Study on the Evaluation of Ecological Livable City in Anhui Based on Intuitionistic Fuzzy Theory

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Abstract. With the rapid development of new urbanization, the construction of ecological livable city has become a hot spot of attention. Through the study and comparison of the ecological livability of the main cities in Anhui Province, it provides a reference for the construction of ecological livable cities. First of all, the evaluation index system is constructed from four aspects: economic development, infrastructure construction, ecological environment and social livelihood. Based on intuitionistic fuzzy theory, an evaluation model of ecological livable city is constructed, and intuitionistic fuzzy entropy is used to calculate index weight. Then by collecting the data of 16 cities in Anhui province from 2014 to 2017, it is proved that the ecological livability of the main cities of Anhui province is ranked. Finally, based on the evaluation results, we can see that the contribution rate of air quality excellence rate, the third industry proportion to the GDP is larger than that of the livable city evaluation, and give some suggestions for building an ecological livable city.

1. Introduction
Over the past 50 years, 1.3 billion people have moved from rural areas to cities, and the rate of urbanization has been rising. By 2016, the urbanization rate in China has reached 57.35%. With the acceleration of urbanization, due to the imperfection of supporting facilities, there are also a series of environmental and social problems, such as air pollution, traffic congestion, housing shortage, lack of schools, deterioration of social order and so on. These problems have seriously affected the development of cities and the living environment of human beings. New urbanization is a major national strategy determined by the 18th National Congress of the Communist Party of China. General Secretary Xi Jinping emphasized that the core of new urbanization is people-oriented, the key is to improve the quality of development, and strive to achieve inclusive growth and green growth. The national new urbanization plan issued by the national development and Reform Commission has made it clear that the guiding ideology, main purpose and strategic task of China's urbanization development are to establish a harmonious, livable, characteristic and dynamic modern city. Therefore, building an ecological livable city is not only to improve people's living space, but also the key to realize the new urbanization.

The concept of eco city was put forward in the research process of “man and biosphere project” initiated by UNESCO in 1970s, but there is no accepted definition of eco city. For the city's ecological livability, domestic and foreign experts and scholars mainly study from two aspects: ecological city and livable city. The theory of livable cities can be traced back to the study of living environment, Jane. In the death and life of big American cities, Jacobs first questioned the livability of cities and
advocated the construction of livable cities. Since 1986, when Yichun, Jiangxi Province, first proposed eco-city as the development goal of urban construction, eco-city has gradually become an important direction for many urban environmental protection work and even urban development [1]. Liu [2] established a model based on neural network variable screening model, analytic hierarchy process and global sensitivity analysis to evaluate the influence of various factors on urban livability. He, Li, Huang et al. [3, 4] evaluated the livability of eight cities in the Huaihai economic zone by using factor analysis and principal component analysis respectively. Jia [5] used entropy method, Arc GIS spatial analysis method and panel data model analysis method to explore the habitability and influencing factors of 37 cities in northeast China. Yang and Wang [6, 7] researched Xuchang and Tianjin by using principal component analysis. Zhan [8] constructed the conceptual model of “residential satisfaction–residential mobility intention” by using exploratory factor analysis and structural equation model. Zhang [9] made a comprehensive evaluation on the livability of major cities in Sichuan by using the TOPSIS model evaluation method, and gave corresponding countermeasures and suggestions. Wang [10] constructed the ecological environment habitability evaluation model from five aspects of topography, climate, hydrology, land cover and natural disasters, and made a quantitative comprehensive evaluation on the spatial pattern, regional characteristics and the relationship between the ecological environment habitability and population distribution in Zhejiang province.

At present, researches on ecological livable cities mainly focus on a certain city. Although comprehensive evaluation has been carried out in Zhejiang province, Sichuan province, southeast Guizhou Province and other provinces, few comprehensive evaluation has been carried out on the ecological livable degree of major cities in Anhui province. The evaluation methods adopted mainly include factor analysis, principal component analysis, entropy method, TOPSIS method and so on. Comprehensive evaluation of urban ecological livability is a multi-attribute decision, with a large number of evaluation indicators, both qualitative and quantitative, and incomplete and fuzzy in data collection. Because intuitionistic fuzzy theory can reflect the subordination and non-subordination factors of data, and reflect the hesitation degree of data and other advantages, this paper establishes the evaluation method model of ecological livable city in Anhui province based on intuitionistic fuzzy theory.

2. Urban Ecological Livability Evaluation Index System
The evaluation of ecological livable cities is a complex systematic engineering, involving a wide range of factors, which need to be considered many factors. In the evaluation, the main factors affecting the urban ecological livability need to be analyzed to build a first-level and second-level evaluation index system, and the overall urban ecological livability can be obtained through the evaluation of each index. On the basis of referring to the domestic and foreign literature, this paper combines the statistics yearbook data of Anhui Province to construct the index system of urban ecological livability evaluation, and divides the urban ecological livability into four dimensions: economic development, infrastructure construction, ecological environment and social livelihood. According to the characteristics of each local city in Anhui Province, the index system of livable city evaluation is formulated, as shown in Table 1.

3. Intuitionistic Fuzzy Sets and Intuitionistic Fuzzy Entropy
3.1. Intuitionistic Fuzzy Sets
Definition 1 Let $X = \{x_1, x_2, \cdots, x_n\}$ be a fixed finite universe set. An intuitionistic fuzzy set (IFS) on $X$ is defined as $A = \{(\mu(x_i), v(x_i)) | x_i \in X\}$ where $\mu(x_i)$ and $v(x_i)$ denote the membership degree and non-membership degree of $x_i$ belonging to $A$ respectively and satisfy the condition that $0 \leq \mu(x_i) \leq 1, 0 \leq v(x_i) \leq 1, \mu(x_i) + v(x_i) \leq 1$. 
Table 1. Evaluation indicator system of urban ecological livability.

| Standard level                | Index level                                      | Positive/ negative | Weight |
|------------------------------|--------------------------------------------------|--------------------|--------|
| Economic development (0.216) | Per capita GDP                                   | P                  | 0.0485 |
|                              | local finance                                    | P                  | 0.0306 |
|                              | Listed company                                   | P                  | 0.0231 |
|                              | Total electricity consumption                    | P                  | 0.0470 |
|                              | Proportion of tertiary industry in GDP           | P                  | 0.0667 |
| Infrastructure construction (0.204) | Gas penetration rate                            | P                  | 0.0257 |
|                               | Water use penetration                            | P                  | 0.0192 |
|                               | Per capita urban road area                       | P                  | 0.0374 |
|                               | Number of public transport operations            | P                  | 0.0276 |
|                               | hospital beds                                    | P                  | 0.0524 |
|                               | Number of patent authorizations                  | P                  | 0.0247 |
|                               | Number of secondary schools                      | P                  | 0.0171 |
| Ecological environment (0.381) | Excellent rate of air quality                    | P                  | 0.0673 |
|                               | Mean value of regional environmental noise       | N                  | 0.0240 |
|                               | Per capita public green area                     | P                  | 0.0654 |
|                               | Water resources per capita                       | N                  | 0.0255 |
|                               | Total industrial waste gas emission              | N                  | 0.0430 |
|                               | Ratio of harmless treatment of municipal solid waste | P                | 0.0176 |
|                               | Ratio of Comprehensive utilization of industrial solid waste | P | 0.0443 |
|                               | Afforestation area                               | P                  | 0.0434 |
| Social livelihood (0.199)     | Per capita disposable income                     | P                  | 0.0505 |
|                              | Per capita residential building area             | P                  | 0.0348 |
|                              | Population urbanization rate                     | P                  | 0.0548 |
|                              | Unemployment rate                                | N                  | 0.0566 |
|                              | Education funds                                  | P                  | 0.0528 |

Definition 2: \( A = \{(\mu(x_i), \nu(x_i)) | x_i \in X \} \) be an intuitionistic fuzzy set on a fixed finite universe set \( X = \{x_1, x_2, \ldots, x_n \} \). Let \( \pi(x_i) = 1 - \mu(x_i) - \nu(x_i) \), we call \( \pi(x_i) \) the intuitionistic fuzzy coefficient or hesitation degree of \( x_i \) to set \( A \). Let \( h(x_i) = \mu(x_i) + \nu(x_i) \), we call \( h(x_i) \) the intuitionistic accuracy of \( x_i \) to set \( A \). We call \( s(x_i) = \mu(x_i) - \nu(x_i) \) intuitionistic fuzzy score function of \( x_i \) to set \( A \).

If \( s(\alpha) < s(\beta) \), then \( \alpha < \beta \).

If \( s(\alpha) = s(\beta) \), then (1) if \( h(\alpha) < h(\beta) \), then \( \alpha < \beta \). (2) If \( h(\alpha) = h(\beta) \), then \( \alpha = \beta \).

3.2. Intuitionistic Fuzzy Entropy

Definition 3: For an intuitionistic fuzzy set \( A = \{(\mu(x_i), \nu(x_i)) | x_i \in X \} \), the intuitionistic fuzzy entropy of \( A \) is defined as follows:

\[
E(A) = \frac{1}{n} \sum_{i=1}^{n} \left\{ \sin \frac{\pi}{4} \left[ 1 + \mu(x_i) - \nu(x_i) \right] + \sin \frac{\pi}{4} \left[ 1 - \mu(x_i) + \nu(x_i) \right] - 1 \right\} \times \frac{1}{\sqrt{2} - 1}
\]
For two intuitionistic fuzzy sets satisfy the four properties of intuitionistic fuzzy entropy.

1. \( E(A) = 0 \) if and only if \( A \) is a crisp set.
2. \( E(A) = 1 \) if and only if \( \mu(x_i) = \upsilon(x_i) \) for all \( x_i \in X \).
3. \( E(A) < E(B) \) if \( A \) is less fuzzy than \( B \).
4. \( E(A) = E(A^c) \).

### 3.3. Score Function of Weighted Intuitionistic Fuzzy Numbers

In order to compare the ecological livability of each city, this paper constructs the score function of weighted intuitionistic fuzzy number, the larger the function value, the stronger the livability.

\[
S = \frac{1}{2} \left( \sum_{j=1}^{n} w_j \mu_{ij} + \sum_{j=1}^{n} w_j (1 - \upsilon_{ij}) \right)
\]

### 4. Evaluation Method of Ecological Livable City

#### 4.1. Normalization Method of Indicators

Let \( C = \{C_1, C_2, \ldots, C_m\} \) means \( M \) cities, \( A = \{A_1, A_2, \ldots, A_n\} \) is the attribute value set of \( N \) evaluation indexes, and the attribute weight is \( w = \{w_1, w_2, \ldots, w_n\} \), where \( 0 \leq w_j \leq 1 \), and \( \sum_{j=1}^{n} w_j = 1 \), \( t \) represents the year, then the original evaluation index data of each city can be expressed by the following matrix:

\[
X = \begin{pmatrix}
    x'_{11} & x'_{12} & \cdots & x'_{1m} \\
    x'_{21} & x'_{22} & \cdots & x'_{2m} \\
    \vdots & \vdots & \ddots & \vdots \\
    x'_{m1} & x'_{m2} & \cdots & x'_{mn}
\end{pmatrix}
\]

According to the above original evaluation index data, the normalization processing is carried out and the normalization matrix is obtained as follows.

\[
R = \begin{pmatrix}
    r'_{11} & r'_{12} & \cdots & r'_{1m} \\
    r'_{21} & r'_{22} & \cdots & r'_{2m} \\
    \vdots & \vdots & \ddots & \vdots \\
    r'_{m1} & r'_{m2} & \cdots & r'_{mn}
\end{pmatrix}
\]

Then, if the evaluation index is benefit index,

\[
r'_{ij} = \frac{x'_{ij} - \min_{i=1, j=1}^{i=m, j=k} \{x'_{ij}\}}{\max_{i=1, j=1}^{i=m, j=k} \{x'_{ij}\} - \min_{i=1, j=1}^{i=m, j=k} \{x'_{ij}\}}, \quad i \in M, \ j \in N,
\]

\( M = (1,2,\cdots, m), N = (1,2,\cdots, n) \).

If the evaluation index is cost type index,

\[
r'_{ij} = \frac{\max_{i=1, j=1}^{i=m, j=k} \{x'_{ij}\} - x'_{ij}}{\max_{i=1, j=1}^{i=m, j=k} \{x'_{ij}\} - \min_{i=1, j=1}^{i=m, j=k} \{x'_{ij}\}}, \quad i \in M, \ j \in N
\]
4.2. Integrate the Normalized Index Values into the Intuitionistic Fuzzy Model

Definition 4: Rank the attribute values of the normalized evaluation indexes in the order of small to large, if the median of each year is \( \text{Median}(r_{ij}^t) \), let \( R^L_{ij} = \{ r_{ij}^t | r_{ij}^t \leq \text{Median}(r_{ij}^t) \} \), \( R^U_{ij} = \{ r_{ij}^t | r_{ij}^t \geq \text{Median}(r_{ij}^t) \} \). And record the average value of set \( R^L_{ij} \) as \( \zeta_{ij} = \text{mean}(R^L_{ij}) \), record the average value of set \( R^U_{ij} \) as \( \xi_{ij} = \text{mean}(R^U_{ij}) \).

Definition 5: The membership degree, non-membership degree and hesitation degree of the attribute value of the normalized evaluation index are defined as, membership degree \( \mu_{ij} = \zeta_{ij} = \text{mean}(R^L_{ij}) \), non-membership degree \( \nu_{ij} = 1 - \xi_{ij} = 1 - \text{mean}(R^U_{ij}) \), hesitation degree \( \pi_{ij} = \xi_{ij} - \zeta_{ij} = \text{mean}(R^U_{ij}) - \text{mean}(R^L_{ij}) \).

Obviously, the above definition satisfies \( 0 \leq \mu_{ij} \leq 1 \), \( 0 \leq \nu_{ij} \leq 1 \), and \( \mu_{ij} + \nu_{ij} + \pi_{ij} = 1 \).

4.3. Calculation of Attribute Weight of Evaluation Indicators

Considering that some literatures adopt the method of subjective weighting, this paper adopts the method of objective weighting. The higher the intuitionistic fuzzy entropy is, the greater the uncertainty and fuzziness of the information is, and the greater the weight of the information is.

4.4. Calculation Steps

Step 1: Normalization of original data indexes.

In order to better analyze the evaluation method of livable cities, the following article takes per capita GDP as an example to introduce the normalization result of indicators. Table 2 is the original GDP per capita data of Anhui Province from 2014 to 2017, and the processing process of other indicators adopts the same method. Table 3 is the normalized data of table 2.

Step 2: Integrate the normalized index values into intuitionistic fuzzy numbers.

Table 4 is the intuitionistic fuzzy numbers of per capita GDP in Anhui province from 2014 to 2017.

### Table 2. Original data of per capita GDP in Anhui province, 2014-2017.

| City     | 2014   | 2015   | 2016   | 2017   |
|----------|--------|--------|--------|--------|
| Hefei    | 61555  | 67689  | 73102  | 80138  |
| Huaibei  | 32996  | 35324  | 35057  | 36427  |
| Bozhou   | 16071  | 17769  | 18771  | 20611  |
| Suzhou   | 18768  | 20895  | 22415  | 24270  |
| Bengbu   | 31482  | 35542  | 38267  | 41855  |
| Fuyang   | 13839  | 15303  | 16121  | 17642  |
| Huaian   | 34897  | 33631  | 26398  | 27990  |
| Chuzhou  | 27474  | 30562  | 32634  | 35302  |
| Luan     | 17828  | 19211  | 21524  | 23298  |
| Maanshan | 58733  | 60091  | 60802  | 65833  |
| Wuhu     | 58532  | 64039  | 67592  | 73715  |
| Xuancheng| 32928  | 35726  | 37610  | 40740  |
| Tongling | 92599  | 97193  | 57387  | 59960  |
| Chizhou  | 32541  | 36267  | 38014  | 40919  |
| Anqing   | 26596  | 28809  | 31101  | 33294  |
| Huangshan| 34725  | 37306  | 38794  | 41905  |
Table 3. Normalized data of per capita GDP in Anhui province, 2014-2017.

| City      | 2014  | 2015  | 2016  | 2017  |
|-----------|-------|-------|-------|-------|
| Hefei     | 0.573 | 0.646 | 0.711 | 0.795 |
| HuaiBei   | 0.23  | 0.257 | 0.254 | 0.271 |
| Bozhou    | 0.027 | 0.047 | 0.059 | 0.081 |
| Suzhou    | 0.059 | 0.084 | 0.102 | 0.125 |
| Bengbu    | 0.212 | 0.260 | 0.293 | 0.336 |
| Fuyang    | 0     | 0.017 | 0.027 | 0.046 |
| Huainan   | 0.253 | 0.234 | 0.150 | 0.17  |
| Chuzhou   | 0.164 | 0.200 | 0.225 | 0.258 |
| Luan      | 0.048 | 0.064 | 0.092 | 0.114 |
| Maanshan  | 0.539 | 0.554 | 0.563 | 0.624 |
| Wuhu      | 0.536 | 0.602 | 0.644 | 0.718 |
| Xuancheng | 0.229 | 0.262 | 0.285 | 0.323 |
| Tongling  | 0.945 | 1     | 0.522 | 0.553 |
| Chizhou   | 0.224 | 0.269 | 0.29  | 0.325 |
| Anqing    | 0.153 | 0.179 | 0.207 | 0.233 |
| Huangshan | 0.251 | 0.281 | 0.299 | 0.337 |

Table 4. Intuitionistic fuzzy numbers of per capita GDP in Anhui province, 2014-2017.

| City      | μ     | ν     | π     |
|-----------|-------|-------|-------|
| Hefei     | 0.61  | 0.25  | 0.14  |
| HuaiBei   | 0.24  | 0.74  | 0.02  |
| Bozhou    | 0.04  | 0.93  | 0.03  |
| Suzhou    | 0.07  | 0.89  | 0.04  |
| Bengbu    | 0.24  | 0.69  | 0.08  |
| Fuyang    | 0.01  | 0.96  | 0.03  |
| Huainan   | 0.16  | 0.76  | 0.08  |
| Chuzhou   | 0.18  | 0.76  | 0.06  |
| Luan      | 0.06  | 0.90  | 0.05  |
| Maanshan  | 0.55  | 0.41  | 0.05  |
| Wuhu      | 0.57  | 0.32  | 0.11  |
| Xuancheng | 0.25  | 0.70  | 0.06  |
| Tongling  | 0.54  | 0.03  | 0.44  |
| Chizhou   | 0.25  | 0.69  | 0.06  |
| Anqing    | 0.17  | 0.78  | 0.05  |
| Huangshan | 0.27  | 0.68  | 0.05  |

Step 3: Entropy weight method is adopted to calculate the weight of each index.

In this paper, the intuitionistic fuzzy entropy of definition 2 is used to calculate the index weight, and the calculated results are shown in table 1. As can be seen from table 1, the main factors affecting the ecological livability of Anhui Province are: the excellent and good air quality rate, the proportion of tertiary industry in the city’s GDP, per capita public green space area, urban registered unemployment rate, population urbanization rate, the hospital beds for ten thousand people with education funds in each city, per capita disposable income in rural areas, per capita GDP, etc.

Step 4: calculate the weighted score function of each city. The larger the value, the stronger the livability.

From the calculation results of the weighted score function in table 5, it can be seen that the
ecological livability of all the cities in Anhui Province is in the order of the weighted score function of Hefei, Wuhu, Huangshan, Ma’anshan, Chizhou, Chuzhou, Xuancheng, Tongling, Anqing, Bengbu, Fuyang, Liu’an, Suzhou, Huaibei, Huannan and Bozhou. The cities with high livability are Hefei, Wuhu and Huangshan. Cities with good ecological livability mainly include: Ma’anshan, Chizhou, Chuzhou, Xuancheng, Tongling, Anqing, Bengbu; The main ecological livable cities are: Fuyang, Lu’an, Suzhou, Huaibei, Huainan, Bozhou.

Table 5. Overall rankings of 16 cities in Anhui Province.

| City      | Score function | Ranking |
|-----------|----------------|---------|
| Hefei     | 0.65           | 1       |
| Huaibei   | 0.34           | 14      |
| Bozhou    | 0.33           | 16      |
| Suzhou    | 0.34           | 13      |
| Bengbu    | 0.39           | 10      |
| Fuyang    | 0.37           | 11      |
| Huainan   | 0.33           | 15      |
| Chuzhou   | 0.40           | 6       |
| Luan      | 0.35           | 12      |
| Maanshan  | 0.42           | 4       |
| Wuhu      | 0.48           | 2       |
| Xuancheng | 0.39           | 7       |
| Tongling  | 0.39           | 8       |
| Chizhou   | 0.42           | 5       |
| Anqing    | 0.39           | 9       |
| Huangshan | 0.42           | 3       |

In order to improve the ecological livability, cities should increase environmental protection measures to improve the rate of air quality; Improve the proportion of economic structure, increase the proportion of tertiary industry in the city’s GDP; Each city should increase per capita public green space area; Reduce the registered urban unemployment rate; Increase the urbanization rate of the population; Increase funds for education in cities; Increasing the number of hospital beds for 10,000 people; Measures to raise rural per capita disposable income and increase per capita GDP.

5. Conclusions and Policy Recommendations
Building ecological livable cities is the key to realizing new urbanization. In this paper, the intuition on the basis of fuzzy theory, first of all, in 16 cities in Anhui Province as the research object, from the economic development, infrastructure construction, ecological environment and social livelihood four dimensions to build the evaluation index system of ecological livable city, from Anhui statistical yearbook to the data collected in 2013-2016, using intuitionistic fuzzy theory to build an ecological livable city evaluation method; Secondly, the weight of the evaluation index system is calculated by using the intuitionistic fuzzy entropy theory, so as to avoid the one-sidedness of artificial subjective weighting. Finally, the ecological habitability of cities in Anhui province is calculated. The results show that the rate of excellent air quality, the proportion of tertiary industry in the city’s GDP, the per capita public green space contribute a lot to the evaluation of urban ecological livability. At present, Hefei, Wuhu and Huangshan are the most livable cities in Anhui province.

Based on the livability ranking of the 16 cities and several indexes that contribute a large percentage to the urban ecological livability, and combined with relevant theories, the following policy suggestions are proposed for the overall ecological livability construction in Anhui Province:

(1) Adjust the industrial structure and accelerate transformation and upgrading

For the cities such as Tongling and Ma’anshan, which take industry as the economic leading role, actively introduce new industries, make full use of the advantages of the Yangtze river delta economic
circle, adjust the industrial structure and increase the proportion of the tertiary industry. All cities in the province should develop new and high industries and adjust their industrial layout.

(2) Combine history with modernity and carry forward the spirit of the city

Anhui province is an important birthplace of China’s prehistoric civilization, with four cultural circles: Huai river culture, Luzhou culture, Wanjiang culture and Hui culture. Now, the Yangtze River delta city cluster formed by Anhui, Jiangsu, Zhejiang and Shanghai has become one of the six world-class city clusters in the world. Anhui is also the first pilot province of new urbanization in China. Each city should make full use of its own history and culture, combined with modern civilization, to create a distinctive city name card.

(3) Joint efforts of the whole province to build a “green Anhui”

The government should increase investment and supervision, improve infrastructure, and vigorously advocate green, civilized and healthy lifestyles through multiple channels. We will vigorously develop new industries such as new energy sources, new materials, advanced energy conservation and environmental protection.

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