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# Development of a microscale land use regression model for predicting $NO_2$ concentrations at a heavy trafficked suburban area in Auckland, NZ

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## HIGHLIGHTS

- A microscale land use regression model for $NO_2$ concentrations was developed.
- Important microscale predictor variables include presence of awnings and bus stops.
- Within-city transferability was limited due to differences in predictor variables.
- High-density air quality measurements are important to capture small-scale variability.

## GRAPHICAL ABSTRACT


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## ABSTRACT

Land use regression (LUR) analysis has become a key method to explain air pollutant concentrations at unmeasured sites at city or country scales, but little is known about the applicability of LUR at microscales. We present a microscale LUR model developed for a heavy trafficked section of road in Auckland, New Zealand. We also test the within-city transferability of LUR models developed at different spatial scales (local scale and city scale). Nitrogen dioxide ($NO_2$) was measured during summer at 40 sites and a LUR model was developed based on standard criteria. The results showed that LUR models are able to capture the microscale variability with the model explaining 66% of the variability in $NO_2$ concentrations. Predictor variables identified at this scale were street width, distance to major road, presence of awnings and number of bus stops, with the latter three also being important determinants at the local scale. This highlights the importance of street and building configurations for individual exposure at the street level. However, within-city transferability was limited with the number of bus stops being the only significant predictor variable at all spatial scales and locations tested, indicating the strong influence of diesel emissions related to bus traffic. These findings show that air quality monitoring is necessary at a high spatial density within cities in capturing small-scale variability in $NO_2$ concentrations at the street level and assessing individual exposure to traffic related air pollutants.



## 1. Introduction

In many cities, personal exposure to air pollution is primarily determined by time spent in the transport micro-environment (Dirks et al., 2012; McNabola et al., 2009; Kaur and Nieuwenhuijsen, 2009).

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However, time spent in this environment is not limited to commuter activities, and high densities of people are also observed moving through transport corridors as they visit the shops, restaurants and recreational facilities found clustered along busy streets and intersections. In such transport micro-environments the temporal and spatial variability in air pollutant concentrations is large, and may be even greater than variability between cities (Hoek et al., 2008; Gurung et al., 2017).

Measuring air pollutant concentrations at local (representative of a neighbourhood or suburb) or microscales (representative of individual roads) in transport corridors is especially challenging as pollutant concentrations are strongly dependent on short-term traffic conditions and the configurations of buildings and streets (Eeftens et al., 2013; Miskell et al., 2015). For example, significant reductions in pollutant concentrations can be observed just a few meters from emission sources (Grange et al., 2014), and roadside concentrations can differ substantially from local background concentrations (Vardoulakis et al., 2011). Further, buildings modify local air flow patterns causing trapping and recirculatory flows at some locations and increased dispersion of air pollutants at other locations (Salmond and McKendry, 2009; Salmond et al., 2013; Shi et al., 2016). As a result little is known about the relative importance of urban morphology, building design, traffic management and infrastructure (including phasing of traffic lights), and other details such as vegetation or bus stop positions in determining microscale air quality variability. There is therefore a need to improve our understanding about the microscale spatial variability of air pollutants in urban hotspots if we are to develop urban planning and design tools to control and mitigate personal exposure to air pollution in transport corridors, especially at locations where traffic as well as pedestrian activity is high (Borge et al., 2016).

Land use regression (LUR) analysis emerged as a popular method in epidemiological studies to predict air pollutant concentrations and assess individual exposure levels (Hoek et al., 2008; Jerrett et al., 2005). It has the potential to assist urban planners in identifying the key controls on local air quality in transport corridors. Based on selected land use characteristics (e.g. distance to nearest road, land cover or population density), which are now widely available through geographic information (GIS) systems, LUR models allow estimation of air pollutant concentrations at unmeasured sites based on regression analysis (Hoek et al., 2008; Jerrett et al., 2005). Thus, LUR models are often used to complement regulatory monitoring networks, which are usually sparse due to logistical and financial constraints (Hoek et al., 2008; Vardoulakis et al., 2011). Such models have been primarily developed and applied to urban scale analyses ($10^4$–$10^5$ m), with some applied to the regional or country scale where they have been effectively used to identify common determinants of air quality for primarily transport related pollutants such as nitrogen dioxide ($NO_2$). These include factors such as road length, distance to major roads, land cover, traffic volume and density, population density and altitude (Hoek et al., 2008). Final models typically explain around 60–70% of the variability (Beelen et al., 2013) with a range from 51% (Briggs et al., 2000; Gurung et al., 2017; Morgenstern et al., 2007) to 97% (Stedman et al., 1997).

However, there is little evidence to demonstrate their effectiveness (or otherwise) under the highly heterogeneous conditions typical of multi-use transport corridors, and their ability to capture and effectively represent local variability at urban hotspots may be limited (Apte et al., 2017; Ghassoun et al., 2015; Hoek et al., 2008). Further, although LUR models have been used in numerous cities across Europe and North America (Hoek et al., 2008), results from other geographical regions have only recently become available and remain limited (e.g. Australia (Dirgawati et al., 2015); China (Meng et al., 2015); Nepal (Gurung et al., 2017); New Zealand (Miskell et al., 2015); Iran (Amini et al., 2016)).

In this study, we present a LUR model developed for urban microscales and applied to a heavily trafficked suburban street in Auckland, New Zealand. Our study is one of a limited number of studies (such as Miskell et al., 2015) which address local to microscale spatial variability (1–3 km) and use local urban design features as predictor variables (such as presence or absence of shop awnings) rather than standard landuse predictors (such as population and household density) which were homogenous within our study area. In particular, we were interested in examining the transferability of this approach. We also tested the within-city transferability of previously developed LUR models and explored the potential to extend the multi-scale model developed in Auckland's CBD by Miskell et al. (2015) to all spatial scales and sites outside the CBD. This study therefore also offers new insights into the applicability of LUR models developed for a certain area to other locations within the same city at different scales, which has not previously been explored.

## 2. Material and methods

### 2.1. Study area

Auckland is New Zealand's largest and fastest growing city with around 1.5 million inhabitants (Statistics New Zealand, 2013). Vehicle emissions are the largest contributor to air pollution in Auckland with traffic-related $NO_x$ ($NO_2$, NO) emissions accounting for almost 80% of the total $NO_x$ emissions (Xie et al., 2016). However, pollutants are often dispersed by maritime winds, which occur year-round favoured by Auckland's location on a narrow isthmus (Chappell, 2014; Senaratne and Shooter, 2004). The focus of this study was on a heavy trafficked road (Dominion Road) about 4 km south of the city center (Fig. 1). Dominion Road is a main route for buses and commuters in and out of the city as well as to the main airport (Auckland Transport, 2017). The area is also well used by pedestrians visiting shops, bars and cafés along the road, making this an interesting area for air pollution measurements due to the high traffic and potential exposure.

### 2.2. $NO_2$ concentration measurements

$NO_2$ concentrations were measured by Palmes diffusion tubes at 40 sites along a 2 km section of Dominion Road (Fig. 1). Sites were chosen to reflect a range of urban design features (such as the presence of building awnings, proximity to bus stops, greenspace, trees and carparks). Sites were also chosen to represent the range of expected spatial variability of air pollutant concentrations. The number of sites in other LUR studies has ranged from 14 to 107 (see Hoek et al., 2008; Beelen et al., 2013), with sample sizes of 40 commonly used in the ESCAPE project (which is most commonly referenced as the standard methodology for such studies) (Beelen et al., 2013). Given the size of our sample area, and the number of different environments expected, the choice of a sample size of 40 was deemed sufficient and representative within the context of the resources available.

At each site, we deployed two tubes at a height of approx. 2.5 m for four periods of 14 days between the 18th of November 2016 and the 1st of February 2017. To assess the reliability of the $NO_2$ measurements during each campaign we used travel and laboratory blanks (AEA Energy and Environment, 2008). Palmes tubes were analysed using a spectrophotometer and $NO_2$ concentrations calculated following standard methodology (AEA Energy and Environment, 2008). The coefficient of variance (CoV) was used to test the agreement between duplicate readings at each site and results that exceeded a CoV of 0.25 were excluded from the further analysis (Miskell et al., 2015; Mölter et al., 2012). As there was no reference regulatory air quality station near the road section studied here, we were not able to apply a seasonal adjustment to the $NO_2$ concentrations. Thus, we used seasonally averaged $NO_2$ concentrations, representative of typical summer conditions in this study, which are likely slightly below the annual average. For comparison, $NO_2$ measured by routine air quality monitors from 2010 to 2011 by the Auckland Council at another urban road (Khyber Pass, approx. 2 km northeast from Dominion Road) was on average 1 and 3 $\mu g\ m^{-3}$ below the annual average in December and January, respectively. Slightly larger differences were observed in Auckland's Central Business