EnvironmentAsia
The international journal published by the Thai Society of Higher Education Institutes on Environment

Available online at www.tshe.org/ea/index.html
EnvironmentAsia 9(2) (2016) 111-117
DOI

Development Model of Oxide of Nitrogen Concentration and Land Use Characteristics in Bangkok Area

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Abstract

In this study, NO_x concentrations and land use characteristics were correlated to develop a Land Use Regression (LUR) model for application in Bangkok Metropolitan, Thailand. Measured NO_x concentrations data from thirteen air quality monitoring stations located in Bangkok area were analyzed to develop LUR equations. Land use data obtained from site survey method and was characterized into the following categories, i.e., building with 1-2 floors, building with 3-5 floors, building with over 5 floors, green area, road area, space area and open water. The results showed that NO_x concentration positively correlated with percentage areas of building 3-5 floors, building >5 floors and road area while NO_x had a negative relationship with building 1-2 floors, green area, and space area. The obtained regression model was able to predict 89% of the variation in NO_x concentration.

Keywords: nitrogen oxide; land use characteristics; land use regression; building height

1. Introduction

Most of cities around the world have faced the problem of traffic congestion and urban air pollution, including Bangkok Metropolitan of Thailand. Nitrogen oxides (NO_x) include various nitrogen compounds such as nitrogen dioxide (NO_2) and nitric oxide (NO). Nitrogen oxides (NO_x) can react with ammonia, moisture and other compounds to form small particles that can infiltrate deeply into sensitive parts of human lungs. These small particles can cause or worsen respiratory diseases, such as emphysema and bronchitis, and can aggravate existing heart disease (Kongtip *et al*., 2006). Many researchers indicated that road traffic activities were the major cause of air pollution in urban area, and land use characteristics could affect the dispersion and accumulation of air pollution (Beelen *et al*., 2013). Health related air pollutants generated from road traffic such as nitrogen dioxide and other particulates in terms of TSP, PM10 and PM2.5 were mentioned elsewhere (Lebret *et al*., 2000; Nerriere *et al*., 2005). In addition, it has been stated that land use characteristics and traffic in urban environment were related to NO_2 and PM10, as well as, increasing risk of asthma (Son *et al*., 2015). Also, there was an attempt to assess community health risk caused by air toxics in association with land use policy (Willis and Keller, 2007).

In general, air pollution problems in a big city always emphasize on traffic volume and roadways. However, other factors are also influencing the pollution accumulation such as meteorological condition, surface area around the roadways, air flow obstructions, etc. Land use characteristics along roadways have been changed regularly according to development of urban area. In particular, roadways always induce development of infrastructures, resulting in growth of commercial buildings and residential activities. Consequently, this will create a big demand for large buildings, which occasionally become the obstruction of air pollution dispersion in urban area. Superczynski and Christopher (2011) observed a moderate-to-strong correlation between PM2.5 and the urban area surrounding monitoring sites in Birmingham during years of 1998 and 2010. Furthermore, there were some conclusions about the spatial variability of NO_2 concentrations was directly related to characteristics of local geography, i.e., population density and patterns of land use, vegetation, open space, roads and traffic (Crouse *et al*., 2009).

In order to gain insights of the air quality management in a big city like Bangkok Metropolitan, the factors influencing air pollution dispersion should be determined besides pollution sources. This study was aimed to observe and demonstrate the relationship of NO_x concentrations and land use characteristics in Bangkok area. Statistical method such as Land Use Regression Modeling was assigned to develop mathematical equation representing the relationship for further prediction.

2. Materials and Methods

2.1 NO_x monitoring data

NO_x concentrations data were obtained from thirteen routine monitoring stations of Pollution Control Department (PCD) as listed in Table 1. NO_x monitoring data by PCD are regularly recorded as hourly basis. The correlation between NO_x concentrations and land uses in vicinity of each monitoring station were analyzed to develop Land Use Regression model (LUR). Three stations, named as 52R, 53R and 54R, were represented as road side stations and another ten stations as ambient air stations (Fig. 1).

2.2 Land use data

Land use data within 500 meter radius from monitoring station were collected by site survey and supported by map retrieved from Google Earth program. In this study, land use were categorized into the following types, i.e., building with 1-2 floors, building with 3-5 floors, building with over 5 floors, green area, road area, space area, and open water. Open source Geographic Information System (GIS) as Quantum GIS (QGIS) were employed to obtain the characteristics of existing land use and to calculate area percentage of each land use type. These land use percentages were correlated to NO_x concentrations as mentioned above to develop a regression equation for further prediction.

2.3 Correlation analysis

In this study, the aim of correlation analysis is to define relationships between variables, which were land use areas and NO_x concentrations in this study. Correlation is a statistical technique which can show whether and how strongly pairs of variables are related. If “r” is negative number, it means that one variable gets larger while another gets smaller (Sahoo, 2013). Statistical software was used for correlation analysis and correlation coefficient calculation.

2.4 Land use regression model and validation

Land use regression (LUR) Models was based on multiple regression analysis technique. Stepwise and backward techniques are associated with the methodology to generate regression equations. The equation with the highest adjusted R^2 was assigned to be the most appropriate model (Hastie *et al.*, 2008). Multicollinearity between the variables and influential observations were considered. Variance inflation factors (VIFs) of more than ten were excluded from the final equations according to some observation (O’Brien, 2007).

NO_x concentration data in year 2011 and percentage of land use area in the same year were used in LUR development step. Once the appropriate regression equation was obtained, it was validated with NO_x concentrations in year 2012. Predicted NO_x concentrations from the equation were compared with measured data of year 2012. Scattering plot technique was also applied to exhibit the statistical significant difference between predicted NO_x concentrations and measured concentrations. The corrective application was employed and the adjusted

Table 1. Thirteen air monitoring stations of PCD in Bangkok area

Station	Name	Station code
1	Bansomdejchaopraya Rajabhat University (ambient air)	02T
2	Ratburana Post Office (ambient air)	03T
3	Thai Meteorological Department Bangna (ambient air)	05T
4	Chandrakasem Rajbhat University (ambient air)	07T
5	National Housing Authority Klongchan (ambient air)	10T
6	National Housing Authority Huaykwang (ambient air)	11T
7	Nonsi Witthaya School (ambient air)	12T
8	Mathayomwatsing School (ambient air)	15T
9	Public Relations Department (ambient air)	59T
10	Bodindecha Sing Singhaseni School (ambient air)	61T
11	Thonburi Power Sub-Station, Bangkok (road side)	52R
12	Chokchai Police Station (road side)	53R
13	National Housing Authority Dindaeng (road side)	54R

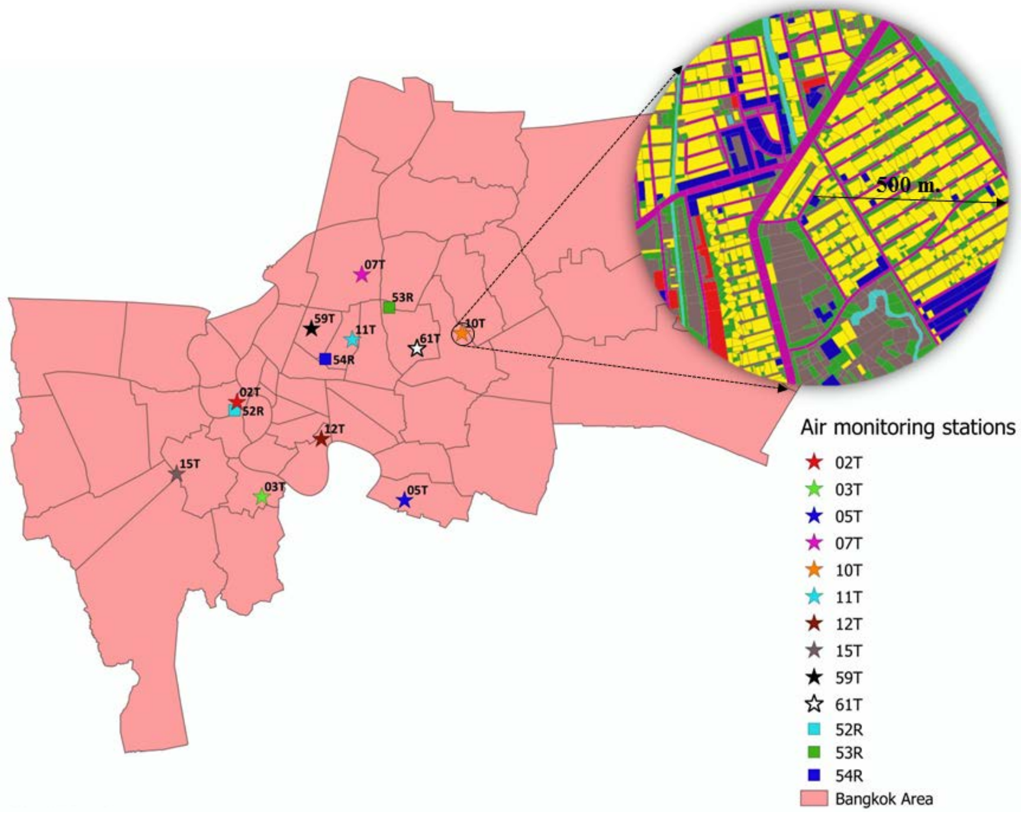

Figure 1. Locations of thirteen air monitoring stations in Bangkok area

equations with high R^2 were selected for better representative of the relationship between studied variables (Mavko *et al*., 2008).

3. Results and Discussion

3.1 NO_x measurements

Due to temporal database of land use area did not show much change during the study year, the correlation analysis using hourly NO_x concentrations did not achieved good quality of statistical results. Therefore, hourly NO_x concentrations obtained from PCD monitoring stations were treated to be monthly average database by the inspiration of some work (Cheewinsiriwat and Chanhow, 2013). Table 2 indicates descriptive statistics of monthly average NO_x concentrations in years of 2011 and 2012. That is, monthly average of NO_x concentrations in year 2011 ranged from 3.9 to 189.8 ppb with an arithmetic mean of 43.1 and standard deviation of 31.4 ppb. For monthly average in year 2012, they ranged from 13.9 to 187.5 ppb with an arithmetic mean of 52.7 and standard deviation of 32.9 ppb.

3.2 Land use characteristics

As shown in Fig. 2, land use characteristics of thirteen study sites were obtained by site survey method assisted with maps from google earth and google street programs. Study areas were in 500m radius from each air monitoring stations. Percentages of land use characteristics area were calculated and summarized in Table 3. These selected thirteen air monitoring stations are located in urban area. Therefore, majority of land use characteristics are buildings, especially building 1-2 floors and building 3-5 floors. In year 2011, percentages of green area were varied and ranged from 7.17 to 17.32 among these thirteen stations. The largest road area was found in the 54R station (National Housing Authority Dindaeng) with the percentage of 16.80.

In case of space areas, which are the land use should not be such a significant proportion in urban area due to high demand of land property including area that uncovered with buildings or certain structures. However, the highest percentage of 46.84 in the 05T station (Thai Meteorological Department Bangna) was the exception due to the duty of Thai

Table 2. Descriptive statistics of measured NO_x in years of 2011 and 2012

Statistics	Monthly average of NO_x concentrations (ppb)	
	year 2011	year 2012
N	101	105
Min-Max	3.9-189.8	13.9-187.5
Range (max-min)	185.9	173.6
Arithmetic mean	43.1	52.7
Std. Deviation	31.4	32.9

Meteorological Department. For 'space' area, most of them are golf field and football field. The smallest land use characteristic was the open water type, which their percentages ranged from 0.29 to 5.25.

For urban area, traffic-related air pollution would not be only affected by changing of their source characteristics (traffic intensity, fuel or engine types, etc.), but also change of land use characteristics. For example, increase of high rise building in urban area, especially nearby the roadway, would be expected. Typically, high rise building could adversely affect dispersion of air pollution. Space area, green areas, or open water might be replaced with residential structures or else. These changes would provide some impact on the dispersion and accumulation of air pollution in urban area.

3.3 Correlation coefficient study

Statistical techniques were used to analyze correlation coefficient of monthly average NO_x concentrations and percentages of land use area surrounding the designated monitoring stations. The results of significant correlated variables at 95% confidence interval are concluded in Table 4. The results exhibited that NO_x concentrations were positively correlated with area percentages of building 3-5 floors, building >5 floors road area and space area while it was negatively correlated with percentages of building 1-2 floors, green area and open water area.

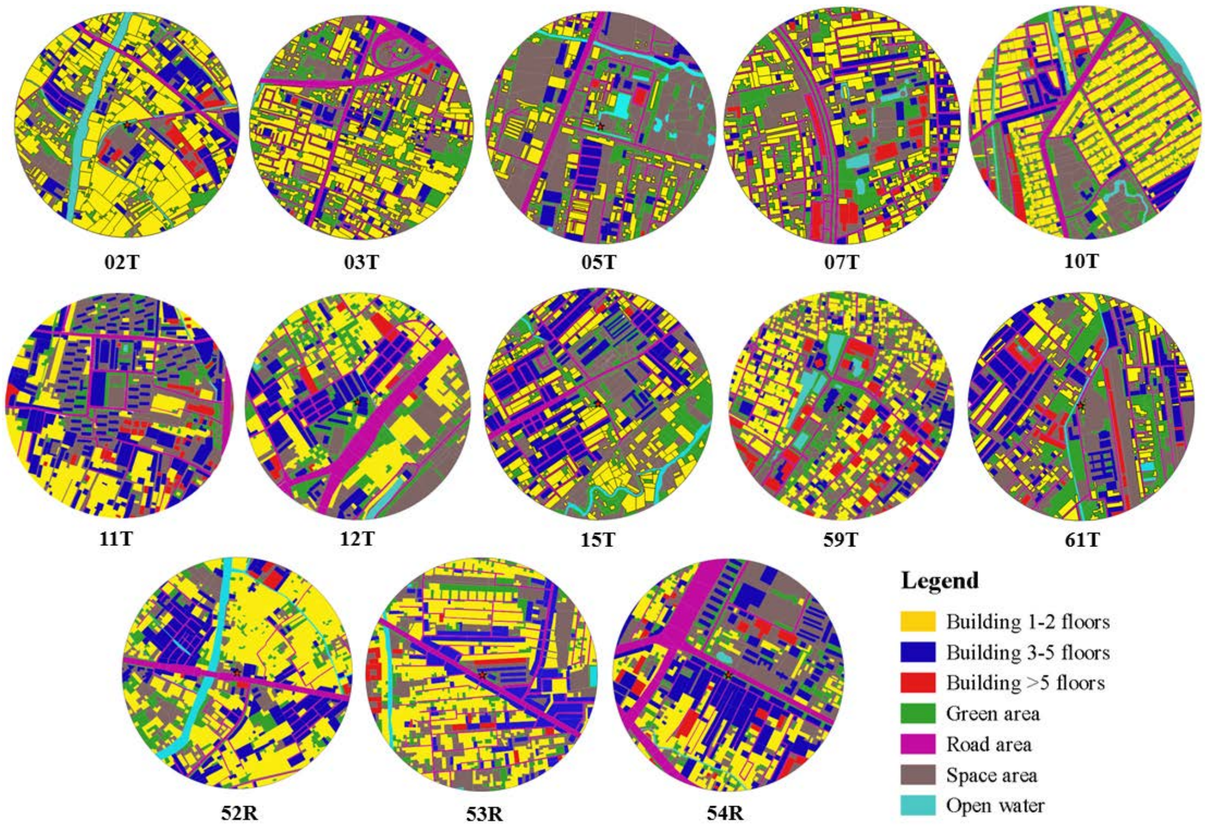

Figure 2. Land use characteristics of thirteen study sites

Table 3. Area percentages of land use characteristics in 500 meters radius of air monitoring stations

Land use characteristics	Percentage (%) of land use characteristics												
	02T	03T	05T	07T	10T	11T	12T	15T	59T	61T	52R	53R	54R
Building 1-2 floors	42.31	39.12	15.09	29.21	38.17	21.04	26.95	27.53	27.51	16.31	42.92	36.63	18.91
Building 3-5 floors	26.92	8.20	8.50	8.38	6.65	27.11	14.57	21.77	9.64	18.33	18.61	17.11	25.15
Building >5 floors	2.41	0.35	0.48	5.64	1.90	4.24	2.49	0.39	7.75	4.32	1.18	2.91	4.39
Green area	7.17	15.35	16.28	17.32	16.87	8.09	16.23	14.75	14.67	16.03	10.91	8.91	8.95
Road area	3.40	16.75	9.69	13.55	15.23	8.30	15.84	10.57	10.30	13.17	8.10	11.12	16.80
Space area	12.72	19.65	46.84	24.41	18.23	30.93	22.75	22.95	27.00	30.70	13.03	21.69	25.07
Open water	5.06	0.60	3.11	1.49	2.93	0.29	1.18	2.04	3.13	1.15	5.25	1.63	0.74

This correlation presented that increase of proportional area of building 3-5 floors, building >5 floors, road and space area will result in higher ambient NO_x concentration. This can be explained that high rise buildings act like an aerodynamic resistance, retarding ventilation efficiency and pollutant removal (Lin *et al*., 2014; Liu *et al*., 2015). In addition, increase of road area may imply to high volume of traffic, which is considered as the important source of traffic-related air pollutants in urban area, especially NO_x (Ning *et al*., 2012). For space area, the positive correlation was quite small (*0.072*) and inconsistent to the assumption that more space area should support better dispersion of air pollution. In this case, the possible explanation might fall on the influence of wind direction in the area. Regarding to the negative correlations, decreasing of low rise building, green area and open water in urban area is generally caused by a replacement for high rise buildings or roads.

3.4 Building regression model and model validation

The most appropriate equation was built by stepwise method (not include constant in equation). The final multiple regression equation of NO_x concentrations and percentages of land use characteristics is shown in Table 5. There are only four variables included in regression model, i.e., area percentages of building 3-5 floors, building >5 floors, green area and road area. Adjusted R^2 of equation was *0.89* with *p*-value less than *0.05* at 95% confidence interval, illustrated that the independent variables can explain the changing of NO_x concentrations within 89% accuracy. This adjusted R^2 was similar to the R^2 of *0.73* and *0.77* reported by Madsen *et al*. (2007) and Aguilera *et al*. (2008), who studied LUR model in Oslo, Norway, and Sabadell, Spain, respectively. The appropriate equation validated with the monitored NO_x concentration data in year 2012. Scattering technique was applied for validation of this equation model, resulting in R^2 value of *0.40* (Table 5). Moreover, the variance inflation factor (VIF) values of all five variables in Table 6 illustrated that the highest values of 5.53, belonging to land use characteristics of green area (G), respectively, were still lower than the value of 10 discussed by O'Brien (2007). Although the recommended number of VIF was varied among researchers, small VIF values could still explain less collinearity between independent variables.

Likewise, LUR models for predicting change of NO_x and NO_2 were developed in many countries in Asia. For example, the study of NO_x in Taipei Metropolis reported their R^2 of *0.81* (Lee *et al*., 2014). In addition, studies of NO_2 in Korea and China presented their R^2 values of 0.984 (Kim and Guldmann, 2015) and *0.82* (Meng *et al*., 2015), respectively. However, these previous LUR studies did not focus on specifically defined land use characteristic such as height of building, an important factor of outdoor ventilation in urban area. Moreover, wind direction and wind speed circulated in urban area were significantly affected by urban morphology (Ramponi *et al*., 2015). Most of LUR studies compiled land use data in term of residential area, commercial area, and industrial area (Beelen *et al*.,

Table 4. Correlation coefficients between NO_x concentrations and area percentages at 95% confidence.

Scenario	Positive correlation	Negative correlation
NOx concentrations (Monthly average)	Building 3-5 floors area (0.501) Building > 5 floors area (0.203) Road area (0.233) Space area (0.072)	Building 1-2 floors area (-0.375) Green area (-0.568) Open water area (-0.338)

Table 5. Performance of land use regression model for NO_x prediction

Significant variables of model [a]	Equations	N	Adjusted R^2	Validation R^2
B2, B3, G, R,	$NO_x = 1.313B2 + 3.526B3 - 4.715G + 5.823R$	101	0.89	0.40

[a] Area percentages of B2 = building 3-5 floors, B3 = building >5 floors, G = green area (tree) and R = road area

2013; Hoek *et al*., 2008). In this study, land use characteristics consist of not only various buildings and structures, but also roadways, space, green area, etc., which can affect more or less on dispersion and accumulation of air pollutants in urban area. According to the results, correlation coefficients indicated that there were positive correlations at 95% confidence interval between NO_x concentrations and land use characteristics, especially, building 3-5 floors (B2), building >5 floors (B3) and road area (R). Therefore, increase of area percentages of road, building 3-5 floors and building >5 floors in the vicinity (500 m. radius) of thirteen air monitoring stations would result in increasing of NO_x concentrations in urban area.

4. Conclusions

Currently, urban planning has been designed according to the major category of land use type such as residential or industrial areas or else, which still are constraints for specific urban design. The obtained land use regression model of NO_x from this study can be useful for land use study and urban planning in more specific level in the future. In conclusions, the land use regression model would assist the analysis of proper height of building in some certain area, especially nearby roadways. That is, not only engineering safety was concerned, but also air pollution dispersion in urban area. Also, the consideration of expansion of roadways, appropriate proportion of green area or replacement of space area or open water area with other types of land uses would also be benefit by this land use regression model.

Acknowledgements

This research work is supported in part by the grant from Center of Excellence on Environmental Health and Toxicology, Science and Technology Postgraduate Education and Research Development Office (PERDO), Ministry of Education. The authors would like to express our thanks for monitored ambient air quality data from Pollution Control Department, Thailand.

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Table 6. Summary of variance inflation factor (VIF) of variables in land use regression model for NO_x prediction

Variables	Unit	SE	*P*-value	VIF
Building 3-5 floors (B2)	%	0.18	<0.001	3.21
Building >5 floors (B3)	%	0.53	<0.001	2.98
Green area (G)	%	0.47	<0.001	5.53
Road area (R)	%	0.76	<0.001	3.62

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Received 17 May 2016
Accepted 28 May 2016

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