The evaluation of urban human settlements based on fuzzy matter-element model: taking 11 prefecture-level cities in Jiangxi Province as examples

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Abstract. A case study is presented in which the fuzzy matter-element model (FMEM) is used to assess the evaluation of urban human settlements (UHS) of the basin of the 11 prefecture-level cities in Jiangxi Province. The regional samples and evaluation standards are all treated as the matter-element, and the compound fuzzy matter-element is constructed with the evaluation indicators and the corresponding fuzzy values of the indicators. Then the Euclid approach degree of the evaluated fuzzy matter-element to the standard fuzzy matter-element is calculated, thus attaining the grade classification of human settlements of the evaluated samples. The study results show that the fuzzy matter-element method is practical for comprehensive evaluation of regional human settlements.

1. Introduction

Human settlement is the foundation of human survival and development, of which quality is not only directly related to human health only but also to mutually accommodating behavior of a population, society, environment and resource coordination problem [1]. What's more, it is also an important symbol of the human society advances and cultural development. The urban human settlements (UHS) environment system is a fragile unstable ecosystem. Compared with the natural one, the system has many unique characteristics, such as a high consumption of energy and material, serious environmental pollution and a low reserve of natural resources [2] which results in the production of "Nightmare City". This impels people to seek and search the proper "living environment" unceasingly, especially in the mega-city with high development speed. The human settlement has been concerned and studied more and more by the scholars at home and abroad, as the same time has been a hot issue of daily life since human settlements has been found by Doxiadis in 1970, who is a famous professor of architecture of the Greeks [3]. He emphasized a comprehensive research on human living environment with combinations of nature, human, society, construction and contact networks. The pretty and ideal-human urban human settlements have become the common pursuit of mankind, and how to build and evaluate it has become the research focus.
In 1961, the World Health Organization (WHO) summed up the basic conditions of human life requirement (namely, Safety, Health, Convenience and Amenity), and proposed further the basic concept of living environment. A milestone of human settlements problems were polled in the United Nations Conference on Human Environment in 1972. Next, in 1976 and 1996, the Istanbul and Vancouver Declaration presented that the primary goal of every human settlements policy is to improve life quality of human, and the Istanbul Declaration explored two global topics of important significance, that is, adequate housing for everyone and sustainable development of human settlements in the urban process (GO, https://unhabitat.org/wpdm-package/istanbul-declaration-on-human-settlements/).

**Figure 1.** Location of the 11 prefecture-level cities in Jiangxi Province.

The study on the UHS is not only to improve people's livelihood, but also the government's plan to provide cities and towns based decision support. In the last 30 years, many studies have been conducted to evaluate UHS. Cap, an American scholar, got meaningful 20 elements from 100 indicators of the most important option for location selection. Then, these elements were divided into 6 types by Knox (1995) [4], namely, Aesthetics, Neighbors, Accessibility, Safety, Noise and Plague. Therefore, he set a precedent for the role of the assessment questionnaire for system, what's more, the corresponding evaluation indicators were determined in the selection of “Best Home Area” from 301 metropolitan areas of America in 1997. The urban human environment security is an important part of the UHS evaluation index system. The accurate evaluation of UHS can help us getting an objective understanding of the development status of the urban human environment to solve the problem emerged in the process of urban environment development and facilitate the development direction planning. Based on the principle of environmental friendliness, Zhang et al. (2009) established evaluation index system of UHS for 30 cities of China [5]. Much later, using RS, GIS and UHS assessment model, Ren et al. (2009), Yang et al. (2012) and Yang et al. (2012) [6-8] evaluated the general conditions of some cities. And, furthermore, based on the statistics during 2003-2012, the assessment indexes of safe community construction and human settlements in Dalian were calculated, which showed safe community construction and the improvement of human settlements environment were highly coordinated and they could mutually support each other and realize coordinated development [9, 10]. Jiangxi Province, including 11 prefecture-level cities as Nanchang, Jiujiang, Ganzhou, Ji’an, Pingxiang, Yingtan, Xinyu, Yichun, Shangrao, Jingdezheng and Fuzhou, is enclosed between latitudes 24°29′14″~30°04′41″ and longitudes 113°34′36″~118°28′58″. Locations of the 11 prefecture-level cities can be referred to figure. 1. This paper applies the FMEM based on matter
element analysis to evaluate and verify the urban residential environment of 11 prefecture-level cities in Jiangxi Province, from the perspective of a series of regional studies on both natural and human systems. The evaluation results are conducive to horizontal or vertical comparison for the assessment and prediction of urban environmental quality so as to identify learning gaps and then seek its developmental direction. What’s more, the evaluation of urban human settlements can provide decision-making for its construction and management and make up the weak links of the research to UHS.

2. FMEM for evaluation of UHS

FMEM is an organic combination of fuzzy mathematics and matter element analysis [5, 11]. It analyzes, integrate, explore and broaden the incompatibility between corresponding magnitude of an object characters, so as to resolve the kind of fuzzy incompatible problem. FMEM of evaluation of UHS is achieved by mainly six steps, which are respectively definition of fuzzy matter-element construction of composite fuzzy matter-element, calculation of optimal subordinate degree, building of standard and difference square fuzzy matter-element, determination of the weight of evaluating indicators and rank of UHS.

2.1. Definition of fuzzy matter-element

For the evaluation of UHS, it is described by an ordered triple \( R = (M, C, u) \) is taken as a city as matter-element \( M \). If the membership grade \( u(x) \) of \( M \) is fuzzy, which is the corresponding standard value \( x \) of evaluating indicator \( C \), the matter-element \( R \) is the so-called fuzzy matter-element, that is:

\[
R = \begin{bmatrix}
M \\
C \\
u(x)
\end{bmatrix}
\]  

(1)

2.2. Construction of composite fuzzy matter-element

The \( n \)-dimensional fuzzy matter-element with \( m \) evaluating indicators \( R_{mn} \) will be written as:

\[
R_{mn} = \begin{bmatrix}
M_1 & M_2 & \cdots & M_m \\
C_1 & u(x_{11}) & u(x_{12}) & \cdots & u(x_{1n}) \\
C_2 & u(x_{21}) & u(x_{22}) & \cdots & u(x_{2n}) \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
C_n & u(x_{n1}) & u(x_{n2}) & \cdots & u(x_{nn})
\end{bmatrix}
\]  

(2)

where \( M_j \) is the \( j \)-th evaluating indicator, \( C_i \) is the \( i \)-th evaluating indicator of the \( j \)-th sample, and \( u(x_{ji}) \) is the corresponding fuzzy magnitude [5, 12].

2.3. Calculation of optimal subordinate degree

The optimal subordinate degree refers to the subordinate degree that fuzzy magnitude corresponding to every evaluating indicator [5, 13]. Because of there exist objective differences of various cities such as nature, society, economy and technology, in which may exist vary significantly in various samples of some indicator’ attribute values, while that of other indicators may vary less. Therefore, the preferred membership grade should be applied to avoid exaggerating the role of indicators. Or more specifically, the bigger the better type indicator is determined by [14]

\[
u(x_{ji}) = x_{ji} / \max x_{ji}
\]

(3)

And the smaller the better type indicator is determined by

\[
u(x_{ji}) = 1 - x_{ji} / \max x_{ji}
\]

(4)

where \( x_{ji} \) is the corresponding magnitude for \( i \) evaluating indicator of the \( j \) sample, \( \max x_{ji} \) is maximum value in all magnitude \( x_{ji} \).
2.4. Building of standard and difference square fuzzy matter-element
A standard fuzzy matter-element $R_{0n}$ of master sample with $n$ dimension can be built by the Formula (2), of which it could be decided by the best extreme and constant of the optimal subordinate degree of evaluating samples. That is,

$$
R_{0n} = \begin{bmatrix}
M_0 \\
C_1 \ u(x_{01}) \\
C_2 \ u(x_{02}) \\
\vdots \\
C_n \ u(x_{0n})
\end{bmatrix}
$$

(5)

Then the difference square composite fuzzy matter-element $R_\Delta$ is obtained by [15]

$$
R_\Delta = \begin{bmatrix}
M_1 & M_2 & K & M_m \\
C_1 \ \Delta_{11} & \Delta_{12} & K & \Delta_{1m} \\
C_2 \ \Delta_{21} & \Delta_{22} & K & \Delta_{2m} \\
\vdots \\
C_n \ \Delta_{n1} & \Delta_{n2} & K & \Delta_{nm}
\end{bmatrix}
$$

(6)

where $\Delta_{ij}$ is the squares of differences of the corresponding values between $R_{0n}$ and composite $R_{mn}$ [5].

2.5. Determination of the weight of evaluating indicator
In the evaluation of UHS, the determination of the weight of evaluating index will directly affect the evaluating results. At present, there are many methods to determine it, such as the Analytic Hierarchy Process (AHP) method [16], Delphi method [17], Entropy method [17, 18], Principal Component Analysis (PCA) [12] and so on. In general, the weight $w_i$ of the $i$th evaluating indicator satisfies $\sum w_i = 1$ and $w_i > 0$ [19].

2.6. Rank of UHS
There are many formulas to calculate the approach degree of two matter-elements that is evaluating and master sample (optimal sample). For the record, the human settlements of the evaluating sample cities can be ordered according to the approach degree. Considering the significance of the comprehensive evaluation in the paper, $M(\cdot, +)$ algorithm, which refers to calculate Euclid approach degree $\rho H_j$ by multiplication first and then addition, as shown below.

$$
\rho H_j = 1 - \sum_{i=1}^{n} w_i \Delta_{ij} \quad j = 1, 2, \ldots, m
$$

(7)

In this case, $P_j$ represents the approach degree. The bigger $\rho H_j$ is, the nearer the two will be; conversely, the farther the two will be. Then the composite fuzzy matter-element of Euclid approach degree $R_p$ can be computed by [12],

$$
R_p = \begin{bmatrix}
M_1 & M_2 & L & M_m \\
P_1 & P_2 & L & P_m
\end{bmatrix}
$$

(8)

3. Empirical study
3.1. Building of the evaluating indicator system of UHS
The harmonious coexistence between human and nature of every city is a relatively unified and independent unit, of which the harmonious principle of man and earth is one of the key principles for UHS. Therefore, the basic framework the evaluation index system of harmonious UHS is divided into three layers, which aim at the evaluation of harmonious UHS for 11 prefecture-level cities in Jiangxi
Province. 4 first-class indicator are harmonious degree between man and earth, living conditions, basic conditions and social-economic conditions, respectively and their weights are determined according to their contribution proportion to the target (namely the evaluation of harmonious UHS). Every first-class indicator includes 27 single indicators of the evaluation as shown in table 1. In addition, their 27×11 indicators are from China City Statistical Yearbook, due to limited space, the article does not list and fully describe them.

Table 1. The basic framework the evaluating indicator system of harmonious urban human settlement [20].

| Target | First class indicator | Single indicator                                                                 |
|--------|-----------------------|----------------------------------------------------------------------------------|
|        | harmony degree human and earth (I) 0.3640 | the frequency of flood disasters (X₁)                                           |
|        |                       | the life garbage treatment rate (X₂)                                           |
|        |                       | the treatment rate of domestic sewage (X₃)                                      |
|        |                       | the degree of drinking water source (X₄)                                        |
|        |                       | the comprehensive utilization rate of industrial solid wastes (X₅)               |
|        |                       | the discharge standard-meeting rate of industrial wastewaters (X₆)               |
|        | living conditions (II ) 0.2061 | the hydrophilic performance (X₈)                                                |
|        | basic conditions (III) 0.1843 | the per capita green area (X₉)                                                   |
|        |                       | the popularity rate of domestic gas (X₁₀)                                       |
|        | socio-economic conditions (IV ) 0.2456 | the per capita road area (X₁₁)                                                  |
|        |                       | the number of buses per ten thousand people (X₁₂)                               |
|        |                       | the number of public book per one hundred people (X₁₃)                           |
|        |                       | the number of doctors per ten thousand people (X₁₄)                             |
|        |                       | the number of hospital beds per ten thousand people (X₁₅)                       |
|        |                       | the urban per capita GDP (X₁₆)                                                  |
|        |                       | the population size (X₁₇)                                                       |
|        |                       | the treatment of pollutant source (X₁₈)                                         |
|        |                       | the investment of environmental facilities (X₁₉)                                 |
|        |                       | the foreign investment in actual use (X₂₀)                                      |
|        |                       | the proportion of the tertiary industry in the GDP (X₂₁)                        |
|        |                       | the operating expenses for social welfare (X₂₂)                                 |
|        |                       | the science investment (X₂₃)                                                    |
|        |                       | the remaining sum of year end savings account (X₂₄)                             |
|        |                       | the quantity of higher educational school (X₂₅)                                 |
|        |                       | the telecommunication consumption (X₂₆)                                         |
|        |                       | the treatment of unemployment per ten thousand people (X₂₇)                    |

3.2. The evaluation of regional human settlements with a harmonious human-earth relationship

According to the principle of fuzzy matter-element analysis and the attribute value of evaluation indicators, we can make an comprehensive assessment for a harmonious human-earth relationship of 11 prefecture-level cities in Jiangxi Province. Follow the evaluation procedure outlined below:

Step 1: The construction of composite matter element. Every evaluating planning prefecture-level cities will be considered as a matter-element, and the 11 matter, each is corresponding 27 indicators and attribute values for constructing complex matter element.

Step 2: The determination of optimal subordinate degree. The xᵢ indicator is the smaller the better for the determined composite matter element in Step 1, and the optimal subordinate degree is calculated using the Formula (4). The other indicators are the bigger the better, and the optimal subordinate degree using the Formula (3). From this we can construct composite fuzzy matter-element $R_{11,27}$.

Step 3: The calculation of standard fuzzy matter-element. The standard fuzzy matter-element $R_{0,27}$ can be defined by minimum or maximum value in various evaluation samples of composite fuzzy matter-element $R_{11,27}$. This article selects the maximum value to compose of the standard fuzzy matter-element, that is $u(x_0) = 1$. 


Step 4: The determination of difference square fuzzy matter-element. The standard fuzzy matter-element $R_{0,27}$ and the squares of differences $\Delta_{ij}$ of the corresponding $R_{11,27}$ based on the Formula (6), and then difference square fuzzy matter-element will be composed by the previous $\Delta_{ij}$.

Step 5: The determination of the weight of evaluating indicators. In order to make more objective comparison, AHP method is adopted to determine the weight of evaluating indicators $w$ [20] (see Table 2).

Step 6: The calculation for closeness degree. The closeness degree $\rho_{Hj}$ between evaluation samples and standard samples can be obtained by the Formula (7) based on difference square compound fuzzy matter-element $R_{\Delta}$ and the weight of evaluating indicators $w$ [21] (see Table 3).

Table 2. The weight of evaluating indicators.

| Indicators | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $w$        | 0.0430| 0.0510| 0.0510| 0.0510| 0.0556| 0.0430| 0.0442| 0.0761| 0.0597|

| Indicators | $X_{10}$ | $X_{11}$ | $X_{12}$ | $X_{13}$ | $X_{14}$ | $X_{15}$ | $X_{16}$ | $X_{17}$ | $X_{18}$ |
|------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| $w$        | 0.0563   | 0.1301   | 0.0519   | 0.0399   | 0.0385   | 0.0443   | 0.0497   | 0.0211   | 0.0206   |

| Indicators | $X_{19}$ | $X_{20}$ | $X_{21}$ | $X_{22}$ | $X_{23}$ | $X_{24}$ | $X_{25}$ | $X_{26}$ | $X_{27}$ |
|------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| $w$        | 0.0273   | 0.0243   | 0.0186   | 0.0186   | 0.0214   | 0.0184   | 0.0184   | 0.0172   |          |

Table 3. The closeness degree between evaluation samples and standard samples and their rank.

| Sample  | $\rho_{Hj}$ | Rank | Sample  | $\rho_{Hj}$ | Rank |
|---------|-------------|------|---------|-------------|------|
| Shangrao| 0.8119      | 6    | Yingtan | 0.6681      | 10   |
| Pingxiang| 0.5314     | 11   | Nanchang| 0.7036      | 9    |
| Ganzhou | 0.8628      | 4    | Fuzhou  | 0.7624      | 8    |
| Jiujiang| 0.8218      | 5    | Jingdezh|n 0.9028    | 2    |
| Yichun  | 0.9304      | 1    | Ji’an   | 0.7875      | 7    |
| Xinyu   | 0.8929      | 3    |         |             |      |

3.3. The analyses of evaluation results

As seen in Table 3, the harmonious human-earth relationship of the 11 regional samples from good to bad is Yichun, Jingdezhen, Xinyu, Ganzhou, Jiujiang, Shangrao, Ji’an, Fuzhou, Nanchang, Yingtan and Pingxiang. The most of closeness degrees of 11 cities are relatively high. The maximum of these is 0.9304, but the closeness degree of Yingtan (0.6681) and Pingxiang (0.5314) need to be improved to a great extent. Further, these cities are graded according closeness degree, or more, specifically, the degree values greater than 0.9 are defined as first grade, the values between 0.9 and 0.8 are second grade, the values between 0.8 and 0.7 are third grade, and the values less than 0.7 are defined as fourth grade. The specific grades see Table 4.

Table 4. The grade of evaluation samples.

| City        | Rank | City | Rank | City | Rank | City | Rank |
|-------------|------|------|------|------|------|------|------|
| Yichun      | 1    | Xinyu| 3    | Ji’an| 7    | Yingtan| 10  |
| Jingdezhen  | 2    | Ganzhou| 4  | Fuzhou| 8    | Pingxiang| 11  |
|             |      | Jiujiang| 5  | Nanchang| 9    |         |      |
|             |      | Shangrao| 6    |       |      |        |      |
Jiangxi Province enjoys superior geographical environment and the warm climate and near by the mountain and by the river, so the province is human settlements you will hesitate to leave once you come to it. Through horizontal comparison with 11 prefecture-level cities in Jiangxi Province, the most of closeness degrees are relatively high, of which standard samples are selected optimal value for every indicator, namely that both two indicators $x_i$ and $x_j$ take the minimum value and the rest of 25 indicators take the maximum respectively.

According to the indicators’ attribute value, contrast analysis based on rank of fuzzy matter-element and table 4 show that the first grade is only two cities, namely Yichun and Jingdezhen, because of the city has many advantages and potential superiors such as higher harmonious degree, good environmental conditions and economic indicators, it tops the list of 2 best prefecture-level cities. And Jingdezhen has a superior Sheung Shui [22], so it obtains the second place. The second and third grade have the most cities, which they set respectively 4 and 3 cities. These cities present better indicators and little difference. The fourth grade includes Yingtai and Pingxiang. Because of traffic inconvenience and backward economy, Yingtai comes in the last but one. While for Pingxiang as the last, it is chiefly because frequent occurrence of natural disaster and most serious pollution lead to worst human settlements in Jiangxi Province. All evaluation results are consistent with actual situation. Thus, we conclude that FMEM for the evaluation of human settlements is reliable and reasonable.

4. Conclusions
On the basis of the fuzzy set theory and the concept of Euclid approach degree, a fuzzy matter-element model for the evaluation of regional human settlements is established. A case study is presented in which the FMEM is used to assess the human settlements of the basin of the 11 prefecture-level cities in Jiangxi Province. The results show that the fuzzy matter-element method is practical for the comprehensive evaluation of regional human settlements.

In the case study, the regional samples and evaluation standards are all treated as the matter-element, and the compound fuzzy matter-element is constructed with the evaluating indicators and the corresponding their fuzzy values. Then the Euclid approach degree of the evaluated fuzzy matter-element to the standard fuzzy matter-element is calculated. Thus, we can attain the grade classification of human settlements of the evaluated samples.

Unprecedented human activity, developed scientific, advanced technologies have influenced the relation of mankind interaction, but they are difficult to change the harmonious human-earth relationship. The good or bad human settlements involve more various indicators such as the natural environment, human activity and developing situation of society and economy. The evaluation of UHS is the foundation and precondition of living environment construction to make the strategic countermeasure of a harmonious human settlements.

In the paper, the evaluation of UHS based on the FMEM was largely analyzed comparing with each prefecture-level city related to human settlements data rather than the degree of UHS of each city. Therefore, there is a further in-depth study on FMEM using RS and GIS technologies, thus these results can be effective application in the evaluation and warning mechanism of human settlements.

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