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Exposure to air pollutants in Vietnam: Assessing potential risk for tourists

*Pallavi Pant, Whitney Huynh, Richard E. Peltier**

Department of Environmental Health Sciences, School of Public Health and Health Sciences, University of Massachusetts, Amherst, MA 01002, USA

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ABSTRACT

Tourism can form an important component of a nation's GDP, and Vietnam is among the most visited countries in Southeast Asia. Most studies on personal exposure focus on the general population, or occupational cohorts with exposure to specific pollutants. However, short-term exposure to air pollutants while visiting regions with high levels of air pollution can lead to acute health effects. A personal exposure study was conducted across three cities in Vietnam to estimate exposure to particulate matter ($PM_{2.5}$) and black carbon for tourists. Measurements were conducted during the wet season in 2014 in Ho Chi Minh City, Da Lat and Nha Trang using portable instrumentation. Average 24-ht $PM_{2.5}$ and BC exposures were estimated as 18.9 ± 9.24 and 3.41 ± 1.33 μg/m^3 and among the three cities, Ho Chi Minh was found to have the highest $PM_{2.5}$ concentrations. Environmental tobacco smoke, commuting and street food stands were found to contribute to highest levels of exposure to $PM_{2.5}$ and BC across all cities.

Introduction

Exposure to fine particulate matter ($PM_{2.5}$, particulate matter with aerodynamic diameter less than 2.5 μm) has been linked with a range of health effects including respiratory and cardiovascular diseases (Dominici et al., 2006; Brook et al., 2010) and lung cancer (Raaschou-Nielsen et al., 2013). Global analyses of $PM_{2.5}$ concentrations using high-resolution satellite data have reported high population-weighted concentrations in Asia (38 μg/m^3), and 72% of the total mortality associated with PM exposure is reported to be in Asia (Apte et al., 2015). While ambient $PM_{2.5}$ levels are much lower in Vietnam compared to other countries in Asia (*e.g.*, India, China), exposure to ambient air pollution is still one of the biggest public health risks and premature mortality rates associated with ambient air pollution exposure in Vietnam are among the highest (Lelieveld et al., 2015). Between 1990 and 2013, average $PM_{2.5}$ levels increased from 19.1 to 25.5 μg/m^3 (Brauer et al., 2015). A global study on air pollution identified residential and commercial energy use to contribute more than 50% of the total ambient air pollution in Vietnam (Lelieveld et al., 2015), while the local government authorities often cite air pollution related to mobile sources as a major environmental concern. Air monitoring was conducted in Hanoi between 2001 and 2004 as part of the Asian Regional Research Program in Environmental Technology (AIRPET); average $PM_{2.5}$ was reported as 124 and 33 μg/m^3 for dry and wet seasons respectively while PM_{10} concentrations were reported as 186 μg/m^3 (dry) and 79 μg/m^3 (wet season) (Kim Oanh et al., 2006). The average $PM_{2.5}/PM_{10}$ ratio was reported as 0.74 and concentrations as high as 200 μg m^{-3} were reported for a residential location (Kim Oanh et al., 2006). Domestic cooking was identified as one of the contributors for high ambient $PM_{2.5}$ in residential location in Hanoi, where the $PM_{2.5}/PM_{10}$ ratio was 0.91. In comparison, based on regulatory monitoring, average PM_{10} concentration between 2004 and 2007 for Ho Chi Minh (HCM) City was reported to be 74 ± 29.7 μg/m^3 (Phung et al., 2016).

* *Corresponding author. E-mail:* rpeltier@umass.edu (Richard E. Peltier).

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A very limited number of studies have conducted chemical characterisation of TSP (Hien et al., 1999) and PM_{10} and $PM_{2.5}$ (Hien et al., 2001; Kim Oanh et al., 2006; Hang and Kim Oanh, 2014), and dust, road transportation emissions, coal fly ash, biomass burning and secondary aerosols have been identified as major contributors. However, such studies have largely focused on characterisation of ambient air quality, and such measurements may not be representative for personal exposure (PE) to air pollutants.

In a recent study in HCM City, ambient PM_{10} was found to be positively associated with respiratory and cardiovascular disease-related admissions (Phung et al., 2016), and in Hanoi, the capital of Vietnam, similar results were reported; an increase of 10 $\mu g/m^3$ in $PM_{2.5}$ concentrations was associated with an 2.2% increase in risk of hospital admission for young children (Luong et al., 2017). The only other epidemiological analysis on health effects of air pollution in Vietnam focused on acute lower respiratory infections (ALRI) in children under five, and PM_{10} was reported to be associated with an increase in ALRI-related hospital admissions during the dry season (Mehta et al., 2013). These studies were based on sampling from centralised or remote sensing monitoring techniques. Overall, there is very limited information on PE to air pollutants in urban areas in Vietnam. A comprehensive assessment was conducted in HCM City, and ambient air quality monitoring data was found to underestimate PE to air pollutants, especially in lower socio-economic status neighbourhoods (Mehta et al., 2014). In a study on PE to benzene in HCM City, an average exposure concentration of 18 $\mu g\ m^{-3}$ was reported for the general population, with commuting identified as a significant contributor to the overall exposure (Lan et al., 2013).

For many developing nations, tourism is often a significant contributor to the country's gross domestic product (GDP) (Sajjad et al., 2014), and for tourists travelling to regions with relatively higher levels of air pollution, acute effects of exposure can be highly relevant. Several epidemiological analyses have reported significant health effects associated with short-term exposure to air pollution (Liu et al., 2008), and currently, there is little to no information available on health impacts associated with higher exposure to air pollution for residents living in low-pollution environments. In China, high levels of air pollution were found to impact tourists' decision-making, and in Paris (France), tourists' perception of air quality was found to be linked to visible smog (Duché, 2013; Zhang et al., 2015; Becken et al., 2017). Similarly, in Hong Kong, international tourists reported concern over poor air quality based on a questionnaire survey, and the authors observed that improvements in air quality, and overall environmental quality could boost tourism numbers (Law and Cheung, 2007). In the US, haze and poor visibility were reported to impact visitor numbers for national parks (Great Smoky Mountain National Park), and based on a modelling assessment, Poudyal et al. (2013) estimated an increase in number of visitors with improvements in visibility. Overall, multiple studies have highlighted the role of poor air quality in tourists' decision-making, and the associated economic impacts (Sajjad et al., 2014; Becken et al., 2017). Vietnam is among the more popular tourist destinations in Southeast Asia, and in 2016, more than ten million international tourists visited the country (http://vietnamtourism.gov.vn/english/index.php/items/11311).

The objective of this study was to quantify average personal exposure to $PM_{2.5}$ and Black carbon (BC) for tourists visiting Vietnam and the results presented here are based on a pilot study conducted in three cities in Vietnam in summer 2014.

1. Methods

Samples were collected in three cities in southern Vietnam in May 2014.

1.1. Sampling sites

1.1.1. Ho Chi Minh

Ho Chi Minh, with an area of ~2095 km^2, is located in the southern part of Vietnam and is the largest city in the country with a population of more than seven million (Fig. 1). It is a large transport hub for Southern Vietnam, and the port in the city is the largest in the country. Motor vehicles are thought to be the largest contributor to ambient air pollution (Phung et al., 2016). The months of May to November are classified as the wet season (May–November) in HCM City, and pollution levels tend to be lower compared to the dry season (December–April) (Phung et al., 2016). Public transportation includes buses and taxis, but motorcycles are the most popular mode of transport in the city.

1.1.2. Da Lat

This hilly town (1500 m ASL) is the capital of the Lam Dong province in inland Vietnam and is one of the most popular tourist centres. In comparison with the rest of the country, Da Lat has a temperate climate, with average temperatures ranging between 15°C and 23°C throughout the year. The economy depends largely on the tourism and service industry and agriculture is also a prominent activity in the area. Buses as well as motor taxis are commonly used for transportation.

1.1.3. Nha Trang

This coastal town is located in the Southern province of Khanh Hoa, and is a popular tourist destination. Tourism and service sector as well as industries (shipbuilding, fishing) are important contributors to the region's economy.

Compared to HCM City, both Da Lat and Nha Trang are smaller towns, and are less congested with traffic. There are significant differences in terms of population density as well, with HCM City averaging at 3888 people/km^2 while the Khanh Hoa province (Nha Trang) and Lam Dong Province (Da Lat) have much lower population densities (231 and 130 people/km^2, respectively) (General Statistics Office of Vietnam, 2017).

1.2. Instrumentation

Sample collection was completed using portable instrumentation. For $PM_{2.5}$, a portable scattering nephelometer (pDR-1500, Thermo Fisher, Franklin, MA, USA) equipped with a $PM_{2.5}$ cyclone was used at a flow rate of 1.52 L/min together with PFTE filters (Zefon International, 37 mm, 2.0 μm) for 24-hour integrated filters for chemical analysis. BC was measured using a microAethalometer AE51 (AethLabs, San Francisco, CA, USA) operated at a flow rate of 50 mL/min and a 5-min time base. Both instruments were placed in a backpack, and the inlets were positioned at breathing height using flexible Teflon tubing with

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