Evaluation of sustainable urban land use based on weighted TOPSIS method: A case study of Chengdu City

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Abstract. In view of the urban land sustainable utilization, this paper selects 17 indicators to construct an urban land sustainable use evaluation system from the four aspects of economic feasibility, social acceptability, resource supportability and environmental tolerability, applies the entropy method and the TOPSIS method to dynamically evaluate the level of sustainable land use in Chengdu from 2007 to 2016, and through the obstacle degree model to carry on the obstacle factor diagnosis analysis, find out the obstacle factor, and put forward the corresponding suggestions according to the obstacle factor.

1. Introduction

Land resources are precious natural resources on which human beings rely. With the declining land resources, the conflicts between people and land in China have become more prominent. In the course of development, due to the irrational use, the arable land area is reduced. These phenomena seriously affect the functioning of land resources and have a certain degree of impact on human survival and development. As one of the key contents of the sustainable development strategy, the sustainable use of land is the basic guarantee for human survival and social economic development.

According to the existing literature, the methods for evaluation of land sustainable use mainly include AHP [1], principal component analysis method [2-3], multi-index comprehensive evaluation method [4] and multi-criterion decision analysis method [5] etc. Among them, Ma Wenjuan et al. [6] evaluated the health status of the land system in Urumqi based on the entropy weight method and the set pair model, and better solved the problem that the index system was not objectively based on specific values as grading standards; Wu Ting and Liu Shenghua [7] adopted the improved entropy method and used the PSR model to evaluate the sustainable land use of Yueyang City; Zeng Lu et al. [8] used the fuzzy comprehensive evaluation method to comprehensively evaluate the utilization of land resources in Jinping County. At present, studies on the evaluation of sustainable urban land use are mostly used in developed cities in eastern and eastern China, and there are few studies on Chengdu. Based on previous studies, this paper uses the weighted TOPSIS method and obstacle degree model to evaluate the land sustainable utilization level and diagnose the obstacle factors in Chengdu, in order to provide a reference for Chengdu's regional land management.
2. Research method

2.1. Determination of evaluation index system

This article refers to related literature [9-11], based on scientific principles, availability principles, comprehensive principles and dynamic principles, mainly from the economic feasibility, social acceptability, resource supportability and environmental tolerability to construct the basic framework of an evaluation system for sustainable urban land use. The indicator system is a hierarchical system composed of 1 target layer, 4 criteria layers, and 17 indicator layers (refer with: Table 1).

**Table 1. Evaluation system for sustainable utilization of urban land.**

| Target layer(A) | Standard layer(B) | Index layer(C) | Unit | Index properties |
|-----------------|------------------|---------------|------|------------------|
| Sustainable utilization of urban land (A) | Economic feasibility (B1) | per capita GDP (C1) | 10^8 yuan/ km^2 | + |
| | | GDP growth rate (C2) | % | + |
| | | The proportion of the third industry to GDP(C3) | % | + |
| | Social acceptability (B2) | Financial income per unit land area(C4) | 10^8 yuan/ km^2 | + |
| | | Per capita disposable income of rural residents(C5) | Yuan / person | + |
| | Resource supportability (B3) | Population density(C6) | Person / km^2 | - |
| | | Natural population growth rate (C7) | % | - |
| | | Per capita Road area (C8) | m^2/ person | + |
| | | Urbanization rate (C9) | % | + |
| | | Per capita arable land area (C10) | hm^2/ person | + |
| | Environmental tolerability (B4) | Total power of agricultural machinery(C11) | 10^4 kw | + |
| | | Machine-cultivated area(C12) | 10^4 hm^2 | + |
| | | Effective cultivated land irrigation area ratio (C13) | % | + |
| | | Per capita park green area(C14) | m^2/ person | + |
| | | Green coverage rate of built-up area(C15) | % | + |
| | | Sewage disposal rate(C16) | % | + |
| | | The amount of fertilizer applied per unit area of cultivated land(C17) | Ton/ hm^2 | - |

2.2. Evaluation model of sustainable urban land use

2.2.1. Standardized processing of evaluation data. In this paper, the standard deviation method is used to perform the non-dimensional processing of the raw data through the standard 0-1 transformation. The specific formula is as follows:

 Benefit type: \[ b_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \] (1)

 Cost type: \[ b_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \] (2)
In the formula, \( b_{ij} \) is the normalized data, \( x_{ij} \) is the original data of the j-th index for the i-th year, \( \min x_{ij} \) and \( \max x_{ij} \) are the minimum and maximum values of the j-th index for the i-th year respectively, \( i=1, 2..., m; j=1, 2..., n \) (set \( m \) to year and \( n \) to the number of evaluation indicators).

2.2.2. Determination of evaluation index weights. Using the entropy method to determine the weight of each evaluation index, and the entropy value of the j-th index is:

\[
e_j = \frac{1}{\ln m} \left( \sum_{i=1}^{m} f_{ij} \ln f_{ij} \right) \quad (i = 1, 2..., m; j = 1, 2..., n)
\]

Among them, \( f_{ij} = \frac{b_{ij}}{\sum_{i=1}^{m} b_{ij}} \), and assume that \( f_{ij} = 0, f_{ij} \cdot \ln f_{ij} = 0 \).

The objective weight value of the j-th indicator is:

\[
w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}
\]

Among them, \( d_j = 1 - e_j \), and \( \sum_{j=1}^{n} w_j = 1 \).

The entropy weight matrix of each evaluation index is \( W \), and \( W = (w_j)_{1 \times n} \).

2.2.3. Weighted TOPSIS method. After determining the weight of each index, calculate the weighted normalization matrix

\[
Z = (z_{ij})_{m \times n} = (b_{ij} \times w_j)_{m \times n}
\]

In the formula, \( b_{ij} \) represents the normalized value of each index; \( w_j \) represents the weight value of the j-th index.

The optimal and inferior vectors formed by the maximum and minimum values of each column are:

\[
\begin{align*}
Z^+ &= (z_{\max 1}, z_{\max 2}, ..., z_{\max n}) \\
Z^- &= (z_{\min 1}, z_{\min 2}, ..., z_{\min n})
\end{align*}
\]

In the formula, \( Z^+ \) represents the optimal solution, and \( Z^- \) represents the worst solution.

The distance between the performance evaluation in year i and the best and the worst scheme is:

\[
\begin{align*}
D_i^+ &= \sqrt{\sum_{j=1}^{n} (z_{\max j} - z_{ij})^2} \\
D_i^- &= \sqrt{\sum_{j=1}^{n} (z_{\min j} - z_{ij})^2}
\end{align*}
\]

The degree of closeness between the evaluation performance and the optimal plan in year i is:

\[
C_i = \frac{D_i^-}{D_i^+ + D_i^-}
\]

Among them, the value of \( C_i \) is between 0 and 1, and its size indicates the level of sustainable land use. The closer the value of \( C_i \) is to 1, the higher the level of land sustainability. Referring to related literature [12], \( C_i \) is divided into five levels: \([0.00~0.30)\) is a low level; \([0.30~0.60)\) is an intermediate level; \([0.60~0.80)\) is a good level; \([0.80~1.00)\) is a high level.

2.3. Factor disorder model

A factor barrier model needs to be established to identify the root causes of land sustainability and fundamentally remove factors that hinder the sustainable use of land. The “factor contribution degree (\( W_j \))”, “index deviation degree (\( P_j \))” and “disorder degree (\( A_j \))” are introduced, where the factor contribution degree (\( W_j \)) is the weight of the single evaluation index to the total goal; the index deviation degree (\( P_j \)) is the gap between individual indicators and sustainable use targets; the degree of obstacle (\( A_j \)) is the impact of single factors on the overall level of sustainable use [13]. The obstacle degree of the j-th index to the sustainable use of urban land is:

\[
A_j = \frac{P_j W_j}{\sum_{j=1}^{n} (P_j W_j)} \times 100\%
\]

Among them, \( P_j = 1 - b_{ij} \).
3. Evaluation of urban land sustainable utilization in Chengdu

3.1. Chengdu City land evaluation results

Table 2. Weights of evaluation indexes for sustainable land use in Chengdu.

| Target layer(A) | Standard layer(B) | Index layer(C) | Index code | Total weight | Index code | Entropy | Total weight |
|-----------------|-------------------|----------------|------------|--------------|------------|---------|--------------|
| Sustainable utilization of urban land (A) | B1 0.3268 | | C1 | 0.872 | | 0.0664 |
| | | | C2 | 0.864 | | 0.0709 |
| | | | C3 | 0.906 | | 0.0489 |
| | B2 0.2541 | | C7 | 0.832 | | 0.0875 |
| | | | C8 | 0.933 | | 0.0348 |
| | | | C9 | 0.893 | | 0.0558 |
| | | | C10 | 0.820 | | 0.0937 |
| | B3 0.2315 | | C11 | 0.879 | | 0.063 |
| | | | C12 | 0.931 | | 0.0359 |
| | | | C13 | 0.925 | | 0.0389 |
| | | | C14 | 0.933 | | 0.0347 |
| | B4 0.1879 | | C15 | 0.940 | | 0.0312 |
| | | | C16 | 0.925 | | 0.0388 |
| | | | C17 | 0.840 | | 0.0832 |

Table 3. Degree of land use appropriateness and performance in Chengdu from 2006 to 2015.

| Year | Economic feasibility closeness degree | Sociology acceptability closeness degree | Resource supportability closeness degree | Environmental tolerability closeness degree | Sustainable use closeness degree | Performance of sustainable utilization |
|------|--------------------------------------|----------------------------------------|----------------------------------------|---------------------------------------------|---------------------------------|---------------------------------------|
| 2007 | 0.3426                               | 0.4668                                 | 0.2908                                 | 0.0688                                      | 0.3341                          | middle level                          |
| 2008 | 0.1959                               | 0.3748                                 | 0.2935                                 | 0.1106                                      | 0.2625                          | low level                             |
| 2009 | 0.2925                               | 0.3887                                 | 0.2940                                 | 0.1909                                      | 0.2979                          | low level                             |
| 2010 | 0.4271                               | 0.4728                                 | 0.2790                                 | 0.3040                                      | 0.3864                          | middle level                          |
| 2011 | 0.4738                               | 0.2660                                 | 0.3290                                 | 0.2439                                      | 0.3461                          | middle level                          |
| 2012 | 0.4040                               | 0.4926                                 | 0.3382                                 | 0.3157                                      | 0.3960                          | middle level                          |
| 2013 | 0.5052                               | 0.3717                                 | 0.3691                                 | 0.3017                                      | 0.3968                          | middle level                          |
| 2014 | 0.5092                               | 0.2832                                 | 0.4122                                 | 0.3037                                      | 0.3896                          | middle level                          |
| 2015 | 0.5297                               | 0.2953                                 | 0.4607                                 | 0.5004                                      | 0.4524                          | middle level                          |
| 2016 | 0.5272                               | 0.3053                                 | 0.5179                                 | 0.5144                                      | 0.4769                          | middle level                          |
According to the formulas (1) to (4), the entropy and final weight of each evaluation index of Chengdu from 2006 to 2015 are calculated (refer with: Table 2).

According to equations (5) to (8), the evaluation values for each year are calculated in Table 3. The above evaluation results are plotted in Figure 1.

3.2. Analysis of evaluation results

From Table 3 and Figure 1, we can see that Chengdu's sustainable utilization level has basically risen in 2007-2016, but it is still at an intermediate level, indicating that the current level of sustainable land use in Chengdu is not enough. The following is the specific analysis of the classification indicators:

1) Economic feasibility: the economic feasibility closeness degree has declined twice, and it has generally risen. In 2016, the degree of closeness to economic feasibility ranks first among the four indicators. This is mainly because the living standards of the people in Chengdu have gradually increased during this period, and the output value of the land is also increasing.

2) Social acceptability: the closeness of social acceptability has declined, and in 2016 ranks last in the four categories. The continuous decline in the degree of closeness to social acceptability is due to the fact that the population density is still increasing, and the natural population growth rate has not been effectively controlled, so the pressure on the land system is heavy.

3) Resource supportability: the supportability of resources showed a steady upward trend. This is because the introduction of various types of agricultural machinery has increased the area of machine cultivation and the area irrigated by arable land, which has improved the utilization rate of land.

4) Environmental tolerability: the environmental tolerability shows a significant upward trend and the rate of increase is ranked first in the four categories. This is mainly due to the increased awareness of environmental protection among Chengdu residents in recent years.

3.3. Diagnostic analysis of obstacle factors

In order to further understand the obstacles that constrain the increase in sustainable land use in Chengdu, according to formula (9), the obstacle degree of the indicators in the criterion layer (refer with: Figure 2) and the obstacles of the indicators in the indicator layer were calculated (refer with: Table 4, 5).

3.3.1. Diagnostic analysis of barrier factors. From Figure 2, we can see that the economic feasibility obstacles increase first and then decrease, and the overall trend shows a downward trend; the social acceptability obstacles have been on the rise since the decline in 2012; the supportability obstacles of resources show an overall steady decline; the overall situation of the degree of environmental tolerability is in a sharp decline. In the period from 2007 to 2013, the changes in the four categories of indicators have been more complicated and turned into a major obstacle. However, from 2013 until 2016, social acceptability is the main reason that hinders the sustainable use of land in Chengdu. From
this we can see that improving social acceptability is the key to improving the sustainable use of land in Chengdu.

![Figure 2. Guidelines for sustainable land use in Chengdu during 2007-2016.](image)

### 3.3.2 Diagnostic analysis of indicator barriers

In Table 4, due to the large number of indicators, according to the size of index barriers, the top five indicators were selected as the key analysis targets.

**Table 4. Obstacles of main indicators of sustainable land use indicators from 2007 to 2016.**

| Year | Classification                                                   | Index sorting |
|------|-----------------------------------------------------------------|---------------|
|      |                                                                 | 1  | 2  | 3  | 4  | 5  |
| 2007 | Obstacle factors(Obstacle degree)                               | C12(34.21)    | C14(28.02) | C16(25.36) | C8(23.82) | C4(22.67) |
| 2008 | Obstacle factors(Obstacle degree)                               | C3(29.09)     | C12(22.51) | C4(21.31)  | C14(21.18) | C11(19.77) |
| 2009 | Obstacle factors(Obstacle degree)                               | C3(21.82)     | C12(20.21) | C4(19.86)  | C1(17.91)  | C11(16.51) |
| 2010 | Obstacle factors(Obstacle degree)                               | C11(15.00)    | C1(14.93)  | C9(14.59)  | C5(14.16)  | C13(12.08) |
| 2011 | Obstacle factors(Obstacle degree)                               | C7(15.09)     | C10(13.57) | C17(13.02) | C5(11.86)  | C6(11.09)  |
| 2012 | Obstacle factors(Obstacle degree)                               | C3(25.45)     | C10(14.00) | C6(12.81)  | C17(9.90)  | C5(9.67)   |
| 2013 | Obstacle factors(Obstacle degree)                               | C2(15.15)     | C6(14.70)  | C10(14.44) | C16(12.22) | C17(9.67)  |
| 2014 | Obstacle factors(Obstacle degree)                               | C15(23.78)    | C2(18.73)  | C6(16.99)  | C7(15.60)  | C10(14.99) |
| 2015 | Obstacle factors(Obstacle degree)                               | C13(34.48)    | C2(21.49)  | C7(18.02)  | C6(15.96)  | C8(10.18)  |
| 2016 | Obstacle factors(Obstacle degree)                               | C13(40.38)    | C2(22.04)  | C7(16.67)  | C8(14.77)  | C6(11.51)  |

As can be seen from Table 5, the top five factors in the frequency of obstacle factors are population density, annual growth rate of GDP, natural population growth rate, per capita cultivated area, and fertilizer application per unit area of cultivated land. The population density factor has the highest frequency of occurrence, up to 60% (6 years), and it has been occurring continuously from 2011 to 2016. This shows that the intensity of population control policies in Chengdu in recent years is not enough, resulting in high population density, so the pressure on the carrying capacity of the land system is greatly increased. The frequency of GDP annual growth rate, the natural population growth rate, and the average cultivated land per capita and the amount of fertilizer applied per unit area of cultivated land were tied for the second with 40% (four years). The impediment factor of the annual
growth rate of GDP is the newly emerging obstacle factor from 2013 and ranked first in 2013. It ranked second for three consecutive years from 2014 to 2016, indicating that the economic development of Chengdu has been slow in recent years. The reasons for the emergence of natural population growth rate are similar to those of population density. Population growth has occupied a large amount of cultivated land resources, which explains the high frequency of obstacles to per capita cultivated land area. The amount of fertilizer application obstacles per unit area of arable land has occurred four times from 2010 to 2013, but it is no longer a top five barrier from 2014, indicating that Chengdu residents’ awareness of land protection has been gradually enhanced, and they reduce chemical fertilizers to reduce land pollution.

4. Conclusions
(1) On the basis of constructing an evaluation index system for city-level land sustainable use, this paper uses the entropy method and TOPSIS method to conduct empirical research on the sustainable land use level in Chengdu from 2007 to 2016. The research results show that from 2007 to 2016, the level of sustainable land use has been slowly increasing. The closeness degree has increased from 0.3341 to 0.4769, and the level has also risen from a lower level to an intermediate level. Among them, economic feasibility rose with an overall upward trend of 53.88%; social acceptability showed a downward trend with a decrease of 34.60%; resources supportability showed a slow upward trend with a rise of 78.09%; environmental tolerability has shown a significant upward trend, with an increase of 647.67%.

(2) In order to further study the obstacles constraining the level of sustainable land use, the obstacle degree model was used to calculate the obstacles of each indicator in the land sustainable use index system. The calculation results show that social acceptability is the main factor hindering the sustainable use of land. Population density, annual growth rate of GDP, natural population growth rate, per capita arable land area, and fertilizer application per unit area of cultivated land are the main obstacles.

This paper uses weighted TOPSIS method to evaluate the sustainable land use level in Chengdu from 2007 to 2016. However, no space research has been conducted. At the same time, the construction of the evaluation system for urban land sustainable use needs further improvement and systematic research.

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