Environmental Modelling & Software 95 (2017) 168–179

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Development of a land use regression model for daily NO_2 and NO_x concentrations in the Brisbane metropolitan area, Australia

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ARTICLE INFO

Article history:
Received 21 August 2016
Received in revised form
5 May 2017
Accepted 16 June 2017

Keywords:
Air pollution
Land use regression (LUR) model
Nitrogen dioxide (NO_2)
Oxides of nitrogen (NO_x)
Urban area

ABSTRACT

Land use regression models are an established method for estimating spatial variability in gaseous pollutant levels across urban areas. Existing LUR models have been developed to predict annual average concentrations of airborne pollutants. None of those models have been developed to predict daily average concentrations, which are useful in health studies focused on the acute impacts of air pollution. In this study, we developed LUR models to predict daily NO_2 and NO_x concentrations during 2009–2012 in the Brisbane Metropolitan Area (BMA), Australia's third-largest city. The final models explained 64% and 70% of spatial variability in NO_2 and NO_x, respectively, with leave-one-out-cross-validation R^2 of 3–49% and 2–51%. Distance to major road and industrial area were the common predictor variables for both NO_2 and NO_x, suggesting an important role for road traffic and industrial emissions. The novel modeling approach adopted here can be applied in other urban locations in epidemiological studies.

1. Introduction

Exposure to ambient air pollution is an important public health concern. A variety of diseases such as lower respiratory infection, lung cancer, chronic obstructive pulmonary disease (COPD), stroke and ischaemic heart disease are linked to ambient air pollutants (WHO, 2014). In order to accurately assess people's exposure to air pollutants in epidemiological studies, it is important to capture the spatial variability in concentrations. Although air quality monitoring networks can capture large-scale spatial variability, their sparseness means that they may not capture variability across spatial areas of interest (e.g. cities) in epidemiological studies (Hoek et al., 2008).

To overcome this limitation, Land Use Regression (LUR) has been widely used to model spatial variability in air pollutants (Hoek et al., 2008). The LUR modeling method includes air quality monitoring data from fixed points along with geographical predictor variables (e.g., land use area, road length, and population density) to predict the pollutant concentration at unmeasured locations (Hoek et al., 2008). With the rapid development of geographic information system (GIS) to calculate spatial predictors, LUR has emerged as an efficient tool for modeling human exposure to ambient air pollutants (Beelen et al., 2013). LUR models have been applied successfully to predict various gaseous (e.g., NO_2 and NO_x) and particle (e.g., $PM_{2.5}$ and PM_{10}) pollutants, incorporating a number of predictor variables such as population density, land usage, and traffic characteristics in urban areas (Hoek et al., 2008; Johnson et al., 2010). The performance of LUR models for estimating NO_2 and NO_x concentrations has been found to be better than a number of GIS-based interpolation methods, such as kriging and inverse distance weighting, as most GIS interpolation methods create a smooth concentration surface without considering underlying land use information (Lee et al., 2014; Meng et al., 2015).

LUR models have been developed to estimate long-term exposure to NO_2 and NO_x in China (Meng et al., 2015), Korea (Kim and Guldmann, 2015), Taiwan (Lee et al., 2014), and Norway (Madsen et al., 2011), among others. In the European Study of Cohorts for Air Pollution Effects (ESCAPE) project, NO_2 and NO_x LUR models were developed and applied in 36 study areas across Europe (Beelen et al., 2013). Allen et al. (2011) found that the transferability

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http://dx.doi.org/10.1016/j.envsoft.2017.06.029
1364-8152/

of a location-specific LUR models is often limited because of poor model performance, and that better performance has been observed in locally-calibrated LUR models. Such models for NO_x, $PM_{2.5}$ and benzene perform better when the number of monitoring stations also is increased (Johnson et al., 2010).

To date, most LUR models in different geographic locations were developed to predict annual average concentrations of NO_2 and NO_x. Therefore, LUR models capable of predicting daily average concentrations would be useful in health studies focused on acute effects of air pollution. Moreover, there have been very few investigations of within-city NO_2 and NO_x LUR models in Australia (Dirgawati et al., 2015; Rose et al., 2011). In this study, we aimed to address the knowledge gaps outlined above by developing and applying LUR models to predict the daily average ambient NO_2 and NO_x concentration across the Brisbane Metropolitan Area (BMA), in Queensland, Australia.

2. Materials and methods

Brisbane is the third-largest city in Australia, and its metropolitan area (BMA) is one of the fastest growing urban areas in Australia, with a population of 2.3 million in 2014 (ABS, 2015). The city is located on the Brisbane River, in the south-east corner of the state of Queensland (Fig. 1). BMA has a subtropical climate with relatively small seasonal variation, and the monthly mean temperatures during the warmer (November–April) and cooler (May–October) months are 29.9 °C and 24 °C, respectively (http://www.bom.gov.au). The major urban pollution sources in the BMA are vehicular traffic and local non-traffic sources, mostly located in the lower reaches of the Brisbane river, approximately 15–18 km NE of the Central Business District (CBD). The main local non-traffic sources of air pollutants in Brisbane include aviation, a seaport, and other local industries (e.g., oil refineries).

2.1. Air pollution monitoring data

In total, 31 sites were selected for this study across the BMA over 2009–2012. The sites consisted of 6 long-term and 25 short-term monitoring locations (Fig. 1). The location and data availability for each site is shown in Fig. 2. All short-term sites were schools located between 1.5 and 30 km from Brisbane city. Traffic emissions were the major emission source to the nearby sites, with significant variability of hourly averaged vehicle counts, ranging from 44 to 1217 vehicles/hour (Laiman et al., 2014). Further details regarding the UPTECH project and its design can be found in our previous publication (Salimi et al., 2013). Long-term regulatory monitoring data were collected from the Queensland Department of Environment and Heritage Protection (DEHP) (coded as sites R1 to R5) (http://www.ehp.qld.gov.au/). DEHP provided hourly averaged NO_2 and NO_x monitoring data. In addition, short-term NO_2 and NO_x monitoring data were collected at 20 (coded S05 to S25) and 25 (coded S01 to S25) sites, respectively, during the Ultrafine Particles from Traffic Emissions and Children's Health (UPTECH) project between October 2010 and August 2012 (https://www.qut.edu.au/research/research-projects/uptech). NO_2 data was not recorded at five sites (S01–S05) due to data logging malfunction. Measurement campaigns were conducted at one site at a time for two consecutive weeks. Also, a one-year-long ambient NO_2 and NO_x monitoring campaign was conducted at an inner city site (S26) as part of the UPTECH project. An outdoor NO_x monitoring station was located at each site. The NO_x concentration was measured by an Ecotech NO_x analyzer (EC9841A). Zero checks were conducted using GasCal (Ecotech 1100) and a ZeroAir Generator (Ecotech 8301LC) for the NO_x analyzer. Span and zero checks were performed regularly. More details on the data collection scheme and project design have been published previously (Salimi et al., 2013). The NO_2 and NO_x measurement method at the DEHP reference sites (R1 to R5) used analogous methods (e.g. chemiluminescence approach. The sampling interval was 30 s. Negative and zero values (2%) were considered missing and removed. All data was converted to hourly averages for further analysis.

Four reference sites (R1, R2, R4, and R5) data were used to adjust temporal variability in short–term monitoring sites (S01–S25), which is a similar approach to previous studies (Beelen et al., 2013; Dirgawati et al., 2015; Hoek et al., 2002). R3 site was not considered for the adjusted average calculation, as the data did not cover the

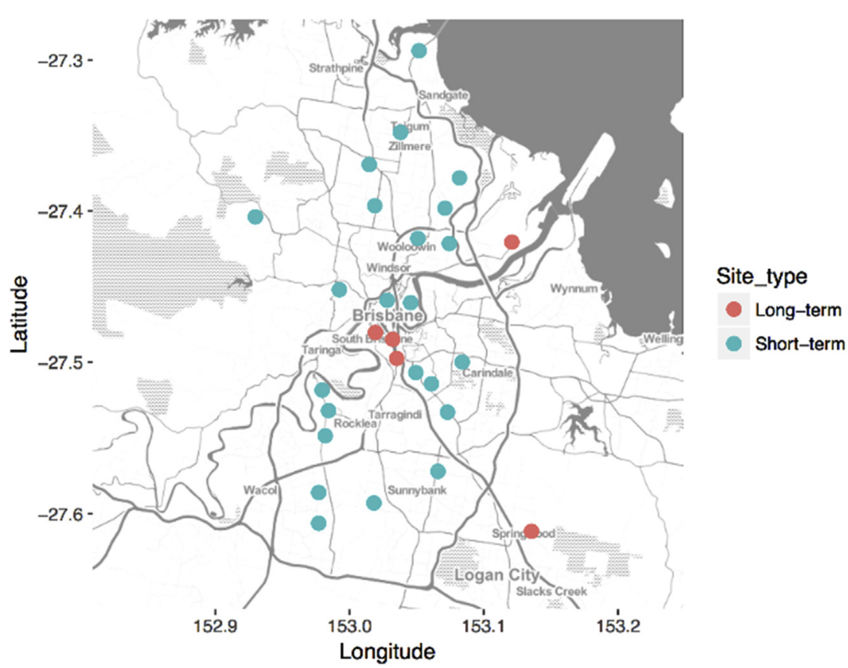

Fig. 1. The map (openstreetmap.org) shows the geographical location of short-term and long-term monitoring stations across Brisbane Metropolitan Area (BMA), Australia.