# EVALUATION OF THE SUITABILITY OF HUMAN SETTLEMENT ENVIRONMENT IN SHANGHAI CITY BASED ON FUZZY CLUSTER ANALYSIS

by

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*Fuzzy clustering analysis is a mathematical method to classify objective things according to their characteristics, affinity, and similarity by establishing fuzzy equivalence relations. It can solve the ambiguity of environment classification better. With the development of cities, the effluent and waste gas discharged by industrial activities have a great impact on the living environment of cities. This paper builds up an evaluation system of urban residential environment by considering society, economy, resources and environment conditions, the results show that the human settlement suitability of Shanghai became better during 2001 to 2016.*

Key words: *human settlement environment, suitability evaluation, fuzzy mathematics, cluster analysis*

## Introduction

The urban human settlement environment is a comprehensive concept, which not only refers to the tangible space for human habitation and activities, but also includes the population, resources, environment, social policies and economic development [1, 2], and involves the activities such as residence, work, culture, education and entertainment carried out under a certain geographical system background [3, 4]. The study of human settlement environment began from the definition of *human settlement science* summarized by the Greek scholar Doussadias after the World War II, focusing on the comprehensive study of human settlement environment. Domestic research on human settlement environment began in the early 1980's. In 1995, Wu Liangyong [5] clearly put forward the concept of *human settlement environment* and expounded its main contents. With the increase of quantitative research, the emphasis is to build a good evaluation system of human settlement environment. In this paper, the living conditions, ecological environment quality, infrastructure and public service facilities reflecting the living environment are evaluated and studied. The time scale from 2001 to 2016 is selected and fuzzy cluster analysis method is used to evaluate and analyze the suitability of the living environment in Shanghai. An in-depth study of the suitability of the urban residential environment is conducive to promoting the construction of the urban residential environment, building a livable city in an all-round way and improving the suitability of the urban residential environment in various administrative regions.

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## Study area and data

### *Study area*

Shanghai city is located in the 18'E ~ 121°57'116°E, 30°45'N ~ 35°20'N, the leading edge of the Yangtze river delta, the east faces the east China sea, the south is near Hangzhou bay, the west is adjacent to Jiangsu and Zhejiang provinces, and the north the Yangtze river estuary. The transportation is convenient, and its geographical position is very superior, it is the world's third largest and China's largest port, being an important part of the Yangtze river delta region. As the economic center of China, Shanghai is striding forward to the goal of becoming a modern international metropolis, shouldering the important task of facing the world, serving the whole country and linking with the Yangtze river delta, and playing a very important role in the national economic construction and social development. Shanghai is under pressure from a growing population and resource and environmental constraints as it moves toward global urban excellence. At the same time, it brings pressure and difficulties to build a suitable urban living environment. While ensuring the social and economic development of Shanghai, it is the top priority of its work to ensure a good urban living environment.

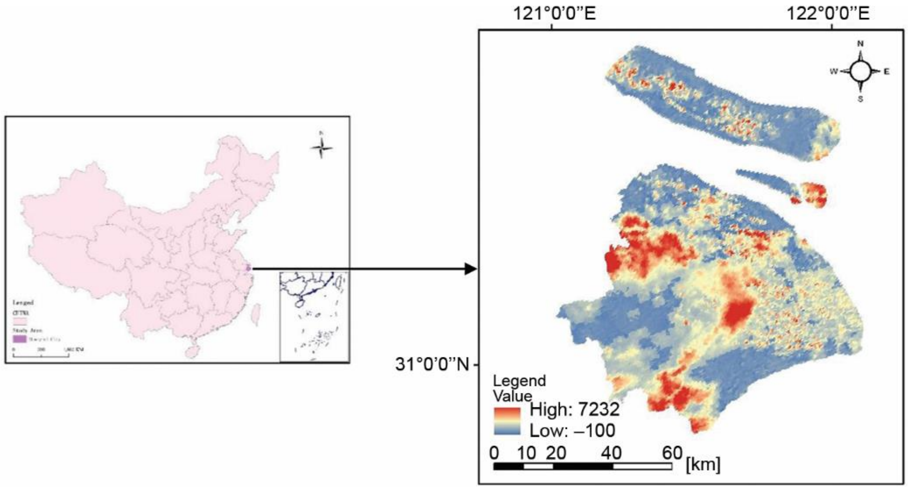


**Figure 1. Location of study area**

### *Data description*

The data required for the evaluation index system of the suitability of Shanghai's human settlement environment constructed in this study are derived from the statistical yearbook of Shanghai from 2001 to 2016 and the Shanghai environmental quality bulletin published by the Shanghai Municipal Bureau of Statistics.

## Methods

### *Fuzzy clustering analysis*

Fuzzy clustering analysis is a method to discuss the quantitative classification of things from the perspective of fuzzy sets [6-8]. The fuzzy matrix is constructed according to the attributes of the research object itself, and the clustering relationship is determined according to a certain membership degree to classify the objective things [9]. Traditional clustering analysis is a kind of hard partitions, which divides every object to be identified into a certain class strictly and has a certain property. In fact, most of the objects in the state and class are intermediary, suitable for soft partition. Fuzzy clustering analysis based on fuzzy set theory provides a powerful analytical tool for this kind of soft partitions [10]. Since the samples obtained by fuzzy clustering belong to the uncertainty degree of each category, the description of the category uncertainty of samples is established, which can reflect the real world more objectively. Land suitability is a qualitative concept. The evaluation model of land suitability can be established by using fuzzy cluster analysis, which can complement each other and make up for each other, thus providing possibility for the objectivity of land suitability evaluation.

### *Establishment of evaluation model*

#### *Data standardization*

Set theory domain $U = \{u_1, u_2, \quad u_n\}$ is a classified object or element, and each element is represented by m data. For the i element, $U_i = \{x_{i1}, x_{i2}, \quad x_{in}\}$ ($i = 1, 2 \dots n$), the original data matrix is:

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

In order to eliminate the impact of dimensionality on clustering analysis, data need to be standardized before using clustering analysis, so that each index value is unified in a certain common range of data characteristics. In this study, translation-standard deviation transformation is adopted for standardization:

$$x'_{ik} = \frac{x_{ik} - \bar{x}_k}{S_k} (i = 1, 2, \cdots n; \quad k = 1, 2, \cdots, \quad m) \tag{1}$$

$$\bar{x}_k = \frac{1}{n}\sum_{i=1}^{n} x_{ik}, \quad S_k = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{ik} - \bar{x}_k)^2} \tag{2}$$

#### *Establishment of fuzzy similarity relationship*

The establishment of fuzzy similarity matrix is to mark the statistics measuring the similarity degree of the classified objects $r_{ij}(i, j = 1, 2 \dots n)$.

The direct distance method is adopted to establish the similarity relationship.

$$r_{ij} = 1 - cd_{(u_i, u_j)} \tag{3}$$

The distance here is the Euclidean distance calculation method, and $c$ is appropriately selected:

$$d(u_i, u_j) = \sqrt{\sum_{k=1}^{m}(x_{ik} - x_{jk})^2} \tag{4}$$

where $m$ is the number of indicators.

#### *Fuzzy equivalent matrix*

The matrix R obtained from the established fuzzy similarity relation is only a fuzzy similarity matrix, which needs to be transformed into an equivalent matrix for classification. Therefore, the equivalent matrix of R is obtained by direct clustering method.

*Fuzzy clustering*

For the equivalence matrix t(R), we should select an appropriate threshold value [0, 1], and conduct dynamic clustering according to the lambda intercept relation.

## Case study

### *Construction of evaluation index system*

Human settlement environment is a complex multi-system influenced by multiple factors such as society, economy, culture, politics and ecological environment [11]. Therefore, the study of human living environment needs to quantify all the elements and follow the principles of feasibility, comprehensiveness and objectivity to establish an evaluation index system that can clearly reflect the quality of human living environment. This paper selects three evaluation indexes of living conditions, ecological environment quality, infrastructure and public service facilities, and 16 individual indexes to constitute the evaluation index system of urban residential environment, tab. 1. The indicators selected involve various aspects such as society, economy, resources and environment, *etc.*, with strong pertinence and clear hierarchy, they can reflect the environmental suitability of Shanghai's residential environment comprehensively [12].

**Table 1. Evaluation index system of Shanghai urban residential environment**

| Target | Category | Indicator | Indicator meaning |
|---|---|---|---|
| Human Settlement environment | Live conditions | Living space per capita | Residential building area/resident population/, [$m^2$ per people] |
| | | Engel coefficient | The proportion of total food expenditure in total personal consumption expenditure, [%] |
| | | Residential completion floor area | The calculated gross floor area of a house surveyed on the spot after completion, [$10^4$ $km^2$] |
| | | Residential investment in the total proportion of fixed assets investment | The total amount of residential investment/fixed asset investment purchased by urban residents, [%] |
| | | The population density | Population/total area, [people per $km^2$] |
| | Ecological environment quality | $SO_2$ emissions | Total $SO_2$ emission, [$10^4$ t] |
| | | Urban sewage treatment rate | Urban treatable sewage volume/total sewage volume, [%] |
| | | Industrial wastewater discharge compliance rate | Discharge of standard wastewater/total discharge of wastewater, [%] |
| | | Green coverage | Forest area/total area, [%] |
| | | Per capita park green space | Park green area/total population/, [$m^2Λ^{-1}$] |
| | | Environmental funding as a proportion of GDP | Environmental input /GDP output, [%] |

→

**Table 1. Continuation**

| Target | Category | Indicator | Indicator meaning |
|---|---|---|---|
| | Infrastructure and public service facilities | Infrastructure investment as a share of GDP | Infrastructure investment /GDP output, [%] |
| | | Per capita road area | Total road area/total population/, $[\mathrm{m}^2\Lambda^{-1}]$ |
| | | Public transport per 10000 people | Number of public transport operation vehicles/urban population + urban temporary residents, vehicles |
| | | Hospital beds per 10000 people (beds) | Total number of hospital beds/urban population (ten thousand), beds |
| | | Number of schools (schools) | The total number of schools of various levels and types in the city, schools |

## *Evaluation*

### *Data standardization results*

**Table 2. Results of original data standardization**

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 | X14 | X15 | X16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | 0 | 1.00 | 0.18 | 0.48 | 0.00 | 0.88 | 0.00 | 0.30 | 0.00 | 0.00 | 0.56 | 0.56 | 0.00 | 0.86 | 0.71 | 1.00 |
| 2002 | 0.11 | 0.60 | 0.25 | 0.74 | 0.06 | 0.81 | 0.00 | 0.20 | 0.41 | 0.34 | 0.15 | 0.60 | 0.38 | 1.00 | 0.93 | 0.45 |
| 2003 | 0.24 | 0.37 | 0.47 | 0.87 | 0.13 | 0.77 | 0.03 | 0.20 | 0.76 | 0.50 | 0.26 | 0.48 | 0.44 | 0.76 | 0.71 | 0.35 |
| 2004 | 0.39 | 0.29 | 1.00 | 1.00 | 0.22 | 0.88 | 0.61 | 0.46 | 0.81 | 0.60 | 0.00 | 0.41 | 0.69 | 0.58 | 0.86 | 0.15 |
| 2005 | 0.44 | 0.24 | 0.76 | 0.72 | 0.29 | 1.00 | 0.68 | 0.61 | 0.88 | 0.70 | 0.93 | 0.50 | 0.70 | 0.62 | 0.93 | 0.09 |
| 2006 | 0.50 | 0.21 | 0.72 | 0.35 | 0.39 | 0.99 | 0.73 | 0.69 | 0.90 | 0.75 | 0.56 | 0.65 | 0.73 | 0.49 | 1.00 | 0.06 |
| 2007 | 0.56 | 0.20 | 0.77 | 0.13 | 0.52 | 0.96 | 0.73 | 0.72 | 0.92 | 0.81 | 0.52 | 0.76 | 0.79 | 0.42 | 0.29 | 0.00 |
| 2008 | 0.63 | 0.31 | 0.26 | 0.04 | 0.62 | 0.80 | 0.75 | 0.00 | 0.95 | 0.86 | 0.78 | 0.82 | 0.81 | 0.05 | 0.29 | 0.07 |
| 2009 | 0.72 | 0.15 | 0.06 | 0.00 | 0.72 | 0.61 | 0.74 | 0.93 | 0.95 | 0.89 | 1.00 | 1.00 | 0.89 | 0.00 | 0.29 | 0.16 |
| 2010 | 0.78 | 0.00 | 0.00 | 0.46 | 0.84 | 0.55 | 0.87 | 0.78 | 0.96 | 0.91 | 0.63 | 0.44 | 0.94 | 0.46 | 0.00 | 0.16 |
| 2011 | 0.83 | 0.20 | 0.08 | 0.82 | 0.90 | 0.20 | 0.87 | 0.81 | 0.96 | 0.92 | 0.44 | 0.16 | 0.96 | 0.31 | 0.00 | 0.15 |
| 2012 | 0.89 | 0.33 | 0.11 | 0.82 | 0.94 | 0.17 | 0.90 | 0.87 | 0.97 | 0.95 | 0.15 | 0.07 | 1.00 | 0.34 | 0.07 | 0.15 |
| 2013 | 0.93 | 0.14 | 0.01 | 0.91 | 0.99 | 0.13 | 0.93 | 0.70 | 0.97 | 0.96 | 0.07 | 0.03 | 0.35 | 0.38 | 0.14 | 0.14 |
| 2014 | 0.98 | 0.15 | 0.07 | 0.91 | 1.00 | 0.05 | 1.00 | 0.96 | 0.97 | 1.00 | 0.67 | 0.00 | 0.37 | 0.35 | 0.29 | 0.15 |
| 2015 | 1.00 | 0.10 | 0.11 | 0.90 | 0.99 | 0.00 | 1.00 | 1.00 | 0.98 | 0.33 | 0.11 | 0.12 | 0.40 | 0.43 | 0.36 | 0.19 |
| 2016 | 0.93 | 0.14 | 0.01 | 0.91 | 0.99 | 0.13 | 0.97 | 0.70 | 1.00 | 0.96 | 0.07 | 0.12 | 0.42 | 0.38 | 0.14 | 0.14 |

X*i* (*i* = 1~16) represent, respectively, living space per capita (X1), Engel coefficient (X2), Residential completion floor area (X3), Residential investment in the total proportion of fixed assets investment (X4), The population density (X5), $SO_2$ emissions (X6), Urban sewage treatment rate (X7), Industrial wastewater discharge compliance rate (X8), Green coverage (X9), Per capita park green space (X10), Environmental funding as a proportion of GDP (X11), Infrastructure investment as a share of GDP (X12), Per capita road area (X13), Public transport per 10,000 people (X14), Hospital beds per 10,000 people (beds) (X15), Number of schools (schools) (X16)

*Establish fuzzy similarity relation matrix*

According to the standardized data, the Euclidean distance method is adopted to obtain the fuzzy relation matrix R:

$$R = \begin{bmatrix}
0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
1.11 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
1.51 & 0.65 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.17 & 1.38 & 0.99 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.15 & 1.60 & 1.24 & 1.04 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.25 & 1.64 & 1.34 & 1.03 & 0.59 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.44 & 1.95 & 1.59 & 1.36 & 1.07 & 0.78 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.49 & 2.10 & 1.77 & 1.85 & 1.47 & 1.30 & 1.03 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.74 & 2.43 & 2.15 & 2.18 & 1.63 & 1.43 & 1.12 & 1.04 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.73 & 2.27 & 1.91 & 1.88 & 1.57 & 1.48 & 1.16 & 1.24 & 1.02 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.86 & 2.37 & 1.98 & 1.86 & 1.77 & 1.74 & 1.51 & 1.59 & 1.45 & 0.67 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.92 & 2.39 & 2.04 & 1.85 & 1.90 & 1.82 & 1.63 & 1.77 & 1.67 & 0.91 & 0.36 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.86 & 2.35 & 1.99 & 1.89 & 1.99 & 1.92 & 1.80 & 1.88 & 1.87 & 1.14 & 0.78 & 0.72 & 0.00 & 0.00 & 0.00 & 0.00 \\
2.93 & 2.52 & 2.16 & 2.06 & 1.86 & 1.88 & 1.82 & 1.91 & 1.69 & 1.10 & 0.79 & 0.90 & 0.68 & 0.00 & 0.00 & 0.00 \\
2.79 & 2.34 & 2.04 & 1.89 & 1.98 & 1.91 & 1.88 & 2.08 & 1.93 & 1.34 & 1.04 & 0.99 & 0.76 & 0.90 & 0.00 & 0.00 \\
2.87 & 2.35 & 1.99 & 1.87 & 1.97 & 1.89 & 1.76 & 1.83 & 1.82 & 1.08 & 0.72 & 0.67 & 0.12 & 0.69 & 0.76 & 0.00
\end{bmatrix}$$

*The fuzzy equivalent matrix is obtained as follows*

$$R = \begin{bmatrix}
1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.62 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.49 & 0.78 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.26 & 0.53 & 0.66 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.27 & 0.46 & 0.58 & 0.65 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.23 & 0.44 & 0.54 & 0.65 & 0.80 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.17 & 0.34 & 0.46 & 0.53 & 0.64 & 0.73 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.15 & 0.29 & 0.40 & 0.37 & 0.50 & 0.56 & 0.65 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.07 & 0.17 & 0.27 & 0.26 & 0.44 & 0.51 & 0.62 & 0.65 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.07 & 0.23 & 0.35 & 0.36 & 0.46 & 0.49 & 0.61 & 0.58 & 0.65 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.03 & 0.19 & 0.33 & 0.37 & 0.40 & 0.41 & 0.48 & 0.46 & 0.50 & 0.77 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.00 & 0.18 & 0.31 & 0.37 & 0.35 & 0.38 & 0.45 & 0.40 & 0.43 & 0.69 & 0.88 & 1.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.03 & 0.20 & 0.32 & 0.36 & 0.32 & 0.35 & 0.39 & 0.36 & 0.36 & 0.61 & 0.73 & 0.75 & 1.00 & 0.00 & 0.00 & 0.00 \\
0.00 & 0.14 & 0.26 & 0.30 & 0.37 & 0.36 & 0.38 & 0.35 & 0.42 & 0.62 & 0.73 & 0.69 & 0.77 & 1.00 & 0.00 & 0.00 \\
0.05 & 0.20 & 0.30 & 0.36 & 0.32 & 0.35 & 0.36 & 0.29 & 0.34 & 0.54 & 0.65 & 0.66 & 0.74 & 0.69 & 1.00 & 0.00 \\
0.02 & 0.20 & 0.32 & 0.36 & 0.33 & 0.36 & 0.40 & 0.38 & 0.38 & 0.63 & 0.75 & 0.77 & 0.96 & 0.77 & 0.74 & 1.00
\end{bmatrix}$$

*Intercept $\lambda$ value for clustering*

The fuzzy equivalence matrix is clustered, and the normal classification relation is obtained by taking different threshold value $\lambda$ [0, 1] with the direct clustering method. The dynamic clustering graph is established by using the system clustering method, as shown in fig. 2.

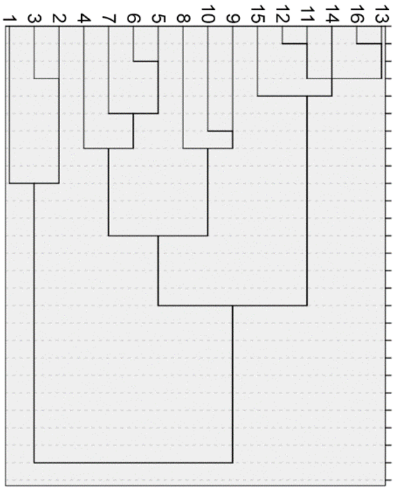


**Figure 2. Fuzzy clustering diagram of human settlement environment indicators**

As can be seen from fig. 2:

When $\lambda$ = 1, human settlement environment suitability is classified into 16 categories:

$$\{x_1\}\{x_2\}\{x_3\}\{x_4\}\{x_5\}\{x_6\}\{x_7\}\{x_8\}\{x_9\}\{x_{10}\}\{x_{11}\}\{x_{12}\}\{x_{13}\}\{x_{14}\}\{x_{15}\}\{x_{16}\}$$

When $\lambda$ = 0.96, human settlement environment suitability is classified into 14 categories:

$$\{x_1\}\{x_2\}\{x_3\}\{x_4\}\{x_5\}\{x_6\}\{x_7\}\{x_8\}\{x_9\}\{x_{10}\}\{x_{11}, x_{12}\}\{x_{13}, x_{16}\}\{x_{14}\}\{x_{15}\}$$

When $\lambda$ = 0.88, we have 13 categories:

$$\{x_1\}\{x_2\}\{x_3\}\{x_4\}\{x_5, x_6\}\{x_7\}\{x_8\}\{x_9\}\{x_{10}\}\{x_{11}, x_{12}\}\{x_{13}, x_{16}\}\{x_{14}\}\{x_{15}\}$$

When $\lambda$ = 0.84, we have 10 categories:

$$\{x_1\}\{x_2, x_3\}\{x_4\}\{x_5, x_6\}\{x_7\}\{x_8\}\{x_9\}\ \{x_{10}\}\{x_{11}, x_{12}, x_{13}, x_{14}, x_{16}\}\{x_{15}\}$$

When $\lambda$ = 0.80 we have 9 categories:

$$\{x_1\}\{x_2, x_3\}\{x_4\}\ \{x_5, x_6\}\{x_7\}\ \{x_8\}\ \{x_9\}\ \{x_{10}\}\{x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

When $\lambda$ = 0.76, we have 8 categories:

$$\{x_1\}\{x_2, x_3\}\ \{x_4\}\ \{x_5, x_6, x_7\}\{x_8\}\ \{x_9\}\ \{x_{10}\}\{x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

When $\lambda$ = 0.73, we have 7 categories:

$$\{x_1\}\{x_2, x_3\}\{x_4\}\{x_5, x_6, x_7\}\{x_8\}\{x_9, x_{10}\}\{x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

When $\lambda$ = 0.65, we have 5 categories:

$$\{x_1\}\{x_2, x_3\}\{x_4, x_5, x_6, x_7\}\{x_8, x_9, x_{10}\}\{x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

When $\lambda$ = 0.53, we have 4 categories:

$$\{x_1, x_2, x_3\}\{x_4, x_5, x_6, x_7\}\ \{x_8, x_9, x_{10}\}\{x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

When $\lambda$ = 0.47, we have 3 categories:

$$\{x_1, x_2, x_3\}\{x_4, x_5, x_6, x_7, x_8, x_9, x_{10}\}\{x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

When $\lambda$ = 0.38, we have 2 categories:

$$\{x_1, x_2, x_3\}\{x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

When $\lambda$ = 0.038, we have only 1 category:

$$\{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}\}$$

## Results

Referring to the four-level classification of the human settlement suitability evaluation system in literature [13, 14], the human settlement suitability in Shanghai is also divided into four levels. The suitability of human settlement environment was level 1 in 2001, 2002 and 2003, level 2 from 2004 to 2007, level 3 from 2008 to 2010, and level 4 from 2011 to 2016. The degree of suitability saw basically the rise. In 2003, due to the SARS epidemic and the once in 60 years hot weather, the ecological environment of Shanghai was worse than that of other years, and the economic and social development was also limited. In 2010, Shanghai hosted the world expo, which paid more attention to the urban environment and accelerated the adjustment of industrial structure, but was more affected by environmental factors (such as precipitation, water resources, *etc.*), showing a fluctuating and rapidly rising state.

## Conclusion

Fuzzy clustering method and its application in evaluating the suitability of urban residential environment in Shanghai can effectively judge the factors affecting urban residential environment. The evaluation results are consistent with the actual situation. This evaluation method objectively reflects the clustering situation of regional index environmental factors and the corresponding confidence degree under the joint action of multiple factors, which has certain guidance for the improvement of urban residential facilities, infrastructure construction and urban ecological environment governance. It also provides necessary scientific basis for local government to make macroscopic decisions on urban human settlement environment [15]. Urban human settlement environment is a complex system with many factors influencing each other, but it is difficult to replace each other. To improve the quality of urban living environment, it is necessary to strengthen macro planning, comprehensive management and sustainable and coordinated development [16].

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