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Land use regression modelling of air pollution in high density high rise cities: A case study in Hong Kong

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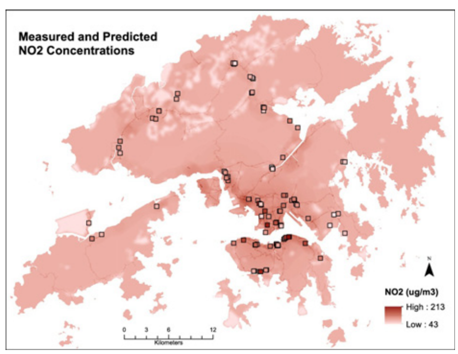
HIGHLIGHTS

- Land use regression models of NO_2, NO, $PM_{2.5}$, and BC were produced for Hong Kong.
- Regions of highest concentrations varied between pollutants.
- There was substantial spatial variation in pollutant concentration across the territory.
- Land use regression is suitable for high-density, high-rise cities.
- The impact of urban complexity on models was reflected in lower R^2 values but not the selected predictors.

GRAPHICAL ABSTRACT



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ABSTRACT

Land use regression (LUR) is a common method of predicting spatial variability of air pollution to estimate exposure. Nitrogen dioxide (NO_2), nitric oxide (NO), fine particulate matter ($PM_{2.5}$), and black carbon (BC) concentrations were measured during two sampling campaigns (April–May and November–January) in Hong Kong (a prototypical high-density high-rise city). Along with 365 potential geospatial predictor variables, these concentrations were used to build two-dimensional land use regression (LUR) models for the territory. Summary statistics for combined measurements over both campaigns were: a) NO_2 ($Mean = 106\ \mu g/m^3$, $SD = 38.5$, $N = 95$), b) NO ($M = 147\ \mu g/m^3$, $SD = 88.9$, $N = 40$), c) $PM_{2.5}$ ($M = 35\ \mu g/m^3$, $SD = 6.3$, $N = 64$), and BC ($M = 10.6\ \mu g/m^3$, $SD = 5.3$, $N = 76$). Final LUR models had the following statistics: a) NO_2 ($R^2 = 0.46$, RMSE $= 28\ \mu g/m^3$) b) NO ($R^2 = 0.50$, RMSE $= 62\ \mu g/m^3$), c) $PM_{2.5}$ ($R^2 = 0.59$; RMSE $= 4\ \mu g/m^3$), and d) BC ($R^2 = 0.50$, RMSE $= 4\ \mu g/m^3$). Traditional LUR predictors such as road length, car park density, and land use types were included in most models. The NO_2 prediction surface values were highest in Kowloon and the northern region of Hong Kong Island (downtown Hong Kong). NO showed a similar pattern in the built-up region. Both $PM_{2.5}$ and BC predictions exhibited a northwest-southeast gradient, with higher concentrations in the north (close to mainland China). For BC, the port was also an area of

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elevated predicted concentrations. The results matched with existing literature on spatial variation in concentrations of air pollutants and in relation to important emission sources in Hong Kong. The success of these models suggests LUR is appropriate in high-density, high-rise cities.

1. Introduction

Land use regression (LUR) modelling is a statistical modelling method commonly used to estimate spatial variation in air pollution concentrations for population exposure assessment. The technique associates spatially heterogeneous air quality measurements with geospatial predictors. LUR models provide a relatively robust method for spatial prediction while having a lower sampling effort compared to geo-statistical models, and a lower data requirement than dispersion models (Hoek et al., 2008).

High-density high-rise cities have become a more prominent feature globally. Air quality is a significant public health risk in many of these cities (World Health Organization, 2016). Modelling concentrations and assessing exposure in these cities are important to better understand the risk and potential interventions. As high-density, high-rise cities become increasingly common in Asia, it is important to understand how modelling spatial variation and exposure may differ from European and North American cities where most LUR modelling has been focused (Hoek et al., 2008). European and North American cities likely have lower pollution and building densities, and fewer small-scale dispersed pollution sources than high-density, high-rise cities.

Hong Kong, a coastal city located in southern China, is one of the most advanced examples of a high-density, high-rise city with significant air quality issues. As one of the most densely populated regions in the world, Hong Kong has an average population density of 6690 people/km^2 with a total population of 7,240,000 as of mid-2014 (Information Services Department, 2015). Due to the clustering of developments and mountainous terrain, <25% of the total territory of 1104 km^2 is developed, leading to extremely high population densities in some areas such as the district of Kwun Tong with density of 57,250 people/km^2 (GovHK, 2015; Information Services Department, 2015). The clustering effect is further enhanced by the prevalence of high-rise buildings in Hong Kong.

The objective of this study (HK2D) was to create ground level LUR models for NO_2, NO, $PM_{2.5}$, and BC to enhance understanding of the spatial distribution of traffic-related air pollutants and describe spatial features that are important determinants of pollutant concentration variability in Hong Kong. However, the presence of high-density high-rise developments within Hong Kong also tests the viability of LUR modelling for other cities with similar urban form. This study was conducted as part of a larger project which integrates two dimensional LUR models with vertical and population mobility components to enhance the estimation of population exposure to air pollution in Hong Kong.

2. Materials and methods

2.1. Field sampling

Two sampling campaigns, corresponding to warm and cool seasons, were conducted to measure roadside NO_2, NO, $PM_{2.5}$, and BC concentrations. Sampling of multiple pollutants over different seasons provided a more complete understanding of long-term air quality patterns. NO_2 and NO were collected together using Ogawa badges (Ogawa USA, Pompano Beach, USA) while $PM_{2.5}$ and BC were sampled using TSI SidePak AM510 Personal Aerosol Monitors (TSI Incorporated, Shoreview, USA) and microAeth AE51 (AethLabs, San Francisco, USA) monitors, respectively, with both deployed in the same monitoring box. The HK2D sampling was coordinated with an NO_2 monitoring campaign conducted by the Environmental Protection Department (EPD) of Hong Kong using Gradko (Gradko International Limited, Winchester, England) diffusion tube samplers. HK2D and EPD sampling occurred during the same periods at many of the same locations. EPD NO_2 data was used to supplement the HK2D NO_2 data.

The first HK2D sampling campaign (SC1) ran from April 24, 2014 to May 30, 2014 (37 days) with EPD sampling also conducted within this period. The second (SC2) campaign was split into two time periods. $PM_{2.5}$ and BC sampling ran from November 18, 2014 to January 6, 2015 (50 days). Due to civil protests in Hong Kong at the end of 2014, which affected traffic patterns, the EPD delayed their sampling from November 2014 to January 2015 (Jan. 3, 2015 to Jan. 26, 2015, 24 days) and the HK2D NO_2 and NO sampling was similarly delayed.

In total, 90 of 100 HK2D sampling sites were selected from the EPD 173 campaign sites. The remaining 73 EPD sites were excluded due to proximity to overpasses. The EPD sites were selected to capture maximum variation in concentrations within districts and were all roadside sites mainly in developed areas. Roadside sites located on a range of road types were used for sampling (final interpolated total values ranged from zero to 623,000). Developed regions of Hong Kong are generally density built up. Outdoor locations at ground-level that can be used for sample collection are therefore mainly found by roads, as in the case in many cities. For these reasons this study follows a common practice in ground-level LUR modelling of collecting samples on lampposts next to roads. While the Hong Kong territory does include large areas without urban development, these areas are not populated and therefore sampling in these locations is of little value for population human exposure assessment. In addition, such locations are often not readily accessible.

An additional 10 sites were selected for the HK2D campaigns to expand spatial coverage and capture variation in land use (Fig. 1). Due to logistics limitations, pollutants were sampled at a subset of these 100 sites with NO_2 samplers deployed at 97 sites (EPD — 97 and HK2D — 43 [SC1] and 63 [SC2]), NO at 43 (SC1) and 63 (SC2), and $PM_{2.5}$ and BC at 84 sites. Site selection was based on geographic location, annual average daily traffic (AADT), land use, and population density, aiming to capture a full range of values for these factors.

Samplers were preferentially deployed on lampposts approximately 2.5 m off the ground. Traffic signs, trees, and portable posts were used in a limited number of cases when a lamppost was not available. Diffusion samplers (Ogawa badges and diffusion tubes) were deployed for durations of 15 to 21 days. Ogawa badges were outfitted with two filters (one to capture NO_2 and one to capture NO_X with the difference used to calculate NO concentrations) and hung within a white shelter to protect them from sunlight and rain. The EPD deployed three diffusion tubes per site during each campaign. SidePak and microAeth sensors were deployed for 24 h, with the exception of four two-week sampling sites, which were used for quality control and to develop temporal correction factors. These sites included the three EPD roadside air quality monitoring sites. The fourth site was one of the roadside sites during SC1 but was moved to a rooftop regulatory monitoring site in SC2. Each