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Determining factors for levels of volatile organic compounds measured in different microenvironments of a heavy traffic urban area

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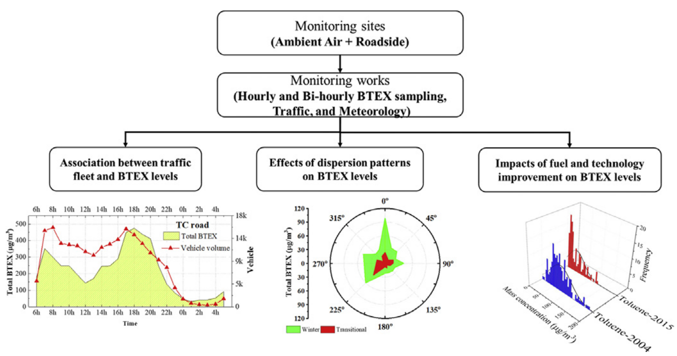
HIGHLIGHTS

- High roadside BTEX levels with diurnal patterns and species ratios showed predominant influence of traffic.
- BTEX levels and species ratios obtained at ambient site indicate interactions of several influencing factors.
- Effects of aging, local wind and regional transport on ambient BTEX were pronounced.
- Traffic technology improvement during last decade lowered roadside BTEX and health risks.

GRAPHICAL ABSTRACT



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ABSTRACT

The levels of BTEX (benzene, toluene, ethylbenzene and xylenes) in a congested urban area of Hanoi were characterized in a winter and a transitional period in 2015. Monitoring was conducted at two roads simultaneously with traffic flows and one ambient site together with meteorology. Hourly and bi-hourly BTEX samples collected using charcoal tubes were analyzed by GC-FID. BTEX levels in winter, 131 ± 71 $\mu g/m^3$ in heavy traffic Truong Chinh (TC) road, 101 ± 29 $\mu g/m^3$ in small residential Nguyen Ngoc Nai (NN) road, and 30 ± 15 $\mu g/m^3$ in the ambient air site (AA, about 150 m from each road) were 1.3–2.1 times higher than the respective levels in the transitional period. Hourly benzene levels exceeded the Vietnam national standard more frequently at TC (45%) than at NN (32%) and least at AA (5%) out of 120–180 measurements, respectively. Roadside hourly levels well reflected the diurnal traffic flow pattern and higher BTEX levels were measured at TC than NN. The ambient site exhibited lower BTEX levels and different diurnal patterns, with more pronounced evening peaks than morning rush hour peaks. BTEX pollution rose showed a strong influence of wind to levels measured at AA. Species ratios (T/B and X/E) showed typical ranges for traffic emissions at roadsides. Ratios for AA and NN after midnight with no vehicles operating showed the aging effects with typical low X/E ratios. Multivariate analysis results suggested association of gasoline vehicles with BTEX at roadsides. Backward trajectory analysis indicated potential regional transport of long-lived benzene associated with continental airmass categories. BTEX at TC our study were 2–3 times lower for every species compared to those previously reported, showing results of fuel quality and vehicle technologies improvement. Health risks of people working at the roadside also reduced by about 3 times during the 10 years.

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1. Introduction

Volatile organic compounds (VOCs) have long been an issue of urban air quality due to their toxic effects to human health and also their roles in the formation of photochemical smog involving ozone and secondary particles (Reimann and Lewis, 2007). The aromatic group of VOCs, in particular benzene, toluene, ethylbenzene and xylenes, collectively known as the BTEX group, have been a subject of intensive studies. In populated cities of developing Asia, substantial BTEX emissions have been attributed to large fleets of high mileage gasoline fueled vehicles, including the dominant motorcycle fleet (Kim Oanh et al., 2012a). The situation is of more concern when the aromatic compounds, including benzene, are used as anti-knock additives in unleaded-gasoline (Reimann and Lewis, 2007) which fortunately is regulated in the Asian developing countries to address the lead (Pb) pollution. The low engine standards and lack of efficient catalyst converters in the existing gasoline fleets make them large emission sources of BTEX (Trang et al., 2015). Consequently, high levels of these toxic BTEX, in urban environment of Asian cities, especially in proximity to traffic lanes are often reported (Chan et al., 2002; Giang and Kim Oanh, 2014; Truc and Kim Oanh, 2007; Wang and Zhao, 2008; Yamamoto et al., 2000).

Other local activities could also be substantial emission sources of BTEX in Asian urban areas, including residential cooking, open burning of solid waste and agricultural residues, loading and refueling activities at gasoline stations, and industry if is still located inside cities. In addition, regional transport of relatively long-lived species, i.e. benzene (Monod et al., 2001), may contribute to the levels measured in urban areas located downwind of large emission source regions. Meteorology plays an important role for both local and regional transport of air pollution. Therefore, there is always a big challenge to identify the main contributing factors to the BTEX levels in given urban areas. Such information would help to prioritize the efforts and identify strategies to reduce the toxic BTEX levels and resulting health risks.

Today, there still lacks of comprehensive studies on health effects of BTEX in Asian developing countries (Kim Oanh et al., 2012a) in comparison with other parts of the world (Bruno et al., 2008; Mainka and Kozielska, 2016; Masiol et al., 2014; Raysoni et al., 2013). The same situation is applied for Hanoi, the capital of Vietnam and the second largest city in the country, which has experienced a drastic population growth, industrialization and urbanization along with its economy development. The city has seen a significant increase in the vehicle population. By the end of 2015, the private vehicular population in the Hanoi capital (expanded Hanoi city) consisted of 4.9 million motorcycles and 540,000 private cars (Hanoi Department of Traffic Police (DTP), 2016) that was about 1.8 times above the fleet population in 2009 of 2.76 million motorcycles and 304,000 cars (Hieu et al., 2013). This drastic increase in the vehicle population was not accompanied by the same pace of the road infrastructure development. The road network was only slowly expanding and most of inner city areas had the space limitation for the road expansion (Asian Development Bank (ADB), 2011). This leads to frequent traffic congestions, especially during rush hours, and disproportionately increases vehicular emissions. Specifically, the large fleet of motorcycles, not equipped with any exhaust control device (Kim Oanh et al., 2012a), moving in streets with heavy traffic jams is among the major causes of high levels of traffic-related pollutants including fine particulate matters or $PM_{2.5}$ (particles with aerodynamic diameter not above 2.5 μm) and BTEX in Hanoi (Hai and Kim Oanh, 2013; Truc and Kim Oanh, 2007). Several previous research works reported high BTEX levels in Vietnam and their association with road traffic but focusing more on the situation in Ho Chi Minh city (Giang and Kim Oanh, 2014; Lan et al., 2013; Lan and Minh, 2013). The only published study for BTEX in Hanoi (Truc and Kim Oanh, 2007) was conducted in 2004. During this 10 year time period there were significant changes in the traffic conditions in the city, including the fleet population growth, progressive engine technology intrusion (No.49/2011/QD-TTg, 2011; No.249/2005/QD-TTg, 2005), and improvement of fuel quality (Standard, Metrology and Quality (STAMEQ) of Vietnam, 2013). Our attempt therefore was to fill in the data gap and quantify the changes in the BTEX levels and associated potential health effects between 2015 and 2004.

This study is a part of our efforts to assess the major contributing sources to BTEX and particulate matters (PM) pollution in a congested urban area of Hanoi, and to quantify the health risks to local people in the current scenario and a proposed scenario of the modal shift (increase in public transport service accompanied by reduction in the motorcycle use for passenger transportation). This paper focuses on the characterization of BTEX levels at roadside at two selected roads and an ambient site located between these roads to reveal the influencing factors on the measured BTEX levels. The BTEX levels were comparatively analyzed with those reported in the previous study (Truc and Kim Oanh, 2007) for the same road to assess the changes over the 10 year period.

2. Methodology

The monitoring periods included a more polluted dry season period of 13rd January–9th February (dry winter season with stagnant air and less wet removal) and a transitional period between summer and winter (also dry season) of 13rd October–9th November in 2015, i.e. covering 28 days in each period. The monitoring was designed to capture both the day to day fluctuations and the diurnal variations of BTEX levels. Simultaneously, the meteorology conditions at the ambient site and traffic flows in the two selected roads were recorded.

2.1. Sampling sites

The Hanoi capital is stretching between coordinates of 20.88°–21.38°N and 105.73°–106.03°E with a population of 7,216,000 (as of 31st December 2015) and an average population density of 2171 people/km^2 (Vietnam General Statistical Office (GSO), 2016). Hanoi has a typical tropical monsoon climate of Northern Vietnam with two main seasons, i.e., winter (November to March) and summer (May to September), and two transitional periods of spring (April) and fall (October) (Ngu and Hieu, 2004). In winter, a high-pressure ridge is frequently observed extending from the central China to Northern Vietnam and brings in cold weather spells with associated low mixing height and calm wind. These conditions, typically observed in areas under influence of stable high pressure systems, normally allow accumulation of ambient air pollution to considerably high levels during the winter season in Hanoi (Hai and Kim Oanh, 2013; Hien et al., 2011; Kim Oanh et al., 2006).

The monitoring was done in two roads crossing the congested Dong Da and Thanh Xuan districts of Hanoi. The roads were selected to represent traffic conditions of the city: Truong Chinh (TC) road is an inner ring road of the city with heavy traffic and Nguyen Ngoc Nai (NN) is a small and less travelled residential street. Each road had two traffic lanes (inbound and outbound), running through a populated residential area. The road sections chosen for monitoring had east-west orientation, with the road angle of 107° to the north-south line, as seen in Fig. 1 and further detailed with colorful Fig. S1, Supplementary Information (SI). This orientation induces one upwind and one downwind roadside given the prevailing of northeast and southwest monsoon in the city. The monitored section of TC had a width (W) of 15 m with 2 m pavement at each side while that of NN was 8 m wide plus 1.5 m pavement at each side. The narrow road of NN has both sides bordered by residential buildings with the average height (H) of 9 m, hence resulting in a canyon street configuration (i.e., H/W ration of 1.25). TC has a semi-street canyon configuration with an open space at the southern side, extending to about 20 m from the outmost traffic lane, i.e. toward the AA site. The monitoring sections of both roads were not located close to any road crossing locations or bus stations hence would represent the normal traffic flows. There was a gasoline station located in TC, about