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Chemical characterization and sources apportionment of fine particulate pollution in a mining town of Vietnam

Nguyen Thanh Hang, Nguyen Thi Kim Oanh *

Environmental Engineering and Management, School of Environment, Resources and Development, Asian Institute of Technology, Pathumthani, Thailand

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ABSTRACT

Monitoring for $PM_{2.5}$ was conducted in a mining town in Northern Vietnam in both dry and wet seasons from 2009 to 2010. Levels and compositions of PM were characterized at two sites representing two separate air bubbles; an industrial site in Mong Duong (MD) and a reference rural site in Cam Hai (CH). Two MiniVol samplers were collocated to collect 24 h $PM_{2.5}$ samples for about 30 days at each site in a season, simultaneously with meteorological data recording. All samples were analyzed for mass, black carbon (BC), water soluble ions and elements, while selected samples were also analyzed for OC (organic carbon) and EC (element carbon). Higher $PM_{2.5}$ levels were observed in the dry season than the wet season at both sites in spite of abnormal rainfall occurrences observed on some days during the dry season. In both seasons, higher $PM_{2.5}$ levels were observed in the industrial site than the reference rural site. The differences in PM, BC or EC and OC levels between two sites and between two seasons at one site, respectively, were all statistically significant except for that in OC between two sites, and BC between two seasons at MD. The reconstructed $PM_{2.5}$ mass indicated major contributing groups being organic matter, secondary inorganic particles, crustal and soot in both seasons. Higher values of K-Smoke in the dry season suggested more contribution from biomass burning. The PMF results revealed the largest contribution to $PM_{2.5}$ mass from secondary PM (35–40%); followed by biomass burning, ship and road traffic (diesel) each had a share of 15–22%; and a small contribution from miscellaneous sources such as industry and construction activities (3–8%). Analysis of HYSPLIT backward trajectory patterns showed a high potential contribution of the long range transport (LRT) pollution when air masses had long continental pathways before arriving at the study area.

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1. Introduction

Fine particles or $PM_{2.5}$ (particles with aerodynamic diameter below 2.5 μm) reduce atmospheric visibility (Watson, 2002), poses serious health concerns (Donaldson and MacNee, 1998) and can affect the Earth's climate (Bond et al., 2013). Atmospheric particles research, which continues to attract increasing worldwide interest, reports high levels of $PM_{2.5}$ for many Asian cities (Hopke et al., 2008; Kim Oanh et al., 2006). However, there is still a general lack of systematic and long term records of mass and composition of particulate matter (PM), particularly $PM_{2.5}$, in Asian developing countries. This prevents a comprehensive assessment of the adverse effects so as to raise adequate awareness leading to actions to reduce air pollution.

Quang Ninh province is located in Northern Vietnam and is an important coal mining area with about 90% of the national coal reserve. The province is also the location for many popular tourist attraction sites, including Ha Long Bay. These resources help enable a fast economic development but also put a great pressure on the environment. Currently, Quang Ninh's environment management is still a challenging task that lags behind the rapid pace of its economic development. The PM pollution was reported to be high in several locations in the

* Corresponding author.
E-mail address: kimoanh@ait.ac.th (N.T. Kim Oanh).

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province, especially in the mining areas, where hourly total suspended particle (TSP) levels monitored at some sites exceeded 530 μg m^{-3} (Asian Development Bank, 2006). Besides mining, various other economical and residential activities also contribute to the high ambient PM levels. These include industrial activities (e.g., coal processing, cement plants, coal-fired thermal power plants), road transport along the National Road No. 18 connecting to the border between Vietnam and China, ship emission in ports and sea, residential cooking and biomass open burning. High levels of PM may already cause substantial health effects to people in the area but have not yet been adequately characterized. Coal dust, for example, was proven to be the cause of "Coal Workers' Pneumoconiosis" known as the black lung disease (Finkelman et al., 2002). The available monitoring data produced by the provincial Department of Environment and Natural Resources (DONRE) primarily focused on short-term average (hourly) of TSP (Asian Development Bank, 2006) and no data on $PM_{2.5}$ was ever reported. Therefore, it was important to monitor $PM_{2.5}$ levels and determine the sources to prioritize the local pollution control efforts. This study was accordingly designed to provide the information on mass and chemical compositions of $PM_{2.5}$ in two selected sites in Cam Pha town of Quang Ninh in both the wet and dry seasons of 2009–2010.

2. Methodology

2.1. Study area

Quang Ninh province is located along the northeastern coastline of Vietnam (Fig. S1, Supplementary Information, SI) and is stretched between latitudes of 20°40′ to 21°40′ North and longitudes of 106°25′ to 108°25′ East. The mountain area consisted of 80% of the total provincial area (8239 km^2 with 5938 km^2 mainland area and the rest is islands, bays and sea). The province is one of the most important economic regions in northern Vietnam and, with a large coal reserve, it contributes significantly to the related industrial sectors. Quang Ninh has many tourist attractions including the Ha Long Bay UNESCO's World Heritage site. Currently, industrial activities related to coal mining, processing, transportation, and shipping release a huge amount of PM pollution which visibly affects the air quality, especially, in mining areas.

The province has the typical climate of Northern Eastern Vietnam with two main seasons, winter (November–March) and summer (May–September), and two transitional seasons, spring (April) and fall (October). During winter, the northeast monsoon is prevalent, hence cold weather with low rainfall is observed, i.e. the monthly average temperature is generally below 20 °C and monthly precipitation amount is below 100 mm. During summer months, the average monthly temperature is commonly above 20 °C and the monthly precipitation amount is above 100 mm (Ngu and Hieu, 2004). The total annual rainfall in the area is between 1700 and 2400 mm. Total number of rainy days in a year is between 90 and 170 days of which over 85% occurred during the months of July and August (General Statistics Office of Vietnam, 2013). The summer months, thus, can be considered the rainy months with the highest precipitation observed in July and August when the area is under influence of southwest monsoon. In addition, because of the location along the coastal line, many areas of Quang Ninh experience sea–land breeze that potentially leads to air pollution circulation back and forth in the area between daytime and nighttime.

2.2. Monitoring design

The overall research design is given in Fig. S2, SI. The sampling was conducted at two sites, the Mong Duong ward (MD) and Cam Hai village (CH), with the aim to capture main features of the province which has urban, rural and industrial areas located adjacently and largely mixed. Both sites belong to Cam Pha town and although they were only 4 km apart, they were separated by hills of an average elevation of 80–100 m (Fig. S1, SI). Accordingly, they may represent 2 different air bubbles of interest. The MD site represented the mining industrial area while CH was the rural area located close to the coastal line.

Mong Duong ward has an area of 130 km^2 and a population of 3874. The National Road/Highway No. 18 runs across the southern part of the town while its northern part is largely covered by forest. The MD sampling site (21° 03.7′ N; 107° 20.2′ E) was located at about 30 m above the sea level, about 2 km from the shore line, and approximately 100 m to the South of the National Road No. 18 (Fig. S1, SI). The samplers were placed on the roof of a supply water treatment plant, about 2 m above the ground level. It was observed that a large number of heavy trucks running on this road may be linked to the intensive transportation of goods between the two neighboring countries. To the east and northeast, about 100 m away, the site was surrounded by a coal storage area (of Vinacomin-Mong Duong coal Joint stock Company). Several low hills are located to the southeast and south of the site, about 50 m away. The domestic cooking in the town relied mainly on manually produced coal briquettes (made of the rejected coal particles from the coal washing plant and commonly mixed with mud). Solid waste burning was also observed around the town. In some days, burning for clearing grass land was also observed.

The Cam Hai village sampling site (21° 5.831′ N, 107° 21.773′ E) was located on a rooftop of the Cam Hai commune head office, approximately 15 m above the sea level. The National Road No. 18 runs about 1000 m to the west of the site. About 5 m to the south of the site runs a local residential road (Fig. S1, SI) occasionally travelled by motorcycles. As compared to MD, the CH site was located farther away from the industrial area but closer to the sea, i.e. at 500–600 m from the shore line.

2.3. Sampling and chemical analysis

The 24 h $PM_{2.5}$ samples were collected daily during the wet (23 July–20 August 2009) and dry (December 2009–January 2010) periods. At each site, two Airmetrics MiniVol samplers (Airmetrics, 2008) were used simultaneously, one with quartz fiber filters and the other with mixed cellulose ester (MCE) filters. In total, 23 pairs of samples were collected at each site during the wet season. During the dry season, 34 pairs of samples were collected at MD as compared to 25 pairs at CH (detail is given in Table S1, SI).

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