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Land use regression as method to model air pollution. Previous results for Gothenburg/Sweden.

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Abstract

In the past 20 years, considerable progress has been made to improve urban air quality in the EU. However, road traffic still contributes considerably to the deterioration of urban air quality to below standards, which requires a method to measure properly and model pollution levels resulting from road traffic. In order to visualize the geographical distribution of pollution concentration realistically, we applied the Land Use Regression (LUR) model to the urban area of Gothenburg.

The NO_2 concentration was already obtained by 25 samplers through the urban area during 7-20 May, 2001. Predictive variables such as altitude, density, roads types, traffic and land use were estimated by geographic information system in buffers ranging 50 to 500 m-radii. Linear regression (α=5%) between NO_2 and every predictive variable was calculated, and the most robust variables and without collinearity variables were selected to the multivariate regression model. The final formula was applied using Kriging in a grid map to estimate NO_2 levels.

The average of measurements was 23.5 µg/m³ (± 6.8 µg/m³) and 180 predictive variables were obtained. The final model explained 59.4% of the variance of NO_2 concentration with presence of altitude and sum of traffic within 150 m around the sampler sites as predictor variables. The correlation measured versus predicted levels of NO_2 was r = 0.77 (p < 0.001).

These results highlight the contribution of traffic in air pollution concentration, although the model is not precise in regions outside the urban area (e.g. islands and rural area). Moreover, future analyses should include meteorological data to improve the LUR modelling.

Keywords: Air pollution; Nitrogen Dioxide; Exposure modelling; Geographic information system; LUR model.

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1. Introduction

Exposure assessment can be used to evaluate, at various levels of detail, the degree and linkage between contaminant sources and concentration of hazards and receptors (e.g. humans) in the environment by studying the different exposure pathways (e.g. air, water, and soil) and routes (e.g. inhalation, ingestion, and dermal contact) between them. As one kind of exposure assessment air pollution exposure assessment indicates human exposure to air pollutants. [1].

The most exposed receptors to air pollution include residents, students, workers and road users (e.g. pedestrians and drivers) whose residences, schools, universities or offices are located near to heavy traffic roads or individuals that remain long time on roads (bus drivers, traffic guards, street vendors etc.). Therefore, the environment may enable the exposure to pollutants and thereby trigger various outcomes [2].

Although the literature has documented significant variation of outdoor air pollution at small scales within urban areas for important pollutants, such as NO_2 and black smoke [3-5], many studies assessed exposure based on the average of pollutants concentration measured by regulatory monitoring stations. Due to economic and administrative reasons, the number of stations are sparse and limited, besides their measurements involve only regional pollutants concentration [6,7] which cannot be detected accurately at some places such as street canyons, busy traffic roads, industry, railway stations, airports and ports,.

Several models are based on the proximity to polluted source, e.g. proximity to busy traffic [8]. This approach is limited because it disregards others parameters that may influence the dispersion of pollutants such as altitude, land use, population, road type, traffic intensity, temperature and atmospheric stagnation [8]. Therefore, recent models became more refined including some of those parameters [1].

Ordinary dispersion modelling requires good databases which are updated frequently (at least every five years); however measurements are expensive if they are conducted at numerous places [1]. In many of urban areas where the exceedances of environmental standards most frequently take place, it is rather suitable to perform specific modelling, e.g. a CFD-model for street canyons. The result is usually satisfactory since the emission variability within those areas is more limited than the emissions variability of a whole city. Nevertheless, in comparison with environmental standard values, total concentrations are required, meaning that areas outside street canyon areas (urban, regional and long distance shares) have to be included. This can be accomplished through the boundary conditions for the calculations based on larger scale modelling, such as Land Use Regression (LUR) modelling.

The main advantage of LUR is because it is based on characteristics related to the overall trends of air pollutants concentrations mainly for longer time scales. It adopts measurements of pollution using samplers as dependent variable and land use, traffic, demographic and geographic characteristics as predictor variables [9]. Thus, LUR predicts the concentrations of pollution based on surrounding land use and traffic characteristics within circular areas (buffers) as predictors of measured concentrations [3]. Moreover, the enhancement of geographic information system (GIS) techniques has contributed to the dissemination of LUR method.

Hence we aimed to develop a LUR model to map the geographical distribution and the level of air pollution concentrations in the urban area of Gothenburg and Mölndal, Sweden.

Nomenclature

µg/m³	microgram per cubic meter
GIS	Geographic information system
LUR	Land use regression
m	meter(s)
NO_2	Nitrogen dioxide
SD	Standard deviation

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2. Methods

2.1. Study area

The study was carried out in urban areas of Gothenburg and Mölndal, at the west coast of Sweden. There are several factors that affect air quality in both cities. For instance, the varied altitude, with mountains and valleys, affects the levels of air pollutants due to the limited dispersion in the valleys, especially during winter inversion. Furthermore, there are also pollutants coming by long distance transportation from mainly Europe, which contribute to the air quality. Both harbor at Göta River estuary and industrial operations around the city contribute to air pollution emissions. However, the air quality in the city centre

is affected by mainly the road traffic emission. Despite having fewer inhabitants, Gothenburg exhibits higher levels of NO_2 than Stockholm[1] .

2.2. NO₂ sampling

NO_2 is considered a good indicator to traffic-related air pollution and easy to measure [10]. In 2001 a monitoring campaign of NO_2 named GÖTE-2001 was carried out during 2 weeks in spring of 2001 during 7-20 May. The measurements were taken at a height of approximately 2-2.5 m above ground. This monitoring campaign was a partnership between local government, Chalmers University of Technology and University of Gothenburg.

The measurements were done in 25 sites using IVL passive samplers across the study area. The placement of each site was determined by specific criteria: twenty passive samplers were distributed by dividing the region into 1 x 1 km cells covering a 20 km^2 grid area. In addition to the grid, five instruments were positioned in the western and north parts close to main roads of the city and also in the vicinity of the main valleys in the region Göta Älv valley, Säve valley, and Mölndal valley [11].

We checked if the average of NO_2 concentration measured by passive samplers represented the annual average of NO_2 concentration for the year 2001 measured at the regulatory monitoring stations Femman, Gårda, Järntorget and Mölndal through T-Student test ($\alpha = 5\%$).

2.3. Land use

The digital cartographic databases on altitude, land use and roads were obtained from the Lantmäteriets geodatabase (http://www.lantmateriet.se). The land use data included 9 classifications by type of use (industrial, arable, forests and water) and building patterns (enclosed, low, high, recreational). As the road data contained many classifications, they were summarized in 4 main groups based on their width and speed: Types I and II representing local roads (until 50 km/h) and types III and IV representing expressways (> 50 km/h). Demographic and traffic information for the year 2001 were provided by Earth Sciences Department of Gothenburg University.

The independent variables were created on the GIS software MapInfo (Professional version 10.5; MapInfo Corporation, New York, NY, USA) in buffers of 50, 100, 150, 250 and 500 m-radii around 25 sampling locations. The variables consisted in five broad categories:

- Physical geography – altitude (m);
- Land use – shortest distance to industrial use (m), area of different land uses (km^2) estimated within buffers around each sampling location;
- Road – shortest distance to roads type IV (m), lengths of different roads (m) within buffers of different radii;
- Traffic – sum of traffic flow counts (annual average daily traffic) within buffers of different radii;
- Demographic – available in a grid of points with a resolution of 500 m. Thus number of inhabitants and population density within 500 m were estimated.

2.4. Statistical Analysis

The measured ambient NO_2 concentration was used as dependent variable. Independent variables were individually screened using bivariate regression analysis. After ranking all variables by the absolute strength of their correlation with NO_2, we eliminated other variables that were correlated (Pearson's $r \geq 0.6$) with the most highly ranked variable. Through multivariate analysis, there was obtained variable(s) with statistical significance ($\alpha = 5\%$). A grid of points was created for the studied area and buffers were created around each point in order to capture the variable(s) derived from multivariate regression model.

The final equation is presented below:

$$NO_2 = \left(\beta_0 + \beta_1 X_1 + \beta_2 X_3 + \cdots + \beta_x X_x \right) \tag{1}$$

NO_2 represents the predicted value of the dependent variable. The constant is β_0. X represents the key covariables of traffic volume, road type, land use, altitude and demography and their respective coefficients (β_x). The bivariate regression and correlation analysis were calculated on SPSS for Windows software. The multivariate regression was calculated on Statistics Data Analysis (STATA) software.

Finally, the predicted LUR-NO_2 for each point was calculated. The lattice interpolation using kriging was applied to visualize the surface of the LUR model on the GIS software ArcMap 10.1 (ESRI, Redlands, CA, USA).

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[1] Luftkvaliteten i Göteborg. Available in http://goteborg.se/wps/portal/invanare. Access in Jan/2014.

3. Results

3.1. LUR modelling

NO$_2$ samples had an arithmetic mean of 23.5 μg/m³ with values ranging from 11.8 to 40.9 μg/m³ (SD = 6.8). There were 4 samples that exhibited a greater value than the one standard deviation from the mean ($\geq$ 30.4 μg/m³). All of these were located in proximity to expressways and industrial area. NO$_2$ measured at the monitoring stations (Femman, Gårda, Järntorget and Mölndal) had an average of 30.2 μg/m³ (SD = 5.7) for the year 2001.

T-Student test did not exhibit significant difference between annual average (monitoring stations) and 7-20th May period average (passive samplers). From the study, it can be assumed that the measurements obtained by passive samplers represent the annual average for 2001.

The variables most related to NO$_2$ levels were altitude, deciduous forests, sum of traffic, high buildings, industrial areas, roads type I, roads type IV and buildings with internal courtyard (more clustered in the city centre) (table 1).

As seven variables did not exhibit correlation with each other (Pearson r < 0.6), they remained in the multivariate regression analysis. Industrial land use, enclosed buildings and roads type IV were associated with increasing of NO$_2$ concentration whereas altitude, recreational buildings, high buildings and roads type I were associated with decreasing of NO$_2$ levels (table 1).

Table 1. Statistical characteristics of variables with p-values ≤ 0.2 in bivariate regression models.

Variables	Buffer (m)[‡]	R	r²	β	p-value
Altitude	-	0.677	0.459	-0.197	<0.001
Deciduous forest[*]	500	0.63	0.397	-53.345	0.001
Sum of traffic	150	0.62	0.384	2 x 10^5	0.001
High building	500	0.566	0.32	-30.6	0.003
Deciduous forest[*]	250	0.544	0.296	-134.710	0.005
Deciduous forest[*]	150	0.504	0.254	-275.263	0.010
Sum of traffic[*]	100	0.496	0.246	3 x 10^5	0.011
High building[*]	250	0.481	0.232	-72.497	0.015
Average of traffic[*]	50	0.47	0.221	7.9 x 10^4	0.018
Sum of traffic[*]	50	0.466	0.217	7 x 10^5	0.019
High building[*]	150	0.453	0.205	-181.897	0.023
Deciduous forest	100	0.447	0.2	-483.949	0.025
Average of traffic[*]	150	0.444	0.197	6 x 10^4	0.026
Industrial use	500	0.445	0.198	17.392	0.026
Roads type IV	100	0.431	0.186	2.4 x 10^2	0.031
High building[*]	100	0.431	0.186	-369.833	0.031
High building[*]	50	0.405	0.164	-1,215.930	0.045
Sum of traffic	250	0.4	0.16	3 x 10^6	0.048
Roads type 4[*]	150	0.388	0.150	0.012	0.056
Deciduous forest[*]	50	0.379	0.144	-1,536.954	0.062
Shortest distance to road 4	-	0.369	0.136	9 x 10^3	0.069
Enclosed building	500	0.365	0.133	21.066	0.073
Industrial use[*]	250	0.36	0.129	46.005	0.077
Shortest distance to industries	-	0.422	0.178	-8 x 10^3	0.103
Enclosed building[*]	250	0.321	0.103	59.879	0.118
Roads type 1	250	0.319	0.102	-5 x 10^3	0.120
Roads type 1[*]	500	0.306	0.094	-2 x 10^3	0.136
Recreational building	500	0.297	0.088	-438.056	0.149
Industrial use[*]	150	0.293	0.086	84.453	0.156
Average of traffic[*]	100	0.283	0.08	4 x 10^4	0.170
Enclosed building[*]	100	0.265	0.07	150.434	0.200

[‡] Buffer radius refers to the distance of the circular zone around each site for which the variables were calculated.
[*] excluded by collinearity

Table 2 shows variables with statistical significance, which were attained in the multivariate analysis. The final model explained 59.4% of NO$_2$ variance. Altitude exhibited the strongest interaction with levels of NO$_2$ (p<0.001), thus the most elevated areas had the lowest air pollution concentration (negative coefficient). On the other hand, sum of traffic within 150 m was related to the increase of NO$_2$ concentration (positive coefficient), and it was the second strongest variable related to the dependent variable (p=0.004). The correlation between measured and predicted levels of NO$_2$ was robust with Pearson's r = 0.77 (p < 0.001).

Table 2. Results of multivariate regression final model.

Variables	B	Std. Err.	z	p
Constant	23.99528	3.117506	7.70	<0.001
Altitude	-0.1469365	0.050859	-2.89	0.004
Traffic ≤ 150 m	14.3 x 10^6	6.4 x 10^6	2.24	0.025

r² = 0.594

3.2. Mapping the LUR model

The final formula was applied on 7,257 lattice points with a cell resolution of 300 m to calculate the NO_2 concentration for each point. The average of LUR-predicted NO_2 was 19.1 µg/m³ (SD = 4.7 µg/m³). Figure 1 exhibits the interpolated NO_2 concentration in the urban area of Gothenburg and Mölndal. The areas within the city with lower altitude combined with proximity to the busiest traffic corridors indicated the highest levels of NO_2.
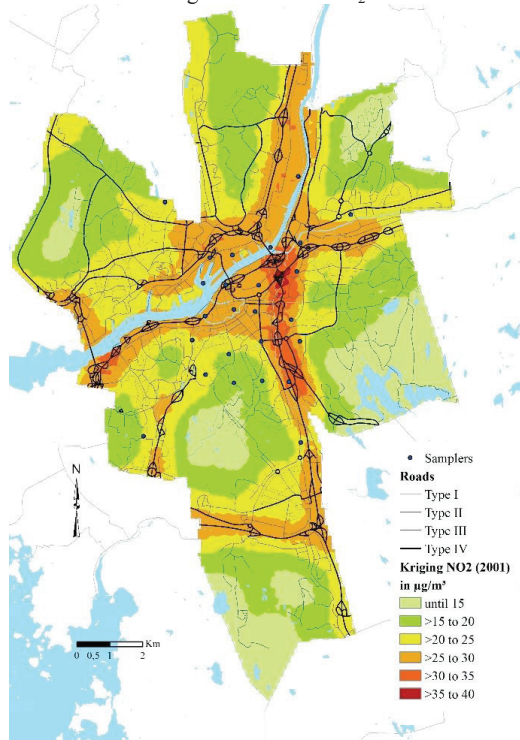

Fig. 1. Concentration of NO_2 (in µg/m³) in the urban area of Gothenburg and Mölndal predicted by the LUR model for 200l.

The application of the LUR model at the monitoring stations (Femman, Gårda, Järntorget and Mölndal) demonstrated Pearson's correlation higher between LUR-modelled concentration *versus* measured annual average (r = 0.87) than the correlation between LUR-modelled concentration *versus* measured May/2001 average (r = 0.57).

Figure 2 exhibits the measured and modelled concentration of NO_2 for each monitoring station. The LUR modelling is overestimated at Gårda station due to its proximity to a busy highway (route E6), and underestimated at Järntorget station due to lower traffic volume detected within 150 m.
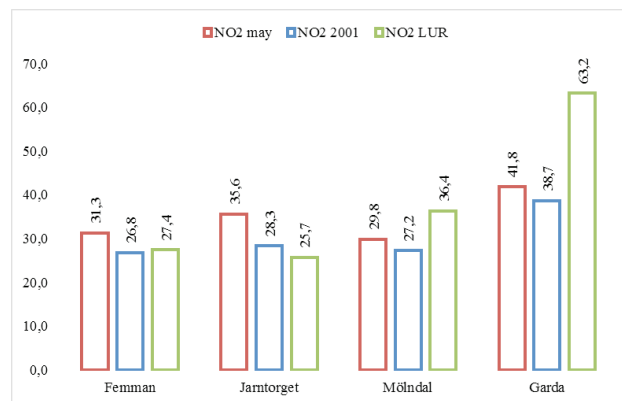

Fig. 2. Concentrations of LUR-estimated NO_2 for 2001 and measured (May and 2001 averages) at monitoring stations.

4. Discussion

In this study, the concentrations of ambient NO_2 throughout the urban area of Gothenburg and Mölndal have been modelled. The LUR model included two independent variables (elevation and traffic within 150 m radius) and it predicted almost 60% of NO_2 variability for 2001.

Comparing to other LUR models [3,6,9,12-15], our results also highlight vehicular traffic as the most important variable responsible to increase air pollutant levels, mainly in areas where cars are more concentred such as the city centre, or close to busy expressways.

LUR method has generally been applied successfully to model annual mean concentrations of NO_2, NO_x, $PM_{2.5}$, and VOCs. The method has been applied in different settings, including non-industrial and industrial cities and its performance is typically better or equivalent to geostatistical methods such as kriging and conventional dispersion models. Nonetheless, the method has some limitations [7].

- LUR models have a restricted capacity to separate the impact of some priority pollutants because they are collinear to each other, although the same problem affects other methods of exposure assessment.
- Most LUR studies do not include temporal variation or have limited calibration for different years, because they were based on short term monitoring campaigns with no much historic pollution data.
- LUR model is designed to predict the total concentration of pollutants. In contrast, dispersion models are superior when the interest is in a specific source-related component of the total concentration (e.g. traffic-derived particulates).
- Although LUR models provide individual estimates of ambient exposure (e.g. residential address), their predictor variables do not include infiltration of outdoor air into the home, or only estimates concentration at rooftop levels. This problem may affect all methods of environmental exposure assessment due to a lack of available data, complexity and high costs of data collection.

Regarding possible differences between ambient predicted and personal exposure to air pollution, Montagne et al. [16] assessed the agreement of LUR models with measured personal exposure to $PM_{2.5}$, soot (reflectance of $PM_{2.5}$), NO_x, and NO_2 in Helsinki (Finland), Utrecht (The Netherlands), and Barcelona (Spain). Soot LUR models were significantly correlated with measured average outdoor and explained 39%, 44%, and 20% of personal exposure variability in Helsinki, Utrecht, and Barcelona. NO_2 LUR models significantly predicted outdoor concentrations and personal exposure in Utrecht and Helsinki. LUR-predicted and measured outdoor, indoor, and personal concentrations were highly correlated with all pollutants when data from the three cities were combined.

Non-inclusion of data on height of buildings is another limitation of LUR method. This data can be an important issue since air pollution may exhibit different levels according to the height. In a metropolitan area of Korea VOC concentrations were significantly higher for low floors (1st and 2nd floors) than high floors (10th to 15th floors) in both winter and summer for inversion periods. During non-inversion periods of summer some VOC compounds (MTBE, Benzene and Toluene) exhibited similar results [17].

Moreover, little attention has been given in LUR studies regarding potential problems associated with datasets as accessibility, completeness and precision. Sometimes data may not be available to the period of interest. In this LUR model we were able to obtain traffic and demographic data for the year 2001, although there are limitations in the accuracy and representativity of the covariate data applied in this study. The demographic data was available only with a resolution of 500 m. Furthermore, neither land use nor traffic data were available in categories which have enabled detailed urban land uses (e.g. residential, commercial or governmental) and type of traffic (e.g. truck traffic, bus traffic or light traffic).

Promising new developments in LUR include additional predictor variables such meteorological or emission data and raster GIS environment [7]. Although few studies included meteorological variables in LUR modelling such as temperature [18], humidity [12], atmospheric stability [18], wind speed [9,12], wind direction [6,9,12], we did not include meteorological variables in our LUR model. This fact may restrict the precision of the model because these variables have an influence on the dispersion and air pollutants concentration [9,3].

In our LUR model for Gothenburg predictor variables were computed for circular zones around each monitoring site ranging 50 to 500 m radii. Radii upper than 500 m were not included in our modelling since they could be overlapped due to the proximity of the samplers' sites to each other. The radius is crucial to determine the performance of the model because it should consider known dispersion patterns e.g., the use of 150-200 m radii are sufficient to detect the exposure to vehicle traffic since most constituents of automotive exhaust decrease to ambient concentrations within this distance [4]. In this study we found significant influence of traffic on the NO_2 concentration at this distance.

In comparison to air dispersion models, LUR is a less costly option to assess the intra urban variability of air pollution as it combines air pollution monitoring at a smaller number of locations and development of models using predictor variables obtained through GIS [7].

Even though our results identified higher concentrations of pollutants related to the proximity to busy traffic roads and/or to low altitude, we have limitations regarding extrapolation of the analysis to others areas e.g., rural areas or islands, since the samplers were located only at the urban area of Gothenburg and Mölndal.

When LUR models represent annual average concentrations it is possible using continuous routine monitoring data to adjust for the temporal component [7]. In our LUR model the temporal coverage sampling campaign fulfilled the annual average of NO_2 for 2001, so we could extrapolate the model for later years.

Additionally, as personal measurements in epidemiological studies are expensive and logistically difficult, we emphasize the importance on developing indirect approaches to assessment exposure as our LUR model and the possibility of its application in future epidemiological studies to be carried out in Gothenburg.

Epidemiological retrospective studies are based on several metrics to evaluate association between air pollution exposure and adverse health outcomes (e.g. pregnancy outcomes, cardiorespiratory morbidity and mortality, etc.) [1]. In future health studies, air pollution exposures can be determined and the LUR can be calculated for homes or work locations within the studies, as described in the literature [15, 19].

Despite some limitations, LUR is a fast method to carry out to access air pollution exposure when there is data availability. LUR quantifies parameters related to deterioration of air quality, e.g. high density land uses, industrial or busy traffic areas, as well it may support policymaking regarding the decrease of air pollution concentration.

Potential benefits of this model for health effects research include improved spatial estimations of atmospheric pollutant exposure and reduced need for extensive pollutant measurements. Nonetheless, the model could be more accurate with the inclusion of meteorological variables.

5. Conclusion

This paper documents the development of an LUR model which predicts ambient NO_2 concentrations in the urban area of Gothenburg and Mölndal, Sweden. Results showed that geographic characteristics as altitude and traffic intensity contribute considerably to the urban air quality. In future research, additional meteorological will be incorporated into the model and then will be extrapolated for later years based on measurements of monitoring stations.

Furthermore, the LUR model can be used to estimate outdoor concentrations at the home address of participants in epidemiological studies regarding air pollution, as well as it could support policymaking about the improvement of urban air quality.

Acknowledgements

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