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Relationships between Wind Fields and Nitrogen Dioxide Concentration : Inner Bangkok Case Study

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Abstract

Nitrogen Dioxide (NO_2) is considered globally as one of the major air pollution components. Although the NO_2 concentration in the inner Bangkok areas is still below the emission standard defined by the Pollution Control Department (PCD), the levels have constantly been monitored by the 13 stations set up by the PCD to cover inner Bangkok. The highest levels of NO_2 concentration have been detected in the busy inner-Bangkok areas. This work aims to verify a suggestion made by a few previous research works that the wind fields variable could be incorporated into the land use regression model to improve the NO_2 concentration prediction by using the data collected from the inner areas of Bangkok. Data of wind directions and wind speeds measured at the meteorological stations located in the wider Bangkok area have been spatially interpolated by a geographic information system to obtain wind directions and speeds for each PCD station at selected dates and times. The resultant data reveal that at the 0.01 significant level wind direction has a weak positive correlation (0.11) while wind speed has a small negative correlation (-0.232) with NO_2 concentration. Although the wind fields factor has a very small influence on the level of NO_2 concentration in the inner Bangkok areas, the results seem to underline the influences of the wind directions created by urban area physical configuration that divert the NO_2 from its normal paths to the PCD stations. High wind speeds, however, seem to have the opposite effect as it carries NO_2 away from the PCD stations.

Keywords: Wind fields, Nitrogen Dioxide, GIS

1. Introduction

Nitrogen Dioxide (NO_2), a reddish-brown and acid smelling gas, is formed where there is combustion of fuel from vehicles and factories. It can cause haze in the atmosphere. And, whenever combining with water, Nitric acid is formed and causes nitric rain. When the concentration is beyond its quality standard, NO_2 is known as a cause of short-term and long-term respiratory diseases, the most vulnerable of which is the delicate structure of lung tissue. In Thailand, NO_2 concentrations have been measured and monitored by the Pollution Control Department (PCD) in order to control air quality for human health.

In general, NO_2 concentrations are measured at select locations throughout an area. To obtain the level of NO_2 concentrations at a certain location where no measurement has been made, a spatial interpolation process needs to be done. Spatial interpolation is a method of estimating the data values of unsampled locations by using the data values of the observed locations. Spatial interpolation processes could be formulated as linear or weighted calculations. However, the distribution of NO_2 concentration over an area could be affected by other factors apart from distance. Recently, researches on NO_2 concentration prediction have implemented a new model called land use regression (LUR) (Briggs *et al.* 1997; Gilbert *et al.* 2005; Hoek *et al.* 2008). The LUR model uses a raster GIS to predict NO_2 concentration at each raster grid cell based on NO_2-generated factors within the cell boundary. Although the combustion of fuel from vehicles and factories have been considered as a major cause, climatic factors such as wind fields also affect the NO_2 concentration (Arain *et al.* 2007) .

Although NO_2 concentration has been studied extensively in many countries, only a few researches have been done in Thailand. Leong and Laortanakul (2003) measured NO_2 concentration at six locations in Bangkok to examine the influence of traffic volume and physical terrain on NO_2 concentration. Pangsang (2004) reproduced a risk map of NO_2 concentration in Bangkok based on the traffic volume data. This paper is a study of the relationships between wind fields and NO_2 concentrations, which is the first phase of the project "NO_2 prediction using the LUR model and GIS". This research aims to study how wind fields influence NO_2 concentrations at the PCD stations in Bangkok using GIS and statistical methods as the main tools.

2. NO_2 Concentration in Bangkok

Air pollution is one of major problems of big cities all over the world. Industrialization, transportation systems developments, high population density have been identified as major causes. Although NO_2 concentrations in the inner Bangkok areas are still below the emission standard defined by the PCD, highly increasing traffic volume and urbanization has sent an alarm to Bangkok people to be cautious on NO_2 concentration levels. Understanding causes and impacts of NO_2 concentration, exploring factors that affect NO_2 concentration, modeling the relationships between factors and NO_2 concentration, and predicting how much NO_2 concentration will be at certain locations in the future, are needed to be accomplished.

Bangkok, covering about 1,600 sq.kms., is located in the central part of Thailand near the Thai Gulf with the average elevation being less than 10 meters above mean sea level. Bangkok has been the capital of Thailand for almost 230 years. Today, Bangkok is the most urbanized and densely populated city in Thailand. As a tropical country, there are three seasons in Thailand; summer in Febuary-May, rainy around June-September, and winter in October-January. The study area of this paper covers the inner area of Bangkok, which is about 430 sq.kms. as shown in Figure 1. Thirteen PCD stations measuring NO_2 concentration are located within the study area.

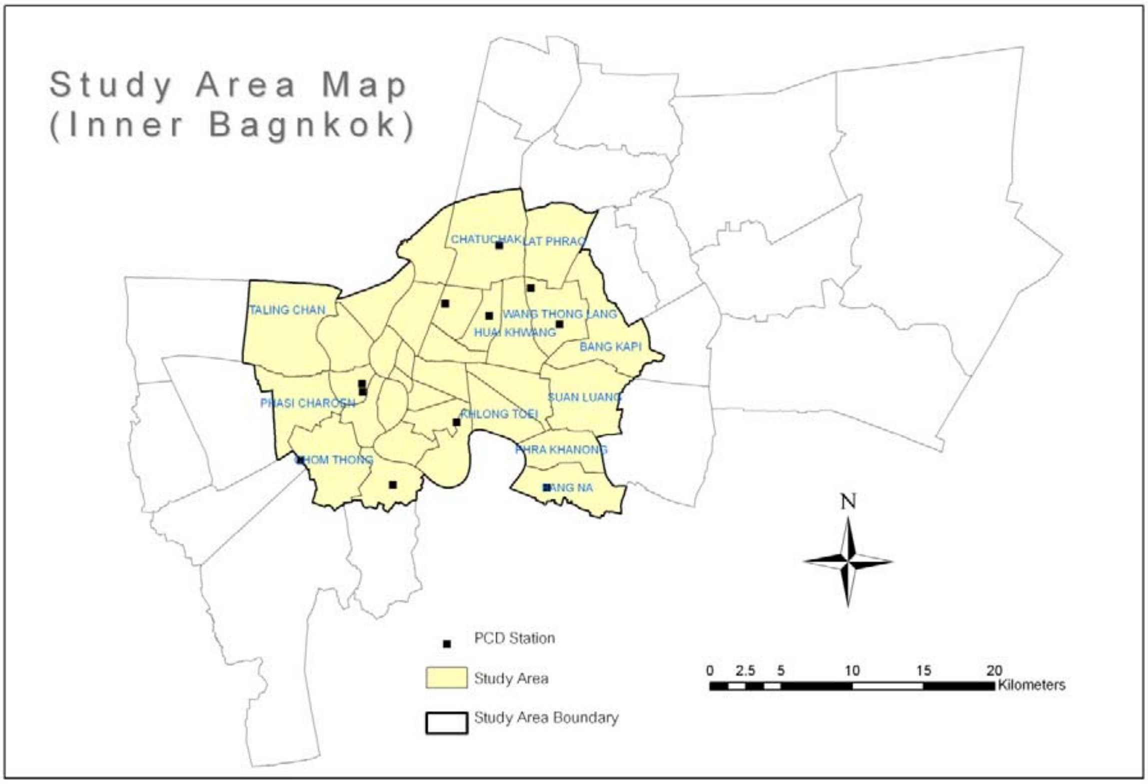

Figure 1 A map of the study area, inner Bangkok, with locations of PCD stations

Leong et al. (2003) studied relationships between levels of NO_2 concentration and related factors in six locations in Bangkok where the traffic volume was heavy. The study reported that levels of NO_2 concentrations are influenced by road characteristics (i.e. number of lanes), vehicle characteristics (i.e. types, volume, speeds), and meteorological characteristics (i.e. temperature, wind speeds, rainfall). The study also revealed that the NO_2 concentration levels rise and fall in a seasonal cycle; the high levels were in winter season, and the low levels were in summer season. The concentration levels are also different between weekdays and weekends, due to different traffic volumes. In addition, within a day, the concentration levels during rush hours in the morning and evening were higher than during the non-rush hours.

Based on hourly NO_2 concentrations collected by the PCD stations in Bangkok during 2008-2010, the rise and fall of the average monthly concentration is shown in Figure 2. The average of each month of the three year period is shown in Figure 3. This shows that the concentration reaches its peak around December to January and its lowest point around June to August. The concentration gradually decreases from January to June and rises from September to December.

The average hourly of NO_2 concentrations in the months of high (December 2009), intermediate (March 2010), and low (July 2010) concentrations are plotted as shown in Figure 4. The graph shows that there are two peaks; one in the morning (8-9am) and another in the evening (8-9pm), which coincide with the traffic peak hours in Bangkok.

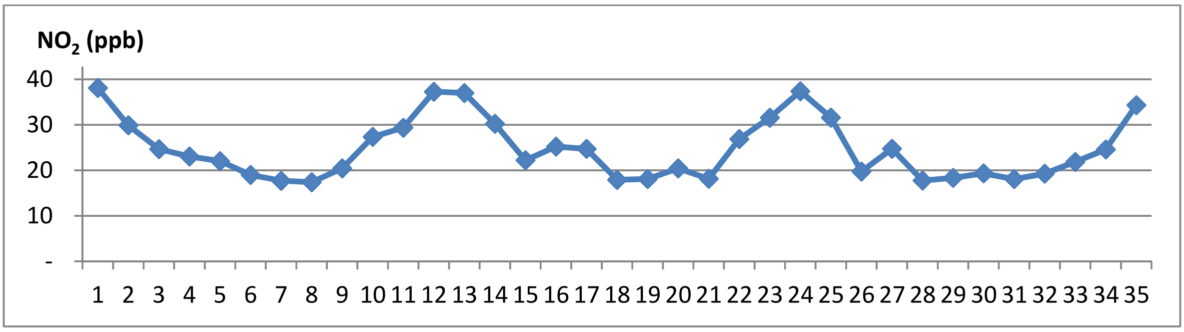

Figure 2 Daily average of NO2 concentration (ppb) from January 2009 (month 1) to November 2010 (month 35)

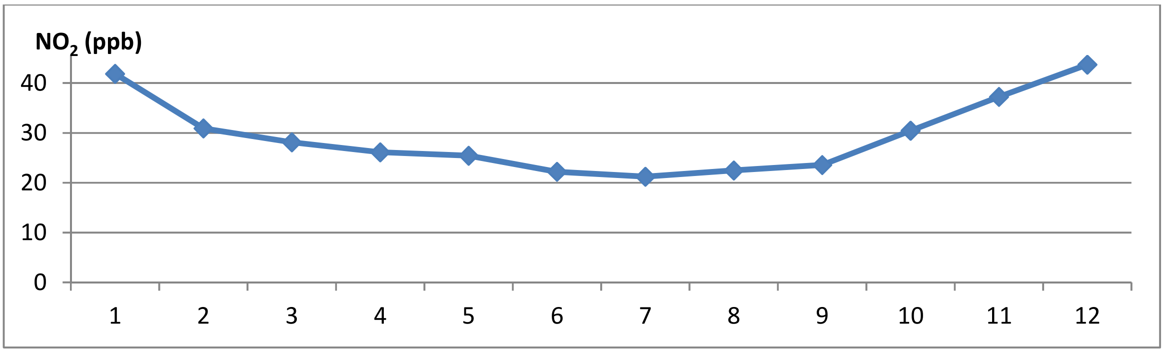

Figure 3 Monthly average of NO2 concentration (ppb) from January 2009 to November 2010

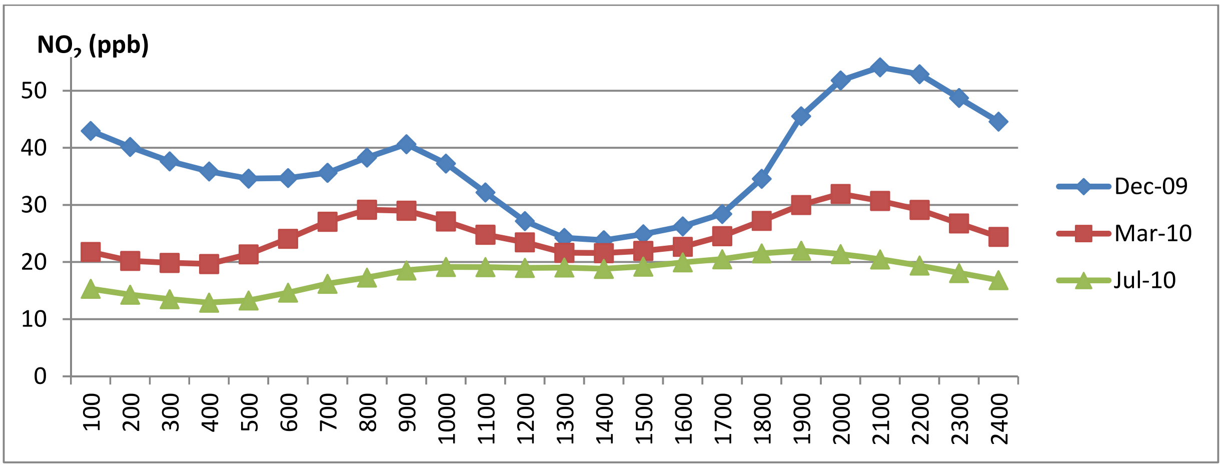

Figure 4 Hourly average of NO_2 concentration (ppb) in December 2009, March 2010, and July 2010

3. Data Model and Analysis

Data of wind directions and wind speeds were monitored by meteorological stations every three hours (0100, 0400, 0700, … , 2200). There are only three stations in Bangkok. In order to be able to perform spatial interpolation for inner Bangkok, thirty-two meteorological stations within Bangkok and provinces adjacent to Bangkok were used. However, the data from stations might not be available for certain hours. Another data used in the model are roads. Road data was represented as centerlines with attributes of road name, road type, road length (meters) and number of lanes. Length and number of lanes were later used in the calculation to find out how wind directions relate to the NO_2 concentration.

The data used in the model were wind fields and NO_2 collected at 10am every day during December 2009, March 2010 and July 2010. This paper studied the relationship of wind fields and NO_2 concentrations by performing two models; wind direction model and wind speed model. The details of the data models and the result of the analysis are reported in the following subsections.

3.1 Wind Direction Model and Analysis

Relationship between wind direction and NO_2 concentration can be determined by comparing total amount of NO_2 concentration carried by the wind with the NO_2 concentration at the end of the wind path. Unfortunately, NO_2 concentrations have not been measured at all locations. Thus, in this paper, potential sources of NO_2 generation were then used as representatives of NO_2 concentration amount at given locations. That is, if the wind blows in a direction passing NO_2-generated sources to a location, the higher NO_2 sources carried by the wind the higher NO_2 concentration should be at that location. As the combustion from vehicles on the roads is considered a major source of such pollutant in an urban area, this paper evaluates how wind direction influences NO_2 concentration by calculating how many road values are in the direction of wind paths. Road values are measured by multiplying road length with number of lanes of each road. The accumulated road values in the direction of a wind path are considered *weighted road values* which are used to compare with the NO_2 concentration at each PCD station.

Since wind direction data were collected at meteorological stations, the interpolation technique, Radial Basic Function (RBF), was implemented to generate wind directions over the study area. The RBF was performed by a GIS function using at least 10 stations as input in the calculation. The result was a raster file with a wind direction of each grid cell. The GIS flow direction function was then performed to obtain flows of the wind over the area. As a result, wind paths from a location to another can be traced. Thus, wind paths to each PCD station can be acquired. Weighted road values of each raster grid in the direction of wind path within 1 kilometer from each PCD station were then calculated and accumulated. The accumulated weighted road values of each PCD station were then compared to NO_2 concentrations at the stations.

Figure 5 shows locations of meteorological stations and PCD stations used in the model of March 11^{th}, 2010. It can be seen that data from some stations were not available at the specified date and time. Numbers next to the stations indicates wind direction measured at the stations. Wind directions are given in numbers between 1 to 360; where 90 means wind blows from a given location to the east, 180 means wind blows to the south, 270 means wind blows to the west, and 360 means wind blows to the north. Figure 6 portrays a zooming into the study area and shows the result of the interpolation (RBF) of the data shown in Figure 5 as a raster file.

The raster of the study area is at the resolution of 100x100 sq.meter. After the interpolation, wind direction at each grid cell was assigned. Figure 7 shows wind paths or flow directions generated by a flow direction function in GIS (Figure 6). Values assigned to each target cell are the addition of values from its eight neighboring cells where the wind originated and blew to the target cell. In Figure 6, cells in orange with a value of 16 are where wind blows from its western neighboring cell, while cells in yellow-green with a value of 8 are where wind blows from its south-western neighboring cell. Figure 8 shows weighted road values of each cell within 1 kilometer from a PCD station (Rajapad Chankaseam University). Flow accumulated function in GIS was then used to accumulate weighted road values from those cells the wind blew to the target cells (PCD stations). The accumulation was calculated on only those cells within 1 kilometer of each PCD station.

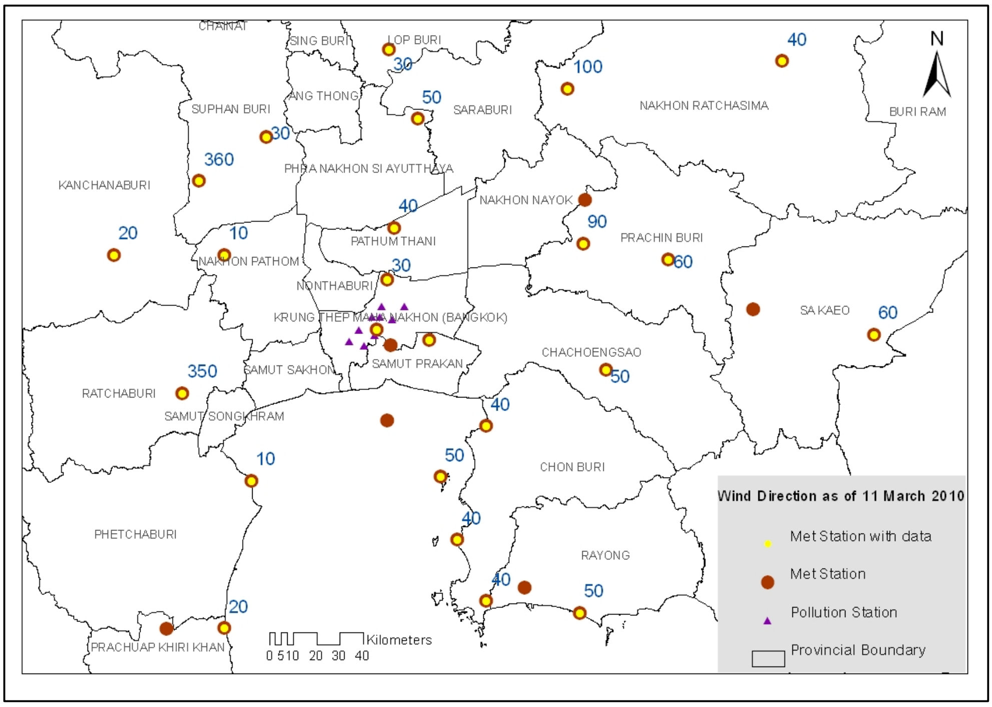

Figure 5 Locations of the meteorological stations and their wind direction values, the data of March 11th, 2010

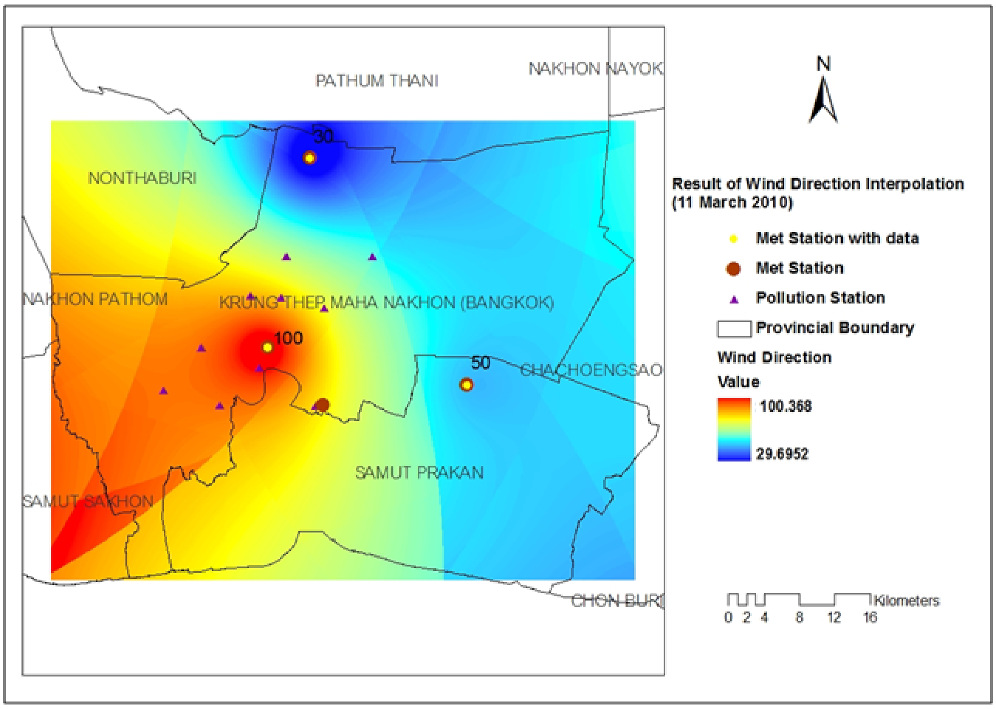

Figure 6 An example of wind directions surface resulted from the RBF interpolation, the data of March 11th, 2010

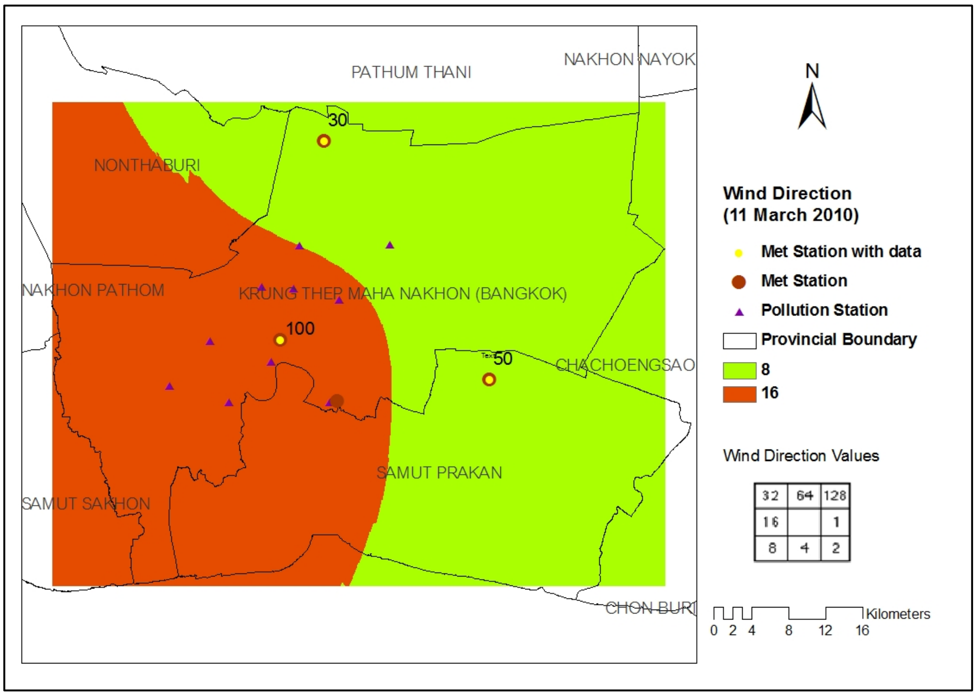

Figure 7 An example of wind flow directions result, the data of March 11th, 2010

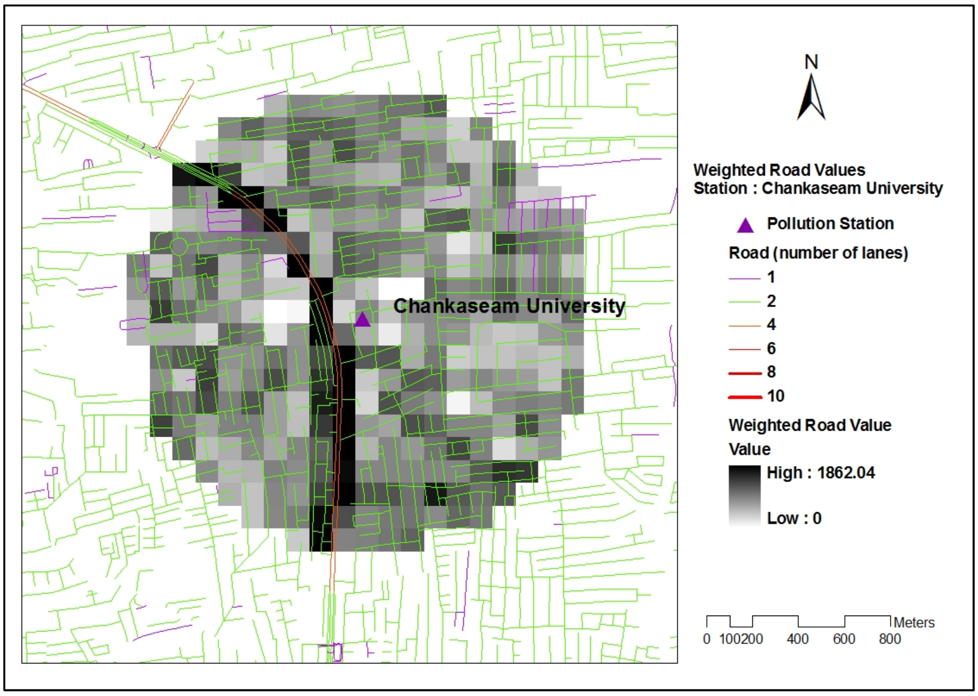

Figure 8 An example of weighted road values of each grid cell within 1 km. from a PCD station, the data of March 11th, 2010

The model was performed for ninety data sets (data of wind direction and NO_2 concentration measured at 10am daily during December 2009, March 2010, and July 2010) at 10 PCD stations. However, data may not be available for certain dates and times. Results from the model were used to find out a relationship between wind directions and NO_2 concentrations by using the Pearson Correlation function in SPSS as shown in Table 1. The resultant data reveal that at the 0.01 significant level (one tail) wind direction has a weak positive correlation (0.11). This can be interpreted that if the wind blows in the direction that passes more NO2-generated sources higher NO_2 concentration can be found at a target location. However, the low correlation value (0.11) indicates the weak relationship.

Table 1 The correlation of wind direction and NO_2 concentration

		NO_2	GRIDCODE (weighted road value)
NO_2	Pearson Correlation	1	.110
	Sig. (1-tailed)	.	.001
	N	784	784

** Correlation is significant at the 0.01 level (1-tailed).

3.2 Wind Speed Model and Analysis

The spatial relationship between wind speed and NO_2 concentration was tested to examine how wind speed influences NO_2 concentrations at each PCD station. Unfortunately, wind speed was not measured at the PCD stations, but meteorological stations. Wind speed data from meteorological stations were then interpolated to generate a surface, or raster, of wind speed at the given date and time (10am daily during December 2009, March 2010, and July 2010). The wind speed model also employed the RBF interpolation technique, similar to the wind direction model. Figure 9 shows a sample of the resultant raster of wind speeds generated from the data from March 11th, 2010.

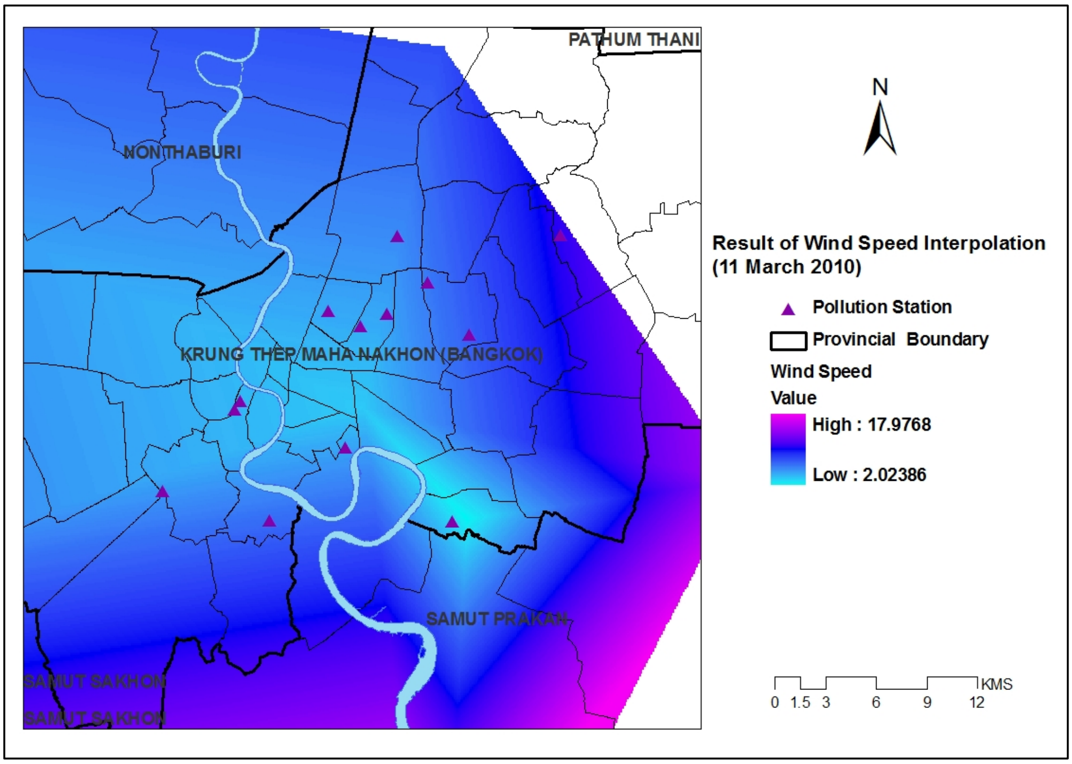

Figure 9 The resultant surface of wind speed generated from the data of March 11th, 2010

From the resultant raster, wind speed at the PCD stations were then measured and evaluated with the NO_2 concentration of the same locations. The pairs of wind speed and NO_2 concentration were submitted to Pearson Correlation function in SPSS as shown in Table 2. The resultant data reveal that at the 0.01 significant level (one tail) wind speed has a small negative correlation (-0.232) with NO_2 concentration. This can be interpreted that stronger wind speed generates less NO_2 concentration. However, the low correlation value (-0.232) indicates a weak relationship between the two variables.

Table 2 Correlation of wind speed and NO_2 concentration

		NO_2	Wind speed
NO_2	Pearson Correlation	1.000	-.232
	Sig. (1-tailed)	.	.000
	N	1209	1209

** Correlation is significant at the 0.01 level (1-tailed).

4. Concluding Remarks

NO2 in Bangkok has been measured by the PCD to monitor whether its concentration reaches the risk level for human health. Although, the NO_2 concentration level in the inner area of Bangkok has not reached that dangerous point, it is necessary to monitor and model NO_2 concentration prediction based on NO_2-generated factors in order to control emissions. Even though vehicles on the roads are the most common cause of NO_2, climatic conditions also affect how NO_2 concentrates at different locations. This paper focused on wind direction and wind speed and tested the relationships with NO_2 concentration by using GIS and statistical methods. Although the wind fields factor has a very small influence on the level of NO_2 concentration in the inner Bangkok areas, the results seem to underline the influences of the wind directions created by urban area physical configurations that divert the NO_2 from its normal paths to the PCD stations. High wind speeds, however, seem to have the opposite effect as it carries NO_2 away from the PCD stations. As Arian *et al* (2007) suggested, including wind fields as additional factors into the land use regression (LUR) model will improve the prediction results. The models described in this paper will be a part of the next phase, the NO_2 prediction by using the LUR model and GIS.

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