Original Research

A Land Use Regression Application into Simulating Spatial Distribution Characteristics of Particulate Matter (PM$_{2.5}$) Concentration in City of Xi'an, China

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Abstract

Decreasing of PM$_{2.5}$ concentration in the heating season was not significant in Xi'an. This article determined a land use regression (LUR) model and researched the distribution characteristics of PM$_{2.5}$ in heating and non-heating seasons in Xi'an. The results showed that: (1) The R^2 of LUR was larger than 0.9, and the simulation results were better than previous studies. (2) The PM$_{2.5}$ concentration in the heating season was larger than in the non-heating season. In Xi'an, the distribution of PM$_{2.5}$ concentration was low in the southeast and high in the northwest in the non-heating season and was low in the southeast and high in the main urban region in the heating season. (3) The PM$_{2.5}$ concentration was affected by temperature, average air pressure, altitude, humidity and precipitation in non-heating season and was influenced by precipitation, altitude, average air pressure, vegetation, and density of roads in heating season. (4) This paper showed some improvements in selection of potential variables for LUR model, and the conclusion can provide a scientific basis for PM$_{2.5}$ pollution control and a reliable method for simulating PM$_{2.5}$ concentration in other cities.

Keywords: ambient air pollution, geographic information system (GIS), uapping, modelling, urban areas

Introduction

China has been making tremendous achievements in economic development since the reform and opening-up policy and has become the second-largest economy in the world. However, economic development has also led to a series of environmental issues, and China is currently facing serious air pollution challenges [1]. It is unhealthy to be exposed to ambient air pollution, and it increases the probability of mortality, and morbidity decreases life expectancy.

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Therefore, the report in Global Burden of Disease Study (GBD) identified air pollution as a leading cause of global diseases, especially in low-income and middle-income countries [2]. At the same time, some of research results revealed that $PM_{2.5}$ was the fifth largest death risk factor in 2015 [3]. Xi'an, a famed tourist destination as well as the largest national central city in northwest China, has been experiencing severe air pollution which has become an urgent issue that threatens people's health and quality of life. Xi'an has taken several measures to improve air quality since 2013, such as coal reduction, vehicle control, dust suppression, source of contamination control and green area enhancement. As a result, a statement released by the Bureau of Xi'an ecological environment in 2017 indicated the air quality achieved "one increase", "two decreases" and "four declines" compared with 2013, those were the number of excellent days increased from 138 days to 180 days, the number of heavy pollution days decreased from 67 days to 39 days, the number of extraordinary pollution days decreased from 8 days to 0 days, and the average annual $PM_{2.5}$ concentration declined by 30.5% from 2013 to 2017, respectively. However, the number of excellent days in the heating season was only 68 of 180 excellent days, the improvement of air quality was not very ideal in the heating season, and the air quality was still inferior and showed an obvious difference between the heating season and the non-heating season. At the same time, the conclusion that the concentrations of multiple air pollutants during the heating season were higher than those during the non-heating season resembled results from different regions, such as Czech Republic [4], Italy [5] and China [6-7].

Most of the previous studies in Xi'an focused on the chemical composition of $PM_{2.5}$ in a small scale [8-15]. However, the current studies seldom simulate $PM_{2.5}$ concentration on a small grid-scale, so the existing results could hardly meet the needs of precision for further study. At present, there were two main methods for spatial distribution simulation of $PM_{2.5}$ concentration. One was the spatial interpolation method, and the other was remote sensing inversion through aerosol optical depth (AOD) products. Firstly, the spatial interpolation method used limited in-situ sampling data to establish an approximation function to simulate the $PM_{2.5}$ concentration outside the in-situ sites. However, the precision of spatial interpolation method had some uncertainties [16]. Moreover, the spatial interpolation method could not be implemented in some places if in-situ sampling sites data was sparse or missing, so the results would not be reasonable [17]. Secondly, remote sensing inversion method took advantage of the relationship between AOD and $PM_{2.5}$ concentration to simulate $PM_{2.5}$ concentration [18]. However, the spatial resolution of $PM_{2.5}$ concentration products based on remote sensing inversion were also coarse and were inadequate to satisfy simulation for $PM_{2.5}$ concentration on a small-scale [19]. Besides, there were field sampling methods for measuring small-scale concentration of $PM_{2.5}$ [10], nighttime lighting data simulation method [20], and a model between other pollutants concentration and $PM_{2.5}$ concentration [12]. Although field sampling method could acquire high precision data, it was costly, time-consuming and inefficient. The nighttime lighting data simulation method could be used for obtaining the spatial distribution of $PM_{2.5}$ concentration on a large scale. However, the accuracy was low for $PM_{2.5}$ concentration simulation in a small scale. Therefore, we should find a new method to simulate $PM_{2.5}$ concentration and analyze the probable influences from nature and human beings. At the same time, Xi'an is undergoing unprecedented urbanization process that leads to obvious landscape change [21]. In addition, Xi'an appears some unreasonable land use cases, and the urban planning of Xi'an may neglect the effects of natural factors and human activities on the landscape [22]. Land use change is due to human activities and natural factors [23]. Some of previous studies used land cover maps derived from remote sensing images to evaluate the changes in urban development and green areas [23-33]. Furthermore, some recent studies are to develop a landscape plan according to the aims of sustaining the natural and cultural landscape values of an area by considering landscape variables such as the number of potential visitors, vegetation cover, cultural values and the topographic structure. ArcGIS was used to evaluate the landscape variables, and the study data were obtained through a land survey, questionnaires and maps [23-35]. Besides, some of the previous studies have revealed that urban planning including land use, urban spatial structure, spatial form, transportation and green space may affect concentrations of air pollutants [36-38]. Moreover, particulate matter can be purified and absorbed by urban green spaces [39], and the landscape pattern of green spaces (such as edge density and patch density) can also influence $PM_{2.5}$ concentration [40]. Hence, the $PM_{2.5}$ concentration is not only affected by natural factors but also influenced by human activities especially land use and urban planning, so it is feasible to control $PM_{2.5}$ concentration through optimizing land use structure, urban planning, spatial form, transportation and green space [37]. Therefore, it is possible to simulate $PM_{2.5}$ concentration through land use and urban planning perspective, and the LUR model supply probability for simulating $PM_{2.5}$ concentration. The LUR model was often used to predict pollutant distribution, including NO_2, NO_X and $PM_{2.5}$ [41-44]. The LUR model is based on monitoring data and land use information within a certain radius of the monitoring sites, road traffic characteristics and other relevant geographic variables to construct regression model [45]. The LUR model is able to generalize regression relationship to simulate the spatial distribution of pollutants in unmonitored areas [46]. In short, LUR model can simulate $PM_{2.5}$ concentration with higher simulation precision for further study.

The purposes of this study were: (1) to establish the LUR model for $PM_{2.5}$ in a heating season and a non-heating season in Xi'an. (2) to map the distribution of $PM_{2.5}$ on a grid scale. (3) to analyze the influence factors for $PM_{2.5}$. (4) to supply some suggestions for improving air quality in Xi'an.

Materials and Methods

Study Area

Xi'an is located in the center of the Guanzhong Basin. The overall terrain is elevated in the north and south and low in the center. It has a warm, temperate, semi-humid, continental monsoon climate with four distinct seasons. The annual average temperature is 15.6°C and the average annual precipitation is 649.0 mm. Xi'an is a National Central City and an important tourist destination. In 2017, it received 18,093,140 visitors from home and abroad, and the GDP was 747.189 billion yuan (1 $ = 6.87 yuan). The city has a total area of 10096.81 km², a built-up area of 832.16 km², and a population of 4.66 million in the main region, accounting for 47.90% of the city's total population. The six districts in the main urban region are the Xincheng district, the Beilin district, the Lianhu district, the Baqiao district, the Weiyang district, and the Yanta district, respectively (Fig. 1).

Data Sources

$PM_{2.5}$ Data

$PM_{2.5}$ concentration data with a period from November 15, 2016 to November 14, 2017 was collected from the Xi'an Air Quality Daily Reporting System (http://www.xianemc.gov.cn/). There are 13 air quality monitoring stations in Xi'an (Fig. 1, Table 1). The mean concentration during a heating season (From November 15, 2016 to March 15, 2017) and a non-heating season (From March 16, 2017 to November 14, 2017) was calculated respectively.

Potential Independent Variable Data

(1) Land use data with 30m resolution was collected from the Department of Earth System Science of Tsinghua University (http://data.ess.tsinghua.edu. cn/), and the land use classes were divided into cropland, forest, grassland, shrub land, wetland, water, impervious surface and bare land, respectively. (2) The DEM data with 30 m resolution was derived from the Geospatial Data Cloud (http:// www.gscloud. cn/). (3) Meteorological data including the average daily temperature, precipitation, average wind speed, maximum wind speed and relative humidity from 21 meteorological stations with a period from November 15, 2016 to November 14, 2017 was collected
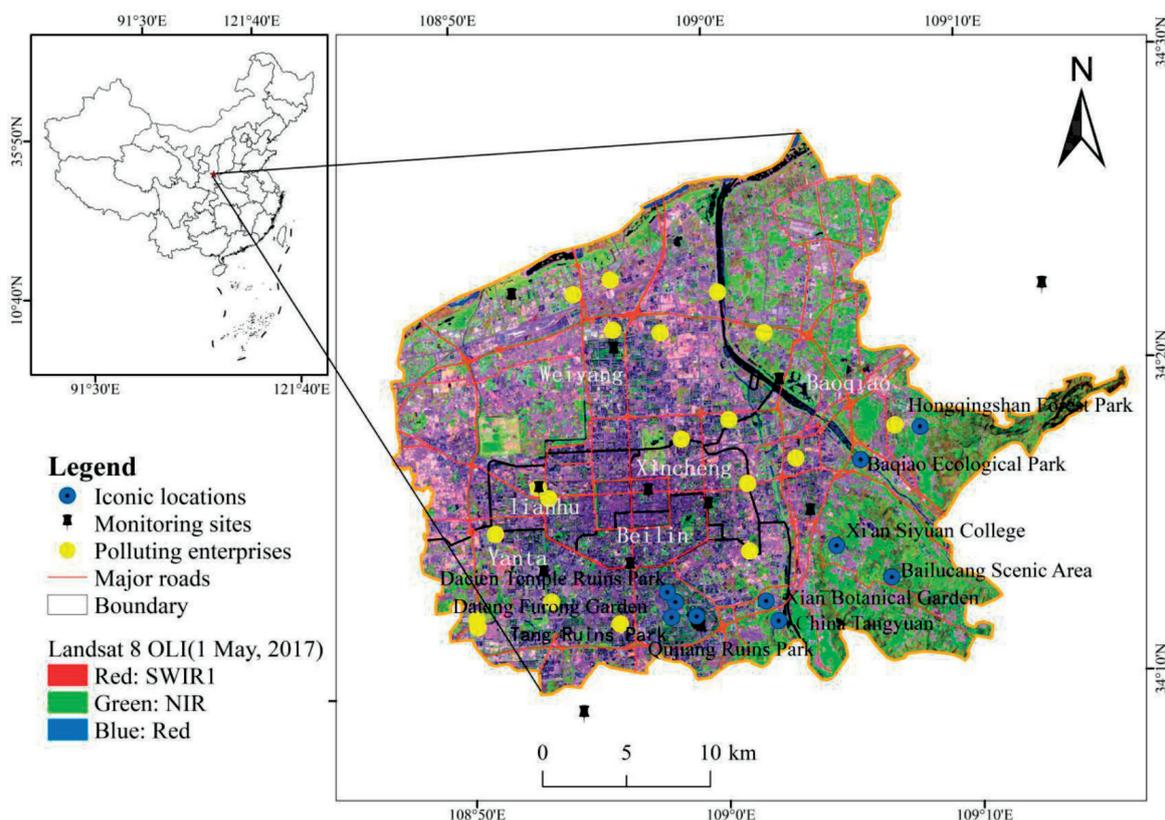

Fig. 1. Map of study area.

from the China Meteorological Data Center (http://data. cma.cn/). The mean value of meteorological parameters was calculated and the data layers with 30m resolution were obtained by Kriging interpolation method. (4) The population data with 1km spatial resolution was collected from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/), and the original spatial resolution (1 km) was reclassified to 30 m for further analysis. (5) Roads data was derived from the wiki world map database (http://www.open street map.org/) (Table 1).

LUR Model

In this study, the LUR model (Equation 1) was used to simulate the spatial distribution of PM$_{2.5}$ in Xi'an. The dependent variable was PM$_{2.5}$ concentration, and the potential independent variables were land use, transportation, topography, population and meteorological factors, respectively. The multivariate stepwise regression was implemented to determine the quantitative relationship between PM$_{2.5}$ concentration and potential independent variables. The processes for LUR were as follows: (1) This paper selected natural and human factors as independent variables for the LUR model, and 98 potential independent variables were extracted (Table 1). (2) The multivariate stepwise regression model with screening rules was used to determine the LUR model. Screening rules were as follows, when the F probability of the variable was less than 0.05, the variables would be chosen to the model; when the F probability of the variable was larger than 0.1, the variable would be removed from the model. At last, the retained variables were selected as independent variables for the LUR model.

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \cdots + b_i X_i \quad (1)$$

Table 1. Potential variables for the LUR model.

Groups	Variable	Extracting Methods	Remarks	Variable Number
Land use	Cropland (X_{c-i})	Using Zonal Statistics tool of ARCGIS 10.3 to extract the area of different land use types in different buffer zones. The buffer radii are 100 m, 300 m, 500 m, 1000 m, 1500 m, 2000 m, 2500 m, 3000 m, 3500 m, 4000 m, respectively.	X_{c-i} represents the area of cropland in the buffer zone of i; the same principle applies for other land use types.	10
	Forest (X_{f-i})			10
	Grassland (X_{g-i})			10
	Shrubland (X_{s-i})			10
	Wetland (X_{wte-i})			10
	Water ($X_{water-i}$)			10
	Impervious surface (X_{I-p-i})			10
	Bareland(X_{b-i})			10
Road	Road length (X_{road-i})	Using statistical analysis tool of ARCGIS 10.3 to extract the length of the roads in different buffer zones, The buffer radii are: 100 m, 300 m, 500 m, 1000 m, 1500 m, 2000 m, 2500 m, 3000 m, 3500 m, 4000 m.	X_{road-i} represents the total road length in the buffer zone with a distance of i.	10
	Nearest road distance (X_{n-road})	Using the Nearest Neighbor Analysis tool of ARCGIS 10.3 to determine the closest distance from the monitoring sites to the roads.	X_{n-road} represents the distance from the Monitor point to the nearest road.	1
Terrain	Elevation(X_{dem})	Using the Extract Multi Values to Points tool of ARCGIS 10.3 to obtain the elevation value of each monitoring site.	The elevation value of the monitoring sites.	1
Population	Population(X_{pop})	Using the Extract Multi Values to Points tool of ARCGIS 10.3 to get the population value of each monitoring site.	The population value of monitoring sites.	1
Mete-orological factors	Precipitation (X_p)	Using the Extract Multi Values to Points tool of ARCGIS 10.3 to obtain precipitation, average air pressure, wind speed, temperature, and average relative humidity of each monitoring site.	The different Mete-orological values of the monitoring sites.	1
	Average pressu-re (X_{a-p})			1
	Wind-speed (X_w)			1
	Temperature (X_t)			1
	Average relative humidity (X_{rhu})			1

...where: Y was the simulated value of $PM_{2.5}$ concentration; b_0 was constant; X_1, ..., X_i were independent variables; b_0, b_1, ..., b_i were correlation coefficients corresponding to X_1, X_2, ..., X_i

The model accuracy was validated based on the cross-validation method [46-47]. The coefficient of determination (R^2), root mean square error (RMSE) (Equation 2) and mean percentage error (MPE) (Equation 3) were calculated to evaluate the precision of the model.

$$RMSE = \sqrt{\frac{1}{n}\sum_1^n(A-B)^2} \tag{2}$$

$$MPE = \frac{100\%}{n}\sum_1^n\frac{A-B}{A} \tag{3}$$

...where: A is the real $PM_{2.5}$ concentration collected from monitoring sites, $\mu g/m^3$; B is the simulation $PM_{2.5}$ concentration based on the LUR model, $\mu g/m^3$; n is the number of samples.

Simulating Distribution of $PM_{2.5}$

Simulating distribution of $PM_{2.5}$ on a grid-scale was based on the LUR model and ArcGIS10.3. Firstly, using the fishnet tool of ArcGIS10.3 to create a fishnet (100 m × 100 m) in the study area. Secondly, using the polygon to point tool of ArcGIS10.3 to convert the fishnet into a point layer. Thirdly, taking advantage of the spatial analysis tool of ArcGIS10.3 to obtain the independent variables value of each fishnet point. Fourthly, the LUR model was used to calculate the $PM_{2.5}$ simulation concentration at each fishnet point. Finally, using the Kriging interpolation tool of ArcGIS10.3 to interpolate the simulation concentration of $PM_{2.5}$, and the distribution maps of $PM_{2.5}$ concentration were obtained in the study area (The resolution is 100 m). Furthermore, the maps of $PM_{2.5}$ concentration were reclassified based on the criteria published by the Chinese government (Table 2) (GB3095-2012).

Table 2. The air quality classification.

$PM_{2.5}$ daily average concentration/ ($\mu g.m^{-3}$)	Air quality level
0~35	Excellent
35~75	Good
75~115	Mild pollution
115~150	Moderate pollution
150~250	Heavy pollution
250~500	Severe pollution

Results and Discussion

Descriptive Statistics

The mean $PM_{2.5}$ concentration in 2017, non-heating season and heating season were 72.64 $\mu g/m^3$, 43.62 $\mu g/m^3$ and 144.96 $\mu g/m^3$, respectively. According to the national criteria (Table 2), the air quality in the whole year of 2017 and the non-heating season was good and the heating season was moderate pollution. The $PM_{2.5}$ concentration ranged from 56.1 $\mu g/m^3$ to 225.9 $\mu g/m^3$ during the heating season and was obviously larger than during the non-heating season (4.1 $\mu g/m^3$-61.3 $\mu g/m^3$).

LUR Model and Validation

The LUR was implemented to determine the relationship between $PM_{2.5}$ concentration and independent variables including precipitation, temperature, average air pressure, relative humidity, DEM, grassland area within 300 m buffer, and the distance between monitoring sites and the nearest road , respectively (Equation 4, Equation 5).

$$Y_{non-heating\ season} = 16167.499 + 519.003x_{tem}$$
$$- 28.750x_{a-p} - 0.239x_{dem} + 33.390x_{rhu} - 5.909x_p \tag{4}$$

$$Y_{heating\ season} = 529.103 + 17.446x_p + 0.080x_{n-road}$$
$$- 2.252 \times 10^{-4}x_{g-300m} - 0.305x_{dem} - 0.606x_{a-p} \tag{5}$$

...where X_{tem}, X_{a-p}, X_{dem}, X_{rhu}, X_p, X_{n-road}, and X_{g-300m} denote the temperature, the average air pressure, the elevation, the relative humidity, the precipitation, the distance from the a monitoring site to the nearest road, and the area of grassland in a 300 m buffer zone, respectively. Clearly, in the non-heating season, the $PM_{2.5}$ concentration was affected by temperature, average pressure, elevation, relative humidity, and precipitation, respectively (Equation 4, Table 3), and the strongest impact factor was temperature (regression coefficient = 519.003, R^2 = 0.461). In the heating season, the $PM_{2.5}$ concentration was influenced by precipitation, roads, vegetation, elevation, and average pressure, respectively (Equation 5, Table 3), and the strongest impact factor was precipitation (regression coefficient = 17.446, R^2 = 0.377). In the non-heating season and the heating season, the R^2 were 0.986 and 0.963, respectively, the adjustable R^2 were 0.976 and 0.937, respectively (Table 3), the R^2 based on crossing validation were 0.85 and 0.92, respectively (Fig. 2). RMSE were 2.84 $\mu g/m^3$ and 3.55 $\mu g/m^3$, respectively, and MPE were 0.68 $\mu g/m^3$ and -0.39 $\mu g/m^3$, respectively. The relative error rate was between 0.42% and 15.31%. The comparison between observed values and predicted values showed the model worked very well (Fig. 3).

Table 3. Parameters of the LUR model.

Category	Independent variables	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	R^2	Adjusted R^2
		B	Std. Error	Beta				
Non-heating season	(Constant)	16167.499	1012.259		15.972	0.000		
	x_{tem}	519.003	34.883	28.938	14.878	0.000	0.461	0.412
	x_{a-b}	-28.750	1.899	-26.983	-15.138	0.000	0.808	0.769
	x_{dem}	-0.239	0.043	-0.639	-5.624	0.001	0.925	0.900
	x_{thu}	33.390	6.698	2.262	4.985	0.002	0.962	0.943
	x_{p}	-5.909	1.692	-1.080	-3.492	0.010	0.986	0.976
Heating season	(Constant)	529.103	190.239		2.781	0.027		
	x_{p}	17.446	2.888	1.664	6.041	0.001	0.377	0.320
	x_{n-road}	0.080	0.016	0.453	4.847	0.002	0.699	0.639
	x_{g-300m}	$2.252*10^{-4}$	$6.804*10^{-5}$	-0.273	-3.310	0.013	0.839	0.785
	x_{dem}	-0.305	0.073	-0.898	-4.164	0.004	0.924	0.886
	x_{a-p}	-0.606	0.223	-0.660	-2.716	0.030	0.963	0.937

a)

$y = 0.8387x + 23.853$
$R^2 = 0.8459$

b)

$y = 0.9902x + 0.0249$
$R^2 = 0.9239$
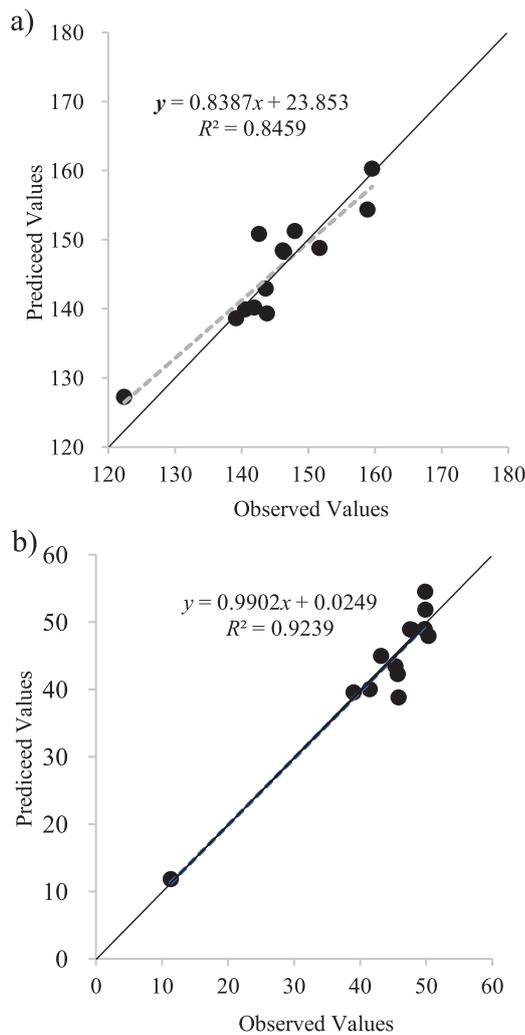
Fig. 2. Scatter plot of $PM_{2.5}$ concentration: a) Non-heating season, b) Heating season.

The Spatial Distribution Characteristics of $PM_{2.5}$

In the non-heating season, the pattern of $PM_{2.5}$ concentration was low in the southeast and high in

a)

b)
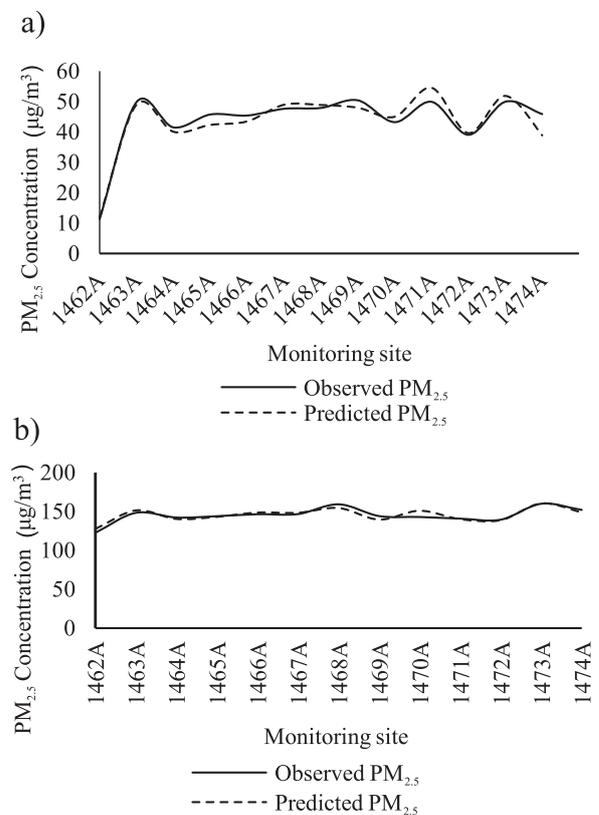
Fig. 3. Simulation quality assessment: a) Non-heating seasons, b) Heating seasons.

the west of Xi'an (Fig. 4a). Clearly, $PM_{2.5}$ concentration in scenic spots, colleges, residences, and ecological zones were relatively low (Fig. 4a, Fig. 1). The lowest $PM_{2.5}$ concentration distributed mainly in the Baqiao Ecological Park, the Bailucang Tourism Scenic Spot and the Qujiang District (Fig. 1, Fig. 4a). On the contrary, the $PM_{2.5}$ concentration of industrial areas and under construction areas was relatively high (Fig. 1, Fig. 4a). Besides, 85.74% of the area had good air quality and 14.26% of the area had excellent air quality distributed mainly in the southeast of the study area (Fig. 5a). The rank of $PM_{2.5}$ concentration from high to low was the Weiyang District, the Lianhu District, the Beilin District, the Xincheng District, the Yanta District, and Baqiao District, respectively (Fig. 4a). The largest $PM_{2.5}$ concentration ranged from 43.48 $\mu g/m^3$ to 61.29 $\mu g/m^3$ in the Weiyang District, and the lowest $PM_{2.5}$ concentration ranged from 4.14 $\mu g/m^3$ to 56.18 $\mu g/m^3$ in the Baqiao District. Overall, the air quality in the main urban region of Xi'an was good during the non-heating season (Fig. 5a).

In the heating season of Xi'an, the distribution pattern of $PM_{2.5}$ concentration was low in the southeast and high in the textile industrial areas that distributed in northeast (Fig. 4b). 52.10% of the study area was polluted heavily that distributed mainly in the Weiyang District and the northern part of the Baqiao District. 39.38% of the study area was moderately polluted that distributed mainly in the central and the west of the Baqiao District. 5.67% and 2.85% of the study area that distributed mainly in the southeast of the main urban area were slightly polluted and good air quality, respectively (Fig. 5b). The rank of $PM_{2.5}$ concentration from high to low was the Lianhu District, the Weiyang District, the Yanta District, the Beilin District, the Xincheng District, and the Baqiao District, respectively (Fig. 4b), Fig. 5b). The largest $PM_{2.5}$ concentration ranged from 139.92 $\mu g/m^3$ to 172.28 $\mu g/m^3$ in the Lianhu District. The lowest $PM_{2.5}$ concentration ranged from 56.08 to 225.89 $\mu g/m^3$ in the Baqiao District. In short, the mean $PM_{2.5}$ concentration in the heating season was obviously higher than in the non-heating season, and
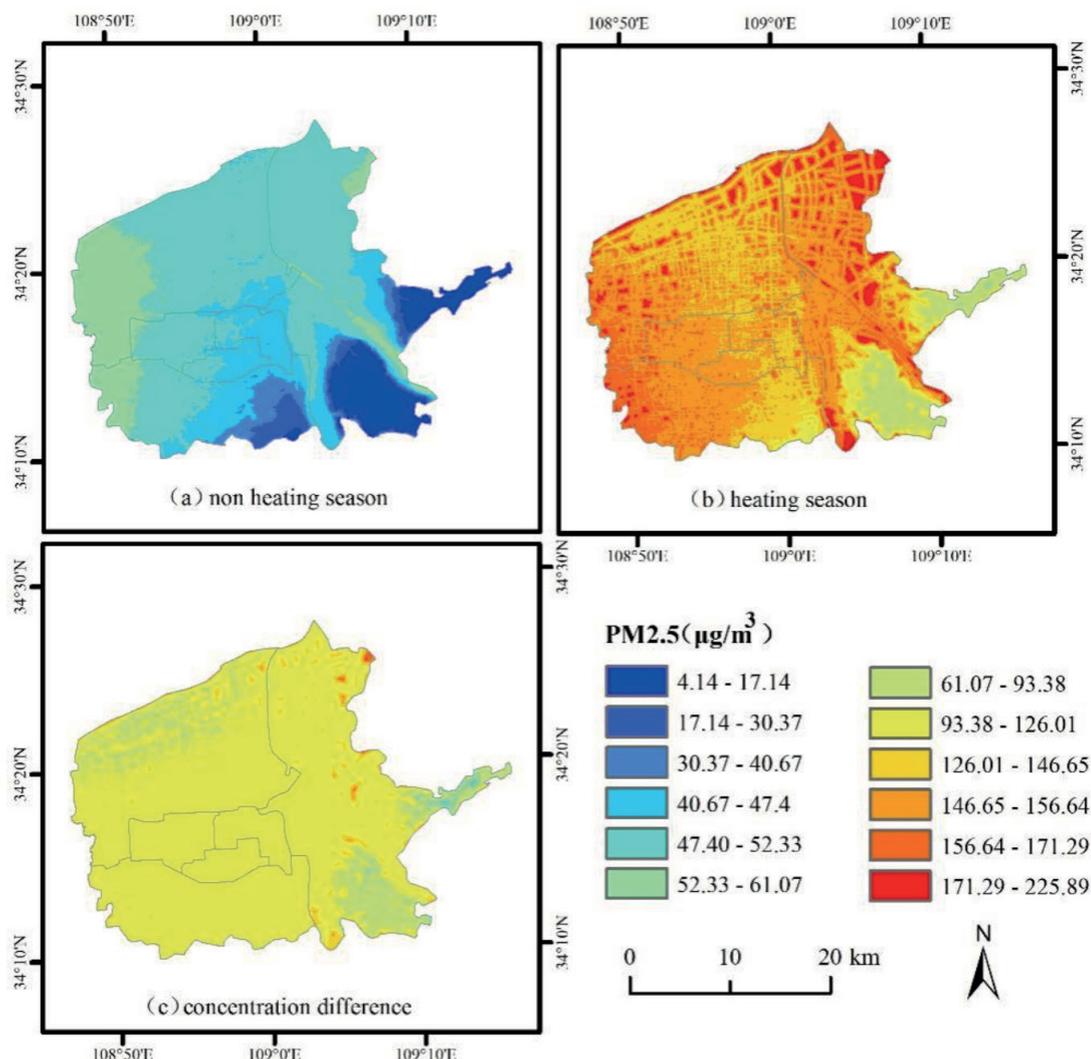

Fig. 4. The distribution of PM2.5 on a raster scale in 2017, Xi'an.
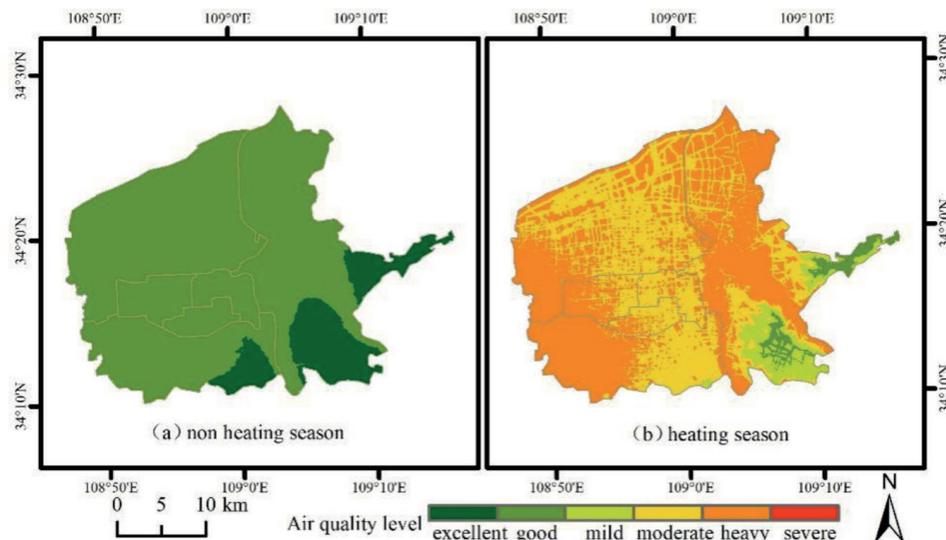
Fig. 5. Air quality distribution during non-heating season and heating season in 2017, Xi'an.

Influencing Factors of PM$_{2.5}$

Energy Structure and Land Use

In the heating season, coal combustion played an important role in PM$_{2.5}$ concentration. A previous study analyzed the distribution of PM$_{2.5}$ in Beijing and reported that coal combustion contributed 22.7 mg/m^3 PM$_{2.5}$ in January, in contrast with 0.7 mg/m^3 PM$_{2.5}$ in July in 2000 [48]. At the same time, the Bureau of Xi'an Ecological Environment announced that organic matter and coal contributed about 26% to PM$_{2.5}$ in 2017 and indicated that coal combustion and biomass burning had a significant impact on PM$_{2.5}$. Besides, in the southwest and northeast of the study area where the air quality was polluted heavily during the heating season as there were several thermal companies and electrical companies located in these areas. (Fig. 1, Fig. 4, Fig. 5). The lowest PM$_{2.5}$ concentration distributed mainly in the southeastern part of Xi'an because the vegetation coverage was better than other regions in both heating season and non-heating season (Fig. 1, Fig. 4, Fig. 5). This conclusion was similar to previous studies. For example, forests can be used for reducing PM$_{2.5}$ concentration [49]. A large scale of green space played an important role in decreasing PM$_{2.5}$ concentration [50].

Topography and Meteorology

The PM$_{2.5}$ concentration was strongly influenced by temperature (Equation 4) in the non-heating season, and the higher temperature might promote PM$_{2.5}$ concentration. Wang pointed out that the temperature was proportional to PM$_{2.5}$ concentration. The higher temperature will enhance the photochemical reaction of the atmosphere that will accelerate the formation of a secondary aerosol was also an important source of particulate matter [51]. Besides, the average air pressure negatively correlates with PM$_{2.5}$ due to the static wind often occurs in low-pressure weather conditions (Equation 4), and sufficient clouds may prevent to produce PM$_{2.5}$. Furthermore, PM$_{2.5}$ concentration decreased significantly with the increasing elevation gradient [52]. In the study area, the better vegetation coverage areas probably corresponded with high altitude, so PM$_{2.5}$ concentration was absorbed by the vegetation in the southeast part of the study area (Equation 4). Moreover, the relative humidity positively correlated with the concentration of PM$_{2.5}$ (except for precipitation occurs) (Equation 4). The large relative humidity was beneficial to PM$_{2.5}$ adhere to the water vapor, and PM$_{2.5}$ concentration would be increased. This result was similar to the study that humidity played an important role in PM$_{2.5}$ pollution in Beijing. The secondary organic aerosol would be produced as
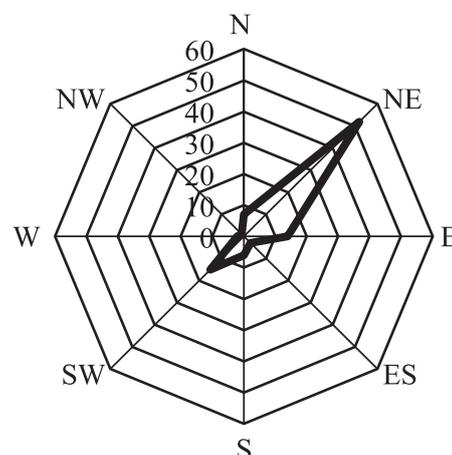

Fig. 6. The rose map of prevailing wind in 2017, Xi'an.

the relative humidity increased [53]. Precipitation had a significant effect on purifying the air in non-heating season. Contaminants in the atmosphere were easily removed by rainfall (Equation 4).

Unlike the non-heating season, precipitation positively correlated with $PM_{2.5}$ during the heating season (Equation 5). Xi'an was not only cold but also dry during the heating season and there often occurred the inversion weather phenomenon, and $PM_{2.5}$ was hard to diffuse due to the inversion weather condition. Furthermore, the prevailing wind direction in Xi'an was northeast and southwest that may cause pollutants to spread to the southwest and northeast (Fig. 6).

Traffic

Obviously $PM_{2.5}$ concentration was affected by the density of roads and vehicles flows (Equation 5). The $PM_{2.5}$ concentration on both sides of roads in the heating season was larger than that in the surrounding area (Fig. 4b), and it proved that density of roads and traffic flows might be reasons for the increasing of $PM_{2.5}$.

Different Affecting Factors for $PM_{2.5}$ between Heating Season and Non-Heating Season

There were significant differences in the influencing factors of $PM_{2.5}$ between the heating season and non-heating season in Xi'an. The affecting factors in the non-heating season came from mainly natural factors (Equation 4). On the contrary, the affecting factors in the heating season were not only natural factors but also human factors. Therefore, the results remind us that people need to pay more attention to the impact of human activities on atmospheric environment in the heating season. Furthermore, this paper's results confirmed $PM_{2.5}$ concentration was simultaneously affected by both human activities and the natural environment [54].

Simulation Results

There were several improvements in this study compared with the previous results of the LUR model. Firstly, the regression equation had better R^2, smaller RMSE and MPE (Fig. 2, Fig. 3). The adjustable R^2 was larger than the R^2 (0.65-0.84) in the previous study [55-57]. Secondly, the improvement of precision might be related to the detailed land use classification. In the previous research, vegetation was always divided into a coarse class. By contrast, vegetation was divided into detailed categories in this study (Table 1). Thirdly, the majority of scholars used sum of lengths of roads as the independent variable to quantitatively describe the influence of roads for $PM_{2.5}$. In contrast, the nearest distance from the monitoring sites to the road was used as an independent variable to participate in modeling in this paper. Last but not the least, the fishnet tool of ArcGIS10.3 was used to obtain the distribution of $PM_{2.5}$

[55, 58], and the fishnet (100m) greatly increased the number of spatial interpolation sites. Besides, the multi-source heterogeneous data could be effectively merged in the LUR model with the help of ArcGIS10.3, and the precision of distribution for $PM_{2.5}$ concentration was significantly improved.

Objectively speaking, this paper still has some limitations. For example, the simulation accuracy may be further improved if the pollutant discharge data of key polluting enterprises can be directly obtained and allowed to participate in modeling. Besides, although the influence of wind direction on $PM_{2.5}$ was discussed in this paper, it was only a qualitative evaluation. The simulation accuracy may be improved if the wind direction can be used as a potential independent variable. In summary, $PM_{2.5}$ was affected by both natural and human factors, and its influencing mechanism was very complicated. This paper's results can supply a reference for the further study of $PM_{2.5}$. In conclusion, the future study should focus on the influencing factors of $PM_{2.5}$, source analysis for $PM_{2.5}$, health risks and the relationship between epidemics and $PM_{2.5}$ concentration.

Prevention and Control Measures for Air Pollution

Firstly, it recommended the government further reduce the consumption of coal, vigorously promote the conversion of energy structure, increase the supervision of emissions from polluting enterprises, and force some enterprises to use air pollution purification equipment for treating exhaust emissions. Secondly, the government should continue to implement vehicle restriction policy, and promote urban public transport infrastructure. Thirdly, the government should strengthen dust control on construction sites. Fourthly, it recommended to planting grass and trees to improve urban vegetation coverage. Finally, it is very important to improve residents' awareness of environmental protection.

Conclusions

This study collected $PM_{2.5}$ monitoring sites data, land use data, and socio-economic data to establish the LUR model for simulating $PM_{2.5}$ concentration in the heating season and non-heating season. The conclusions are as follows: (1) This paper improved the precision of the LUR model. (2) The $PM_{2.5}$ concentration showed different distribution patterns in a heating and non-heating season in Xi'an. (3) The $PM_{2.5}$ concentration was affected by both human factors and natural factors, and human factors play significant role in heating season than in non-heating season. (4) The government should implement specific air quality improvement measures based on influence factors in different seasons for $PM_{2.5}$ concentration.

Acknowledgements

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