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Coupling coordination measurement of land use and air quality in Heilongjiang Province

Jiaxin Luo, Jia Cui* and Yanfang Liu

College of Management, Harbin Normal University, Harbin, Heilongjiang, 150025, China

*Corresponding author's e-mail: ccc13936400919@163.com

Abstract. The coordinated development of land use and atmospheric environment is the key link to promote the healthy operation of regional economy and society. The gray correlation TOPSIS model was used to comprehensively evaluate the land use levels and air quality of 12 prefecture-level cities in Heilongjiang Province from 2015 to 2018, and the spatial-temporal evolution characteristics of the coordinated development degree of the two cities are explored by using the coupling coordination degree model. The results show that: The land use efficiency and air quality in Heilongjiang Province both fluctuate and increase, during which no city has achieved the ideal synchronous development, and the lag of land use level is the main factor limiting the degree of coordination; The coupling degree of land use and atmospheric environment is relatively high. 91.67% of the cities are always in a high-level coupling stage with little change. The coordination relationship between land use and atmospheric environment is gradually optimized, and the trend of temporal change is "N" type, and the type of coordination transitions from mild imbalance to barely coordinated. In space, it shows the pattern characteristics of "high in the West and low in the East". Daqing has the highest level of coordinated development, while Harbin and Hegang need to improve their coordination.

1. Introduction

Air pollution, as the most urgent environmental health risk facing human beings, has always been the focus of academic attention. Although the country's air quality has generally improved in recent years, the situation is still not optimistic. According to the 2019 World Air Quality Report, 48 cities in mainland China are among the 100 cities with the most serious air pollution in the world, and only 2% of the cities have an average annual PM2.5 concentration that meets WHO standard values. Land use is an important link that connects nature with human activities. It can not only change human production and lifestyle, but also have a corresponding impact on ecosystems[1]. Since the reform and opening up, China's rapid urbanization process has led to changes in land use. Vegetation has been gradually replaced by high-rise buildings and traffic roads, and some waters have been landfilled. This has caused a series of ecological and environmental problems, of which the most obvious and direct it is atmospheric pollution. Overburdened urban construction, industrial production, human activities, etc. are the root causes of frequent "PM2.5 burst meter" and "heat island effect" in many places [2]. Air pollutants are largely derived from the land surface, and a reasonable land use model can effectively and continuously relieve the atmospheric environmental pressure [3]. Therefore, it is of great significance to explore the coupling relationship between land use and the atmospheric environment and improve the degree of coordinated development of the two, for optimizing the allocation of land resources, improving regional air quality levels, and promoting the balanced operation of ecosystems.

At present, domestic and foreign scholars' research on land use and air pollution mainly focuses on two aspects. One is to use land as an impact factor to simulate and predict the spatial distribution of various pollutant concentrations [4,5]; The other is to explore the atmospheric environmental effects of changes in land use types and spatial patterns from the average annual and seasonal scales [6-8]. Research methods include spatial interpolation simulation, land use regression model, correlation analysis and so on. Romero H.et al. [9] showed that the reduction in the "filtering capacity of the vegetation surface"and the impact on air pollution brought about by the rapid urban development have caused a climate change from rural to urban. Liang Z.F.et al. [10] explored the correlation between regional land intensive use levels and six atmospheric pollutants using partial least squares regression and path analysis based on the division of land functional areas. Wei J.et al. [2] took the typical urban area of Shandong Province as an example, analyzed the response and sensitivity of air particle pollution to land cover change, and concluded that the particle pollution effect of land use change in different types of cities was significantly different due to the impact of environmental factors. Ooi M.C.G.et al. [11] used WRF Chem, a chemical weather forecasting tool, to control external factors while comparing land-use time series changes, and to explore the characteristics of land-use changes on the ground ozone in the suburbs of tropical cities. Previous studies on land use and air pollution have mostly targeted specific areas within a short period of time and there are few comprehensive evaluations of atmospheric pollutants. Starting from the two aspects of land use and atmospheric environmental quality, there is a lack of discussion on the coupling and coordination relationship.

Heilongjiang Province is located in the northeastern part of China. It has a large proportion of resource-based cities, with vast land area but low utilization efficiency. The blind expansion of urban construction land, the reduction of forest coverage, and the limitations of agricultural land cultivation techniques have all put pressure on the atmospheric environment. In the winter heating period, energy consumption increases, and the problem of atmospheric pollution is particularly prominent. The region is currently facing the dual responsibility of optimizing the land use structure and improving air quality. The coordinated development of the two systems plays a key role in realizing the new round of revitalization of the Northeast. This article takes 12 prefecture-level cities in Heilongjiang Province as the research object, builds a comprehensive evaluation index system of land use and air quality, uses the gray correlation TOPSIS model and coupled coordination model to measure the level of coordinated development of the two systems over the past four years, and reveals the characteristics of its spatial and temporal changes. It is expected to provide reference for promoting the sustainable development of regional economy and society.

2. Index selection and data sources

Based on reference to existing research [12,13], combined with regional characteristics, the article quantifies the land use level of each city from four dimensions: "degree-economy-society- ecology". Take the urban construction land area per capita, residential land area per capita, road area per capita and built-up area ratio as factors to measure the degree of land use; The economic benefits of land use are characterized by the added value of secondary and tertiary industries per unit area, agricultural output value per unit area, public fiscal revenue per unit area and total retail sales of consumer goods per unit area; Select the per capita area of public management and service land, the number of urban employees per unit area, the per capita disposable income of urban residents and the per capita disposable income of rural residents to measure the social benefits of land use; The ecological benefit of land use is measured by the green area per capita, the green coverage rate of built-up areas, the rate of domestic garbage treatment and the rate of sewage treatment. In terms of air quality, the comprehensive index of ambient air quality covers the pollution status of six pollutants NO_2, SO_2, PM2.5, PM10, CO, and O_3. The larger the value, the greater the overall pollution level, and it accurately reflects the city Air quality level; The ratio of days to reach the air standard can compare the regional air condition with the standard value as a whole, so these two indicators are used as comprehensive evaluation factors of the atmospheric environment.

This article uses the data samples of 12 prefecture-level cities in Heilongjiang Province from 2015 to 2018 for calculation and analysis. The data related to land use is derived from the "Statistical Yearbook of Heilongjiang Province", "Statistical Yearbook of China's Urban Construction" and the national economic and social development of various cities Statistical bulletin; Atmospheric-related data are derived from the monthly air quality report and environmental status bulletin of cities in Heilongjiang Province. Among them, some indicator data of Daxinganling are not available, so it is not included in the scope of the study. Considering the obvious difference in dimension and magnitude between the original index data, the range method was used to standardize it to eliminate the interference of scale, magnitude and direction.

3. Research methods

3.1. Grey correlation TOPSIS model

The traditional TOPSIS model ranks by judging the distance between the evaluation object and the ideal solution, and gray correlation analysis reflects the closeness of the evaluation object and the ideal solution from the geometric shape. Combining the two methods can make up for the shortcomings of the respective methods, making the evaluation results more comprehensive and accurate [14]. The method steps are as follows:

Based on the standardized data, the index weight w_j is determined by the entropy weight method [15], and the Euclidean distance from the sample object to the positive and negative ideal solutions is calculated:

$$d_i^+ = \sqrt{\sum_{j=1}^{m} [w_j (z_{ij} - z_j^+)]^2} \quad (i = 1,2,...,n; j = 1,2,...,m) \tag{1}$$

$$d_i^- = \sqrt{\sum_{j=1}^{m} [w_j (z_{ij} - z_j^-)]^2} \quad (i = 1,2,...,n; j = 1,2,...,m) \tag{2}$$

Based on the weighted standardized matrix, calculate the gray correlation coefficient matrix R^+ and R^- from the sample index to the positive and negative ideal solutions, where:

$$R^+ = (r_{ij}^+)_{m\times n} \qquad r_{ij}^+ = \frac{\min\limits_i \min\limits_j \left|z_j^+ - z_{ij}\right| + \rho \max\limits_i \max\limits_j \left|z_j^+ - z_{ij}\right|}{\left|z_j^+ - z_{ij}\right| + \rho \max\limits_i \max\limits_j \left|z_j^+ - z_{ij}\right|} \tag{3}$$

$$R^- = (r_{ij}^-)_{m\times n} \qquad r_{ij}^- = \frac{\min\limits_i \min\limits_j \left|z_j^- - z_{ij}\right| + \rho \max\limits_i \max\limits_j \left|z_j^- - z_{ij}\right|}{\left|z_j^- - z_{ij}\right| + \rho \max\limits_i \max\limits_j \left|z_j^- - z_{ij}\right|} \tag{4}$$

In the formula, $\rho \in (0,1)$ is the resolution coefficient, which is generally 0.5.

Calculate the gray correlation between sample i and the positive and negative ideal values:

$$r_i^+ = \frac{1}{n}\sum_{j=1}^{m} r_{ij}^+, \qquad r_i^- = \frac{1}{n}\sum_{j=1}^{m} r_{ij}^- \quad (i = 1,2,...,n.) \tag{5}$$

Perform dimensionless processing on the distances d_i^+, d_i^- and relevance r_i^+, r_i^-, respectively:

$$D_i^+ = \frac{d_i^+}{\max\limits_i d_i^+}, \quad D_i^- = \frac{d_i^-}{\max\limits_i d_i^-}, \quad R_i^+ = \frac{r_i^+}{\max\limits_i r_i^+}, \quad R_i^- = \frac{r_i^-}{\max\limits_i r_i^-}, \tag{6}$$

In the formula, the larger the values of R_i^+ and D_i^-, the closer the urban land use level or air quality to the ideal value; on the contrary, the larger the values of R_i^- and D_i^+, the farther the city score is from the ideal solution.

A comprehensive analysis of the dimensionless Euclidean distance and the gray correlation degree results in:

$$S_i^+ = \alpha D_i^- + \beta R_i^+ \quad (i = 1,2,...,n) \qquad S_i^- = \alpha D_i^+ + \beta R_i^- \quad (i = 1,2,...,n) \tag{7}$$

In the formula, α and β reflect the degree of emphasis on the two evaluation methods of position and shape, satisfying $\alpha + \beta = 1$, and α, $\beta \in (0,1)$, this study believes that the two have the same proportion. S_i^+ comprehensively reflects the similarity between the sample level and the ideal value, the larger the value, the better; S_i^- indicates the similarity between the sample level and the negative ideal value, the smaller the value, the better.

Calculate relative closeness:

$$T_i = S_i^+ / (S_i^+ + S_i^-) \quad (i = 1,2,\ldots,n) \tag{8}$$

In the formula, T_i represents the comprehensive evaluation scores of land use and air quality of prefecture-level cities, sorted according to the numerical value.

3.2. Coupling coordination model

Coupling refers to the phenomenon of multiple systems interacting and influencing each other. Coupling degree is used to describe the degree of mutual influence. As a measurement tool to promote the system to an orderly mechanism, there are no pros and cons [16]. The larger the coupling value, the more orderly the development direction between the systems and the more stable the relationship. When the system number is two, the calculation formula of the coupling degree is [17]:

$$C = 2 \times \left\{ \frac{U_1 \cdot U_2}{[U_1 + U_2]^2} \right\}^{\frac{1}{2}} \tag{9}$$

In the formula, $0 \le C \le 1$, U_1 and U_2 represent the land use and atmospheric environment evaluation values, respectively. According to the research results, the coupling degree of land use and air quality is divided into low-level coupling stage ($0.5<C\le0.7$), antagonistic stage ($0.7<C\le0.8$), running-in stage ($0.8<C\le0.9$) and high-level coupling stage ($0.9<C\le1$) 4 types.

In order to fully reflect the coordination relationship between land use and atmospheric environment system in Heilongjiang Province, the coordination degree model is introduced, and the coupling coordination degree calculation formula is:

$$D = \sqrt{C \times T}, \quad T = \alpha U_1 + \beta U_2 \tag{10}$$

In the formula, D represents the coupling coordination degree between the systems, T represents the coordination index of the two systems, α and β are undetermined coefficients, satisfying $\alpha + \beta = 1$. In this paper, land use level is considered to be as important as air quality, so α and β are both 0.5. According to the results of the coordination degree calculation, it is divided into the following 5 grades in order to clarify the development stage: severe disorders ($0.5<D\le0.6$), mild disorders ($0.6<D\le0.7$), barely coordinated ($0.7<D\le0.8$), intermediate coordination ($0.8<D \le0.9$) and high-quality coordination ($0.9 <D \le 1$).

4. Results analysis

4.1. Analysis on the development characteristics of land use level

The overall land use efficiency of Heilongjiang Province showed a volatile upward trend. The index increased from 0.3992 in 2015 to 0.4240 in 2018, but it has always been at a low level and has dropped in 2017. It can be seen from the weights that the indicators reflecting economic benefits are the main factors affecting the comprehensive level of land use, and the factors that can express the ecological benefits of land use have the least impact on the score. From the perspective of prefecture-level cities, Daqing is rich in oil resources, and the high-end emerging industries are gradually expanding. The added value of its secondary and tertiary industries is far higher than the provincial average level. Economic and social development promotes the strengthening of land investment and utilization, so the land use efficiency is the highest. Harbin, as a provincial political and economic center, gathers capital and human resources, leading agricultural output value, so the comprehensive level of land use is relatively good. Hegang and Shuangyashan, as resource-declining cities, have insufficient endogenous power for transformation and development, so their land use is low. During the study period, the land use index of Shuangyashan, Jiamusi and Mudanjiang declined in 2017 respectively due to a large number of population urbanization, urban construction land reduction, public finance revenue reduction and other factors, while the rest cities were in a steady development state, but the speed was relatively slow. The overall difference between cities is not obvious.

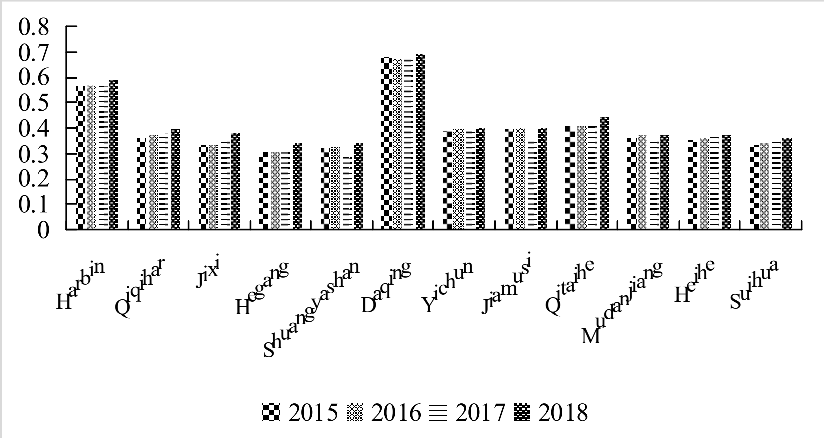

Figure 1. Changes in land use level of prefecture-level cities in Heilongjiang Province.

4.2. Analysis on the development characteristics of atmospheric environmental quality

In the past four years, the air environment quality in Heilongjiang Province has shown a "N" upward chronological change. The average annual index is 0.6435, which is generally above the medium level. It is spatially characterized by the pattern of "high in the northwest and low in the southeast". Through calculation, we can see that the standard deviation of air quality in 12 prefecture-level cities shows a declining trend, indicating that the degree of regional differentiation is gradually weakening. Cities with superior air quality are represented by Yichun and Heihe. Yichun is known as the "Chinese Forest Capital". The forest coverage rate reaches 82.2%, which plays a good role in purifying air pollution. Heihe's economic development mainly relies on agriculture and tourism, with a very low proportion of industry and favorable conditions for atmospheric environment construction. Harbin and Qitaihe are the cities with low air quality, among which Qitaihe takes coal as the main energy source, industrial exhaust emissions are large, so soot-type pollution is more serious. Harbin has issued a series of laws and regulations since 2016, which effectively prevented and controlled urban motor vehicles, coal and key pollutants, and strengthened the supervision of pollutant discharge enterprises. Therefore, the air pollution improvement effect is the most significant. The increase of atmospheric environment index from 2015 to 2018 reached 259.74%, but there is still a certain gap compared with other cities in the province.

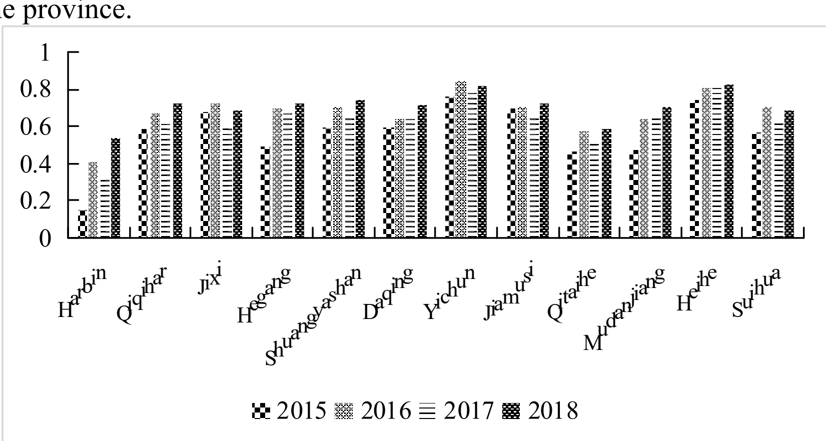

Figure 2. Changes in air quality of prefecture-level cities in Heilongjiang Province.

During the study period, the land use and atmospheric environment of 12 prefecture-level cities in Heilongjiang Province did not achieve ideal synchronous development. Among them, the gap between the two systems in Daqing is narrowing and gradually becoming equal. Except for Harbin, the rest of the cities are in the lagging development stage of land use, which shows that the benefits of regional land use generally fails to keep up with the level of air quality development, and the problem of inefficient land use is more prominent. In the future, while improving the industrial production mode and maintaining the ecological environment, cities should focus on the optimization of land stock and structure layout, so as to promote the land use and air quality to the ideal standard of synchronous development.

4.3. Analysis of coupling degree between land use and atmospheric quality

According to the calculation results of formula (9), the coupling degree of land use and air quality in Heilongjiang Province is generally high from 2015 to 2018, with an average annual index of 0.9553, and the time sequence trend is V-shaped, with little fluctuation in four years. During the period, the coupling level of land use and air quality in Harbin transitioned from the run-in stage in 2015 to the high-level coupling stage, and the gap between the systems gradually narrowed. The other 11 prefecture-level cities were always in a high-level coupling state, but the coupling degree of most cities has declined, indicating that the interaction between land use and air environment was relatively weakened, and the development tended to be disordered.

4.4. Spatial-temporal evolution analysis of coordination degree between land use and air quality

Use formula (10) to calculate the coupling degree value of land use and atmospheric quality of each city in Heilongjiang Province from 2015 to 2018, and use ArcGIS 10.2 for spatial connection, according to the best natural discontinuity method to divide the numerical interval (Figure 3). On the whole, the coordination of land use and air quality in Heilongjiang Province is gradually developing to benign. The coordination value has undergone an "up-down-up" process, transitioning from a mild disorders phase to a barely coordinated phase,but the coordination level has not been improved obviously, the average growth rate is 9.34%. It can be seen from Table 1 that cities with better coordination between land use and air quality are Daqing, Yichun and Heihe in turn. Among them, Daqing ranks first in land use, reasonable industrial layout and resource allocation provide the foundation for ecological environment construction and air quality maintenance; Yichun and Heihe have good natural conditions advantages, healthy air environment brings strong support for regional land use, and the two systems promote each other to achieve synchronous development at a higher level. The ranking of coupling coordination ranks lower is Harbin and Hegang. The urban construction and production of Harbin has caused overload pressure on the ecological environment. Although the air quality has improved in recent years, the comprehensive level is still some distance from the land use benefits; The atmospheric environment in Hegang has improved significantly since 2016. However, the land use level has been steadily advancing, which has caused the development of the two to be out of sync. The standard deviation of the coordination degree of 12 prefecture-level cities fluctuates between 0.0355 and 0.0624, and the degree of dispersion is small, indicating that the regional level of coordination between land use and atmospheric quality in Heilongjiang Province is not significant, and the interaction between cities is relatively strong.

Table 1. Development level of coordination degree between land use and air quality in Heilongjiang Province.

City	2015(Coordination)		2016(Coordination)		2017(Coordination)		2018(Coordination)	
	degree	type	degree	type	degree	type	degree	type
Harbin	0.5375	severe disorders	0.6926	mild disorders	0.6604	mild disorders	0.7492	barely coordinated
Qiqihar	0.6760	mild disorders	0.7078	barely coordinated	0.6947	mild disorders	0.7309	barely coordinated
Jixi	0.6883	mild disorders	0.7015	barely coordinated	0.6700	mild disorders	0.7141	barely coordinated
Hegang	0.6205	mild	0.6806	mild	0.6797	mild	0.7056	barely

		disorders		disorders		disorders		coordinated
Shuang yashan	0.6607	mild disorders	0.6925	mild disorders	0.6640	mild disorders	0.7071	barely coordinated
Daqing	0.7974	barely coordinated	0.8086	intermediate coordination	0.8109	intermediate coordination	0.8377	intermediate coordination
Yichun	0.7365	barely coordinated	0.7589	barely coordinated	0.7478	barely coordinated	0.7555	barely coordinated
Jiamusi	0.7233	barely coordinated	0.7277	barely coordinated	0.6964	mild disorders	0.7340	barely coordinated
Qitaihe	0.6565	mild disorders	0.6933	mild disorders	0.6834	mild disorders	0.7133	barely coordinated
Mudan jiang	0.6433	mild disorders	0.6986	mild disorders	0.6971	mild disorders	0.7148	barely coordinated
Heihe	0.7164	barely coordinated	0.7329	barely coordinated	0.7361	barely coordinated	0.7458	barely coordinated
Suihua	0.6581	mild disorders	0.6999	mild disorders	0.6856	mild disorders	0.7048	barely coordinated

From the perspective of time dimension, in 2015, the coupling coordination index interval of land use and air quality of prefecture-level cities in Heilongjiang Province was [0.5375,0.7974], in which the proportion of cities with mild disorders and barely coordination was 7:4, and the overall level was dominated by slightly unbalanced cities. In 2016, the coupling coordination value range was [0.6806, 0.8086]. During this period, the ratio of cities with mild disorders and barely coordination was 6:5. Compared with the previous year, the coordination level of all prefecture-level cities was improved, but half of the cities were still in a state of imbalance. Harbin has realized the transformation from severe disorders to mild disorders, and the growth rate of coordination value has reached 28.86%. Qiqihar and Jixi developed from mild disorders to barely coordination, while Daqing reached the intermediate coordination state and maintained the leading position. At this stage, the municipal governments have taken a number of measures to strictly supervise key enterprises and road construction, and great progress has been made in the prevention and control of air pollution, which has played a role in promoting the coordinated development of land use and air quality. In 2017, the index interval of land use and air quality coupling coordination was [0.6604, 0.8109], the proportion of cities with mild disorders and barely coordination was 9:2. 83.33% of the cities have a decline in coordination level due to the adjustment of land use structure and the pressure of environment, among which the coordination degree of four cities has dropped by more than 4%. Qiqihar, Jixi and Jiamusi have all dropped from barely coordination stage to mild disorders stage. It shows that the synchronicity between the two systems of regional land use and air quality is reduced, and the overall development of the city is restricted. In 2018, the value range of the coordination degree in Heilongjiang Province was [0.7048, 0.8377], all prefecture-level cities were in a coordinated state, and the ratio of cities with barely coordinated and intermediate coordinated classes was 11:1. The social and economic development of this period led to the improvement of the comprehensive benefits of land use, and the city paid more attention to the protection of the atmospheric environment while effectively using the land, so as to enhance the unity and coordination between them.

From the perspective of spatial dimension, the coordination degree of land use and air quality in Heilongjiang Province is generally characterized by "high in the West and low in the East". In 2015, the average coordination value of prefecture-level cities in the north was higher than that in the south, and the distribution of median areas was more scattered; In 2016, the "city belt" composed of Heihe, Yichun and Jiamusi had a good coordination degree of land use and air quality, and the low- and medium-value areas were located on both sides of the province. The cities with poor coordination were surrounded by Jiamusi; In 2017, the characteristic of the coordination index "high in the west and low in the east" was obvious, with low-value areas clustered on both sides of Qitaiher; In 2018, the area of the medium- and high-value areas of coordination degree expanded and distributed around Suihua, while the low- and medium-value areas covered the southeast corner of the province.

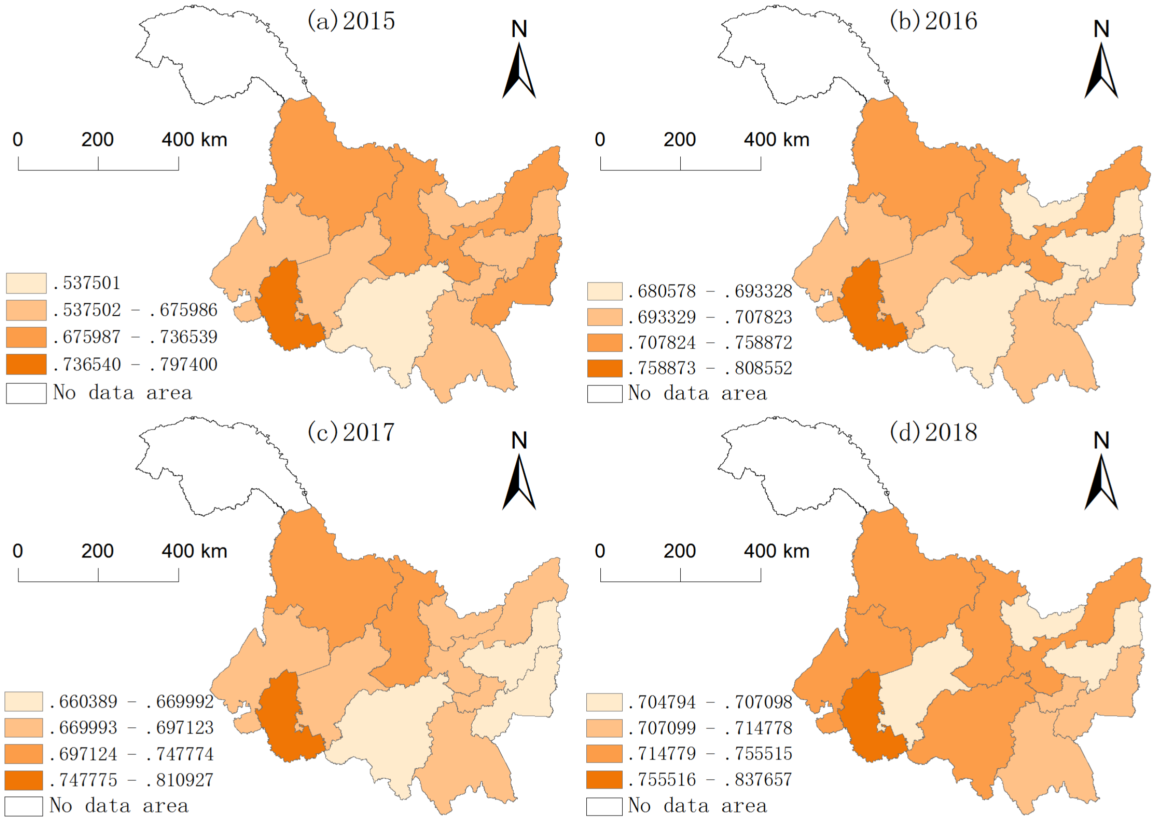

Figure 3. Spatial pattern of land use and air quality coordination degree in Heilongjiang Province.

5. Conclusion and discussion

This paper builds an evaluation system by selecting 18 indicators that can reflect the land use level and atmospheric environmental quality of Heilongjiang Province, and the comprehensive index and coordinated development degree of them are quantitatively analyzed by using the grey correlation TOPSIS model and coupling coordination degree model. The conclusions are as follows:

Although the overall land use level of Heilongjiang Province is advancing in a good direction from 2015 to 2018, the degree of improvement is relatively small, and it is always in a low-medium state, with an average annual index of 0.4078. Daqing has the highest comprehensive benefits of land use, and the cities in the northeast of the province, represented by Hegang and Shuangyashan, are ranked behind. Economic output is the key factor to measure the level of land use. In recent years, the improvement of policies and the strengthening of supervision have improved the overall regional atmospheric environment, but it has slightly declined while steadily developing. The air index of 83.33% of cities has declined in 2017. The air quality in the northwest region of the province where Yichun and Heihe are located is good, and the air environment in Harbin needs to be improved. From the comparison results of the two subsystems of land use and air quality, the 12 prefecture-level cities have not achieved the ideal synchronous development, and the lagging land use level is the main factor restricting the coordinated development of the region.

The coupling degree of land use and air quality in Heilongjiang Province is generally high, and the change range is not large, which indicates that the relationship between the regional land use level and air environment quality is stable and the interaction is strong. During the study period, except for the transition of "running in - high level" coupling degree in Harbin, the other prefecture-level cities remained in a high level coupling state. The coupling coordination degree of the province is characterized by "N" upward chronological change, and the coordination type develops from mild imbalance to barely coordination, with an average annual index of 0.7073. The spatial distribution pattern of coordination degree shows a trend of "high in the West and low in the East". The ratio of cities in mild disorders, barely coordination and intermediate coordination is 7:4:1. The coordination level of land use and air quality in Daqing, Yichun and Heihe is leading. The coordination level of Harbin, Hegang and Shuangyashan is weak, which should be adjusted according to the actual development situation of their respective regions.

The stable coordination of land use and atmospheric environment is an important driving force for the sustainable development of regional economy and society. At present, the development and construction of Heilongjiang province still stays in the stage of low-level expansion of land, important investment and light industry upgrading to a large extent. This kind of operation mode makes the development of most areas dominated by resource-based cities stagnate. In the future, regional construction should focus on the rational allocation and optimization of land resources, revitalize the stock of land, improve the efficiency of land use, and effectively promote the shantytown renovation projects in resource-based cities, while accelerating the cultivation of strategic emerging industries and driving economic development through innovation. In terms of air quality, it is important to prevent and control atmospheric particulate pollution during heating and straw burning pollution after autumn harvest, strengthen the supervision and rectification of industrial enterprises' exhaust gas, construction dust and automobile exhaust emissions. Pay attention to creating a good atmospheric environment in the process of improving land use efficiency. In addition, to play the role of radiation in a highly coordinated city with Daqing as the core, strengthen technical exchanges, project cooperation and differentiated management between regions, and transform the overall regional coordination to a higher type, so as to provide strong support for the realization of a new round of Northeast revitalization. This study limited to the availability and representativeness of the data, the evaluation year and the determination of indicators may not be comprehensive. In future related studies, we will further improve the data, increase the time span, and explore the influencing factors and mechanism of the two systems.

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