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Roadside air quality and implications for control measures: A case study of Hong Kong

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HIGHLIGHTS

- Traffic induced roadside air pollution and control measures investigated.
- Six-year concentration data from roadside monitoring stations analyzed.
- Pedestrian-level concentration of pollutants along roadside measured.
- Nitrogen dioxide posts long-term exposure risk to roadside workers.
- Particulate matters post short-term exposure risk to roadside passengers.

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ABSTRACT

Traffic related air pollution is one of major environmental issues in densely populated urban areas including Hong Kong. A series of control measures has been implemented by Hong Kong government to cut traffic related air pollutants, including retrofitting the Euro II and Euro III buses with selective catalytic reduction (SCR) devices to lower nitrogen dioxide (NO_2) emissions. In order to reveal the real-life roadside air quality and evaluate the effectiveness of the control measures, this study first analyzed the recent six-year data regarding concentrations of pollutants typically associated with traffic recorded in two governmental roadside monitoring stations and second conducted on-site measurements of concentration of pollutants at pedestrian level near five selected roads. Given that there is a possibility of ammonia leakage as a secondary pollutant from SCR devices, a special attention was paid to the measurements of ammonia level in bus stations and along roadsides. Important influencing factors, such as traffic intensity, street configuration and season, were analyzed. Control measures implemented by the government are effective to decrease the traffic emissions. In 2014, only NO_2 cannot achieve the annual air quality objective of Hong Kong. However, it is important to find that particulate matters, rather than NO_2, post potentially a short-term exposure risk to passengers and pedestrians. Based on the findings of this study, specific control measures are suggested, which are intended to further improve the roadside air quality.

1. Introduction

1.1. Background

Air pollution is one of the major environmental issues today. Exposure to air pollution is closely associated with increased human morbidity and mortality (Brunekreef and Holgate, 2002; EEA, 2014). The recent WHO report (WHO, 2014) regarding global burden of disease indicates that exposure to ambient air pollution caused 3.7 million deaths worldwide in 2012, including 936,000 in South East Asian regions. Among others, traffic exhausts have long been recognized as one of the major sources of air pollution in urban areas (Pfeffer, 1994; Clark and Ko, 1996; Zhang et al., 1999; Colvile et al., 2001; Wang and Xie, 2009; Ai and Mak, 2015). The main traffic related pollutants include nitrogen oxides (NOx), particulate matters (PMs), carbon monoxide (CO), Sulphur dioxide (SO_2) and ozone (O_3) (Vardoulakis et al., 2003; Thorpe and Harrison, 2008). Owing to increased traffic emissions and/or adverse dispersion conditions, traffic related pollutants can

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accumulate to reach very high concentrations at street level in comparison with background concentrations (Spadaro and Rabl, 2001; Gietl et al., 2010; Weijers et al., 2004; Zwack et al., 2011; Zhao et al., 2004; Ai and Mak, 2015), which could also make their incursion into the indoor environments through infiltration and ventilation (Ai and Mak, 2014, 2016). Therefore, efforts that are devoted to cut the traffic related pollutants and thus to improve the street-level air quality are of great significance.

Source control is always the most effective method. Since 1999, a wide range of measures (HKEPD, 2015a; Ning et al., 2012) have been implemented in Hong Kong to control traffic emissions, such as retrofitting franchised buses and pre-Euro diesel commercial vehicles with particulate reduction devices, retrofitting Liquefied Petroleum Gas (LPG) and petrol vehicles with catalytic converters to reduce NOx emissions, assigning low-emission franchised buses to low-emission zones (HKLC, 2015), tightening the fuel and emission design standards of new vehicles, and introducing LPG vehicles to replace the light buses and diesel taxis. The Environmental Protection Department of Hong Kong (HKEPD) reported that, from 1999 to 2014, the roadside concentrations of respirable suspended particulates (RSP), SO_2 and NOx have decreased by 45%, 67% and 45%, respectively. However, the level of NO_2 has increased by 3% from 1999 to 2014 (HKEPD, 2015b).

In order to tackle the roadside NO_2 problem, the Hong Kong government has adopted specific control measures. As one of important measures, the government subsidizes franchised bus companies for retrofitting their Euro II and Euro III buses with selective catalytic reduction (SCR) devices (HKEPD, 2013, 2015a). SCR devices use a metallic or ceramic wash-coated catalyzed substrate, or a homogeneously extruded catalyst and a chemical reductant to convert NOx into benign nitrogen gas and water in oxygen-rich exhaust streams (Shelef, 1995; HKEPD, 2013). In Hong Kong, SCR systems are installed in a few models of franchised buses and heavy duty vehicles. According to the trial test of HKEPD (2012), SCR technology is effective in reducing NOx emission, the average NOx emission reduction efficiency ranged from 66% to 86%. However, some mechanical problems have been detected during the trial test (HKEPD, 2012), such as blockage of exhaust pipe due to crystallization of urea (a reductant), exhaust gas leakage and urea leakage resulting in the thermal lagging material being burnt. Owing to mechanical problems, there is a risk of ammonia leakage from SCR devices, which would cause secondary roadside air pollution. It is necessary to examine the ammonia concentrations along roadsides and at bus stations, where there are buses with SCR devices passing through.

1.2. Objectives

Although the HKEPD has reported the achievement of air pollution control in terms of the concentration decrease of major pollutants, detailed analyses of the evolution of roadside pollutant concentrations have not been made. In addition, the roadside air quality in comparison with the air quality objectives of Hong Kong (HKEPD, 2015c) was still unclear. Therefore, this study analyzed the roadside concentrations of pollutants typically associated with traffic during the period from 2009 to 2014, which were retrieved from two governmental monitoring stations in Mong Kok and Central districts (HKEPD, 2015d). The yearly and seasonally variation of the concentrations of pollutants typically associated with traffic were analyzed. In particular, the yearly averaged concentrations of pollutants were compared with the air quality objectives of Hong Kong, which thus can verify the effectiveness of the control measures and identify areas where further measures should be implemented.

Given that the governmental monitoring stations were located above the pedestrian level (HKEPD, 2015e), specifically at a height of 3–4.5 m, on-site measurements at a height of 1.5 m above the ground were conducted in this study to (a) reveal the pedestrian-level roadside air quality and (b) evaluate the short-term exposure risk of passengers and pedestrians who normally do not stay for a long time along roadsides. Considering that concentrations of some pollutants could attenuate vertically along height (Weber et al., 2006; Vakeva et al., 1999; Chan and Kwok, 2000), the pedestrian-level measurements may reveal some new information. On-site measurements were conducted from winter 2012 to summer 2013 at five major roads and five busy bus stations in Hong Kong. Among the five roads, two roads were categorized as busy roads in low-emission zones (HKLC, 2015) and three as normal traffic roads. In order to determine whether there was any leakage of ammonia as secondary pollutant from SCR devices, the levels of ammonia along roadsides and at the bus stations were measured when (and after) a bus with SCR systems was passing (and passed) through. In addition, at the five roads, roadside concentrations of pollutants typically associated with traffic including NO_2, PM_{10}, $PM_{2.5}$, CO, SO_2 and O_3 were measured. Together with these pollutants, environmental parameters including air temperature, relative humidity and wind speed as well as general weather condition were also recorded for analyses.

2. Roadside concentrations retrieved from HKEPD

The hourly data recorded at two governmental roadside monitoring stations in Mong Kok and Central, from 2009 to 2014, was retrieved from HKEPD (2015d) for analysis. Fig. 1 illustrates the locations of the two roadside monitoring stations. Note that Mong Kok and Central are two of the most densely populated districts in Hong Kong. Concentrations of pollutants typically associated with traffic including NO_2, PM_{10}, $PM_{2.5}$, CO, SO_2 and O_3 were recorded hourly at both Stations, except for O_3 at both stations before 2011 and $PM_{2.5}$ at Mong Kok before 2011.

The yearly averaged daily traffic intensity at the two roads in Mong Kok and Central is presented in Fig. 2. It shows that the traffic intensity at Mong Kok was nearly two times of that at Central. In addition, the yearly averaged traffic intensity at each road was relatively stable from 2009 to 2012, which decreased since 2013. On average, the percentage decreases of traffic intensity from 2009 to 2014 are 13.3% and 16.8% at the roads in Mong Kok and Central, respectively. Figs. 3 and 4 present the yearly averaged concentrations of the six pollutants from 2009 to 2014 in Mong Kok and Central, respectively. The roadside concentrations of pollutants in Mong Kok were very close to those in Central. The combined analysis of traffic intensity and air quality data indicates that the large difference in yearly averaged traffic intensity between Mong Kok and Central did not produce a same degree of difference in pollutant concentrations. This inconsistency between traffic intensity and air quality suggests that the yearly averaged traffic intensity cannot be used alone to indicate the long-term air quality, as the atmospheric flow and turbulence would migrate and homogenize the local traffic emissions.

The results presented in Figs. 3 and 4 reveal generally a tendency of decrease in concentration level of the six pollutants over these years, except for CO and O_3, which showed a fluctuation in yearly averaged concentration. Taking Central as an example, the SO_2, PM_{10}, $PM_{2.5}$ and NO_2 levels have been decreased from 2009 to 2014 by 41%, 21%, 20% and 7%, respectively. Parallel with the decrease of traffic intensity, such decreases of pollutant concentrations indicate that the measures implemented by the Hong Kong government in recent years (HKEPD, 2015a, 2015b) are effective to control the traffic emissions and improve roadside air quality.

Table 1 presents the air quality objectives of Hong Kong (HKEPD,