SUITABILITY EVALUATION OF URBAN HUMAN SETTLEMENTS BASED ON FUZZY CLUSTERING ANALYSIS A Case Study of Hebei Province

by

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The suitability evaluation of urban human settlements is an important foundation to promote the sustainable development of urban human settlements. This paper took 11 prefecture-level cities in Hebei Province as the research area, and selected 18 indicators from four aspects of ecological environment quality, socio-economic status, living conditions, infrastructure and public services to construct an evaluation index system for the suitability evaluation of the human settlement environment in Hebei Province. The fuzzy clustering analysis method was used to divide the suitability of the human settlement environment in Hebei Province in 2017. The results showed that there are obvious regional differences of human settlement environment suitability in Hebei Province, the findings provide experience for the sustainable development of human settlement environment in Hebei Province.

Key words: *sustainable development, urban human settlements, suitability evaluation, fuzzy clustering analysis*

Introduction

With the continuous acceleration of urbanization in China and the improvement of urban social and economic levels, a series of urban living environment problems have been arisen, making people gradually think about how to improve the urban human settlement environment and build a livable city [1, 2]. Due to differences in regional conditions, economic foundations, social policies, resource allocation and other factors of cities, there is still an obvious gap between regions in the suitability of urban human settlement environment, which makes us pay more attention to urban human settlement environment [3, 4]. With the in-depth research on the suitability of urban human settlements, the research on the suitability evaluation method of urban human settlements has achieved fruitful results, including analytic hierarchy process, entropy weight method, ecological footprint and fuzzy comprehensive evaluation method. The research scales involve cities, provinces and regions [5-7]. Based on the 2017 cross-section data of Hebei Province, this study used the fuzzy clustering analysis method based on fuzzy set theory to analyze the suitability of urban human settlements in 11 cities in Hebei Province, and conducted a further study of the regional difference of urban human settlements environment suitability in Hebei Province. Regional differences provide experience for eliminating unbalanced development between cities and promoting co-ordinated development between regions.

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Materials and methods

Study area

Hebei Province was selected as the research area in this study. Hebei Province is located in North China, between 113°27 'E~ 119°50'E and 36°05 'N~ 42°40' N. It is surrounded by the capital Beijing, adjacent to Tianjin in the east and Bohai Sea. Under the jurisdiction of Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang and Hengshui 11 prefectural cities. Relying on geographical advantages and abundant resource endowment, Hebei Province has actively carried out the construction of new-type urbanization and urban-rural coordinated demonstration zones. The quality of economic development has been greatly improved, and significant progress has been made in improving the urban and rural human settlements. However, the human settlement environment in Hebei Province still can not meet the needs of residents for a better life, and the gap between regions in the province is still obvious. While ensuring the steady development of Hebei's social economy, optimizing resource allocation and narrowing regional differences are the top priorities in the future work. The geographical location of Hebei Province and its 11 prefectural cities in China is shown in fig. 1.

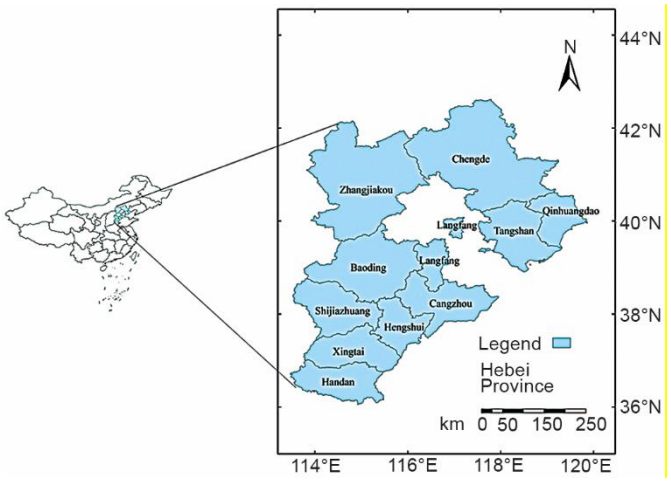

Figure 1. Geographic location of Hebei province

Data description

In this study, 2017 was used as the base year for evaluation, and the data required for the evaluation index system of human settlements environment suitability in Hebei Province were obtained from Hebei Economic Yearbook 2018, Hebei Province Ecological and Environmental Status Bulletin 2017, China City Statistical Yearbook 2018 and statistical yearbooks of each city in 2018.

Fuzzy clustering analysis

Fuzzy clustering analysis is a mathematical method to discuss the classification of things from the perspective of fuzzy sets [8]. The fuzzy similarity matrix is constructed according to the characteristics, affinity degree, similarity and other attributes of the research objects, and the clustering relationship is determined according to a certain membership de-

gree on this basis, so as to cluster things objectively and accurately [9]. Due to the classification of the real problems with fuzziness mostly, and fuzzy clustering analysis is different from the hard division of traditional clustering analysis (divide each object to be identified forced it to a specific category, simplifying to the accuracy), by depicting the gradual change of samples, It establishes the description of the uncertainty of the sample category and provides an effective means to objectively reflect the fuzzy problems and phenomena in the real world. There are a large number of indexes for the evaluation of human settlement environment suitability, which have certain fuzziness and indeterminacy [10, 11]. The method of fuzzy clustering analysis is used to establish the evaluation model of human settlement environment suitability, which provides possibility for the objectiveness of the evaluation of human settlement environment suitability.

Establishment of evaluation model

Step 1. Feature extraction, the establishment of original data matrix

Assume that the set of objects to be classified is $X = \{x_1, x_2, \ldots, x_n\}$, each element in the set has m features, let the j^{th} (j = 1, 2... , m) of the i^{th} object X_i features are x_{ij}, then X_j can be described by the values of these m features, denoted as:

$$X_i = \{x_{i1}, x_{i2}, \ldots, x_{im}\} \quad (i = 1, 2, \ldots, n)$$

Thus, the original data matrix is:

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}$$

Step 2. Data standardization

In order to eliminate the influence of multi-dimensional data on comprehensive analysis and ensure the reliability of results, it is necessary to standardize the original index data. In this study, translation – range standardization is adopted to process the original data.

$$x_{ik}^{''} = \frac{x_{ik}^{'} - \min\limits_{1 \le i \le n}\{x_{ik}^{'}\}}{\max\limits_{1 \le i \le n}\{x_{ik}^{'}\} - \min\limits_{1 \le i \le n}\{x_{ik}^{'}\}} \ (k = 1, 2, \ldots, n) \tag{1}$$

Step 3. Establishment of fuzzy similarity matrix

The establishment of fuzzy similarity matrix is to mark the statistic $r_{ij}(i, j = 1, 2, \ldots, n)$. There are many ways to calculate r_{ij}, and the direct distance method is used in this study:

$$r_{ij} = 1 - cd \quad (u_i, u_j) \tag{2}$$

where c is the appropriately selected coefficient, such that $0 \le r_{ij} \le 1$, $d(u_i, u_j)$ – the distance, and Euclidean distance is used in this study:

$$d(u_i, u_j) = \sqrt{\sum_{k=1}^{m} (x_{ik} - x_{jk})^2} \tag{3}$$

Step 4. Calculation of transitive closure

Only when R is a fuzzy equivalent matrix can clustering, so it is necessary to transform R into a fuzzy equivalent matrix.

The n-order fuzzy similarity matrix R can be transformed into the n-order fuzzy equivalent matrix $t(R)$ by compute the transitive closure. Starting from the fuzzy matrix R, square the fuzzy matrix $R \to R^2 \to R^4 \to \ldots$, while $R^k \circ R^k = R^k$ appears for the first time, it indicates that R^k has been transitive, and it is the desired transitive closure t(R).

Step 5. Calculation of the λ – intercept matrix

After R is transformed into the fuzzy equivalent matrix R^k, the required classification can be obtained by intercepting the appropriate limited value.

Take $\lambda \in [0, 1]$ in turn, R_λ is a classical equivalence relation, which induces a partition X/R_λ on X and divides X into some equivalence classes. Determine the corresponding λ-intercept matrix, then it can be classified.

Case study

Construction of evaluation index system

Urban human settlements environment is a complex system involving population, nature, economy, society and residence. It is necessary to establish a suitable index system to objectively, comprehensively and systematically evaluate the urban human settlements environment. On the basis of the specific development situation, data collection and statistical

Table 1. Index system for evaluating Hebei urban human settlements

Category	Indicators	Mark	Unit
Ecological environment quality	Per capita public green space	I1	[m^2 per people]
	Green coverage rate of urban built-up area	I2	[%]
	Good air quality rate	I3	[%]
	Urban sewage treatment rate	I4	[%]
	Harmless treatment rate of household garbage	I5	[%]
Social and economic status	GDP per capita	I6	10000 yuan
	Engel coefficient of urban residents	I7	[%]
	Registered urban unemployment rate	I8	[%]
	The proportion of tertiary industry in GDP	I9	[%]
	The proportion of education expenditure in general public budget expenditure	I10	[%]
Living conditions	The population density	I11	[people per km^2]
	Per capita housing floor area	I12	[m^2]
	Urban water supply coverage	I13	[%]
	Gas penetration in cities	I14	[%]
Infrastructure and public service	Urban road area per capita	I15	[m^2 per people]
	Number of buses per 10,000 population	I16	[car per 10^4 people]
	Number of health technicians per 10,000 population	I17	[people per 10^4 people]
	Library collection per capita	I18	volume

analysis, with reference to the Evaluation Index System of Chinese Habitat Environment Award (Ministry of Housing and Urban-Rural Development, PRC, 2016) and based on the existing research results of domestic and foreign scholars, the evaluation index system of urban human settlement environment suitability in Hebei Province was constructed from 18 indexes in four aspects, ecological environment quality, social and economic status, living conditions, infrastructure and public service.

Evaluation

Data standardization

The original data were standardized according to eq. (1), and the data standardization results are shown in tab. 2.

Table 2. Data standardization results

	SJZ	TS	QHD	HD	XT	BD	ZJK	CD	CZ	LF	HS
I1	0.5017	0.425	0.5669	0.5293	0.4196	0.0686	0	1	0.1406	0.3114	0.1809
I2	0.8	0.3871	0.3251	0.8296	0.6648	0.623	0.1354	0.7099	0	1	0.3239
I3	0.06	0.4227	0.8455	0	0.0404	0.1141	0.9664	1	0.3221	0.4832	0.1612
I4	0.89	0.5402	0.3678	0.569	0.4215	0.6628	0.2414	0	0.9828	0.0651	1
I5	1	1	1	1	1	1	0	0.9715	1	1	1
I6	0.3871	0.6197	0.2816	0	0.0044	0.0858	0.0391	0.2744	1	0.6417	0.2388
I7	0.3235	0.2206	0.4265	0.6471	0.4265	0.2206	0.7059	1	0.1324	0	0.8382
I8	0.86	0.4545	0.4785	0.7943	0.7512	1	0.5933	0.7895	0.5933	0	0.7177
I9	0.8569	0	0.8372	0.5645	1	0.3976	0.6917	0.6565	0.5124	0.865	0.486
I10	0.7477	0.6414	0.4937	0.8342	0.8703	0.9279	0.0541	0.5459	1	0	0.3928
I11	0.6091	0.0835	0.3892	0.3649	1	0.5204	0.2323	0	0.3373	0.1494	0.1028
I12	0.8757	0.4216	0.3243	0.4865	0.7568	1	0.267	0	0.8757	0.7459	0.9081
I13	1	1	0.8058	1	1	0	1	1	1	1	0.9976
I14	1	1	0	0.9428	1	0.4575	0.9073	0.9845	1	1	0.6522
I15	0.902	0.3787	0.5216	1	0.1728	0.8555	0.0515	0	0.4967	0.5316	0.1395
I16	1	0.3709	0.5143	0.3504	0.1045	0.125	0.748	0.1906	0	0.1168	0.2152
I17	1	0.5389	0.7962	0	0.054	0.2283	0.0339	0.4467	0.2716	0.3827	0.1754
I18	0.5049	0.4443	0.8042	0.034	0.0968	0.0559	0.3391	0.1981	0.1122	1	0

Note: SJZ, TS, QHD, HD, XT, BD, ZJK, CD, CZ, LF, HS represent Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang and Hengshui, respectively.

Establishment of fuzzy similarity matrix

Let $c = 0.5$, using Euclidean distance to calibrate, fuzzy similarity matrix R was obtained:

$$R=\begin{pmatrix}
1.00 & 0.97 & 0.85 & 0.76 & 0.80 & 0.78 & 0.92 & 0.85 & 0.80 & 0.75 & 0.75\\
0.97 & 1.00 & 0.82 & 0.79 & 0.83 & 0.81 & 0.95 & 0.88 & 0.83 & 0.72 & 0.78\\
0.85 & 0.82 & 1.00 & 0.61 & 0.65 & 0.63 & 0.77 & 0.70 & 0.65 & 0.90 & 0.60\\
0.76 & 0.79 & 0.61 & 1.00 & 0.97 & 0.99 & 0.85 & 0.92 & 0.96 & 0.52 & 0.98\\
0.80 & 0.83 & 0.65 & 0.97 & 1.00 & 0.98 & 0.88 & 0.95 & 0.99 & 0.55 & 0.95\\
0.78 & 0.81 & 0.63 & 0.99 & 0.98 & 1.00 & 0.86 & 0.93 & 0.97 & 0.53 & 0.97\\
0.92 & 0.95 & 0.77 & 0.85 & 0.88 & 0.86 & 1.00 & 0.93 & 0.89 & 0.67 & 0.83\\
0.85 & 0.88 & 0.70 & 0.92 & 0.95 & 0.93 & 0.93 & 1.00 & 0.96 & 0.60 & 0.90\\
0.80 & 0.83 & 0.65 & 0.96 & 0.99 & 0.97 & 0.89 & 0.96 & 1.00 & 0.56 & 0.94\\
0.75 & 0.72 & 0.90 & 0.52 & 0.55 & 0.53 & 0.67 & 0.60 & 0.56 & 1.00 & 0.50\\
0.75 & 0.78 & 0.60 & 0.98 & 0.95 & 0.97 & 0.83 & 0.90 & 0.94 & 0.50 & 1.00
\end{pmatrix}$$

Calculation of transitive closure

According to the calculation, the transitive closure $t(R)$ was obtained:

$$t(R)=\begin{pmatrix}
1.00 & 0.97 & 0.85 & 0.93 & 0.93 & 0.93 & 0.95 & 0.93 & 0.93 & 0.95 & 0.93\\
0.97 & 1.00 & 0.85 & 0.93 & 0.93 & 0.93 & 0.95 & 0.93 & 0.93 & 0.95 & 0.93\\
0.85 & 0.85 & 1.00 & 0.85 & 0.85 & 0.85 & 0.85 & 0.85 & 0.85 & 0.90 & 0.85\\
0.93 & 0.93 & 0.85 & 1.00 & 0.98 & 0.99 & 0.93 & 0.96 & 0.98 & 0.85 & 0.98\\
0.93 & 0.93 & 0.85 & 0.98 & 1.00 & 0.98 & 0.93 & 0.96 & 0.99 & 0.85 & 0.98\\
0.93 & 0.93 & 0.85 & 0.99 & 0.98 & 1.00 & 0.93 & 0.96 & 0.98 & 0.85 & 0.98\\
0.95 & 0.95 & 0.85 & 0.93 & 0.93 & 0.93 & 1.00 & 0.93 & 0.93 & 0.85 & 0.93\\
0.93 & 0.93 & 0.85 & 0.96 & 0.96 & 0.96 & 0.93 & 1.00 & 0.96 & 0.85 & 0.96\\
0.93 & 0.93 & 0.85 & 0.98 & 0.99 & 0.98 & 0.93 & 0.96 & 1.00 & 0.85 & 0.98\\
0.95 & 0.95 & 0.90 & 0.85 & 0.85 & 0.85 & 0.85 & 0.85 & 0.85 & 1.00 & 0.85\\
0.93 & 0.93 & 0.85 & 0.98 & 0.98 & 0.98 & 0.93 & 0.96 & 0.98 & 0.85 & 1.00
\end{pmatrix}$$

Calculation of the λ-intercept matrix

The fuzzy equivalence matrix was clustered, and the normal classification relation was obtained by taking different threshold value λ [0, 1] with the direct clustering method.

When $\lambda = 1$, urban human settlement environment suitability was classified into 11 categories:

$$\{u_1\}\{u_2\}\{u_3\}\{u_4\}\{u_5\}\{u_6\}\{u_7\}\{u_8\}\{u_9\}\{u_{10}\}\{u_{11}\}$$

When $\lambda = 0.99$, urban human settlement environment suitability was classified into 9 categories:

$$\{u_1\}\{u_2\}\{u_3\}\{u_4,u_6\}\{u_5,u_9\}\{u_7\}\{u_8\}\{u_{10}\}\{u_{11}\}$$

When $\lambda = 0.98$, urban human settlement environment suitability was classified into 8 categories:

$$\{u_1\}\{u_2\}\{u_3\}\{u_4,u_5,u_6,u_9\}\{u_7\}\{u_8\}\{u_{10}\}\{u_{11}\}$$

When $\lambda = 0.97$, urban human settlement environment suitability was classified into 7 categories:

$$\{u_1,u_2\}\{u_3\}\{u_4,u_5,u_6,u_9\}\{u_7\}\{u_8\}\{u_{10}\}\{u_{11}\}$$

When $\lambda = 0.96$, urban human settlement environment suitability was classified into 5 categories:

$$\{u_1,u_2\}\{u_3\}\{u_4,u_5,u_8,u_9,u_{11}\}\{u_7\}\{u_{10}\}$$

When $\lambda = 0.95$, urban human settlement environment suitability was classified into 4 categories:

$$\{u_1,u_2,u_7\}\{u_3\}\{u_4,u_5,u_8,u_9,u_{11}\}\{u_{10}\}$$

When $\lambda = 0.93$, urban human settlement environment suitability was classified into 3 categories:

$$\{u_1,u_2,u_4,u_5,u_7,u_8,u_9,u_{11}\}\{u_3\}\{u_{10}\}$$

When $\lambda = 0.90$, urban human settlement environment suitability was classified into 2 categories:

$$\{u_1,u_2,u_4,u_5,u_7,u_8,u_9,u_{11}\}\{u_3,u_{10}\}$$

When $\lambda = 0.85$, urban human settlement environment suitability was classified into 1 category:

$$\{u_1,u_2,u_3,u_4,u_5,u_7,u_8,u_9,u_{10},u_{11}\}$$

Results

In this study, a fuzzy clustering analysis method was used to analyze the suitability of urban human settlements environment in 11 cities in Hebei province in 2017. According to the five-grade classification method of human settlement environment suitability evaluation in [6], the suitability of urban human settlement environment in Hebei Province can be divided into five categories: Type I very high suitability, Type II high suitability, Type III general suitability, Type IV low suitability and Type V very low suitability. Based on the above analysis, taking $\lambda = 0.96$, the urban human settlement environment suitability of Hebei Province in 2017 can be divided into the following five categories, Type I, Shijiazhuang and Tangshan have strong economic strength, urban infrastructure construction and public service development, and suitability is very high. Type II, Qinhuangdao occupies the coastal geographical position advantage, develops its Marine economy, the transportation is convenient, the ecological environment quality is good, the suitability is high. Type III, Handan, Xingtai, Baoding, Chengde, Cangzhou and Hengshui ranked moderate in economic strength, ecological environment quality, living conditions and infrastructure in the province, with general suita-

bility. Type IV, Zhangjiakou is located in the northern Hebei, with relatively slow economic development and urban construction, and its suitability is low. Type V, Langfang is greatly affected by Beijing and Tianjin, although its economic development is high, it has very low suitability for human settlements due to low education ratios, poor ecological environment quality, and low public service levels. The research results are basically consistent with the existing research [12], the distribution of mountains and rivers might also affect the difference [13], additionally the sample's uncertainties will lead to an uncertain chaotic system [14, 15], this phenomenon will also affect the difference.

In summary, there are obvious regional differences in the suitability of urban human settlement environment in Hebei Province, and the regional characteristics and existing problems of each city are not the same.

Conclusion

In this study, 11 prefectural-level cities in Hebei province were selected as the research region, and a fuzzy clustering analysis method was proposed and applied to the clustering analysis of urban human settlement environment suitability evaluation in Hebei Province in 2017. We selected 18 indicators from four aspects to construct the evaluation index system for the suitability evaluation of the human settlement environment in Hebei Province. The results showed that there are obvious regional differences of human settlement environment suitability in Hebei Province, and the regional characteristics and existing problems are not the same in each city. The method has good applicability to the clustering analysis of urban human settlement environment suitability evaluation index data with fuzzy characteristics. At the same time, this study provides a theoretical basis for eliminating the imbalance and promoting the coordinated development among cities in Hebei Province, which has great practical significance.

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