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Livability Evaluation of Land Ecological Space in Beijing, China Based on Geographical Conditions Census

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The general survey of geographical conditions based on remote sensing technology has been the main land space monitoring activity in China in recent years. To make census results better serve society, in this paper, we evaluate the livability of Beijing's land space. Based on socio-economic data and the data from the census of national geographical conditions, an analytic hierarchy process was used to quantitively calculate the livability scores. Six subsystems were included in our calculations: social development, economic development, ecological environment, resource carrying capacity, infrastructure, and public safety, and finally, a comprehensive score is calculated. The Xicheng, Chaoyang, and Haidian Districts of Beijing are ranked highest for livability, and Yanqing, Daxing, and Fangshan Districts are ranked lowest. We find that social development, economic development, infrastructure, and the ecological environment contribute the most to livability scores, while public safety and resource carrying capacity contribute the least. To improve comprehensive regional livability, it is necessary to pay attention to the balanced development of public security and resource carrying capacity.

1. Introduction

In February 2013, the State Council of the People's Republic of China issued Document 9, formally launching the first census of national geographical conditions. Remote sensing images are an important data source for the general survey of geographical conditions, and technology for interpreting remote sensing images is used to rapidly extract and accurately interpret geographical information. In June 2015, the first census database of national geographical conditions was formed, then the work of collating, summarizing, and statistical analysis was gradually implemented to obtain basic statistics, comprehensive statistics, and special statistics(1) from the census results. With the smooth development of the census of national geographical conditions, the effective application of results has become one of the most important aspects of census work.(2–5) On April 30, 2015, *Collaborative Development Plan of Beijing–Tianjin–Hebei*

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Region was formally reviewed and approved, marking a turning point in the integration of the region. The coordinated development of the Beijing–Tianjin–Hebei region is based on the integrated development of the three cities. Its core aim is to alleviate the non-capital functions and solve the problem of "metropolitan disease"[6,7] in Beijing. The Beijing Municipal Government has set a "millennial plan"[8] to construct the Tongzhou Sub-center, which has become the top priority for alleviating the non-capital functions of Beijing. The planning and implementation at three levels, the country, the Beijing–Tianjin–Hebei region, and Beijing City, are all aimed at building a harmonious and livable city.[9,10]

The study of the residential suitability of urban areas is of great significance to economic development and the coordinated development of humans and the natural environment. Based on the development goal planning of livable cities in Beijing and the major mapping event of the general survey of geographical conditions, in this study, we use remote sensing images to interpret production data and its statistical results, which are combined with social and economic development data, and we apply the analytic hierarchy process (AHP) to evaluate the livability of urban land space. The results provide an evaluation reference for the construction of livable cities and have practical significance for improving the livability of regional land space.

2. Study Area and Data

The study area is Beijing City, located at 115.7–117.4°E, 39.4–41.6°N. Beijing has a typical temperate continental monsoon climate and is hot and rainy in summer and cold and dry in winter. Its annual average temperature is 11.5 °C, and its average annual precipitation is about 600 mm. The total area of Beijing is 16406 km^2, with 16 districts under its jurisdiction. The data in this paper is derived from the results of the first national census of geographical conditions in Beijing in 2015, as well as from socio-economic statistics.

3. Methods

3.1 Choice of method

For the comprehensive evaluation of multiple objects, modern evaluation methods mainly include the AHP, principal component analysis, factor analysis, fuzzy evaluation, and gray-related analysis.[11] The comprehensive evaluation of the livability of national land space includes many intricately related areas, such as the economy, society, environment, and so forth. Consequently, indicators related to these evaluation contents are also detailed and complex. Given the multifaceted evaluation of livability, evaluation indicators require hierarchical classification. A clear hierarchy is beneficial for effective and comprehensive evaluation and ensuring the authenticity of the evaluation results. Therefore, we use the AHP to evaluate the livability of land space.

The AHP is a qualitative, quantitative, systematic, and hierarchical analysis method proposed by the American operations researcher T. L. Saaty in the mid-1970s.[12,13] This method quantifies the decision maker's experiences and is suitable for cases with a complex target structure and a lack of data.[14,15] Although the AHP has effectively considered and integrated various qualitative and quantitative information in the comprehensive evaluation process, it still cannot eliminate randomness, subjective uncertainty, and the cognitive ambiguity of the evaluation experts.[16,17] To overcome this shortcoming, it is necessary to invite as many industry experts as possible to participate in the process[18] during its practical application. At the same time, the designer must control the number of comparative factors within a certain range. According to relevant research,[19] the comparison factor of the matrix is preferably controlled to nine or less, so that the expert's scoring of the factor comparison is not susceptible to a large number of factors. The construction of a judgment matrix is a key step in the decision analysis of the AHP. The judgment matrix represents the condition for assessing the relative importance of each element in the hierarchy. Its form is as follows:

$$R = \begin{vmatrix} r_{11} & r_{12} \cdots r_{1n} \\ r_{21} & r_{22} \cdots r_{2n} \\ \vdots & \vdots \ \ddots \ \vdots \\ r_{n1} & r_{n2} \cdots r_{nn} \end{vmatrix}, \tag{1}$$

where r_{ij} represents the judgment value of the relative importance of elements i and j when they are compared. The scale of 1–9 is generally used to quantify the comparison results (Table 1).

3.2 Construction of indicators

The indicator system for evaluating national land space livability should be a comprehensive system composed of various factors involving economic, social, and ecological aspects. On the basis of the construction principle of the indicator system, the livability of the national land space is divided into three levels, namely, the target layer, the criterion layer, and the indicator layer. The target layer is the core issue of the research, and the criterion layer links the preceding and following layers. Through the relevant research results and China's first national standard, *Livable City Science Evaluation Standards*, it divides the criterion layer of the indicator system into six subsystems: social development, economic development, ecological environment, resource carrying capacity, infrastructure, and public safety. With reference to relevant research

Table 1
Indicator scale.

Contrast Results	Scale
Comparison of two factors with the same importance	1
Former factor slightly more important than the latter	3
Former factor noticeably more important than the latter	5
Former factor significantly more important than the latter	7
Former factor extremely more important than the latter	9
Intermediate values between the above judgments	2, 4, 6, 8
If the importance ratio of factor i to factor j is r_{ij}, then the importance ratio of factor j to factor i is $r_{ji} = 1/r_{ij}$	$r_{ji} = 1/r_{ij}$

and the operability of data sources, a total of 39 indicators were selected for the specific indicators of the six subsystems as follows. Social development includes the density of permanent residents, the natural population growth rate, the proportion of persons receiving minimum living allowances, the per capita housing living space, the proportion of education expenditure, the proportion of cultural and recreational services, and the rate of urbanization; economic development includes the per capita gross domestic product (GDP), the proportion of tertiary industry GDP to total regional GDP, the proportion of foreign trade to GDP, the elasticity coefficient of energy consumption, the proportion of high-tech industries, the proportion of fiscal revenue to GDP, and the proportion of fixed social assets investment to GDP; the ecological environment includes the vegetation coverage, the grassland coverage, the water area, the hardened surface area, the sewage treatment rate, and the annual average concentration of fine particulate matter (PM2.5); the resource carrying capacity includes the land development intensity, the per capita construction land, the per capita cultivated land, the GDP per unit of construction land, the energy consumption per 10000 yuan of GDP, and the per capita road area; the infrastructure includes the building density, the road density, the density of transport facilities, the proportion of administrative villages within 1 km of a school, the proportion of administrative villages within 3 km of a hospital, and the proportion of administrative villages within 5 km of a social welfare institution; public safety includes the number, scale, and spatial distribution of urban water storage points, surface water sources, garbage stations, hazardous waste disposal sites, key pollution sources, and emergency shelters.

3.3 Data preprocessing

According to Table 2, the corresponding indicators are obtained from *Beijing Statistical Yearbook*, the statistical yearbooks of each district, and the data on national geographical conditions. Some of the indicators are obtained through simple calculations based on the basic indicators, such as the elastic coefficient of energy consumption. In this study, we take the negative of the contrary indicator,

$$x' = -x, \tag{2}$$

where x' is the new value after its sign has been changed and x is the original value of the index. After contrary processing, the new indicator changes in the positive direction, which is consistent with the change in livability.

Table 2
Ratio of each criterion layer to livability total target.

Criterion layer	Ratio to total target
Social development	0.2456
Economic development	0.2209
Ecological environment	0.1561
Resource carrying capacity	0.1341
Infrastructure	0.1375
Public safety	0.1056

After the contrary indicator is processed, it is necessary to standardize the indicators with different dimensions. This is implemented by adopting the ratio to the maximum absolute value of the indicator to obtain the new standardized value of each indicator, as follows:

$$y' = \frac{y}{|y|_{max}}, \tag{3}$$

where y' is the normalized variable and y is the original variable.

3.4 Calculation of indicator weights

On the basis of the results obtained by 10 experts scoring the weights of the seven groups of judgment matrices, YAAHP software (Shanxi Meta Decision Software Technology Co., Ltd., China) is used to calculate the weight score of the criterion layer relative to the livability index, as shown in Table 2. The objective weight is calculated by the same method.

4. Results and Analysis

4.1 Results of evaluation

Based on the normalized values of the 39 indicators and the corresponding weights (Table 2), the following formula is applied:

$$Z = \sum_{i=1}^{n=39} x_i w_i. \tag{4}$$

In this formula, Z is the comprehensive livability score, x_i is the standardized value of the ith indicator, and w_i is the weight of the ith indicator.

Through the calculation, the comprehensive scores for the land and space livability of the 16 districts in Beijing are obtained (Table 3). Similarly, if Z is set as a livability subsystem in the application of Eq. (4), for example, social development, six subsystems can be scored, as shown in Table 4.

Table 3
Comprehensive scores of livability in Beijing.

Administrative division	Score	Administrative division	Score
Dongcheng District	0.3249	Shunyi District	0.2122
Xicheng District	0.3665	Changping District	0.2972
Chaoyang District	0.3276	Daxing District	0.1955
Fengtai District	0.2626	Mentougou District	0.2472
Shijingshan District	0.3008	Huairou District	0.2656
Haidian District	0.3264	Pinggu District	0.2091
Fangshan District	0.1854	Miyun District	0.2487
Tongzhou District	0.2418	Yanqing District	0.2053

Table 4
Subsystem scores of livability in Beijing.

	Social development	Economic development	Ecological environment	Resource carrying capacity	Infrastructure	Public safety
Dongcheng District	0.1075	0.0891	0.0265	−0.0213	0.1178	0.0052
Xicheng District	0.0997	0.1088	0.0454	−0.0143	0.1229	0.0039
Chaoyang District	0.1078	0.0945	0.0476	−0.0255	0.1042	−0.0010
Fengtai District	0.1129	0.0543	0.0448	−0.0301	0.0891	−0.0084
Shijingshan District	0.1200	0.0943	0.0365	−0.0269	0.0769	0.0000
Haidian District	0.1260	0.0996	0.0512	−0.0183	0.0790	−0.0111
Fangshan District	0.1123	0.0407	0.0363	−0.0601	0.0420	0.0143
Tongzhou District	0.1116	0.0482	0.0620	−0.0363	0.0563	0.0000
Shunyi District	0.1026	0.0453	0.0515	−0.0457	0.0515	0.0070
Changping District	0.1288	0.0617	0.0390	−0.0288	0.0484	0.0481
Daxing District	0.0986	0.0418	0.0305	−0.0323	0.0532	0.0037
Mentougou District	0.1281	0.0395	0.0365	−0.0245	0.0314	0.0361
Huairou District	0.1341	0.0499	0.0471	−0.0247	0.0235	0.0358
Pinggu District	0.1270	0.0271	0.0516	−0.0330	0.0413	−0.0048
Miyun District	0.1238	0.0359	0.0856	−0.0293	0.0277	0.0049
Yanqing District	0.1245	0.0171	0.0499	−0.0229	0.0262	0.0105

4.2 Analysis of results

The average score of livability in Beijing is 0.2635. From the internal composition (Table 4), social development, economic development, infrastructure, and ecological environment contribute the most to the comprehensive livability score, whereas public safety and resource carrying capacity contribute the least. This indicates that Beijing's livability is relatively low in terms of public security and resource carrying capacity, which directly adversely affects the overall livability.

From the perspective of the spatial characteristics of the subsystems, Miyun, Pinggu, Huairou, and Mentougou Districts, and other ecological conservation areas have higher scores in social development and ecological environment and lower scores in economic development and infrastructure. Tongzhou, Shunyi, Daxing, and Changping Districts, and other plain districts and counties have low scores in social development and resource carrying capacity and medium scores in economic development, ecological environment, and infrastructure; Dongcheng, Xicheng, Chaoyang, Haidian, Fengtai, and Shijingshan Districts, and other central urban areas have higher scores in economic development and infrastructure and lower scores in ecological environment and public security. The livability subsystem has significant spatial characteristics of a circle distribution in ecological conservation areas, central urban areas, and plain areas.

According to the comprehensive score of livability, the most livable area is Xicheng District and the least livable area is Fangshan District, with a difference of 0.1811 between the two. The areas with superior livability are mainly the central urban areas, where the economy and infrastructure are relatively well developed. Huairou District, located in the mountainous area of Beijing, lags behind the other counties and districts, having the lowest score for infrastructure. However, it scores more highly for social development and public safety, increasing its ranking in overall livability. Because of its low scores in social development, ecological environment, and resource carrying capacity, Daxing and Fangshan Districts rank lowest in overall livability.

The spatial distribution of livability is high internally and low externally (Figs. 1 and 2); that is, the livability score gradually decreases from the central area to the peripheral areas, which is

Fig. 1. (Color) Radar map of livability scores of all districts in Beijing.

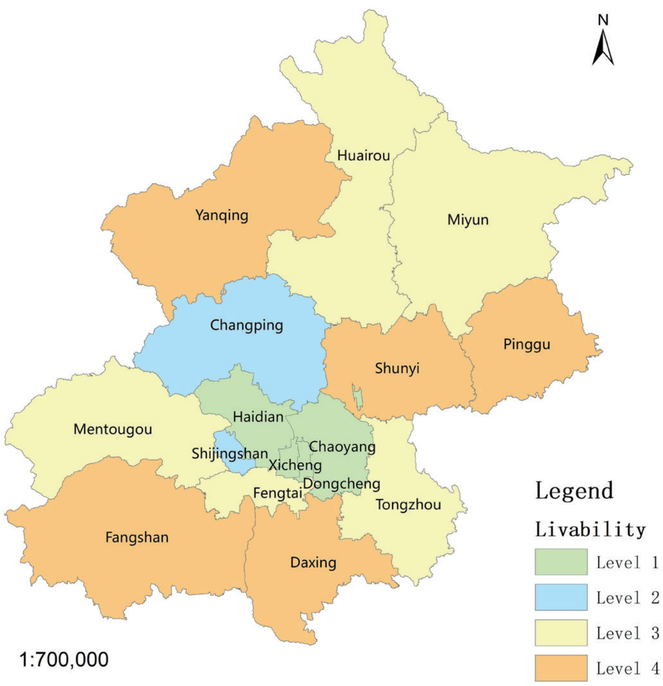

Fig. 2. (Color) Ranking of livability in Beijing.

consistent with relevant studies.(20–22) The central area is more livable than the suburbs, mainly because of the absolute advantages of economic development and infrastructure in the former. In contrast, the suburbs are relatively poor. Although the outer suburbs have an inequitable natural environment, it impacts the livability score only to a limited degree; the overall livability is more affected by the combination of six subsystems.

5. Conclusions

On the basis of the results of the national geographical census and socio-economic statistics, we employed the AHP to calculate the scores of livability in Beijing for six subsystems: social development, economic development, ecological environment, resource carrying capacity, infrastructure, and public safety. Finally, we calculated the comprehensive scores of livability. The conclusions are as follows:

(1) We constructed a comprehensive indicator system that reflects the livability of cities, including six subsystems: social development, economic development, ecological environment, resource carrying capacity, infrastructure, and public security, using 22 indicators in the geographical space category and 17 indicators in the socio-economic category. The index system can provide an evaluation reference for the construction of livable cities.

(2) The spatial data obtained through remote sensing has the advantages of being intuitive, accurate, and easy to obtain. Moreover, it is first-hand information and can be used as an important data source for evaluating urban livability.

(3) Based on the results of the general survey of geographical conditions and social and economic data of Beijing, we adopt the classical AHP to evaluate and analyze the livability of Beijing's land and space. The research results are authentic, reliable, current, and comprehensive and can be used as a reference for urban planners.

(4) Social development, economic development, infrastructure, and ecological environment contribute the most to the comprehensive score of livability, whereas public safety and resource carrying capacity contribute the least to livability. To improve comprehensive regional livability, it is necessary to pay attention to the balanced development of public security and resource carrying capacity.

(5) From the perspective of the spatial distribution, the comprehensive score of livability gradually decreases from the central city to the surrounding counties, which to a certain extent represents the comprehensive strength of the economic and social development of each district.

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