Distance Decay Effects of Traffic Flows and Land Uses on Air Quality Model

Youngkook Kim[1)], Youn Taik Leem[2)], Jong Sub Kim[2)]

Abstract

Emission sources closer to receptors are expected to have greater impacts on pollution concentrations than the sources located farther away from receptors. Therefore, it is necessary to consider distance decay effects when an air quality model is constructed based on emission sources. The parameters of distance decay functions are estimated to maximize the explanatory power of independent variables. The results of this paper present that considering the distance decay effects would enhance the significance of air quality regression model.

Keywords: distance decay effect, vehicle-kilometers-traveled, land uses, air quality model

1. Introduction

The intensity of emissions influences the spatial variations of pollution concentrations. In addition, several other factors, such as the formation and destruction of pollutants through chemical and physical reactions, the impacts of meteorological factors, and the assimilative effects of vegetative areas, also impact on pollution concentrations. Since transportation is responsible for a substantial share of urban air pollution emissions, vehicle-kilometers-traveled (VKT) and land uses are considered as good explanatory variables to explain pollution concentrations measured at air quality monitoring station (AQM) (Kim & Guldmann, 2008). VKT and land-use areas around AQMs measured with GIS techniques can be used as input variables in air quality model to explain concentration. As presented in Figure 1, pollution concentrations monitored at each AQM are used as the dependent variables.

Link VKT in the Seoul transportation network is estimated based on the results of a traffic assignment model. The areas of five land uses - residential, commercial, industrial, transportation, and vegetative - are calculated using a biotope map and satellite imagery. These explanatory variables are measured over 11 buffers and 8 sectors, and wind-direction (WD) frequencies are used to calculate WD weighted VKT (WVKT) and land uses (WLU).

[1] The Korea Transport Institute, Center for Future Cities Research, Goyang-si, 411-701, Korea
Tel: 82-31-910-8426, Email: youngkim@koti.re.kr

[2] Hanbat National University, Department of Urban Engineering, Daejeon 305-719, Korea
Tel: 82-42-821-1193, Email: ytleem@hanbat.ac.kr
Tel: 82-42-821-1189, Email: joskim@hanbat.ac.kr

Since emission sources located closer to the AQMs are expected to have greater impacts on concentrations than those located farther away, distance decay effects are expected to occur. Therefore, distance decay parameters need to be estimated, that maximize the explanatory power of WVKT and WLU. The purpose of this paper is to calculate the optimal distance decay parameters for WVKT and WLU variables.

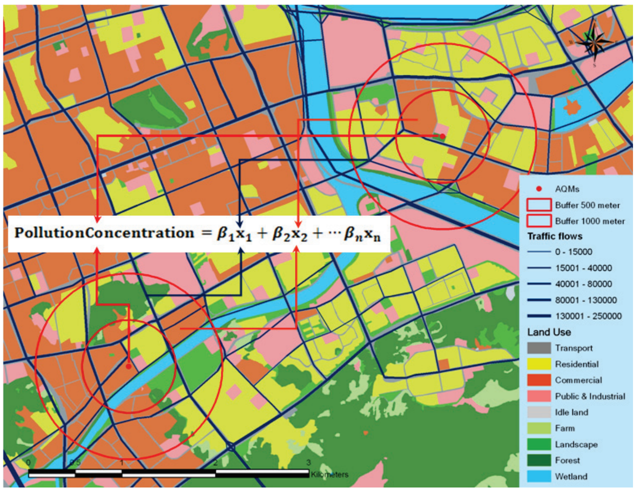

FIGURE 1 Air quality model based on traffic flows and land uses

2. Data and Method

Eleven circular buffers, with radii varying from 500 to 5,500 meters, and eight sectors are delineated around each AQM. VKTs for entire transportation links are calculated and then apportioned to each buffer and sector. WD frequencies are used to calculate WD-weighted VKT (WVKT). The same process is applied to the five land uses (WLU). Generally, concentrations at receptors are closely related to the distances between emission sources and receptors, and thus it is logical to expect that closer sources have more impacts on receptors than farther ones. VKT and land uses calculated based on the buffer system generate several variables, depending on their radii (e.g. VKT_R0500→ VKT_R5500). As expected, high correlations are observed among these variables with different radii. Additive functional forms (e.g. $\sum_r \alpha_r WVKT_r$) induce multicollinearity in regression models, making this additive form unsuitable for measuring distance decay effects. In addition, if the number of observations is limited, estimation may not be possible because of the number of degrees of freedom. Since pollution concentrations decrease exponentially with the distance from emission sources (Roorda-Knape et al., 1998) and dispersion modeling generally assumes that the dispersion of pollutant follows a Gaussian distribution (Karppinen et al., 2000; Lin & Lin, 2002), an appropriate mathematical function for measuring the distance decay effects is likely to be an exponential form. To investigate the optimal distance decay function, an exponentially decreasing form is proposed, depending on the radius, with:

$$X^p\_DD = \sum_{r=1}^{11} X_r^p \times R_r^{-\alpha_X^p} \qquad (1)$$

where:

p: Pollutant ($p = 1 \rightarrow 5$),

r: Eleven radii ($r = 1 \rightarrow 11$),

X^p_DD: Explanatory variable accounting for distance decay for pollutant p,

X_r^p: Measures of WVKT and WLU for each ring r and pollutant p,

R: Radius for each ring (500 to 5,500 meters with intervals of 500),

$-\alpha_X^p$: Parameter of the exponential decay function for pollutant p and explanatory variable X (α is always positive),

$R_r^{-\alpha_X^p}$: Distance decay factor for radius R_r .

An optimal solution means maximizing the explanatory power of explanatory variable. To find the optimal solution, an objective function is formulated as correlation between pollution concentrations and explanatory variable. The parameter of the exponential function, α, is a decision variable. The optimization problem is solved by Solver program® implemented in Microsoft Office Excel®. The distance decay factors for each pollutant p and explanatory variable X are presented in the following results sections. If the distance decay factor does not improve explanatory power, the best radius among the 11 buffers can be chosen and included in the air quality model.

3. Results

The parameters of the distance decay functions presented in Eq. (1) are estimated and the results are presented in Table 1. The estimated parameters for the distance decay functions vary across emission sources and pollutants. Some pollutants and emission sources have no distance decay effect. If there is an optimal solution, then the parameters for the closer rings are greater than those for the farther ones, suggesting that the distance decay approach can improve the results of air quality models. If there are no distance decay effects, then the best radius buffer can be used instead. As expected, the closest ring to the AQM gives the greatest parameters, indicating the existence of distance decay effects from pollution sources to receptors. Therefore, the inclusion of these effects, when we construct independent variables in air quality models, would increase the explanatory powers of independent variables, such as traffic and land use related variables.

	Variables	Ring Radius										
		500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500
O3	Commercial	4.5	3.2	2.6	2.2	2.0	1.8	1.7	1.6	1.5	1.4	1.3
NO_2	WVKT	1.4	0.7	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1
	Commercial	1.8	1.5	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9
SO_2	WVKT	1.8	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
CO	WVKT	1.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Commercial	3.6	1.5	0.9	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.2
PM10	Residential	6.4	1.3	0.5	0.3	0.2	0.1	0.1	0.1	0.0	0.0	0.0
	Industrial	1.0	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0

TABLE 1 Optimized parameters for measuring distance decay effects

References

Kim, Y., & Guldmann, J. (2008). Traffic volumes and wind directions impacts on air pollution concentrations in Seoul, Korea. Paper presented at the 7Th *Annual Community Modeling and Analysis System Conference,* Chapel Hill, North Carolina.

Karppinen, A., Kukkonen, J., Elolähde, T., Konttinen, M., Koskentalo, T., & Rantakrans, E. (2000). A modelling system for predicting urban air pollution: Model description and applications in the Helsinki metropolitan area. *Atmospheric Environment, 34*(22), 3723-3733.

Lin, M., & Lin, Y. (2002). The application of GIS to air quality analysis in Taichung city, Taiwan, ROC. *Environmental Modelling and Software, 17*(1), 11-19.

Roorda-Knape, M. C., Janssen, N. A. H., De Hartog, J. J., Van Vliet, Patricia H. N., Harssema, H., & Brunekreef, B. (1998). Air pollution from traffic in city districts near major motorways. *Atmospheric Environment, 32*(11), 1921-1930.