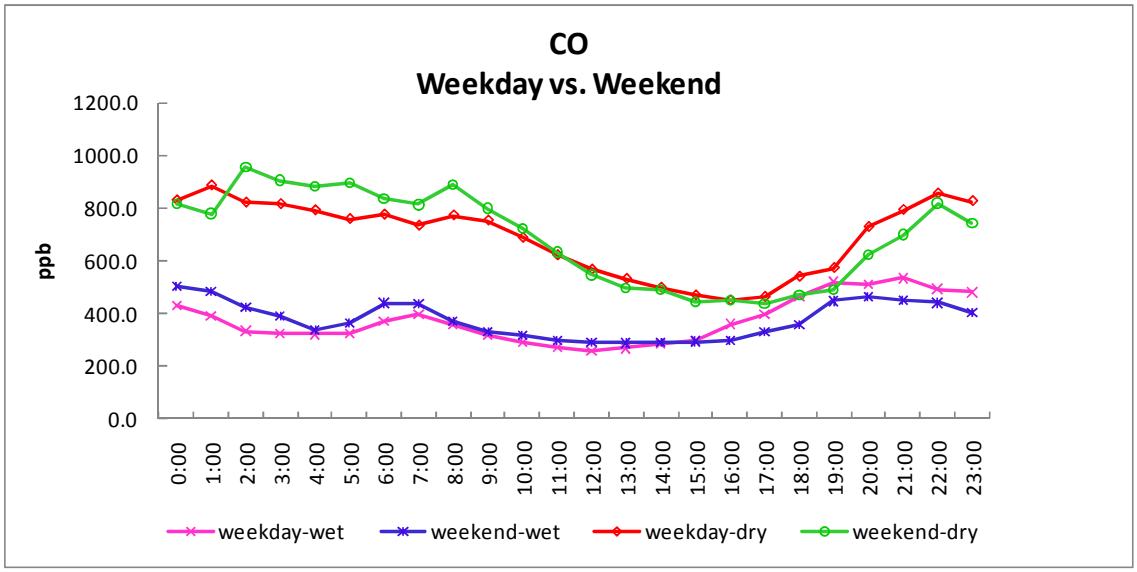


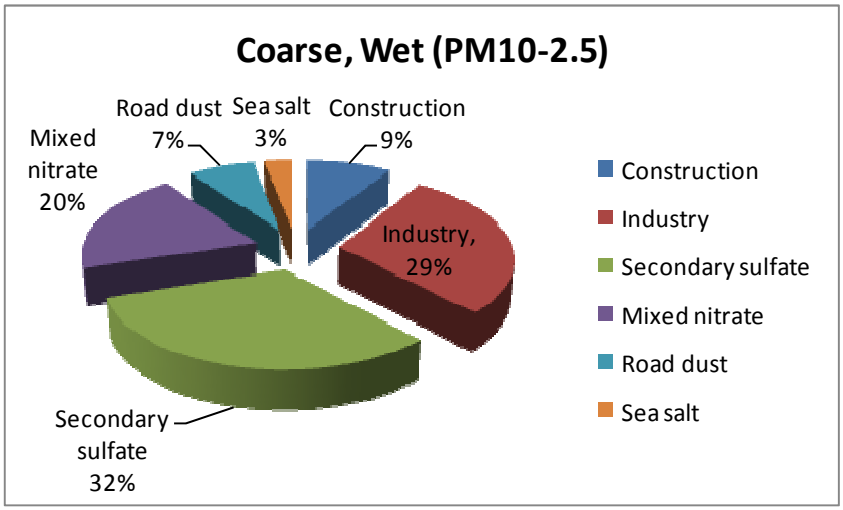

Figure 31. CO variation during weekday and weekend, dry versus wet season

### *3.4 Source contribution to PM2.5 and PM10-2.5 in BMR*

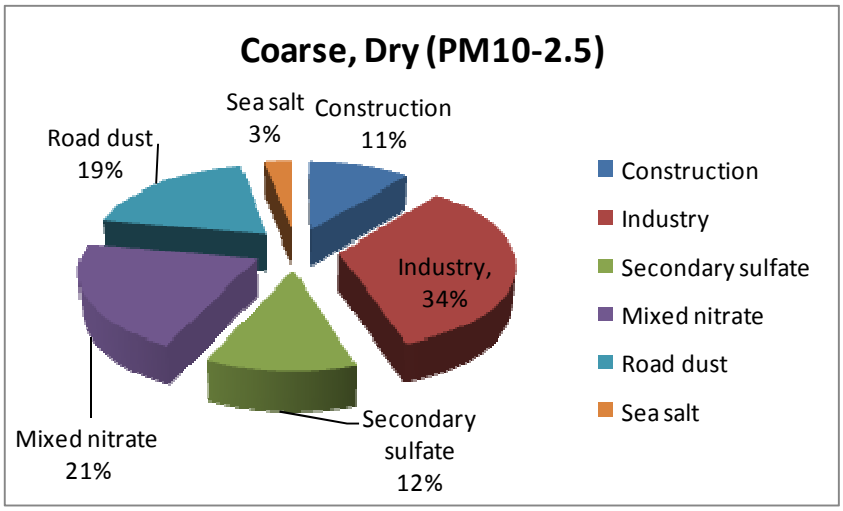
This source apportionment study was based on 24-h sampling using 2 dichotomous samplers to specifically identify the leading contributing sources in wet and dry seasons. PMF2 model was applied to obtain the source apportionment for PM10-2.5 and PM2.5. Mass concentration, chemical compositions (i.e. black carbon, ionic species, and elemental concentration) and their uncertainties of 24-h sampling samples were the inputs for PMF. For duplicate chemical components i.e. $Cl^-$ and Cl, or $Mg^{2+}$ and Mg, only $Cl^-$ and $Mg^{2+}$ were selected for the input. Rotation of factor was done to obtain a best-fit of results. The output of PMF was shown in terms of source contributions and source profiles

For coarse PM, the PMF identified six contributing sources including construction, industry, secondary sulfate, secondary nitrate, road dust and sea salt for both wet and dry seasons. The first source profile contains large fraction of calcium and black carbon, which can be indicated as construction activities (Figure 32a). This is because the sampling site is located close to a construction site, where construction activities were intensively deployed. This source accounts for 9% (10 $\mu g/m^3$) and 11% (28 $\mu g/m^3$) of total mass in wet and dry season, respectively. The second source profile is considered as industry source due to high portion of black carbon, copper, lead and silicon, which accounts for 29% and 34% of total mass in wet and dry season, respectively, and contributed the highest to PM10-2.5. The third and forth source profile are secondary sulfate and mixed nitrate which contributed 32% and 12% of sulfate, 20% and 21% of nitrate in wet and dry season, respectively. High portion of black carbon, potassium, iron, zinc and aluminum was observed in fifth source profile, road dust, accounts for 7% in wet season and 19% in dry season of PM10-2.5 mass. The last source profile, sea salt, was identified by high portion of sodium and calcium. As shown in Figure 32a and b, most of these sources contributed highly during dry season than wet season with the exception of secondary. High mixed nitrate was observed during the beginning of year 2008, which may be attributed to the burning of fire crackers on New Year celebration. High sea salt levels were observed during

February. Road dust and construction have the same contribution, possibly due to the presence of heavy-duty trucks in the construction site in the area.




a)

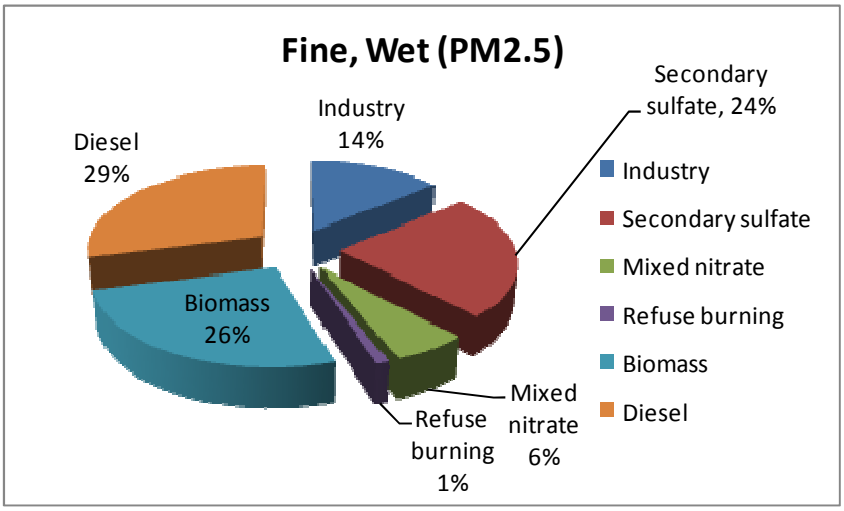



b)

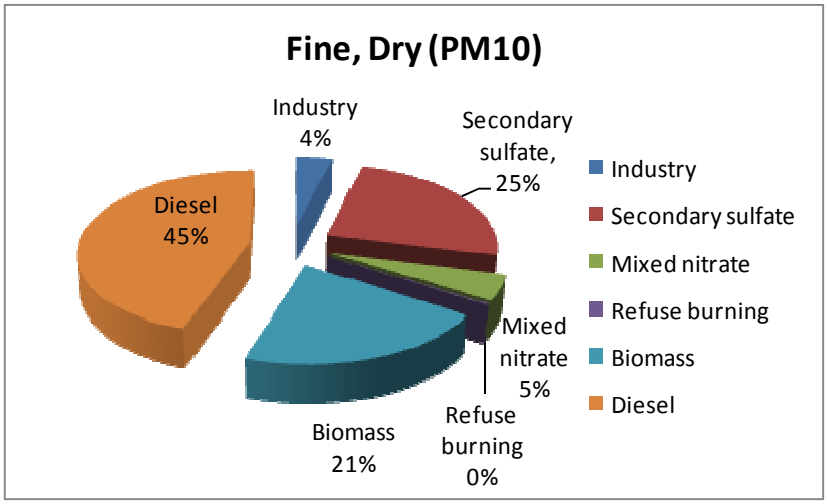
Figure 32. Source apportionment for Coarse PM in wet a) and dry b) season in BMR

For fine PM, six sources were also identified during wet and dry season, which are secondary sulfate, road dust, secondary nitrate, biomass burning, industry and diesel exhaust (Figure 33a and b). The first source profile is secondary sulfate, which has large portion of ammonium and sulfate. This source accounts for 24% in wet season (15 μg/m$^3$) and 25% of total PM 2.5 mass in dry season (46 μg/m$^3$). The second profile is refuse burning, which contains high portions of black carbon, silicon, iron, and potassium. This source accounts for only 1% and 2% in wet and dry season, respectively. Mixed nitrate may possibly be the third source, which categorized by the high portion of nitrate and sodium (6% and 5 % if total PM mass in wet and dry season, respectively). The forth source profile was biomass burning due to high portion potassium and black carbon. It accounts for 26% and 21% (in wet and dry,

respectively) of PM2.5 mass. The high contributions of this source were generally observed during the dry season, due to the high frequency of agro-residuals (especially rice straw) burning during that period. The fifth source profile is industry, which has large portion of zinc, iron, lead and copper. This source accounts for 14% and 4% (in wet and dry, respectively) of PM2.5. The highest contribution for PM2.5 is diesel exhaust, which has high portion of black carbon, iron and zinc, accounts for 29% in wet and 45% in dry season of fine fraction mass. All sources had higher contribution in dry season, especially secondary nitrate and sulfate, as they can be formed in the atmosphere under high solar radiation. High fluctuation of diesel was observed particularly during December. During dry season, significant biomass burning was observed while only small burning occurred in wet season.




a)




b)

Figure 33. Source apportionment for Fine PM in wet a) and dry b) season in BMR

## 4 Conclusions

This research project generated data that contribute to a better understanding of the air pollution levels and the climate relevant aerosol properties in Bangkok and Hanoi Metropolitan Regions. The PM levels in Hanoi are high during the dry season, with all PM2.5 measurements exceeding the US EPA 24-h standard of 35 $\mu g/m^3$. Normally, the levels of CO and PM are high in the morning and evening during rush hours (6-10 am and 8-10 pm), when road traffic and residential cooking activities are more intensive. Receptor modeling revealed that major sources contributing to high levels of PM2.5 in the city are diesel vehicles and secondary inorganic particles. In BMR, the EC concentration in PM2.5 was higher during the morning (6-7 am) and early evening (7-10 pm), which may link to the contribution from traffic emission. OC concentration tended to elevate during afternoon and evening, especially on dry days, which suggest the contribution from biomass open burning as well as photochemical reactions.

High EC concentrations in the atmosphere of both cities suggest that the climate forcing strength of the aerosols in the region may be significant. Diesel vehicles may be one of the leading sources contributing to this EC levels. As EC is an important air pollutant parameter in terms of health effects and climate forcing, reducing EC emission would benefit clean air and reduce the potential for climate warming. To this end, a concerted effort towards vehicle technology improvement, traffic management and the formation and effective implementation of public policies is necessary.

During the past 2 years, the project has contributed successfully to the capacity building by making available training programs for AIT students and staffs as well as providing financial support (fellowship) to young researchers. The workshops and scientist exchange visits between AIT, HUS and TU have fostered strong networks between the institutions that are essential for project cooperation activities. The participants from partner institutions, international experts, local experts, UNEP and AIT students attending the workshops benefited from its presentations and discussions. The data collected by the project as well as the equipment for OC/EC measurements were demonstrated to the AIRPET research partners and other AIT collaborators who visited the measurement site, which generated strong interest. The APN research partners also indicated that they plan to do similar air pollution and climate change research in the future. This demonstrates the high potential to sustain the project activities in the future. The final results had been disseminated to a wider audience, including policy makers and researchers at the BAQ08 conference. The project findings enhance the understanding among researchers and policy makers in the region of the opportunities of co-control for the air quality and climate change co-benefits, especially through measures to reduce black carbon emission

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## Appendix

## Appendix 1

Launching Workshop at AIT, Bangkok, Thailand

Launching Workshop of Workshop of APN2006-13NMY Project:

"INVESTIGATION ON THE IMPACTS OF URBAN-RURAL AIR POLLUTION ON AIR QUALITY AND CLIMATE IN SOUTHEAST ASIA"

**Interaction between Air Pollution and Climate: Aerosol and Climate**

Venue: Room B206, AITCC, Pathumthani, Thailand

Time: April 2, 2007

**Background**

Air pollution is directly related to human health, food production, ecosystem, and climate. In Southeast Asian countries, air pollution is becoming more and more serious as economy develops. In order to develop control strategies it is important to characterize and evaluate anthropogenic emission sources and to understand behavior of key chemical species and aerosols. Complexity in the interaction of urban and rural air pollution plumes emitting from multiple sources calls for increasing scientific research. Recently, attention is paid to the rural or suburban sources such as open biomass burning which may contribute significantly to the atmospheric brown clouds hence consequently affecting regional air quality and climate. Despite the importance of these systematic measurements and studies, data in Southeast Asia are still quite limited.

The goal of this research project is to start high temporal resolution of measurements of selected important ambient species (OC/EC in aerosols, CO, etc.) to provide reliable data to assess current air pollution status in Southeast Asia and potential climate forcing. This will also provide the basis to establish the emission inventory for black carbon and particulate matter emissions, which are not yet available in the region. The source apportionment study will be carried to assess the contributions of different urban and rural sources to ambient air pollution at study areas. The following activities are planned:

- Measurements and analysis of ambient air pollution for climate change properties and health hazards,
- Identification of the major sources of selected pollutants in the urban area,
- Trainings for the research partners from developing countries in the network, and
- Dissemination of the results to policy makers, scientific and publics

This project is implemented by a project teams consisting of 3 institutions:

1. Environmental Engineering and Management

School of Environment, Resources and Development

Asian Institute of Technology

Pathumthani, 12120, Thailand

Dr. Nguyen Thi Kim Oanh, kimoanh@ait.ac.th, Project Leader.

2. Research Center for Advanced Science and Technology (RCAST), University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan

Prof. Yutaka Kondo, kondo@atmos.rcast.u-tokyo.ac.jp

3. Faculty of Environment Sciences, Hanoi University of Science (HUS),
334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam
Dr. Hoang Xuan Co, hxco@netnam.org.vn

The launching workshop aims at setting a framework for the collaboration within this project. This is an opportunity for 3 research partners to meet and discuss in detail the planned activities and workplan. This also serves as a forum to disseminate the innovative project ideas to potential collaborating data users in the region.

Interaction between Air Pollution and Climate: Aerosol and Climate

**Workshop Technical Program**

1. Registration: 8:30-9:00
2. Opening: 9:00-9:30
   - Overview of the APN project and workshop objectives: Dr. Kim Oanh (5 mins)
   - Welcome remarks: Professor Sivanappan Kumar, DEAN of SERD
   - Opening remarks: Professor Peter Haddawy, AIT VP-AA
   - Coffee break: 9:30-10:00
3. Morning session: 10:00-12:00; Chair: Prof. Wongpun Limpasani

   Keynote lecture: Prof. Yutaka Kondo, RCAST, The University of Tokyo (40 mins): *Interaction between air pollution and climate: technological and policy measures to address back carbon particle emissions*
   - Presentation 1: Dr. Kim Oanh, AIT (25 mins)

     *Particulate air pollution in Asian countries: sources and composition*
   - Presentation 2: Dr. Yuzo Myazaki, RCAST, The University of Tokyo (25 mins)

     *Issues of primary and secondary aerosols: analytical methodology development*
4. Lunch break: 12:00-13:30, lunch served at AITCC restaurant
5. Afternoon session: 13:30-16:30; Chair: Dr. Kim Oanh
   - Presentation 3: Dr. Prapat Pongkiatkul, AIT (25 mins)

     *Source apportionment studies of ambient particulate matter using receptor models*
   - Presentation 4: Ms. Sunghee Han, The University of Tokyo (25 mins)

     *OC/EC measurements in China*
   - Presentation 5: Mr. Mylvakanam Iyngararasan , UNEP Regional Resource Center for Asia and the Pacific (RRC.AP) (25 mins),

     *Overview of Atmospheric Brown Cloud project*
   - Presentation 6: Dr. Hoang Xuan Co, Hanoi University of Science, Vietnam (25 mins)

     *Air quality management in Vietnam: current status and challenges*
   - Coffee break: 15:10-15:30
   - Presentation 7: Dr. Savitri Garivait (25 mins)

     *Emission inventory for biomass open burning in Thailand*
   - Presentation 8: Mr. Le Hoang Nghiem, (25 mins)

     *Application of CMAQ-MM5 for simulation of air quality in South East Asia*
6. Workshop reception: 18:00-20:30

**List of Participants**

| | Name | Institutions |
|---|---|---|
| 1 | Dr. Nguyen Thi Kim Oanh | Asian Institute of Technology |
| 2 | Dr. Prapat Pongkiatkul | Asian Institute of Technology |
| 3 | Mr. Le Hoang Nghiem | Asian Institute of Technology |
| 4 | Prof. Yutaka Kondo | University of Tokyo |
| 5 | Dr. Yuzo Miyazaki | University of Tokyo |
| 6 | Ms. Sunghee Han | University of Tokyo |
| 7 | Dr. Hoang Xuan Co | Hanoi University of Science |
| 8 | Dr. Wongpun Limpaseni | Chulalongkorn University |
| 9 | Dr. Savitri Garivait | King Mongkut's University of Technology |
| 10 | Ms. Mega Octaviani | King Mongkut's University of Technology |
| 11 | Mr. Mylvakanam Iyngararasan | UNEP RRC.AP |
| 12 | Dr. Arpa Wangkiat | Rangsit University |
| 13 | Ms. Worrarat Thiansathit | Asian Institute of Technology |
| 14 | Mr. Danutawat Tipayarom | Asian Institute of Technology |
| 15 | Ms. Aungsiri Klinmalee | Asian Institute of Technology |
| 16 | Mr. Prapat Pentamwa | Asian Institute of Technology |
| 17 | Mr. Thongchai Kanabkaew | Asian Institute of Technology |
| 18 | Ms. Thipsukon Khumsaeng | Asian Institute of Technology |
| 19 | Ms. Do Thi Thanh Canh | Asian Institute of Technology |
| 20 | Ms. Vo Thi Quynh Truc | Asian Institute of Technology |
| 21 | Ms. Kanogwon Saswattecha | Asian Institute of Technology |
| 22 | Mr. Didin Agustian Permadi | Asian Institute of Technology |
| 23 | Mr. Nguyen Tri Quang Hung | Asian Institute of Technology |
| 24 | Mr. Cao Dung Hai | Asian Institute of Technology |
| 25 | Mr. Hoang Anh Le | Asian Institute of Technology |
| 26 | Mr. Kok Sothea | Asian Institute of Technology |
| 27 | Ms. Bounyaseng Sengkhammy | Asian Institute of Technology |
| 28 | Mr. Sarun Thanavibulsate | Asian Institute of Technology |
| 29 | Mr. Cesar Ortinero | Asian Institute of Technology |
| 30 | Ms. Lalitcha Imchuensri | Asian Institute of Technology |
| 31 | Ms. Sukanya Kiatipongchai | Asian Institute of Technology |
| 32 | Ms. Jarussaeng Molen | Asian Institute of Technology |
| 33 | Ms. Chonthicha Suksuphak | Asian Institute of Technology |
| 34 | Ms. Suthirat Kittipongvises | Asian Institute of Technology |
| 35 | Ms. Javkhlan Ariunbaatar | Asian Institute of Technology |
| 36 | Mr. Bidur Dahal | Asian Institute of Technology |
| 37 | Mr.Chansanouk Khounnouvong | Asian Institute of Technology |
| 38 | Mr. Artid Prakitcharoensuk | Asian Institute of Technology |
| 39 | Ms. Nguyen Thi Mai Thanh | Asian Institute of Technology |
| 40 | Mr. Hoang Ngoc Tuong Van | Asian Institute of Technology |
| 41 | Ms. Nguyen Tran Huong Giang | Asian Institute of Technology |

| | | |
|---|---|---|
| 42 | Mr. Tran Quang Toan | Asian Institute of Technology |
| 43 | Mr. Le Anh Tuan | Asian Institute of Technology |
| 44 | Mr. La Luan | Asian Institute of Technology |
| 45 | Ms. Dang Thi Thuy Duong | Asian Institute of Technology |
| 46 | Mr. Nguyen Quang Huy | Asian Institute of Technology |
| 47 | Ms. Tran Thu Trang | Asian Institute of Technology |
| 48 | Ms. Huynh Thi Cam Hong | Asian Institute of Technology |
| 49 | Ms. Chau Thi Kim Thoa | Asian Institute of Technology |
| 50 | Ms. Thach Huynh Thi Thu Trang | Asian Institute of Technology |
| 51 | Mr. Tran Nguyen Quang Huy | Asian Institute of Technology |
| 52 | Mr. Huynh Minh Khai | Asian Institute of Technology |
| 53 | Ms. Milla Irmeli Siiri | Asian Institute of Technology |

## Appendix 2

### Data Analysis Workshop of APN project, Oct. 2008, Halong, Vietnam

*Presentations:*

1. Overview of APN project and completed activities
   Speaker: *Dr. Nguyen Thi Kim Oanh*
2. Preliminary analysis of data collected under the AIT-TU-HUS APN project at AIT
   Speaker: *Dr. Prapat Pongkiatkul*
3. EC/OC data in Tokyo, Japan
   Speaker: *Dr. Makoto Koike*
4. Monitoring data on PM levels and composition in Vietnam
   Speaker: *Dr. Nghiem Trung Dung*

*Participant list:*

| | |
|---|---|
| 1. Nguyen Thi Kim Oanh | Asian Institute of Technology |
| 2. Makoto Koike | University of Tokyo |
| 3. Prapat Pongkiatkul | King Mongkut's University of Technology Thonburi |
| 4. Le Trong Cuc | Hanoi University of Science, Vietnam National University |
| 5. Hoang Xuan Co | Hanoi University of Science, Vietnam National University |
| 6. Pham Thi Hieu | Hanoi University of Science, Vietnam National University |
| 7. Phan Van Tan | Hanoi University of Science, Vietnam National University |
| 8. Pham Van Cu | Hanoi University of Science, Vietnam National University |
| 9. Nguyen Hong Phuc | Hanoi University of Science, Vietnam National University |
| 10. Nghiem Trung Dung | Institute of Environmental Technology, Hanoi University of Technology |

*Photo: Workshop in Halong, Vietnam*

**Appendix 3**

**Workshop organized at BAQ08 (Nov. 2008, Thailand)**



Asia-Pacific Network for Global Change Research

**"Black Carbon: Air Quality and Climate Change Issue"**

Workshop 14 of "Better Air Quality Workshop 2008"

Imperial Queen's Park, Bangkok, Thailand

13 November 2008, 15:30-17:00

**Background:**

Atmospheric particulate matter (PM) is the most important air pollutant from the health effect point of view. These particles/aerosols also interact directly and/or indirectly with the Earth radiation energy balance and can subsequently affect global climate (IPCC, 2001). The Asian brown cloud, which causes multiple effects on regional air quality and climate is mainly originated from human activities including biomass burning (UNEP & $C^4$, 2002). The types and the degree of potential effects of particles, however, depend on their chemical and physical properties. For example, black particles (BC) normally carry with them a range of carcinogenic pollutants and are at the same time a strong climate forcing agent. The global warming potential of BC is found to be 2000 times of that of $CO_2$, on the mass basis, for 20 years time span (Bond et al., 2004). However, data on the important climate relevant PM properties is still scarce in the World.

The Asian Institute of Technology (AIT) together with the University of Tokyo and Hanoi University of Science has initiate the project "Investigation on the impacts of urban-rural air pollution on air quality and climate in Southeast Asia". The project is sponsored by the financial support from the Asian-Pacific Network for Global Change (APN) for 2 years, 2007-2008. The goal of this project is to start measurements of selected important species (EC/OC aerosols, CO, etc.) in Bangkok and Hanoi to assess current ambient air pollution status and climate forcing strength of ambient aerosols in Southeast Asia.

This special workshop is organized as a part of the project result dissemination. It is organized by Asian Institute of Technology in the framework of the Asian Pacific Network project. The ultimate objective of this workshop is to disseminate the findings among policy makers, scientific and publics who are actively involved in research and management of urban air quality with the climate co-benefit consideration.

**Objectives:** This dissemination workshop is designed with the following concrete objectives:

- To disseminate the project findings to policy makers, scientific and publics;
- To share and provide experiences in black carbon monitoring and data analysis;

To build capacity on BC co-benefit for developing countries

**Location:** Imperial Queen's Park 4, Bangkok, Thailand

**Time:** 13 Nov 2008, 13:30-15:30

Target participants:

The session aims at a mixed audience of policy makers and academics from Asia and beyond.

**Participants sponsored by AIT-APN project:**

Specifically, there were 5 participants sponsored by APN project from different countries.

| | |
|---|---|
| - Dr. Lokesh Kumar Sahu | Tokyo University, Japan |
| - Dr. Prapat Pongkaitkul | King Mongkut's University of Technology Thonburi, Thailand |
| - Hoang Xuan Co | Hanoi University of Science |
| - Mr. Alomlangsy RAJVONG | Environment Research Institute, Laos |
| - Mr. Kok Sothea | University of Phnom Phenh, Cambodia |

**Speakers:**

| | |
|---|---|
| - Dr. Nguyen Thi Kim Oanh | Asian Institute of Technology, Thailand |
| - Dr. Tami Bond | University of Illinois, Urbana-Champaign, U.S. |
| - Dr. Lokesh Kumar Sahu | Tokyo University, Japan |
| - Dr. Prapat Pongkiatkul | King Mongkut's University of Technology Thonburi, Thailand |

**Program:** Wednesday, November 13, 2008

Chair: Dr. Kim Oanh, AIT

13:30-14:00 APN project and preliminary findings on rural-urban air pollution interaction using EC, OC and WSOC measurement data
Speaker: Dr. Nguyen Thi Kim Oanh

14:00-14:30 Assessing black carbon reduction as a 'rapid-response' climate strategy
Speaker: Dr. Tami Bond

14:30-15:00 Analysis of EC/OC and CO in relation to the emission sources in Bangkok Metropolitan Region
Speaker: Dr. Lokesh Kumar Sahu

15:00-15:30 Comparative analysis of BC concentrations in ambient air by different measurement techniques
Speaker: Dr. Prapat Pongkiatkul

**Participant list** (only those signed in the attendance sheet)

| | | |
|---|---|---|
| 1. | Nguyen Thi Kim Oanh | Asian Institute of Technology, Thailand |
| 2. | Bond Tami | UIUC, USA |
| 3. | Prapat Pongakiatkul | KMUTT, Thailand |
| 4. | Lokesh Sohu | University of Tokyo, Japan |
| 5. | Nghiem Trung Dung | Hanoi University of Technology, Vietnam |
| 6. | Lidyayatij A. Malik | National University of Malaysia |
| 7. | Ubonwan Chaiyo | JGSEE KMUTT, Thailand |
| 8. | Hoang Xuan Co | Hanoi University of Science |
| 9. | Dane Westerakl | Cornell University |
| 10. | Muhammad Wahab | Asian Institute of Technology |
| 11. | Carmela Fonbvena | MEOIA |
| 12. | Kanokwan Sawattech | Asian Institute of Technology |
| 13. | Denise Mauzerall | Princeton University, USA |
| 14. | Kok Sothea | University of Phnom Phenh, Cambodia |
| 15. | Hoang Anh Le | KIST, Korea |
| 16. | Ed Burgher | Magree Scientific |
| 17. | Ray Minjares | ICCT, USA |
| 18. | Dennis Clare | IGSD, USA |
| 19. | Arnon Sitdhivej | Chulalongkorn University, Thailand |
| 20. | Wongpun Limpaseni | Chulalongkorn University, Thailand |
| 21. | Panwadee Suwattiga | KMUTNB, Thailand |
| 22. | Narisara Thongboonchoo | KMUTL, Thailand |
| 23. | Jariya Boonjawat | Chulalongkorn University, Thailand |
| 24. | Alomlangsy Rajvong | WREA, Laos |
| 25. | Venonica Gavibay | Bravo INE-Mexico |
| 26. | Ketsiri Leelasakultum | Asian Institute of Technology |
| 27. | Kangraw Cho | KAEC, Korea |
| 28. | Puji Lestari | ITB, Indonesia |
| 29. | Byeong-Byu Lee | University of Ulsan, Korea |

*Photos: Workshop at BAQ08, Bangkok, Nov. 2008*

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- Asian institute of technology: in-kind contribution, equipment for sampling of PM and gases pollutants, scholarship for the students to do research topics related to the project activities
- Hanoi University of Science: in-kind contribution, equipment for sampling of PM and gases pollutants
- Tokyo University: equipment for on-line measurements of OC/EC, BC, CO and meteorology at AIT
- Clarkson University, NY, USA: in kind contribution of equipment and analysis for OC/EC samples from Hanoi

**Glossary of Terms**

| | |
|---|---|
| μg | Microgram |
| $\mu g/m^3$ | Microgram per cubic meter |
| AIT | Asian Institute of Technology |
| BC | Black Carbon |
| BMR | Bangkok Metropolitan Region |
| CO | Carbon Monoxide |
| COSMOS | Continuous Soot Monitoring System |
| EC | Elemental Carbon |
| HUS | Hanoi University of Science |
| IC | Ion Chromatography |
| OC | Organic Carbon |
| PM | Particulate Matter |
| PM10 | PM with aerodynamic diameter less than 10 microns |
| PM10-2.5 | PM with aerodynamic diameter between 10 microns and 2.5 microns |
| PM2.5 | PM with aerodynamic diameter less than 2.5 microns |
| PMF | Positive Matrix Factorization |
| RCAST | Research Center for Advanced Science and Technology |
| TU | University of Tokyo |
| UNEP | United Nation Environmental Program |
| US EPA | United States Environmental Protection Agency |
| WOC | Water Soluble Organic Carbon |