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GIS ANALYSIS OF SPATIAL AND TEMPORAL CHANGES OF AIR PARTICULATE CONCENTRATIONS AND THEIR IMPACTS ON RESPIRATORY DISEASES IN BEIJING, CHINA

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ABSTRACT: *This research reports the spatial and temporal changes of air particulate concentrations in Beijing, China based on field surveys conducted in the summers of 2007 to 2009. The spatial relations of air particulate pollution concentrations and the occurrences of residential respiratory diseases in 2008 were also studied applying the geographically weighted regression (GWR) model. The results indicated that the average concentrations of PM (Particulate Matter) 0.5µM, 1.0µM, and 3.0µM were increased from 2007 to 2008 and average concentrations of PM 0.3µM maintained a similar level and average concentration of 5.0 µM decreased. By contrast, average concentrations of all the particle sizes decreased from 2008 to 2009. GIS map algebra allows us to quantitatively visualize the local changes across the space in the study area. GWR analysis shows that spatial concentrations of PM 0.5µM, 1.0µM, and 3.0µM have positive coefficients or impacts on occurrences of residential respiratory diseases in 2008.*

Keywords: *GIS, Spatial concentration of air particulate pollution, Respiratory diseases*

INTRODUCTION

Airborne solid particulate matter is a major contributor of urban air pollution sources. High concentrations of fine particles in the air may cause respiratory diseases, such as asthma, pneumonia, and bronchitis (Owens, 1991; Houssaini et al., 2007; Babin et al., 2008). Long term exposure to high concentration of air particulate pollution also increases probability of human lung cancer and cardiorespiratory mortalities (Schwartz, 1994; Goldberg et al., 2001; Pope III et al., 2002; Solomon et al., 2003; Kan et al., 2004; Kim et al., 2009; Yan, 2009). Recent studies indicated that a majority of ambient air particles in urban settings are of anthropogenic origin (Dolinoy and Miranda, 2004; Heal et al., 2005; Song et al., 2006; Quan et al., 2008). In comparison to developed countries, developing countries worldwide have even more anthropogenic air particle pollutants, such as urban smog and dust storms (Davis and Guo, 2000; Zhao et al., 2004; Yuan et al., 2008). This is mainly due to the rapid economic development and intensive human land use activities in urban areas.

In this research, field surveys of particulate matter concentrations were conducted in the summers of 2007, 2008, and 2009 in urban region of Beijing City, China. A total of 78 points were sampled across the study area using a hand held laser particle counter. The surveys were conducted around 1.2 meters above the ground for the sample particle sizes: PM 0.3 µm, 0.5 µm, 1.0 µm, 3.0 µm, and 5.0 µm. Sample respiratory disease treatment data from 2008 were collected from a medical database in the City of Beijing. Twenty different respiratory diseases were selected as indicators by local medical doctors. Local residential population distribution data at community level were collected from the Census Bureau of the City of Beijing. Beijing hosted the 29th summer Olympic Games in 2008. In order to improve the natural environment of the city, the government mobilized a large effort to clean up the air and water in the region. The impact of this effort is also reflected in the results of this study. The major focus of this paper is the temporal trend of air particulate pollution in Beijing and the impact of air particulate pollution on the occurrence of respiratory diseases. The detail report of air particulate pollution concentrations and distribution in Beijing were published elsewhere (Tang el al., 2010).

METHODS AND APPROACHES

The air particle counter that was used in this research is Kanomax handheld laser particle counter - Model 3886 GEO-a. A built in air pump draws the sample air into the device. Then, an internal laser beam is used to count and classify the particles. The device samples particulate matter in the air.

The field survey sites were selected randomly from various locations, such as major streets, minor streets, and residential areas. The entire survey of all 78 sites was conducted in a two week period during late June or early July each year. The built in pump flow rate is 0.1 cubic feet/minute. Three minute continuous sampling was conducted for each of the sites. The original data yielded by the equipment is a particle count per cubic meter for each of the five particulate sizes. The data was converted into micrograms per cubic meter using the average density of solid materials on the earth's surface and the size or diameter that the particulate matter was measured.

GIS spatial interpolations of point based survey data were performed by applying universal kriging (UK) model. Kriging analysis applies the spatial autocorrelation methodology to predict the values across the space in between the sampled locations in the study area. Simple kriging (SK) assumes that the trend of distribution of the variable across the space is stationary and can be described in average by a constant. Ordinary kriging (OK) takes the constant trend of the variable as an unknown value. Universal kriging (UK) imposes a drift term temporarily on the stationary trend (Gundogdu and Guney, 2007). The drift is a simple polynomial function that models the average value of the scatter sample points (Huesca et al., 2009).

Universal kriging (UK) was applied to generate raster surfaces of concentrations for each of the five particle sizes. The reason that UK was selected as the interpolation tool in this study is that UK does not assume that the predicted value on average is a constant in the study area. Examples of UK geo-processing results are shown in Figure 1. The concentration surfaces were converted to raster map layers with tangible attribute databases of value distributions. Simple map algebra computations were conducted by subtracting the map layer of the previously surveyed year from the following year. The purpose of doing this is to spatially quantify the temporary changes of the air particle concentrations. The positive values indicate increases of particle pollution concentrations. By contrast, negative values depict the reduction of the concentrations at a local place.

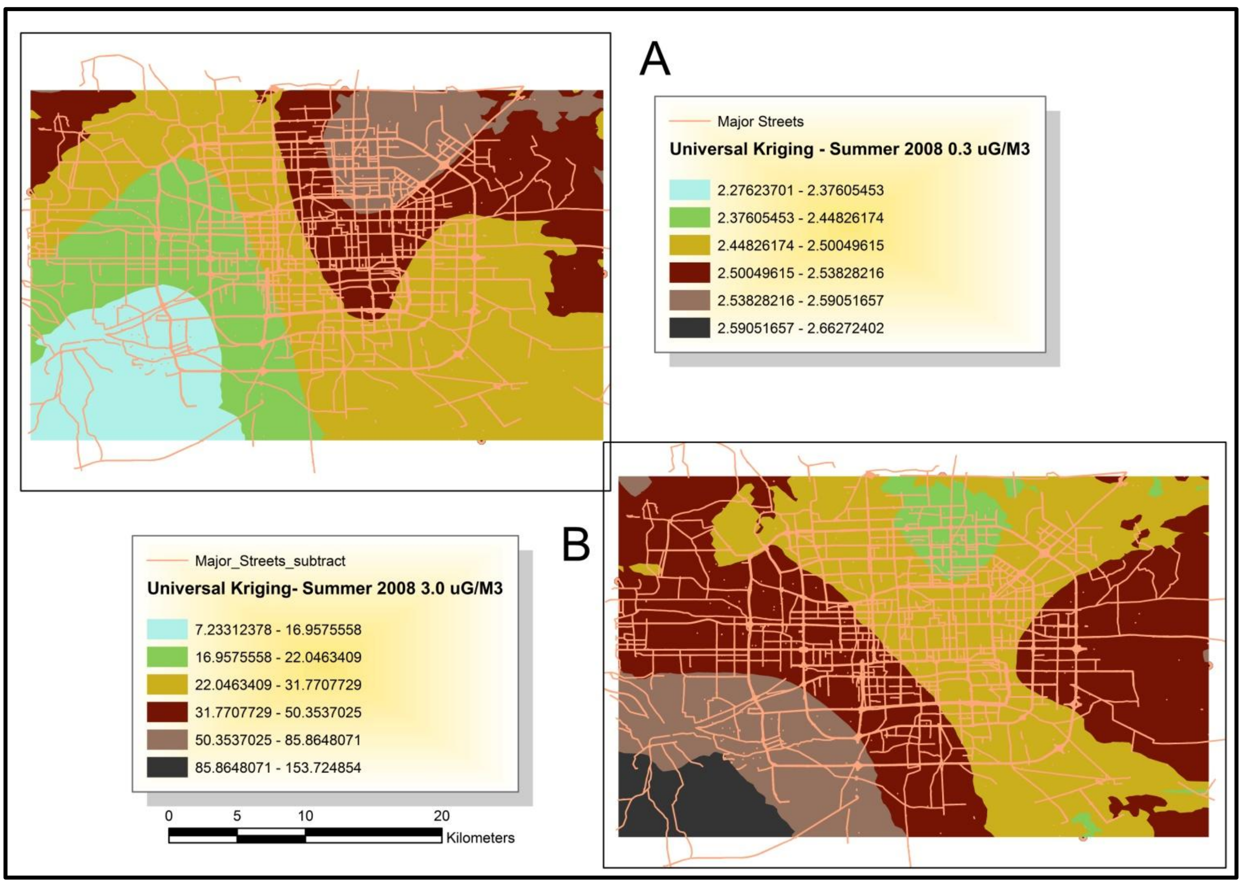

Figure 1. Example of UK modeling of air particle pollution distributions of summer 2008: (A) 0.3 µM; and (B) 3.0 µM.

Cases of respiratory diseases in 2008 were geo-coded according to the home addresses of patients. The geo-coded data were then aggregated to the community level. The occurrences of respiratory diseases were normalized by the community population distribution data as the unit of cases per 100 people. Original universal kriging (UK) raster surfaces of air particle concentrations in 2008 were converted to vector polygons, and intersected to the distributions of respiratory diseases in 2008. Geographically weighted spatial regressions (GWR) were conducted in ArcGIS for each of the five air particle sizes and the occurrences of respiratory diseases. The objective of this approach is to spatially quantify the relations between air particle pollution and occurrences of the diseases in order to evaluate the impacts of former to the latter.

Geographically weighted regression (GWR) provides a local model of the variables you are trying to understand in predicting a variable or a process by fitting a regression equation to every feature in the dataset (Brunsdon et al., 1996, Ogneva-Himmelberger et al., 2009). GWR constructs more than one equation by incorporating the dependent and explanatory variables of features falling within the bandwidth of each target features. One model depicts one relationship of a set of spatial variables. Local R^2 in GWR ranges between 0.0 and 1.0 and indicates how well the local regression model fits observed *y* values. GWR generates a regression residual feature map. It shows the standard deviation values of modeling errors. The ideal GWR regression model presents randomly distributed over or under predictions across the study area. In this study, the dependent variable is cases of respiratory diseases, and the independent variable is the concentration of PM.

Regression coefficients (β) were computed by the regression models imbedded in the GIS software. These are values, one for each explanatory variable, that represent the strength and type of relationship between the predicted variable and the dependent variable. Positive coefficient indicates a positive relationship. By contrast, negative coefficient represents a negative relationship. The larger the coefficient, the stronger the relationship is.

RESULTS

Results of map algebra analysis indicate that the ultra fine particle (PM0.3µM) concentrations, on average, were maintained on the same level from 2007 to 2008 (Figure 2). Spatially speaking, the concentrations increased along the central alley region across the city from south to north. The highest increase occurred in the central northern part of the city. The highest increase is 0.175µG/M^3. Concentrations decreased in both east and west parts of the city. The largest decrease occurred in the southwest part of the city, and the maximum reduction was 0.296µg/M^3. The average concentration of largest particle size tested (PM5.0µM) was decreased by 8.382µg/M^3 from 2007 to 2008. The highest amount of increase occurred in southwest part of the city, and the value was 75.489µg/M^3. The maximum reduction occurred in the northern central region of the city, and the amount was 60.038µg/M^3 (Table 1 and Figure 2).

Table 1. Summary of Results of Temporal Changes by Map Algebra Analysis

Particle Size	**Maximum increase µg/M3 2007 - 2008**	**Maximum decrease µg/M3 2007 - 2008**	**Mean change µg/M3 2007 - 2008**	**Maximum increase µg/M3 2008 - 2009**	**Maximum decrease µg/M3 2008 - 2009**	**Mean change µg/M3 2008 - 2009**
0.3 µm	0.175	0.296	-0.043	0	1.823	-1.378
0.5µm	2.020	2.358	0.277	0	7.111	-5.258
1.0µm	22.045	17.009	1.739	0	28.754	-15.179
3.0µm	108.751	241.701	1.393	0	115.359	-36.330
5.0µm	75.489	60.038	-8.382	0	79.701	-27.656

By contrast, the average concentrations of all the other thee particle sizes, namely PM0.5µM, PM1.0µM, and PM3.0µM, increased from 2007 to 2008. The average amount of increase of PM0.5µM was 0.277µg/M^3, that of PM1.0µM was 1.739µg/M^3, and the value of PM3.0µM was 1.393µg/M^3. The highest increase of PM3.0µM was located in the southwest part of the city, and the amount was 108.751µg/M^3. The highest increase of PM1.0µM occurred in southwest part of the city again, and the amount of increase was 22.045µg/M^3 (Table 1 and Figure 3). Larger increases of PM0.5µM occurred sporadically both in the central west and central east regions. The largest increase was 2.02µg/M^3 (Table 1 and Figure 3). Distribution maps of all three particle sizes show the concentrations decreased in the central north and northeast regions of the study area (Figure 3).

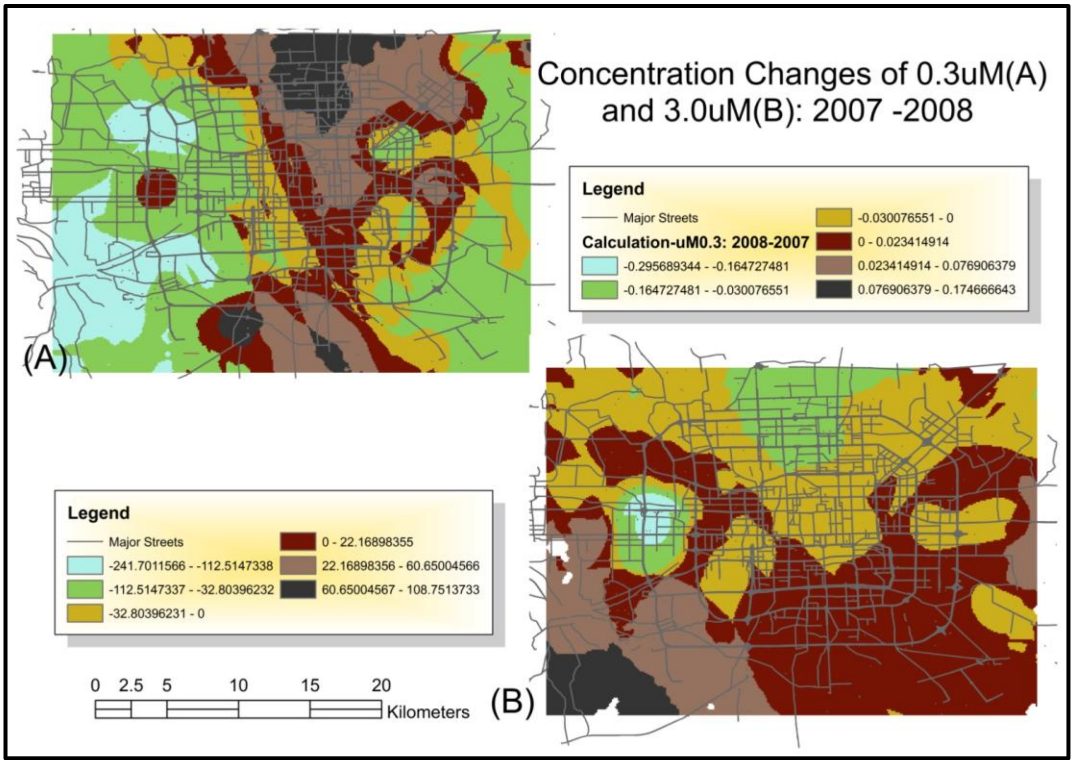

Figure 2. Changes of distribution of air particle concentration from summer 2007 to summer 2008, example 1.

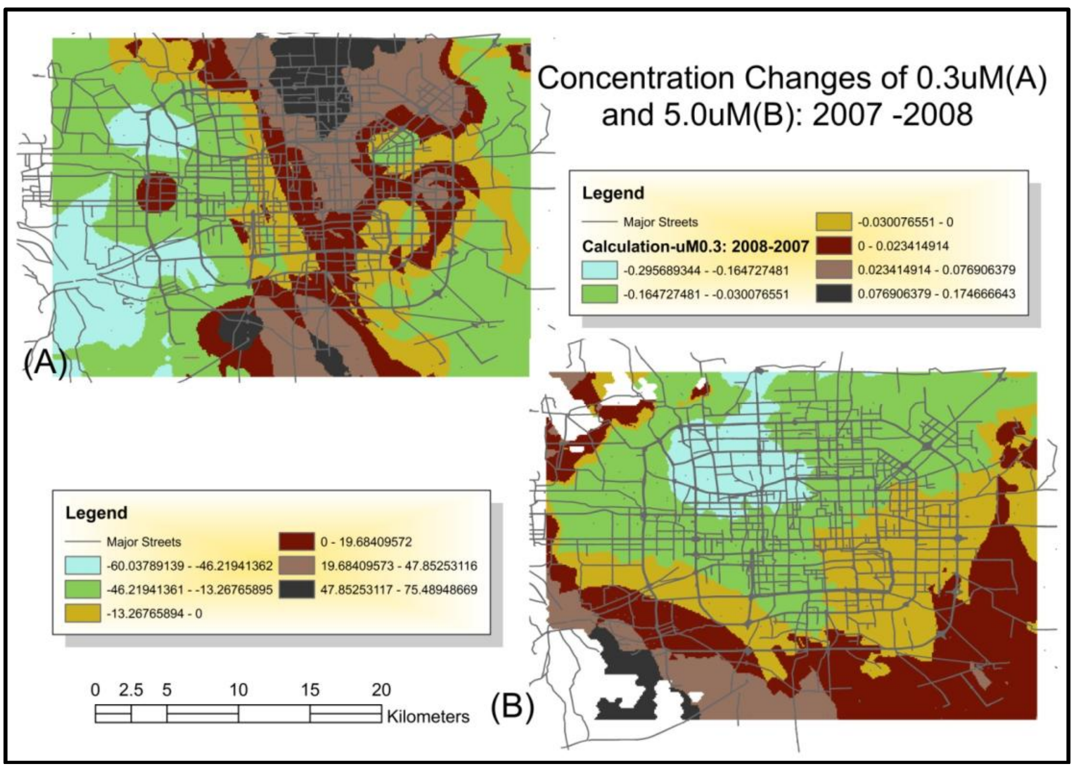

Figure 3. Changes of distribution of air particle concentration from summer 2007 to summer 2008, example 2.

Reviewing the computational results of concentration changes from 2008 to 2009, it was found that the amount of concentrations were decreased for all the five particle sizes surveyed across the space in the study area (Figure 4 and 5). The average reductions of PM0.3µM, PM0.5µM, PM1.0µM, PM3.0µM, and PM5.0 µM are 1.378µg/M^3, 5.258µg/M^3, 15.179µg/M^3, 36.33µg/M^3, and 27.656µg/M^3 respectively. The largest reduction of PM0.3µM occurred in southeast part of the city, and the predicted amount of reduction was 1.823µG/M^3 (Table 1 and Figure 4). By contrast, the largest reduction of PM5.0 µM occurred in southwest part of the city, and the amount was 79.701µg/M^3 (Table 1 and Figure 4). Largest reductions of PM0.5µM, PM1.0µM and PM3.0µM were also occurred in southwest part of the city. These values are 7.111 µg/M^3, 28.754µg/M^3, and 115.359µg/M^3 respectively (Table 1 and Figure 5).

Geo-coding and community respiratory disease mapping of the sample data indicates that the highest occurrence in 2008 was 11 persons per 100 people of residential population (Figure 6). The high frequencies of occurrences took place in the central west part of the city (Figure 6). The Geographically Weighted Regressions (GWR) for each of the five particle sizes and the respiratory disease occurrences in the year 2008 were conducted. Condition numbers (CN) are diagnostic evaluators of local collinearity. The values of CN must be smaller than 30 in order to achieve a valid geographic regression.

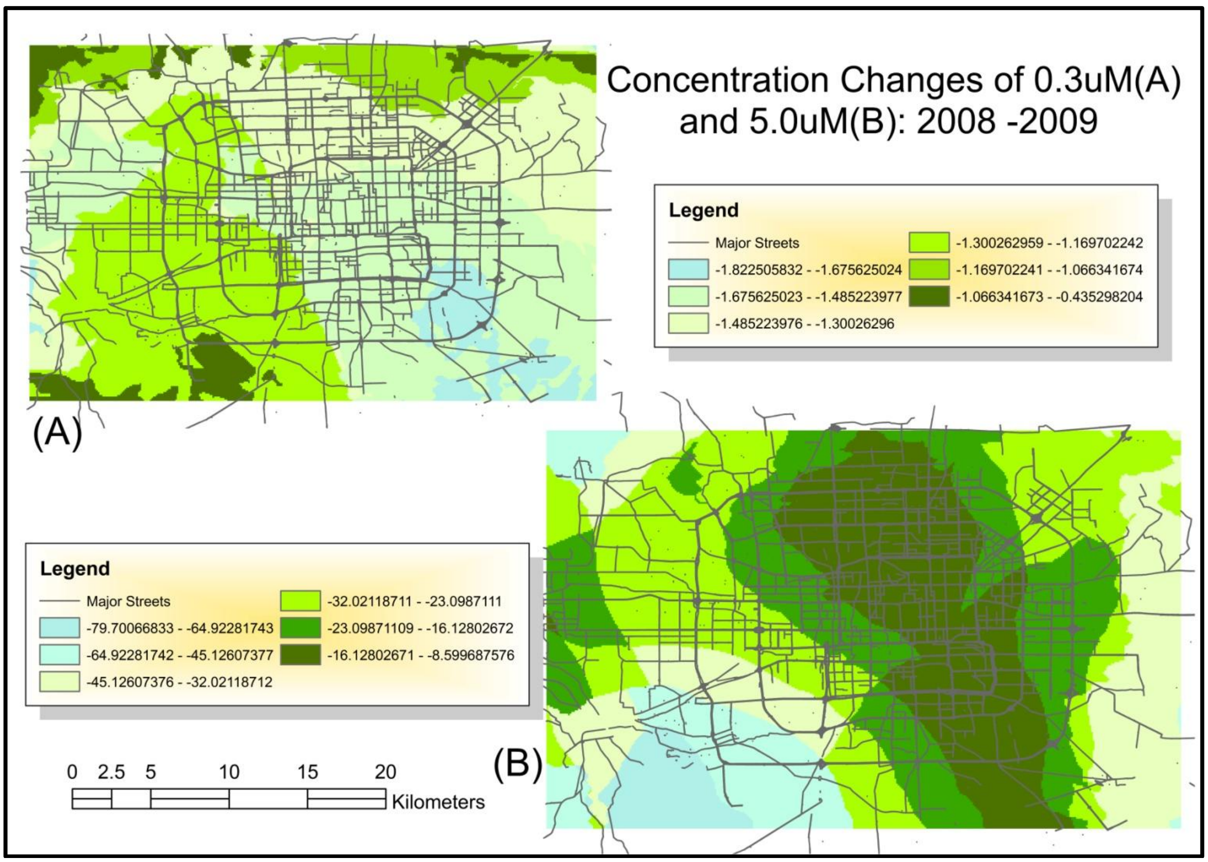

Figure 4. Changes of distribution of air particle concentration from summer 2008 to summer 2009, example 1.

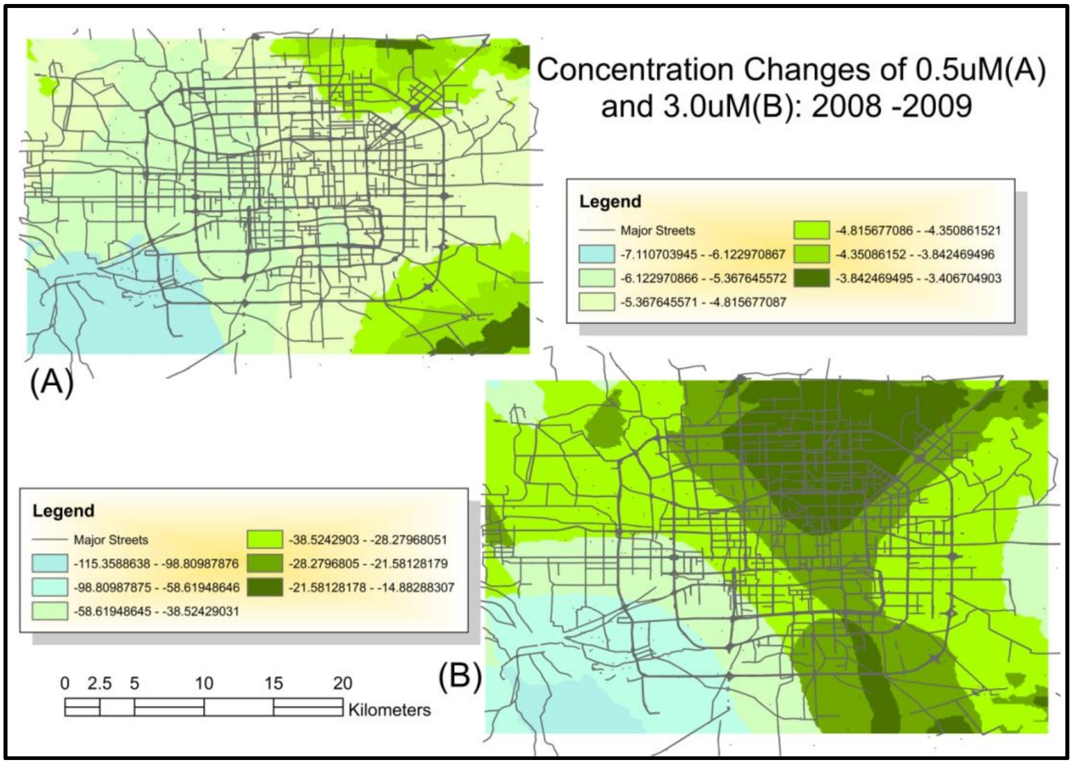

Figure 5. Changes of distribution of air particle concentration from summer 2008 to summer 2009, example 2.

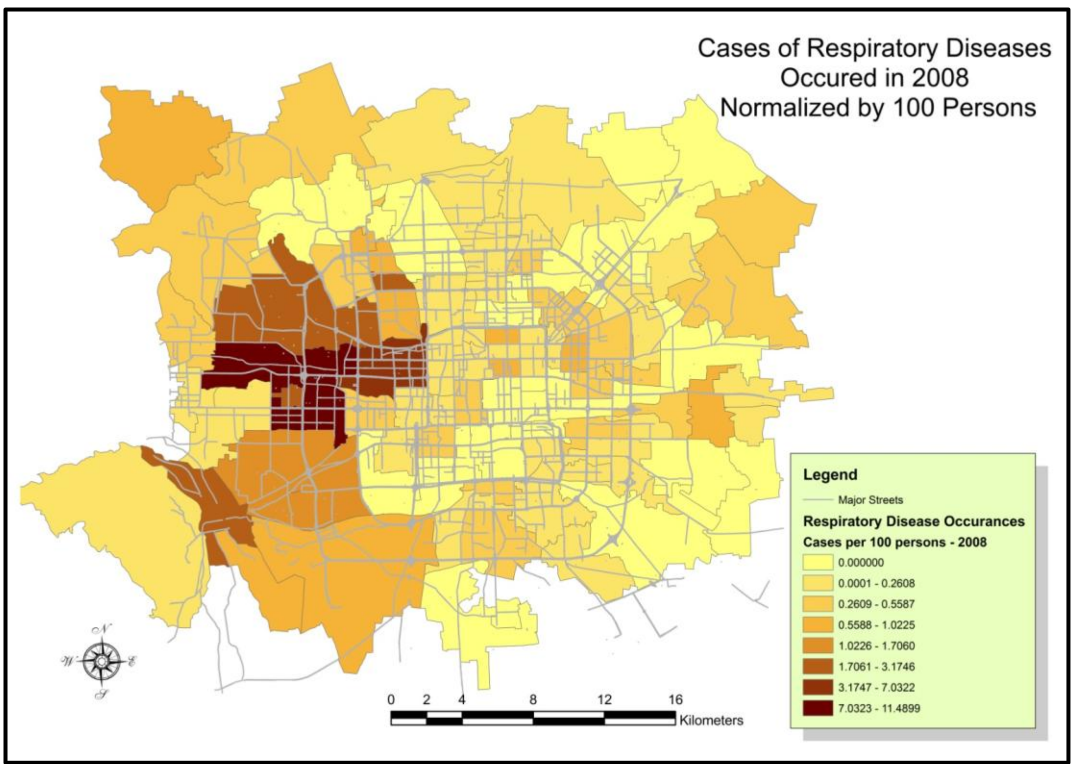

Figure 6. Sample cases of respiratory disease at community level in 2008 normalized by population.

DISCUSSIONS AND CONCLUSION

The PM0.3µM shows a small negative coefficient (-0.58) on average, and the PM5.0µM shows a relative large negative coefficient (-138.13) on average in the study region with sampled respiratory disease data (Figure 7). The results might suggest that these particle sizes are not influential to respiratory diseases because either the particle size is too large or too small to stay in the human's respiratory systems. Alternatively, these results might suggest that the sample medical data are not a realistic representation of the entire cases occurred. Further studies and data collections are needed. The reported highest CN of PM0.3µM is 7.16 and that of PM5.0µM is 6.44. Examine the output residuals of feature classes (Figure 7), over or under predictions are not clustered across the study region.

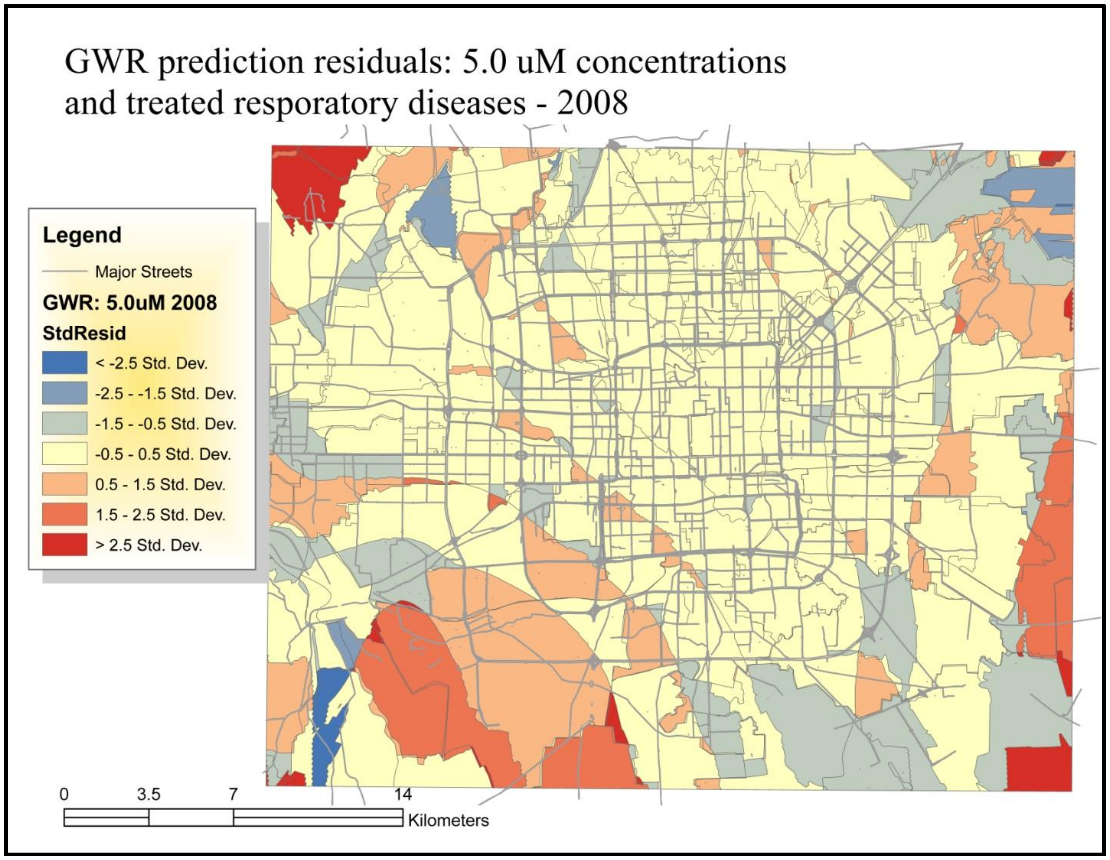

Figure 7. GWR regression residual map of 5.0 µM air particle concentrations and sample cases of respiratory disease in 2008.

GWR of PM0.5µM, PM1.0µM, and PM3.0µM demonstrated the positive coefficients. The average values are 5.23, 81.81, and 0.03, and the highest CN numbers are 10.01, 5.64, and 7.22 respectively (Figure 8). The results suggest that PM size from 0.5µM to 3.0µM impose a strong impact on the occurrences of respiratory diseases in the region. This result coincides with previous researches that lead the US Environmental Protection Agency (EPA) recognition of 2.5µM as the critical size in causing the human health problems and concerns (EPA, 2004). Among the tested particle sizes, PM1.0µM shows the strongest influence to respiratory diseases in this study with highest average regression coefficient and lowest average CN number spatially across the study region. In the future studies, more detail medical treatment data and more localized impact analyses of particulate matter concentration on respiratory diseases are needed. In the meantime, the current prediction of GWR model might not be accurate owning to the limited field samples of the independent variable.

In summary, the cartographic modeling or map algebra of spatial and temporal changes of the air particle pollutions can effectively show the local changes across the space in the study area. It indicates that the concentrations of PM0.5µM, PM1.0µM, and PM3.0µM were increased from the summer of 2007 to the summer of

2008. While the concentrations of PM0.3µM on average did not change, and that of PM5.0µM decreased in some degree from the 2007 to 2008. By contrast, concentrations of all the particle sizes spatially predicted decreased from the summer of 2008 to the summer of 2009. The field work of all the three summers were conducted during the end of June and the beginning of July. The research shows that the drastic reductions of air particle pollutant owing to the environmental cleanup efforts practiced in Beijing in hosting the 2008 Summer Olympic Games. In the clean up process, a great number of steel mills and manufacturing facilities were moved out of the city and the region close by. This transferred the city from a manufacturing center to a financial and management centric metropolis. However, recent reports indicated that there is a trend that the air quality is deteriorating again after the event (Zhu et al., 2010).

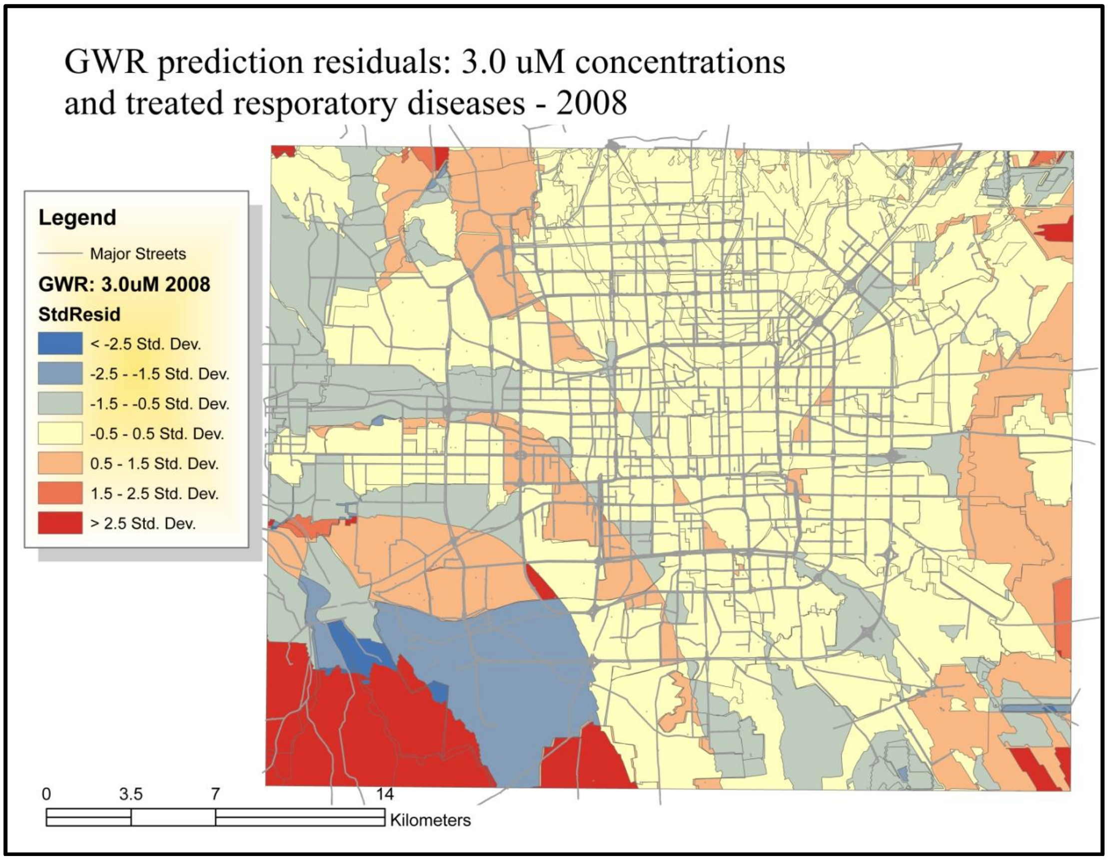

Figure 8. GWR regression residual map of 3.0 µM air particle concentration and sample cases of respiratory disease in 2008.

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