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Incorporating wind availability into land use regression modelling of air quality in mountainous high-density urban environment

Yuan Shi[a,*,1], Kevin Ka-Lun Lau[b,c,d], Edward Ng[a,b,c]

[a] School of Architecture, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong S.A.R., China
[b] Institute of Environment, Energy and Sustainability (IEES), The Chinese University of Hong Kong, Shatin, N.T., Hong Kong S.A.R., China
[c] Institute Of Future Cities (IOFC), The Chinese University of Hong Kong, Shatin, N.T., Hong Kong S.A.R., China
[d] CUHK Jockey Club Institute of Ageing, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong S.A.R., China

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ABSTRACT

Urban air quality serves as an important function of the quality of urban life. Land use regression (LUR) modelling of air quality is essential for conducting health impacts assessment but more challenging in mountainous high-density urban scenario due to the complexities of the urban environment. In this study, a total of 21 LUR models are developed for seven kinds of air pollutants (gaseous air pollutants CO, NO_2, NO_x, O_3, SO_2 and particulate air pollutants $PM_{2.5}$, PM_{10}) with reference to three different time periods (summertime, wintertime and annual average of 5-year long-term hourly monitoring data from local air quality monitoring network) in Hong Kong. Under the mountainous high-density urban scenario, we improved the traditional LUR modelling method by incorporating wind availability information into LUR modelling based on surface geomorphometrical analysis. As a result, 269 independent variables were examined to develop the LUR models by using the "ADDRESS" independent variable selection method and stepwise multiple linear regression (MLR). Cross validation has been performed for each resultant model. The results show that wind-related variables are included in most of the resultant models as statistically significant independent variables. Compared with the traditional method, a maximum increase of 20% was achieved in the prediction performance of annual averaged NO_2 concentration level by incorporating wind-related variables into LUR model development.

1. Introduction

Urban air quality serves an important function in urban living quality. People living in cities, especially those in megacities, are facing severe health threats resulted from urban air pollution issues (Gurjar et al., 2010; Zhu et al., 2012). As a robust and efficient technique to estimate air pollution concentration level, land use regression (LUR) has been widely adopted to map the spatial distribution of outdoor air pollution (Hoek et al., 2008) and assess the long-term human health exposure (Ryan and LeMasters, 2007). Since its first application in the investigation of intra-urban traffic-related air pollution in European cities (Briggs et al., 1997), LUR models have been developed for many cities and regions, such as Europe (Beelen et al., 2013; Vienneau et al., 2009), North America (Hystad et al., 2011; Novotny et al., 2011), Asia (Kashima et al., 2009) and Australia (Knibbs et al., 2014). Using real monitored data, LUR estimates the ambient air pollution concentration at unmonitored locations based on the surrounding land use, population and traffic conditions with empirical regression modelling techniques. Compared with other methods of air pollution concentration modelling, the main advantage of LUR is that the mapping of small-scale variability is able to provide a more accurate evaluation of the health risks in unmonitored sites when dealing with the difficulty of epidemiological studies on the health impacts of human exposure to outdoor air pollution (Briggs et al., 1997).

The model performance of most LUR cases are reasonably good in many air pollution exposure studies (Ryan and LeMasters, 2007). However, its performance in high-density mountainous areas remains unknown, because so far most LUR case cites/regions have either flat terrain or relatively low-density urban development or both. In areas with mountainous topography, the complex surface morphology strongly perturbs the boundary layer wind field (Finardi et al., 1998; Raupach and Finnigan, 1997). The high-density building environment significantly alters the aerodynamic roughness of land surface (Grimmond, 1998; Kastner-Klein and Rotach, 2004), and consequently, changes the sub-layer wind flows and the dynamic potential of atmospheric pollutant dispersion (Bottema, 1997). It has been demonstrated

* Corresponding author.
E-mail addresses: shiyuan@cuhk.edu.hk, shiyuan.arch.cuhk@gmail.com (Y. Shi).
[1] Postal addresses: Rm505, AIT Building, School of Architecture, The Chinese University of Hong Kong, Shatin, NT, Hong Kong SAR, China.

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Nomenclature

Symbols and abbreviations

3D	Three-dimensional
ADDRESS	A Distance Decay REgression Selection Strategy
AICc	Akaike information criterion
AQMN	Air quality monitoring network
AQMS	Air quality monitoring station
AWS	Automatic weather station
CO	Carbon monoxide
DSM	Digital surface model
GIS	Geographical information system
H/W	The aspect ratio of street canyon
HKEPD	Hong Kong Environmental Protection Department
HKO	Hong Kong Observatory
LOOCV	Leave-one-out cross validation
LUR	Land use regression
MM5	National Center for Atmospheric Research Mesoscale Model, version 5
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
O_3	Ozone
PlanD	Hong Kong Planning Department
PM_{10}	Respirable particulate matter
$PM_{2.5}$	Fine particulate matter
PRD	Pearl River Delta
RMSE	Root-mean-square error
SA	Source area
SO_2	Sulfur dioxide
SVF	Sky view factor
VIF	Variance inflation factor
z_0	Roughness length
α	Slope aspect
$\alpha_{r(\theta)}$	The angle between the slope aspect α of a certain location and wind direction θ
β	Slope angle
θ, *Wdir*	Wind direction (*0–360°*)
λ_F, FAI	Frontal area index
λ_P	Building coverage ratio
φ	Horizon angle
Φ	Azimuth direction
A_F	The total frontal area of all buildings in an urban lot along with the a certain wind direction
A_P	Building footprint area
A_T	The area of a certain urban lot
C_{Dh}	Drag coefficient
d	The radius of the hemisphere circle for SVF calculation
K	Kármán's constant
$P_{(\theta)}$	The probability of wind direction θ.
R	Correlation coefficient
v	Wind speed (m/s)

that wind plays an essential role on the movement, concentration and dispersion of air pollution (Cogliani, 2001; Pasquill, 1971; Seaman, 2000). In mountainous and high-density Hong Kong, the interaction between the hilly topography, high-density building morphology and wind fields are very complex, which makes the wind availability vary vastly between different locations (Tong et al., 2005) and leads to significant spatial variations of air pollution concentrations (Wang et al., 2001). Therefore, it is essential to take wind conditions into account, while modelling air pollution using LUR.

However, few efforts have been made to take wind information and meteorological variables into consideration in the LUR modelling of air pollution concentrations (Arain et al., 2007; Su et al., 2008). Wind

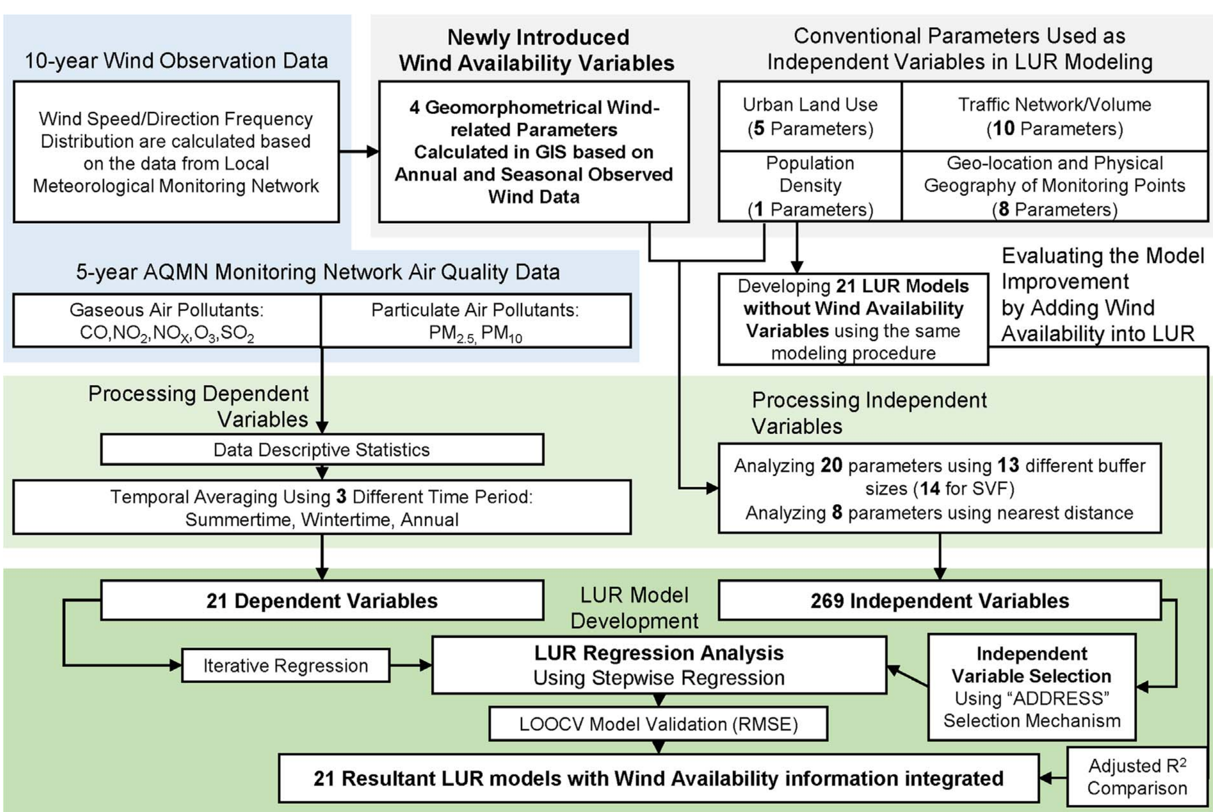

Fig. 1. The workflow chart of this present study.