Atmospheric Environment 103 (2015) 18–24

Contents lists available at ScienceDirect

Atmospheric Environment

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

The application of semicircular-buffer-based land use regression models incorporating wind direction in predicting quarterly NO_2 and PM_{10} concentrations

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HIGHLIGHTS

- Quarterly land use regression models are constructed based on two types of buffer.
- SCBB LUR model explained more fraction of concentration variability than CBB model.
- The improvement of LUR models incorporating wind direction is good.

ARTICLE INFO

Article history:
Received 14 August 2014
Received in revised form
1 December 2014
Accepted 2 December 2014
Available online 3 December 2014

Keywords:
Land use regression (LUR)
Semicircular buffer
Wind direction
Nitrogen dioxide (NO_2)
Particulate matter (PM_{10})

ABSTRACT

Land use regression (LUR) models have proven to be a robust technique for predicting spatial distribution of pollutants with high resolution. Wind direction is an important factor affecting atmospheric environment quality. However, conventional LUR models have difficulties taking wind direction into consideration. This study put forward a semicircular-buffer-based (SCBB) LUR model to overcome this challenge. To assess the impact of wind direction on model performance, we set up two different LUR models for nitrogen dioxide (NO_2) and particulate matter (PM_{10}) in the urban area of Changsha, China. A location-allocation approach was used to identify sampling sites. Integrated 14-day mean concentrations of NO_2 and PM_{10} were measured at 80 sites and 40 sites, respectively. Measured mean concentrations ranged from 17.0 to 75.7 for NO_2 and 34.7 to 118.7 μg/m^3 for PM_{10}. Random samples of 75% of monitoring sites were used to the develop model and the remaining 25% of sites were retained for evaluation. Predictor variables were created in a geographic information system (GIS) and LUR models were developed with the most significant variables. The results showed SCBB LUR models had significantly higher R^2 values than traditional LUR models, supporting the feasibility of this new approach incorporating wind direction in the LUR model.

1. Introduction

In recent decades numerous epidemiological studies have revealed a close relationship between long-term exposure to air pollutants and adverse health effects (Brunekreef and Holgate, 2002; Pope and Dockery, 2006). To better capture individual exposures, a more sophisticated and cost-effective air pollutant analysis method is badly needed. At the present time, widely used

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http://dx.doi.org/10.1016/j.atmosenv.2014.12.004
1352-2310/

methods include interpolation, dispersion models and LUR models (Su et al., 2009). Interpolation methods can identify regional or national patterns but usually have difficulties reflecting localized variation in concentration. Dispersion models can potentially reflect the temporal and spatial variation of pollutants, but they can not meet high resolution requirement (Gulliver et al., 2013; Su et al., 2008; Wu et al., 2011). LUR models have been viewed as promising approach and have been successfully applied in many studies (de Nazelle et al., 2013; Madsen et al., 2011; Johnson et al., 2010; Wang et al., 2012). LUR models can be used to estimate mean annual or quarterly pollutant concentrations at unmeasured locations by establishing a statistical relationship between pollutant measurements and potential predictor variables (Saraswat et al., 2013).

The history of LUR model is relatively short. The first application of LUR model was applied to an air pollution epidemiology study in Europe (Briggs et al., 1997). Since then, the cost-effective approach of LUR modeling is being increasingly used in North American and Asia due to the increasing ability of GIS to provide land-use data (Mukerjee et al., 2009; Kashima et al., 2009). No standardized method exists for conducting LUR modeling, but the general approach include following steps. First, targeted pollutants are measured for one to two weeks at 20 to 100 monitoring sites (Hoek et al., 2008), and potential variables describing each site are extracted using GIS. Next, multiple linear regression (MLR) equations are established based on the most important predictor variables. Lastly, MLR equations are rendered as prediction maps across a given domain.

Most previous studies have ignored wind direction in LUR models, although some studies have demonstrated that wind direction has a very important influence on distribution of air pollutants (Madsen et al., 2007; Arain et al., 2007). Chen et al. (2010) calculated the wind index as a variable applied to a LUR model. However, wind index method can not effectively reflect the nonlinear behavior between wind direction and pollutant concentrations. Arain et al. (2007) introduced a wind field interpolation method in his study. However, wind direction at small scales can change quickly over time.

In this study, we developed two kinds of LUR models to predict spatial distribution of NO_2 and PM_{10}. One is the semicircular-buffer-based (SCBB) model incorporating wind direction, which based on the fact that downwind and upwind pollution sources have a markedly different impact on monitoring sites; the other is the circular-buffer-based (CBB) model that does not take wind direction into account. In theory, SCBB model is a feasible improvement, consistent with the diffusion mechanism of air pollutants. The aim of this paper is to determine if the new method is superior to the conventional approach by comparing the performance of the SCBB model with the CBB model.

2. Materials and methods

2.1. Overview

Both SCBB and CBB LUR modeling framework mainly include five parts: sampling site selection, measurements campaign, buffers and predictor variables selection, model building and model evaluation. The biggest difference of two models lies in buffers and predictor variables selection. SCBB model introduce semicircle buffers divided based on wind direction, while CBB model employ traditional circle buffers. The detailed description of each part is presented below.

2.2. Study area

Changsha, the capital city of Hunan province, China, is located in a typical subtropical monsoon climate zone, with low temperature and little rainfall in winter and high temperature and heavy rainfall in summer. According to the wind direction frequency statistics in 2010 provided by the Changsha weather station, the highest wind direction frequency in spring and winter is NNW (337.5°), in summer S (180°) and in autumn NW (315°). Changsha is an important transportation and shipping center in central China. Similar to other large metropolitan areas, many highways and railways traverse the Changsha region, leading to tremendous flow of vehicles per day and significant amounts of traffic-related pollutants such as NO_2 and PM_{10}.

2.3. Sampling site selection

Considering the insufficiency of government air monitoring networks for our purposes, and in order to capture the small-scale variations of pollutants in the study area, extra representative monitoring sites need to be included. These sites should represent a range of locations with mild to severe pollution. In this study, we adopted a location-allocation model to select 80 sites for NO_2 sampling and 40 sites for PM_{10} sampling (Fig. 1). The location-allocation model includes two-step algorithm that (1) estimates a pollution surface over the study area and (2) solves a constrained spatial optimization problem to determine optimal monitoring sites for a predefined number of samplers (Kanaroglou et al., 2005). The pollution surface was determined based on limited regulatory air quality data and land use coverage. All sites should be located in an open area away from potential pollution sources.

2.4. NO_2 and PM_{10} measurements

Integrated 14-day (Henderson et al., 2007) mean concentrations of NO_2 and PM_{10} were measured in each season. Given equipment

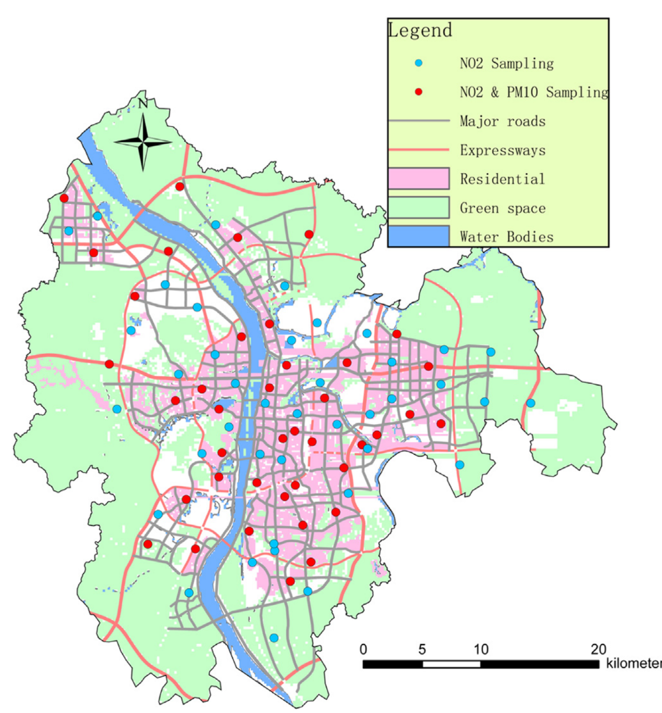

Fig. 1. Map of sampling sites in Changsha urban area.