Hindawi
Advances in Meteorology
Volume 2018, Article ID 4914760, 9 pages
https://doi.org/10.1155/2018/4914760

Research Article

Human Settlement Quality Evaluation Based on Air Quality in Major Cities of China

Xueming Li,[1,2] Songbo Li ,[1,2] Jiaji Gao,[3] Pengfei Zhao,[1,2] and Hang Li[1,2]

[1]*The Research Center of Human Settlements, Liaoning Normal University, 850 Huanghe Rd., Dalian, China*
[2]*School of Urban and Environmental Sciences, Liaoning Normal University, 850 Huanghe Rd., Dalian, China*
[3]*Applied Technology College of Dalian Ocean University, 52 Heishijiao Str., Dalian, China*

Correspondence should be addressed to Songbo Li; 0825lisongbo@sina.com

Received 11 December 2017; Revised 13 March 2018; Accepted 30 April 2018; Published 24 June 2018

Academic Editor: Heshun Wang

Based on the monthly data of 12 months in 30 major cities and combined with the monthly data of the air quality index (AQI) in 30 major cities, this paper analyzed the quality of human settlements in 2015 with the ArcGIS spatial analysis method. On the basis of the quality of air in this analysis, the coupling degree of the five great systems in these human settlements was also calculated. The finding shows that (1) according to the spatial distribution of the human settlements quality index in the main cities, the quality of urban human settlements was gradually decreased from the coastal regions to northwest inland regions, presenting an overall look that the quality was high in the south and low in the north, which converged to the change of the air quality; (2) the human settlements quality index apparently changed with season variation. A significant difference was found in the fourth quarter, and the biggest deviation among cities in China was up to 0.680, while the smallest deviation in the second quarter was 0.448; and (3) on the basis of factors that influenced the quality index, related kinds of norms in the main cities were built in the five great systems of human settlements, and the evaluated coupling degree between the five systems was at the antagonistic stage.

1. Introduction

Since the reform and opening up, as the second largest economy in the world, China's air quality is the second lowest in the world as a whole, which has a tremendous negative impact on the urban human settlements in China [1]. At present, air quality has received widespread attention as a global issue. One of the key indicators in the *2016 Environmental Performance Index Report*, which was released by the Yale University in the United States, is air quality. In *A Study of Livable Cities in China*, Zhang Wenzhong divided the subjective evaluation index of livable cities into six dimensions [2]. He evaluated the human settlements of major cities in China according to air quality and made a brief conclusion about the development of major livable cities in China from 2014 to 2015.

At present, foreign scholars carried out a number of studies related to air quality: (1) the impact of air quality on health: foreign scholars evaluate air quality to determine the relationship between the mortality rate and respiratory disease and air quality [3], and they estimate population exposure and study the change period of air quality monitoring data to protect human health [4, 5]; in addition, the science of related health effects is evolving [6]. (2) Air quality and social development: assessment of potential pollution based on daily transport exposure [7]; analysis of annual and seasonal air quality indexes shows industrial pollution in cities [8], and agricultural burning and especially biofuel use enhanced carbon monoxide concentrations. Fossil fuel combustion and biomass burning cause a high aerosol loading [9], assessing the impact of socioeconomic development on air quality and summarizing the relationship between the two in the future [10–12], putting forward a plan for green space [13], and relying on environmental policy interventions and industrial restructuring measures to protect urban air quality [14]. (3) Scholars pay close attention to the social attributes, and on different scales, and discuss the impact of air quality on the trajectory of space-time behavior of different groups [15] such as children [16] and pregnant women [17] from global [18], national [19], regional [20], and community [21] perspectives. (4) Different pollutants contaminated by air quality, such as emission and control methods of CO_2 [22], control measures of human health risk of air pollution caused by transportation [23], and the effect of $PM_{2.5}$ toxicity on premature death [18].

A variety of methods for air quality research are put forward by domestic and foreign scholars: (1) using fuzzy logic to deal with air quality indicators [24] and neural networks to forewarn air pollution [25] and so on. The AQBI (Air Quality Balance Index) is used to assess air quality and environment in a three-dimensional diffusion model [26], in addition to distance discrimination, matter element analysis, breakpoint regression analysis, parting model, and so on [27]; (2) in the background of the development, we use the statistics of Weibo (microblog), DMSP/OLS (Defense Meteorological Satellite Program/Operational Linescan System), "World Map," and other methods to study on the urban air quality [28–30].

Human settlements science involves many disciplines. Since the 20th century, the study area of urban human settlements has been continuously expanded. The interdisciplinary contents and methods of study carefully analyze human settlements and related factors. From the perspectives of sociology [31], psychology [30], medicine [32], and other subjects, we study human settlements at different scales from the globe to the interior, which focus on the relationship between urbanization and human settlements [33], the impact of socioeconomic development on the environmental and humanistic qualities of communities [34] in the process of urbanization [35], and the inverse study of the health effects of air pollution on residents and the economic benefits and welfare brought by controlling air pollution [36], and then propose the countermeasures and solutions for the optimization of urban soft and hard facilities under the influence of air quality [37] and the sustainable development in the future [38]. Research methods and the evaluation index system are also more refined than before, which include the research on human settlements systems, such as environment, economy, and traffic [39]. With the development of GIS spatial analysis, remote sensing, and network communication [40, 41], this paper evaluates the time-spatial differences and comprehensive evaluation of human settlements in different regions by means of data acquisition and research, such as the analytic hierarchy process, information entropy index, and variation index [42].

Building harmonious and livable cities is an important content in the thirteenth Five-Year Plan for which health is a basic requirement [43]. In conclusion, most researches currently on air quality mainly focus on ecology, human health, pollution prevention and control measures, and the spatial and temporal distribution characteristics of different regions. However, there are few studies on air quality evaluation of urban human settlements. In this paper, we study on the impact of air quality on the human settlements from the perspective of environmental health in the "six dimensions." Based on the collection of air quality index data and monthly data of 30 major cities in China, preliminary analysis is made on the spatial and temporal distribution of air quality and also on the relationship between air quality and human settlements. Finally, based on the air quality, we make the coupling degree among the five major systems of human settlements, and then, we evaluate the coupling degree in the five major systems, which aims at providing a new perspective for the research and development of urban human settlements.

2. Data Method

2.1. Sources of Data. Because of the unpublicized data in Tibet Autonomous Region and different monitoring systems and standards in Taiwan Province, Hong Kong SAR and Macao SAR, the air quality indexes of 30 major cities in the provincial level except the four regions above are analyzed in this paper. The main data are AQI monthly figures around provided by the official website of the Ministry of Environmental Protection (http://www.zhb.gov.cn/) from January to December in 2015. The data of each city are selected from the local statistics bureau, statistics websites, and the Statistical Bureau of the People's Republic of China, which include basic data from January to December in 2015.

2.2. Analysis Methods

2.2.1. AQI Calculation Method. According to the concentration limit of the AQI (GB3095-2012) and various pollutants concentration limits, the Individual Air Quality Index (IAQI) can be drawn by separate calculation on the measured concentration of pollutants (among them, PM_{10} and $PM_{2.5}$ are the average concentration of 24 hours):

$$\mathrm{IAQI_P} = \frac{\mathrm{IAQI_{Hi}} - \mathrm{IAQI_{Lo}}}{\mathrm{BP_{Hi}} - \mathrm{BP_{Lo}}} \left(C_\mathrm{P} - \mathrm{BP_{Lo}}\right) + \mathrm{IAQI_{Lo}}, \quad (1)$$

where $\mathrm{IAQI_P}$ is the air quality index of the pollutant item P; C_P is the mass concentration value of the pollutant item P; $\mathrm{BP_{Hi}}$ is the high value of pollutant concentration limits that is similar to C_P; $\mathrm{BP_{Lo}}$ is the low value of pollutant concentration limits that is similar to C_P; $\mathrm{IAQI_{Hi}}$ is the air quality index corresponding to $\mathrm{BP_{Hi}}$; and $\mathrm{IAQI_{Lo}}$ is the air quality index corresponding to $\mathrm{BP_{Lo}}$.

The second step is to select the maximum value from the IAQI of various pollutants as the AQI.

2.2.2. Data Standardization. Normalized in positive, negative, and moderate indicators, the range of the data for each variable will be between [0, 1] and the data are pure numbers without units. X_{ij} is the raw data for indicators, $X_{ij\min}$ is the minimum value of the original data for indicators, $X_{ij\max}$ is the maximum value of the original data for the indicator, X_o is the appropriate value for the index, and Y_{ij} is the index value after the normalization.

Positive indicator:

$$Y_{ij} = \frac{X_{ij} - \min\limits_{1\le i\le m} X_{ij}}{\max\limits_{1\le i\le m} X_{ij} - \min\limits_{1\le i\le m} X_{ij}} \quad (1 \le i \le m,\ 1 \le j \le n). \quad (2)$$

Negative indicator:

$$Y_{ij} = \frac{\max\limits_{1\le i\le m} X_{ij} - X_{ij}}{\max\limits_{1\le i\le m} X_{ij} - \min\limits_{1\le i\le m} X_{ij}} \quad (1 \le i \le m,\ 1 \le j \le n). \tag{3}$$

Appropriate indicators:

$$Y_{ij} = \begin{cases} 2\dfrac{\left(X_{ij} - \min\limits_{1\le i\le m} X_{ij}\right)}{\left(\max\limits_{1\le i\le m} X_{ij} - \min\limits_{1\le i\le m} X_{ij}\right)} & \left(X_{ij\min} < X_{ij} < X_o\right) \\ 0 & \left(X_{ij} \le X_{ij\min}\ or\ X_{ij} \ge X_{ij\max}\right) \\ 2\dfrac{\left(\max\limits_{1\le i\le m} X_{ij} - X_{ij}\right)}{\left(\max\limits_{1\le i\le m} X_{ij} - \min\limits_{1\le i\le m} X_{ij}\right)} & \left(X_o < X_{ij} < X_{ij\max}\right). \end{cases} \tag{4}$$

Referring to the domestic and international research on the indicator system of urban human settlements, following the general principles of scientificity, validity, objectivity, and integrity of the indicator system and basing on the indicators, the environmental system, social system, residential system, supporting system, and human system which constitute the human settlements were established [44]. Many factors affect air quality: (1) the emission of industrial pollutants has a strong and positive impact on SO_2 pollution in the air; industrial energy consumption is mainly provided by coal, gas, oil, and other energy sources; and high concentration and low efficiency of industrial production aggravate urban air pollution. (2) Residential heating (nonindustrial combustion) is mainly in winter. (3) The increase of built-up areas and the impact of urban expansion cannot be ignored, which is the main cause of dust and traffic pollution. (4) Transportation mainly uses petroleum fuel. Air pollution caused by the automobile exhaust is not easy to be evacuated at high altitudes. SO_2, NO_X, and other pollutants are serious and will all have adverse effects on urban air quality. Therefore, from the perspective of the human settlements environment, it is possible to extract data that can be obtained from monthly data. Among the indicators, the positive index means that the more separated the index value is, the better the evaluation object is; the reverse index means that the lower the index value is, the worse the evaluation object is; and the moderateness index means that the closer the index value is to a certain value, the better the evaluation object is. The Delphi method and analytic hierarchy process are used to determine the weights of indicators. Also, it establishes an indicator system to assess the quality of human settlements in 30 major cities in China (Table 1). The index system includes 8 second-level indicators, such as air quality and environment, economic benefits, living standards, and residents, and 21 third-level indicators, such as per capita public green space, energy consumption per unit of GDP, energy-saving and environmental protection expenditure, and industrial SO_2 emissions [45].

2.2.3. Urban Human Settlements Quality Index (I). The quality of urban human settlements reflects the overall state of human settlements in a certain period and is a comprehensive index to measure the human settlements of urban residents. According to Zhang Zhi's characteristics of the indicator system, the human settlements quality index can be weighted comprehensively as follows [46]:

$$I = \sum_{j=1}^{5} W_j U_j, \tag{5}$$

where I is on behalf of the urban human settlements quality index, W_j is on behalf of the corresponding weight of the evaluation index on the system level, and U_j is on behalf of the corresponding index of the evaluation index on the system level. The grade and quality of the evaluation results are divided as shown in Table 2:

In terms of space, city human settlements' every quality difference in the quality of the urban human settlements environment within their jurisdiction and China's 30 qualities of the urban human settlements environment were classified into five grades according to their numerical size by Jenks, using ArcGIS spatial analysis in China on the map. This can be a more intuitive analysis based on the air quality of urban residential environment quality differentiation and the four quarters' (the first quarter: March–May, the second quarter: June–August, the third quarter: September–November, and the fourth quarter: December–next February) evolution of spatial differentiation [47].

2.2.4. Urban Human Settlements Coupling. Urban human settlements coupling is given as follows:

$$C = \left\{ \frac{\left[f(x) \times g(y) \times h(z) \times l(u) \times s(v)\right]}{\left[f(x) + g(y) + h(z) + l(u) + s(v)\right]^5} \right\}^{1/5}. \tag{6}$$

Based on the human settlements system coupling model, a coupling degree (C) model of the five subsystems of human settlements was constructed. In the formula, the comprehensive evaluation function of the environmental system, social system, residential system, support system, and human system is represented as $f(x)$, $g(y)$, $h(z)$, $l(u)$, and $s(v)$ [48]:

$$\begin{aligned} f(x) &= \sum_{i=1}^{m} a_i x_i, \\ g(y) &= \sum_{j=1}^{n} b_j y_j, \\ h(z) &= \sum_{k=1}^{o} c_k z_k, \\ l(u) &= \sum_{r=1}^{p} d_r u_r, \\ s(v) &= \sum_{t=1}^{q} e_t v_t. \end{aligned} \tag{7}$$

where x_i, y_j, z_k, u_r, and v_t stand for the five-system standardized data; a_i, b_j, c_k, d_r, and e_t represent the weight of the five subsystems; and m, n, o, p, and q stand for the number of elements in the five systems. In the formula, the numerical value is between [0, 1]. The larger the

Table 1: Evaluation index system of the urban human settlements environment.

Target layer A	Target layer weight	Criterion layer B	Weight of the criterion layer	Index C	Index level weight
Environmental system A_1	0.2932	The natural environment B_1	0.1433	Air quality index C_1	0.0568
				Relative humidity C_2 (%)	0.0426
				Average wind speed C_3 (m/s)	0.0439
		Social environment B_2	0.1499	Per capita public green area C_6 (m^2)	0.0586
				The growth of gas and LPG mining industry C_5 (%)	0.0395
				Industrial soot (powder) and dust processing rate C_4 (%)	0.0518
Social system A_2	0.2060	Economic benefits B_3	0.1090	Energy consumption per unit of GDP C_7 (tce)	0.0551
				Gross value of industrial output C_8 (10^8 Yuan)	0.0539
		Economic structure B_4	0.0970	GDP proportion of the secondary industry C_9 (%)	0.0485
				GDP proportion of the third industry C_{10} (%)	0.0485
Living system A_3	0.1309	Living standard B_5	0.1309	Consumer price index C_{11} (%)	0.0344
				Urban residents' per capita consumption expenditures C_{12} (Yuan)	0.0394
				The number of cars per unit C_{13} (unit)	0.0571
Support system A_4	0.3026	Energy-saving and environmental protection B_6	0.1034	Energy-saving and environmental protection financial expenditure C_{14} (10^4 Yuan)	0.0569
				Transport costs per capita C_{15} (Yuan)	0.0465
		Polluting emissions B_7	0.1992	Passenger turnover C_{16} (10^8 person-km)	0.0527
				Freight turnover C_{17} (10^8 ton-km)	0.0527
				Industrial SO_2 emissions C_{18} (10^4 t)	0.0467
				Industrial (powder) dust emissions C_{19} (10^4 t)	0.0471
Human system A_5	0.0673	Resident composition B_8	0.0673	Population density C_{20} (%)	0.0332
				The rate of urbanization C_{21} (%)	0.0341

Table 2: Ratings and index.

Ratings	Level I	Level II	Level III	Level IV	Level V
Index (I)	$0.69 \leq I \leq 0.89$	$0.6 \leq I \leq 0.69$	$0.45 \leq I \leq 0.6$	$0.3 \leq I \leq 0.45$	$0.1 \leq I \leq 0.3$
Condition	A	B/C	D	E	F

value of C, the higher the degree of coupling. At the same time, the synergistic development among subsystems will be more obvious, and vice versa. In this paper, the coupling degree is divided into four intervals with the method of median segmentation (Table 3).

3. Results

3.1. Time Trends of Human Settlements Quality in Major Cities. According to the time sequence, the quality of human settlements in China's major cities showed a significant difference not between the first quarter and the third quarter as a whole but between the first quarter and the fourth quarter (Figure 1). An advantageous order of each quarter is second quarter > third quarter > first quarter > fourth quarter. Among them, the quality of human settlements was similar in the first and third quarters, but the specific values of them were different: in the first quarter, the lowest value was 0.209 in Zhengzhou, the highest value was 0.849 in Kunming, and the difference between them was 0.640. In the third quarter, the lowest value was 0.203 in Beijing, the highest value was 0.835 in Kunming, and the difference between them was 0.632. In the second quarter, the differences in values all over the country is small from city to city; the lowest value was 0.217 in Beijing, the highest value was 0.843 in Kunming, and the difference between them was 0.626. In the fourth quarter, the numerical difference between the regions reached 0.708, the lowest value was 0.178 in Zhengzhou, and the highest value was 0.886 in Kunming. In the four quarters, on centering the urban agglomerations of the Beijing-Tianjin-Hebei Region to the surrounding cities, the quality of human settlements was diminishing from the south to the north. What is more, the quality of human settlements was higher in the southern and coastal cities.

3.2. Spatial Distribution Characteristics of Human Settlements in Major Cities. In the four quarters (Figure 1), the best three cities are Kunming, Fuzhou, and Haikou, which keep in the first-level quality of human settlements. The cities whose human settlements quality reached the second level in three quarters are Hohhot, Taiyuan, Yinchuan, Lanzhou, and four cities of Xining in the north and Chongqing, Guiyang, and Nanchang in the south. In the quarterly change of the urban human settlements quality index, the highest difference among the four quarters was 0.259 in Zhengzhou, followed by cities between 0.120 and 0.200, such as Harbin, Changchun, Shenyang, Shijiazhuang, and Beijing. The top five cities with a smallest difference between 0.050 and 0.080 are Kunming, Guiyang, Nanning, Xining, and Nanchang in turn (Figure 2).

Table 3: Coupling degree classification and coupling level of the human settlements system.

Coupling values	Coupling stage	Coupling characteristics
$0 < C \leq 0.3$	Low-level coupling	Primary development of socioeconomic and infrastructure; poor natural environment carrying capacity
$0.3 < C \leq 0.5$	Antagonistic coupling	Rapid development of social and economy; the increasing contradiction between the natural environment and human society
$0.5 < C \leq 0.8$	Run-in phase	A benign coupling stage of systems
$0.8 < C \leq 1$	High-level coupling	Mutual promotion and development among systems

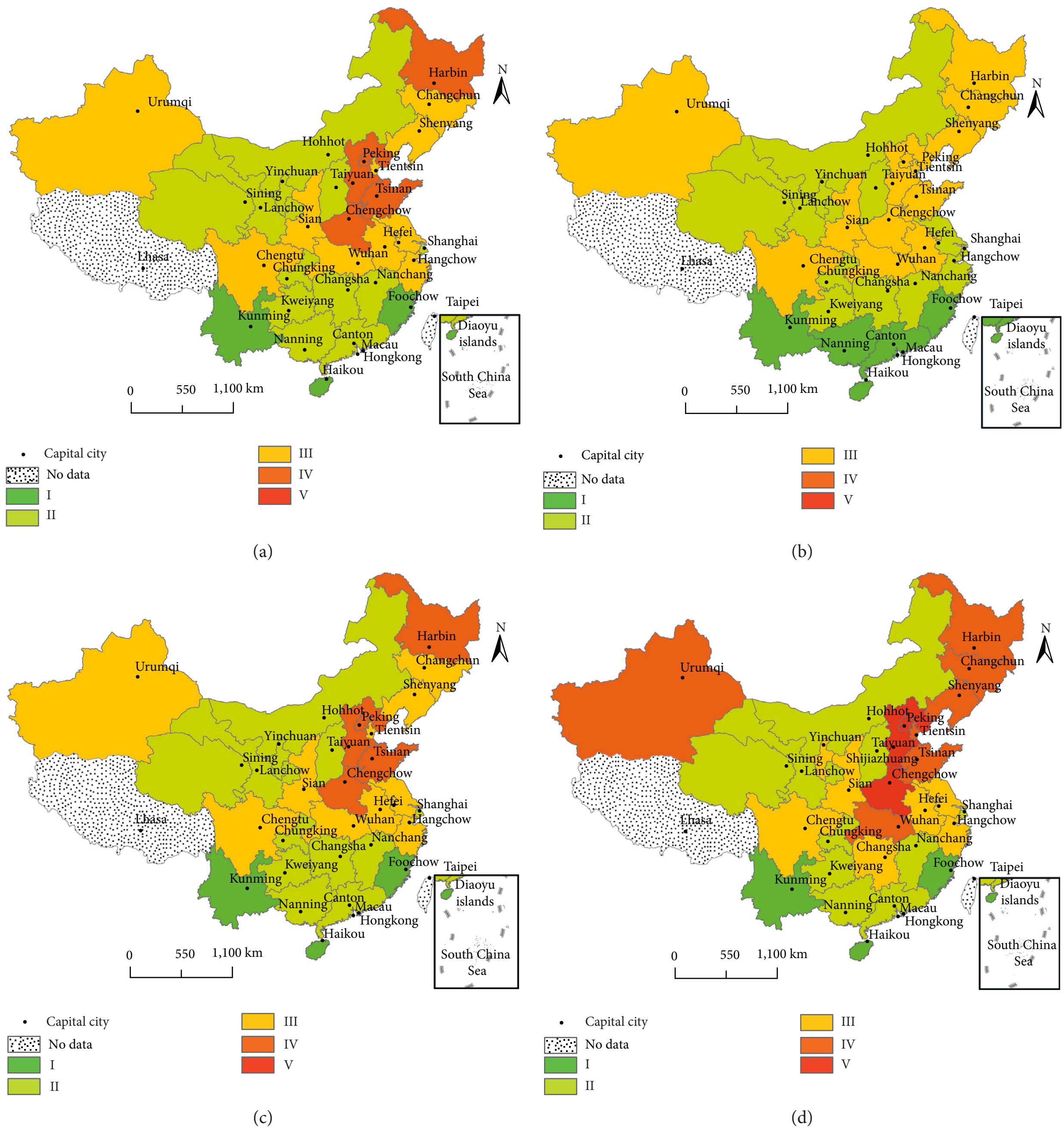

Figure 1: Spatial distribution of the human settlements quality index in provincial capitals: (a) the first quarter; (b) the second quarter; (c) the third quarter; (d) the fourth quarter.

It can be seen from the analysis that the quality of human settlements in the Northeast China and North China has changed a lot during the year, which is relatively poor in the fourth quarter. At the same time, it is generally good in the southern cities whose difference is not particularly obvious within one year. According to the air quality index of 30

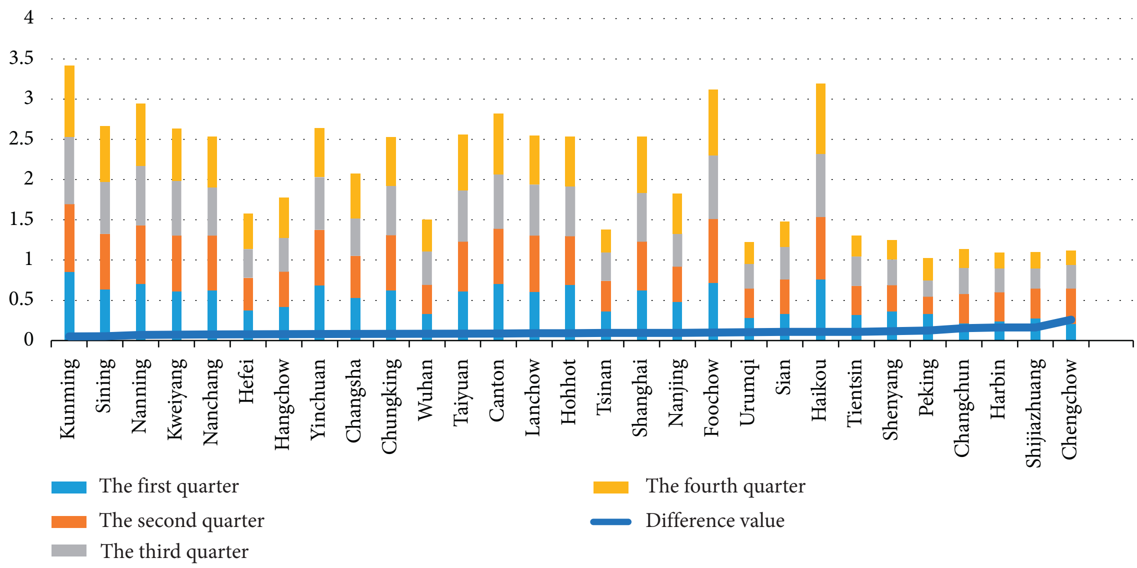

Figure 2: Quarterly change of the urban human settlements quality index.

major cities in 2015, ranking of human settlements quality approximates that of air quality, which shows that the research of air quality contributes to the evaluation of human settlements quality and the study on the coupling degree of the human settlements system.

3.3. Coupling Spatial Differentiation in the Human Settlements System. The coupling degree of the human settlements system in 30 cities in China was calculated with the use of the coupling degree calculation model. Meanwhile, according to the coupling degree level, the spatial heterogeneity map of the coupling degree (Figure 3) was drawn by using ArcGIS software. As a whole, there is no obvious spatial difference in the degree of coupling of the urban human settlements system in 30 cities in China. And the mean of the coupling degree is 0.48, which is in the antagonistic stage that is between 0.3 and 0.5. From the perspective of regional coupling, the differences in the coupling degree are obvious. It is found that 8 cities in China, such as Urumqi, Lanzhou, Taiyuan, Zhengzhou, Harbin, Changchun, Shenyang, and Beijing, are in the antagonistic phase with the lowest coupling degree. It is proved that the contradictions between human settlements and environment systems are more obvious in this stage. Although the social economy in the 8 capitals above has been developing rapidly, the fact that the natural environment in Urumqi and Lanzhou is rather harsh, the pollution caused by the urban development in the Beijing's supportive system is prominent, and the pollution problems in the social environment of the other five cities are prominent and the governance there lags behind, making the contradictions among the systems more prominent. However, the other 22 cities are in the running-in phase, which indicates that the development of overall urban human settlements is good without little air pollution brought by social development. The self-purification of greenbelt and governance methods can both prevent air hazards in time and improve the overall human settlements quality.

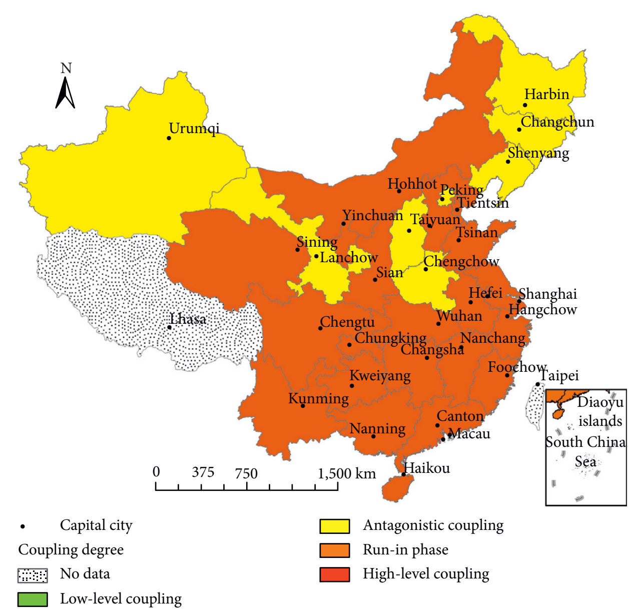

Figure 3: Spatial differentiation of the urban human settlements system's coupling degree in provincial capitals.

4. Discussion

4.1. Surface Environment. The wind velocity influences the distribution of pollutant concentration in the air, and the wind direction determines the transport direction of various pollutants in the air. The wind direction in China as a whole is the northwest in the winter and the southeast from the sea in the summer. Therefore, the humidity increases in the summer, which enhances the adsorption and sedimentation of water vapor and is accompanied by the presence of certain precipitation, and the effectiveness of leaching can significantly improve the urban air environment. The public green area also affects the dust on the ground. During the windy and dry seasons, the impact of the green area on the local air quality in cities should not be overlooked. Because of fewer green areas, the air quality in Northwest China and the Loess Plateau region was reduced by the impact of dust, which in turn affects the human settlements. The quality of human settlements in Urumqi is relatively low, which is close to that of the eastern cities with developed economic and dense population, such as Wuhan, Hefei, and Nanjing. All of this is due to the lack of green areas, the impact of meteorological, the dust throughout the year, and uncoordinated development between environmental protection and control funds while developing industry. Due to the good condition in meteorology and green area, the overall human settlements quality in the south is not much different from the first level to the third level. The fact that closed circulation appears easily in the basin and the temperature inversion in a mountainous area is longer than that in the flatland limits air diffusion ability and aggravates the pollution. As a result, the quality of human settlements in Chongqing shows a poor side due to the traffic, air pollution, economic development, and meteorology.

4.2. Seasonal Changes. The degree of diffusion of air pollutants is influenced by the thickness of the inversion layer in winter and summer. The inversion layer in summer is relatively thin and low; the inversion temperature in winter comes frequently and the atmosphere is relatively stable. At the same time, the impact of human activities on air quality is not conducive to the diffusion and dilution of pollutants discharged. The overall air quality index was clearly high in winter and low in summer. During the heating period, the burning amount of coal increased sharply, and the discharge of fireworks led to a heavy atmospheric pollution and the decline of air quality in the north. A sharp increase in coal consumption during the heating season in the northern region, combined with the release of fireworks and firecrackers in the winter, has caused a heavy atmospheric pollution and reduced air quality. Affected by the strong El Niño phenomenon, the frequent occurrence of static weather and frequent discharge of pollutants during the heating season led to a repeated heavy air pollution from the north to Beijing, Tianjin, Hebei, and the surrounding areas. The impact on productions and lives is relatively large, resulting in a low state of the human settlements environment under such circumstances, according to the calculation results: the human settlements quality of some cities is in the fifth level, such as Beijing, Shijiazhuang, Tianjin, and Zhengzhou.

Dust caused by municipal construction traffic is increased; population growth leads to the increase of emissions from industry and motor vehicles year by year, and the consumption of energy and fuel also increase. The impact of the urban population on air quality is a positive effect; higher energy consumption and industrialization levels can lead to deterioration of air quality. Therefore, the unfavorable factors such as the speed of economic development in each city and the influence of the environmental system are very important to the quality of human settlements in a city.

4.3. Artificial Influence. In addition, in the developed cities like Beijing and Shenyang, various types of human activities are frequent and continuous. Increased demand for gas and oil leads to increased mining speed, energy consumption, and dust removal, which affects the urban environment and reduces the annual overall living quality. With the increasing awareness of environmental protection, government increases expenditure on energy-saving and environmental protection and more residents choose public transportation, which have improved the urban air quality. What is more, industrial restructuring, improvement of energy efficiency and green coverage, reducing energy consumption by various means, and formulation of governance laws can lead urban air quality to show a turnaround trend. As a complex system, the five systems of human settlements interact and coordinate with each other. The coupling degree in southern China is relatively high, which shows that the social environment and natural ecological environment have a significant driving effect on the coupling degree of regional human settlements. The regions with a lower coupling degree are mainly concentrated in the northeast and northwest of China. The industrialization and urbanization there develop too fast with corresponding lags in the construction of the infrastructure, ecological environment, and so on.

5. Conclusions

Based on other indexes of air quality and human settlements, this paper takes 30 major cities in China as an example; it introduces the evaluation index system and summarizes the spatial and temporal distribution of human settlements quality based on air quality and the evaluation of the coupling degree of human settlements system.

Firstly, according to the temporal characteristics of the human settlements quality, there is almost no difference in the first and third quarters of major cities in China and 16 cities above the average quality. In the second quarter, the quality is the best in the four quarters and there are 17 cities above the average quality. However, in the fourth quarter, there were significant differences among cities and the city in the fifth level showed up the worst quality of living. The assessment of urban human settlements quality based on the air quality index shows that the quality in terms of urban spatial distribution mainly in North China and Northeast China is low, while the quality of human settlements in most parts of the coast, South China, and Northwest China is high, which generally agrees with the single assessment of human settlements based on $PM_{2.5}$, but some cities show differences.

Secondly, the average coupling degree of the five major systems of human settlements is 0.48, which is in the phase of antagonism. Under the assessment of the air quality of human settlements, the coupling degree of the five major cities in China is not high, which could be improved by industrial upgrading, environment protection, technological progress, and its own resilience. The development of urban depends not only on economic development but also on various factors, such as the interdependence, mutual restraint, and promotion, which forms an integrated system and jointly promotes the coordinated development of the five major systems. Cities should enhance the coupling degree to improve competitiveness.

Thirdly, in the future, a spatial difference in the coupling degree will focus on different time-space scales of specific regions in order to find the weak link among systems and reveal the rules and mechanism of interactions more comprehensively and systematically. In spite of the rapid development of urban governance measures and the raising education on protection of and the increase of green areas, severe air pollution is still concentrated in cities with a relatively fast economic growth in recent years, which needs to balance the internal relations among the systems. Prevention of pollution and protection of air quality need to consider a variety of factors in order to improve the quality of urban human settlements, and it also becomes one of the goals of building a better livable city.

Last but not least, based on the perspective of air quality, this paper analyzes various factors to explore the change of human settlements quality among the major cities in the four quarters in 2015. It explores the impact of air quality on the human settlements in order to construct and improve services in urban human settlements better. However, due to the difficulty in obtaining some data, the index system is not perfect. At the same time, it is not much comprehensive in terms of time and space. There are only four quarters without more detailed classification in time and only 30 cities in China in space. The range of evaluation is small. Urban human settlements is an issue that needs further study in the future.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Li Xueming and Jiaji Gao contributed equally to this work.

Acknowledgments

This work was funded by the National Natural Science Foundation of China (41671158)

References

[1] A. Hsu, D. C. Esty, M. A. Levy et al., *2016 Environmental Performance Index (EPI)*, 2016.

[2] W. Zhang, J. Yu, D. Zhan et al., *A Study of Livable Cities in China*, Science Press, Beijing, China, 2016.

[3] S. Maji, "Air quality assessment and its relation to potential health impacts in Delhi, India," *Current Science*, vol. 109, pp. 902–909, 2015.

[4] G. Kyrkilis, A. Chaloulakou, and P. A. Kassomenos, "Development of an aggregate Air Quality Index for an urban Mediterranean agglomeration: relation to potential health effects," *Environment International*, vol. 33, no. 5, pp. 670–676, 2007.

[5] P. Poursafa, M. Mansourian, M. E. Motlagh et al., "Is air quality index associated with cardiometabolic risk factors in adolescents? The CASPIAN-III Study," *Environmental Research*, vol. 134, pp. 105–109, 2014.

[6] World Health Organization, *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*, WHO, Geneva, Switzerland, 2016.

[7] E. Setton, J. D. Marshall, M. Brauer et al., "The impact of daily mobility on exposure to traffic-related air pollution and health effect estimates," *Journal of Exposure Science & Environmental Epidemiology*, vol. 21, no. 1, pp. 42–48, 2015.

[8] M. Mohan and A. Kandya, "An analysis of the annual and seasonal trends of air quality index of Delhi," *Environmental Monitoring & Assessment*, vol. 131, no. 1–3, pp. 267–277, 2007.

[9] J. Lelieveld, P. J. Crutzen, V. Ramanathan et al., *The Indian Ocean Experiment: Widespread Air Pollution from South and Southeast Asia*, Springer International Publishing, Berlin, Germany, 2016.

[10] X. Lin and D. Wang, "Spatio-temporal variations and socio-economic driving forces of air quality in Chinese cities," *Acta Geographica Sinica*, vol. 71, pp. 1357–1371, 2016.

[11] S. Lehmann, A. U. Zaman, J. Devlin et al., "Supporting urban planning of low-carbon precincts: integrated demand forecasting," *Sustainability*, vol. 5, no. 12, pp. 5289–5318, 2013.

[12] D. Kim and U. Lim, "Urban resilience in climate change adaptation: a conceptual framework," *Sustainability*, vol. 8, no. 4, p. 405, 2016.

[13] Z. Yang, H. Zhang, Y. Ding et al., "Progress and prospect on urban green space research," *Progress in Geography*, vol. 34, pp. 18–29, 2015.

[14] M. Buzzelli, M. Jerrett, R. Burnett et al., "Spatiotemporal perspectives on air pollution and environmental justice in Hamilton, Canada, 1985-1996," *Annals of the Association of American Geographers*, vol. 93, no. 3, pp. 557–573, 2015.

[15] J. Ma, Y. W. Chai, and T. T. Fu, "Progress of research on the health impact of people's space-time behavior and environmental pollution exposure," *Progress in Geography*, vol. 36, no. 10, pp. 1260–1269, 2017.

[16] S. M. Barbosa, S. C. Farhat, L. C. Martins et al., "Air pollution and children's health: sickle cell disease," *Cadernos De Saude Publica*, vol. 31, p. 265, 2015.

[17] R. J. Heitmann, M. J. Hill, A. N. James et al., "Live births achieved via IVF are increased by improvements in air quality and laboratory environment," *Reproductive Biomedicine Online*, vol. 31, no. 3, pp. 364–371, 2015.

[18] J. Lelieveld, J. S. Evans, M. Fnais et al., "The contribution of outdoor air pollution sources to premature mortality on a global scale," *Nature*, vol. 525, no. 7569, pp. 367–371, 2015.

[19] Z. Wang, C. Fang, G. Xu et al., "Spatial-temporal characteristics of the $PM_{2.5}$ in China in 2014," *Acta Geographica Sinica*, vol. 11, pp. 1720–1734, 2015.

[20] Y. Ma, H. Zhao, L. Li et al., "Spatial scale of regional plan environmental impact assessment: the Gaoqiao Town and Pudong New District cases in Shanghai, China," *Progress in Geography*, vol. 34, pp. 739–748, 2015.

[21] K. Wyat Appel, S. L. Napelenok, K. M. Foley et al., "Description and evaluation of the Community Multiscale Air Quality (CMAQ) modeling system version 5.1," *Geoscientific Model Development*, vol. 10, no. 4, pp. 1–41, 2017.

[22] S. Wang, Y. Liu, and C. Fang, "Review of energy-related CO_2 emission in response to climate change," *Progress in Geography*, vol. 34, no. 2, pp. 151–164, 2015.

[23] P. W. Li, H. Alias, N. Aghamohammadi et al., "Control measures and health effects of air pollution: a survey among public transportation commuters in Malaysia," *Sustainability*, vol. 9, no. 9, p. 1616, 2017.

[24] M. H. Sowlat, H. Gharibi, M. Yunesian et al., "A novel, fuzzy-based air quality index (FAQI) for air quality assessment,"

Atmospheric Environment, vol. 45, no. 12, pp. 2050–2059, 2011.

[25] M. Sharma, S. Aggarwal, P. Bose, and A. Deshpande, "Meteorology-based forecasting of air quality index using neural network," in *Proceedings of the IEEE International Conference on Industrial Informatics (INDIN)*, pp. 374–378, Banf, AB, Canada, August 2003.

[26] P. Trivero, W. Biamino, M. Borasi et al., "An air quality balance index estimating the total amount of air pollutants at ground level," *Environmental Monitoring & Assessment*, vol. 184, no. 7, pp. 4461–4472, 2012.

[27] N. Moussiopoulos, E. Chourdakis, and G. Tsegas, *An Air Quality Management System for Cyprus: Evaluation and Improvements*, Springer International Publishing, Berlin, Germany, 2017.

[28] N. Chen, "The design and implementation of Jiangsu Province air quality of $PM_{2.5}$ monitoring platform based on "Map World"," *Geomatics &Spatial Information Technology*, vol. 2, pp. 116–118, 2014.

[29] H. Letu, M. Hara, G. Tana et al., "Generating the nighttime light of the human settlements by identifying periodic components from DMSP/OLS satellite imagery," *Environmental Science & Technology*, vol. 49, no. 17, pp. 10503–10509, 2015.

[30] S. Yi, J. Li, X. Li et al., "Relationship between air quality and residents' emotion—A case of Xi'an and Shanghai," *Journal of Arid Land Resources and Environment*, vol. 31, no. 5, pp. 39–44, 2017.

[31] Programme UNHS, *Planning and Design for Sustainable Urban Mobility: Global Report on Human Settlements 2013*, Vol. 29, UNHS, Nairobi, Kenya, 2015.

[32] E. Matisoo-Smith, "Ancient DNA and the human settlement of the Pacific: a review," *Journal of Human Evolution*, vol. 79, pp. 93–104, 2015.

[33] X. Li, C. Zhang, X. Zhang et al., "Quantitative research on urbanization and environment for human settlements-take Dalian as an example," *China Population·Resources and Environment*, vol. 14, pp. 93–98, 2004.

[34] N. Huang, S. Cui, Q. Liu et al., "Study on the characteristics of community human settlements in peri-urban area during urbanization: a case of Jimei District, Xiamen City," *Progress in Geography*, vol. 31, pp. 750–760, 2012.

[35] Y. Xiong, G. Ceng, L. Dong et al., "Quantitative evaluation of the uncertainties in the coordinated development of urban human settlement environment and economy: taking Changsha city as an example," *Acta Geographica Sinica*, vol. 62, pp. 397–406, 2007.

[36] Y. Xie, H. Dai, G. Hua et al., "Health and economic impacts of $PM_{2.5}$ pollution in Beijing-Tianjin-Hebei area," *China Population·Resources and Environment*, vol. 11, pp. 19–27, 2016.

[37] C. W. Van Niekerk and A. L. Roux, *Human Settlements*, 2017.

[38] S. Mwaguni, E. Ayiemba, and J. Onyari, *Dancing to the Tune of Opportunities–Human Settlements Aligned to Share the Jackpot of Kenya's Coastal Tourism Benefits Spoil: The Broth*, 2017.

[39] J. E. Innes and D. F. Booher, "Indicators for sustainable communities: a strategy building on complexity theory and distributed intelligence," *Planning Theory & Practice*, vol. 1, no. 2, pp. 173–186, 2000.

[40] S. Perveen, M. Kamruzzaman, and Y. Tan, "Developing policy scenarios for sustainable urban growth management: a Delphi approach," *Sustainability*, vol. 9, no. 10, p. 1787, 2017.

[41] K. Faisal and A. Shaker, "An investigation of GIS overlay and PCA techniques for urban environmental quality assessment: a case study in Toronto, Ontario, Canada," *Sustainability*, vol. 9, no. 3, p. 380, 2017.

[42] W. Zhang, L. Chen, and Y. Yang, "Research progress on human settlement evolution," *Progress in Geography*, vol. 32, pp. 710–721, 2013.

[43] W. Zhang, "The core framework of the livable city construction," *Geographical Research*, vol. 35, pp. 205–213, 2016.

[44] L. Wu, *Introduction to Sciences of Human settlements*, China Architecture & Building Press, Beijng, China, 2001.

[45] X. Li and P. Jin, "Characteristics and spatial-temporal differences of urban human settlement environment in China," *Stientia Geographica Sinica*, vol. 32, pp. 521–529, 2012.

[46] Z. Zhang and Z. Wei, "Study and application of urban human settlements assessment system," *Ecology and Environment*, vol. 15, pp. 198–201, 2006.

[47] Y. Liu, Q. Yan, J. Huang et al., "Spatio-temporal distribution of API based on GIS in China," *Ecology and Environmental Sciences*, vol. 8, pp. 1386–1394, 2013.

[48] C. Fang, C. Zhou, C. Gu, and S. Li, "Theoretical analysis of interactive coupled effects between urbanization and eco-environment in mega-urban agglomerations," *Acta Geographica Sinica*, vol. 71, pp. 531–550, 2016.