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ORIGINAL RESEARCH ARTICLE

Study on evaluation and construction of ecological livable cities in western underdeveloped areas—Take Guiyang as an example

Yongjie Chen, Zhaoqiong Zhang*, Ji Wang

School of Geographical and Environmental Sciences, Guizhou Normal University, Guiyang 550001, Guizhou, China. E-mail: 1269952660@qq.com

ABSTRACT

Building a sustainable, ecological, and livable city is the inevitable choice of current urban development. The evaluation of ecologically livable cities plays an important role in guiding the construction direction and development trend of ecologically livable cities. From the aspects of economic development, infrastructure, ecological environment, and social people's livelihood, build an urban ecological livable evaluation index system, use the entropy weight method to determine the index weight, and use the matter-element analysis method to build an evaluation model to evaluate the construction of ecological livable cities in Guiyang City, Guizhou Province, from 2005 to 2015. Research shows: that from 2005 to 2015, the level of ecological livability in Guiyang increased significantly, realizing the development transformation from "not livable" to "ideal livable", but the level of "ideal livable" was unstable in 2015. The key factors restricting the construction of an ecologically livable city in Guiyang are the insufficient area of urban roads, the low comprehensive utilization rate of industrial solid waste, and the insufficient investment in the transformation and protection of the ecological environment. The matter-element model can not only obtain the comprehensive quality information of the research object but also reveal the differentiation information of individual indicators, which is suitable for the evaluation of ecologically livable cities.

Keywords: ecological livable city; evaluation of ecological livability; matter element model; less-developed regions; Guiyang City.

1. Introduction

At present, the rapid development of urbanization, excessive population aggregation, and rapid urban expansion in China are accompanied by the aggravation of the overload of resources and environmental carrying capacity, the gradual accumulation of resource and environmental risks, and the decline of ecological environment quality[1]. The quality of the urban living environment and livability have decreased significantly, and building a sustainable livable ecological city has become a necessary choice for people. How to realize the evolution of an ecologically livable city is not only an important topic

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of urban development, but also an important part of realizing the goal of a green city[2]. Through the evaluation of urban ecological livable construction, analyze the key factors restricting the construction of ecological livable cities, so as to provide reference for the theory and practice of ecological livable city construction. At present, the research methods adopted by academic circles for the evaluation of ecologically livable cities mainly include the analytic hierarchy process[3,4], principal component analysis[5], grey correlation analysis[6] and fuzzy comprehensive evaluation[7]. Other scholars use DEA model[8], the state space model[9] and other methods. These models have accumulated rich achievements in the application of eco livable city evaluation, but there are still deficiencies. Firstly, researchers usually divide the urban ecological livable level into several levels artificially, and the subjective color of the evaluation results is strong. The final evaluation result can only be reflected by the missing information between individual indicators[10,11]. The matter-element analysis method is introduced into the study, and the comprehensive evaluation results are obtained by calculating the correlation degree between the single index and each standard level, so as to obtain richer evaluation information and comprehensively reflect the ecological livable status of the city.

Guizhou Province is an underdeveloped province with the most prominent poverty problem in China. It is also an important ecological security barrier in the upper reaches of the Yangtze River and the Pearl River. It has long faced the dual tasks and pressures of environmental protection and economic development. Guiyang is the capital city of Guizhou Province, "China's summer capital", "global summer tourism city", "the first national forest city", "the first national pilot city of circular economy", "national pilot city of ecological civilization construction", "China's top ten livable cities" and "national big data industry development cluster". Guiyang City is selected as the research sample area to evaluate the construction of ecologically livable cities, in order to provide a reference for the construction of ecological civilization and sustainable economic development in Guiyang City and for the sustainable development of cities in underdeveloped areas in the West.

2. Research area and data source

2.1. Overview of the study area

Guiyang is located in the middle of Guizhou Province, on the eastern slope of Yunnan Guizhou Plateau and in the watershed between the Yangtze River and the Pearl River. It is the political, economic, scientific and technological, educational, cultural and transportation center of the province[12], with a total land area of 8,034 km^2[13]. The landform belongs to the Hilly Basin landform dominated by mountains and hills, with an average altitude of about 1,000 m, and the karst landform is widely distributed. The climate belongs to the subtropical humid monsoon climate. The average temperature in the hottest month (July) is 24 °C, and the annual average temperature is 15.3 °C. There is no intense heat in summer and abundant rainfall. It is suitable for human habitation and the growth of a variety of plants, with a forest coverage rate of 45.5%. In 2015, the total population of the whole city was 462.18 million, including 338.55 million urban people, the urbanization rate was 73.25%, the GDP was 2,891.15 billion RMB, the per capita GDP was 630,000 RMB, the tertiary industrial structure was 4.49: 38.34: 57.17, and the comprehensive economic strength ranked first in Guizhou Province[14]. In recent years, Guiyang has thoroughly implemented the five development concepts of "innovation, coordination, green, openness and sharing", vigorously implemented the "green project", "blue sky project", "clear water project" and "tranquility project" to beautify the living environment, and strived to become an innovative central city "suitable for living, industry and tourism".

2.2. Data sources

The research data comes from the Guiyang Statistical Yearbook[13], Guizhou Statistical Yearbook[14], China Urban Statistical Yearbook[15] from 2006 to

2016, the Guiyang Environmental Status Bulletin, and the Guiyang Water Resources Bulletin from 2005 to 2015.

3. Comprehensive evaluation index system and model construction

3.1. Comprehensive evaluation index system and weight

Comprehensive evaluation index system

According to the actual situation of Guiyang, comprehensively considering the economic, social, environmental and other factors, referring to the relevant research results of the index system of ecologically livable cities[5,16,18], and in accordance with the principles of scientificity, guidance and operability, 25 indicators are selected from the four aspects of economic development, infrastructure, ecological environment and social people's livelihood to build a comprehensive evaluation system of urban ecologically livable degree (**Table 1**).

Determine the index weight

The weight determination methods mainly include AHP method, coefficient of variation method, entropy weight method, etc. The entropy weight method is used to determine the index weight. The calculation formula is as follows:

$$e_i = -\frac{1}{\ln n}\sum_{j=1}^{n} f_{ij}\ln f_{ij} \tag{1}$$

$$w_i = (1 - e_i)/(m - \sum_{i=1}^{m} e_i) \tag{2}$$

In the formula, e_i represents the information entropy of the nth evaluation object and the nth evaluation index; f_{ij} represents the normalized value of index data after standardized processing. When $f_{ij} = 0$, take $f_{ij}\ln f_{ij} = 0$; W_i indicates the index weight value. The calculation results are shown in **Table 1**.

Table 1. Evaluation indicator system of urban ecological livability

Target layer	Criterion layer	Index layer	Attribute	Weight
Urban ecological livability	Economic development (0.2279)	x_1 GDP per capita (10,000 RMB)	+	0.0548
		x_2 per capita local finance_ General income (10,000 RMB)	+	0.0545
		x_3 energy consumption per unit of GDP (t standard coal)	-	0.0415
		x_4 water consumption per unit of GDP (m^3)	-	0.0330
		x_5 proportion of tertiary industry in the city's GDP (%)	+	0.0441
	Infrastructure (0.2439)	x_6 water penetration rate (%)	+	0.0171
		x_7 gas penetration rate (%)	+	0.0186
		x_8 per capita urban road area (m^2)	+	0.0942
		x_9 10,000 people own bus operation vehicles (standard set)	+	0.0189
		x_{10} 10,000 people have hospital beds (pcs.)	+	0.0398
		x_{11} 10,000 people have public library collections (10,000 volumes)	+	0.0275
		x_{12} proportion of education investment in GDP (%)	+	0.0278
	Ecological environment (0.2847)	x_{13} excellent rate of air quality (%)	+	0.0261
		x_{14} Average value of environmental noise in area (DB)	-	0.0147
		x_{15} per capita public green space area (m^2)	+	0.0407
		x_{16} greening coverage rate of built-up area (%)	+	0.0421
		x_{17} urban domestic sewage treatment rate (%)	+	0.0483
		x_{18} harmless treatment rate of municipal solid waste (%)	+	0.0290
		x_{19} comprehensive utilization rate of industrial solid waste (%)	+	0.0402
		x_{20} proportion of environmental protection investment in GDP (%)	+	0.0436
	Social livelihood (0.2435)	x_{21} per capita disposable income (10,000 RMB)	+	0.0413
		x_{22} per capita residential building area (m^2)	+	0.0913
		x_{23} population density ($person/km^2$)	-	0.0359
		x_{24} urban registered unemployment rate (%)	-	0.0384
		x_{25} Engel coefficient (%)	-	0.0366

3.2. Determination of matter-element model and classical domain

Matter element model

Matter element analysis was proposed by Professor Cai Wen in 1983. Its core is to study the possibility of expanding things and solve incompatible problems. It is suitable for multi index analysis and evaluation[19]. The influencing factors of eco livable city construction have the characteristics of diversity and fuzziness. Using matter-element analysis method, we can get more objective and scientific comprehensive evaluation results the construction of evaluation model mainly includes the following four steps[11,19–21]:

(1) Constructing urban ecological livable matter element.

Urban ecological livable *N*, evaluation index *C,* and magnitude *V* together constitute urban ecological livable matter element *R* = (*N*, *C*, *V*), which describes *N* with *n* characteristics C_1, C_2, …, C_n and corresponding magnitudes V_1, V_2, …, V_n.

(2) Determine the classical domain and node domain.

The classical domain matter element R_{oj} of urban ecological livability can be expressed as:

$$R_{oj} = (N_{oj}, C_i, V_{oji}) = \begin{bmatrix} N_{oj} & c_1 & (a_{oj1}, b_{oj1}) \\ & c_2 & (a_{oj2}, b_{oj2}) \\ & \cdots & \cdots \\ & c_n & (a_{ojn}, b_{ojn}) \end{bmatrix} \quad (3)$$

where, N_{oj} represents the *j*-Class evaluation grade of ecological livability of (*j* = 1, 2, …, *m*) the C_i divided city; represents the *i*th evaluation index V_{oji} = (a_{oji}, b_{oji}) selected; C_i Indicates the evaluation level; the range of magnitude, i.e., classical domain.

The matter-element of urban ecological livable area R_p can be expressed as:

$$R_p = (N_p, C_i, V_{pi}) = \begin{bmatrix} N_p & c_1 & (a_{p1}, b_{p1}) \\ & c_2 & (a_{p2}, b_{p2}) \\ & \cdots & \cdots \\ & c_n & (a_{pn}, b_{pn}) \end{bmatrix} \quad (4)$$

where, *P* represents the overall evaluation level of urban ecological livability. It indicates the range of V_{pi} = (a_{pi}, b_{pi}) quantity value related to the matter C_i element of the node domain, i.e., the node domain.

(3) Determine the correlation function and correlation degree.

The correlation function *K*(*x*) of urban ecological livable evaluation index is defined as:

$$K(x_i) = \begin{cases} \dfrac{-\rho(X, X_o)}{|X_o|}, X \in X_o \\ \dfrac{\rho(X, X_o)}{\rho(X, X_p) - \rho(X, X_o)}, X \notin X_o \end{cases} \quad (5)$$

where, it $K(x_i)$ represents the correlation degree of the ith index corresponding to each evaluation grade, where:

$$\begin{cases} \rho(X, X_o) = \left|X - \frac{1}{2}(a_o + b_o)\right| - \frac{1}{2}(b_o - a_o) \\ \rho(X, X_p) = \left|X - \frac{1}{2}(a_p + b_p)\right| - \frac{1}{2}(b_p - a_p) \end{cases} \quad (6)$$

where, $\rho(X, X_0)$, $\rho(X, X_p)$ respectively represent the distance from point x to interval $X_o = |a_o, b_o|$ and interval; $X_p = |a_p, b_p|10$, respectively represent the X_o quantity X_p value of the ecological livable matter element of the city to be evaluated, the quantity value range of the classical domain matter element and the quantity value range of the node domain matter element.

(4) Calculate the comprehensive correlation degree and determine the evaluation grade.

The comprehensive correlation degree N_x of the object to be evaluated with respect to K_jN_x grade *j* is:

$$K_j(N_x) = \sum_{i=1}^{n} w_i K_j(x_i) \quad (7)$$

where, it K_jx_i represents the single index N_x correlation degree () of the object to be evaluated with *j* = 1, 2, …, m respect to grade W_{ij}; evaluation index weight representation; if yes, $K_{ji} = \max\{K_j(x_i), j = 1, 2, …, m\}$, it is determined that the ith index belongs to grade j; if yes, $K_{jx} = \max\{K_j(N_x), j = 1, 2, …, m\}$, it is determined that the object N_x to be evaluated belongs to grade j.

Determination of classic domain and section domain of urban ecological livable degree evaluation

Drawing on the comprehensive evaluation research results of ecological environment, water resource carrying capacity, and land ecological security[20–22], according to the scalability of urban ecological livability, it is divided into 4 grades: ideal livability, relatively livable, critically livable and unlivable, represented by I, II, III, and IV, respectively. The evaluation of the classic domain mainly refers to the Ministry of Housing and Urban-Rural Development's "National Ecological Garden City Grading Evaluation Standards," the Ministry of Environmental Protection's "Ecological County, City and Provincial Construction Indicators (Revised Draft)" and "China Habitat Environment Award Evaluation Index System (Trial Implementation)" standard values, the national average level, the relevant research standards of other domestic cities, etc.[23,24]. See **Table 2** for the range of values.

Table 2. Range of classic domain and joint domain values

Evaluating indicator	Value range of classical domain				Section value range
	I	Π	Ш	V	
x_1	[5.5, 7)	[4, 5.5)	[2.5, 4)	[1, 2.5)	[1, 7)
x_2	[0.7, 0.9)	[0.5, 0.7)	[0.3, 0.5)	[0.1, 0.3)	[0.1, 0.9)
x_3	[0.5, 1)	[1, 1.5)	[1.5, 2)	[2, 2.5)	[0.5, 2.5)
x_4	[30, 100)	[100, 160)	[160, 220)	[220, 290)	[30, 290)
x_5	[55, 65)	[45, 55)	[35, 45)	[25, 35)	[25, 65)
x_6	[95, 100)	[90, 95)	[80, 90)	[70, 80)	[70, 100)
x_7	[95, 100)	[90, 95)	[80, 90)	[70, 80)	[70, 100)
x_8	[15, 18)	[11, 15)	[7, 11)	[4, 7)	[4, 18)
x_9	[15, 21)	[11, 15)	[7, 11)	[3, 7)	[3, 21)
x_{10}	[80, 110)	[65, 80)	[50, 65)	[30, 50)	[30, 110)
x_{11}	[1.6, 2)	[1.2, 1.6)	[0.8, 1.2)	[0.4, 0.8)	[0.4, 2)
x_{12}	[4, 5)	[3, 4)	[1.5, 3)	[0, 1.5)	[0, 5)
x_{13}	[330, 365)	[300, 330)	[270, 300)	[240, 270)	[240, 365)
x_{14}	[50, 55)	[55, 60)	[60, 65)	[65, 70)	[50, 70)
x_{15}	[13, 16)	[10, 13)	[8, 10)	[6, 8)	[6, 16)
x_{16}	[40, 45)	[30, 40)	[20, 30)	[15, 20)	[15, 45)
x_{17}	[90, 100)	[65, 90)	[40, 65)	[20, 40)	[20, 100)
x_{18}	[95, 100)	[85, 95)	[75, 85)	[65, 75)	[65, 100)
x_{19}	[90, 100)	[80, 90)	[60, 80)	[40, 60)	[40, 100)
x_{20}	[3.5, 5)	[2, 3.5)	[1, 2)	[0, 1)	[0, 5)
x_{21}	[2.2, 3.2)	[1.6, 2.2)	[1, 1.6)	[0, 1)	[0, 3.2)
x_{22}	[28, 35)	[20, 28)	[15, 20)	[10, 15)	[10, 35)
x_{23}	[300, 600)	[600, 1,400)	[1,400, 2,300)	[2,300, 3,500)	[300, 3,500)
x_{24}	[25, 35)	[3.5, 4)	[4, 4.5)	[4.5, 5.5)	[2.5, 5.5)
x_{25}	[30, 35)	[35, 40)	[40, 45)	[4.5, 50)	[30, 50)

4. Results and analysis

4.1. Calculation of evaluation results

Input the matter-element to be evaluated into the model to obtain the corresponding calculation results. Taking the index of x_1 per capita GDP (10,000 RMB) in 2015 as an example, input $x_1 = 6.3$ into Equations (5)–(7), and the correlation degrees of the index corresponding to each evaluation level are $K_1(x_1) = 0.4665$, $K_2(x_1) = 0.5335$, $K_3(x_1) = 0.7668$, $K_4(x_1) = 0.8445$. It can be determined that the index belongs to the level I, i.e., "ideal livable". Similarly, the evaluation results of other indicators can be obtained (see **Table 3**). On this basis, input the correlation degree of each index corresponding to each grade and its weight (**Table 1)** into formula (7), and then the comprehensive correlation degree of the urban ecological livable degree evaluation index (**Table 4**) can be obtained. In 2015, the comprehensive correlation degree of ecological livability degree of Guiyang corresponding to each evaluation grade was $K_1(N_{2015}) = 0.0011$, $K_2(N_{2015}) = 0.4149$, $K_3(N_{2015}) = 0.5802$, $K_4(N_{2015}) = 0.6530$. It can be determined that the ecological livability degree of Guiyang belongs to grade I, that is, "ideal livability". Similarly, the ecological livable grade of Guiyang in other years can be obtained. See **Table 4** for details.

Table 3. Correlation of the ecological livable degree evaluation indexes of Guiyang

Correlation degree	2015					2010 grade	2005 grade
	N_1	N_2	N_3	N_4	Grade		
$K_j(x_1)$	0.4665	–0.5335	–0.7668	–0.8445	Ideal livable	Critical livability	Not livable
$K_j(x_2)$	0.4525	–0.5475	–0.7738	–0.8492	Ideal livable	Critical livability	Not livable
$K_j(x_3)$	0.1200	–0.1200	–0.5600	–0.7067	Ideal livable	Critical livability	Not livable
$K_j(x_4)$	0.0907	–0.9093	–0.9512	–0.9666	Ideal livable	Ideal livable	Not livable
$K_j(x_5)$	0.2160	–0.2160	–0.6080	–0.7387	Ideal livable	More livable	More livable
$K_j(x_6)$	0.2420	–0.2420	–0.6210	–0.8105	Ideal livable	Ideal livable	Not livable
$K_j(x_7)$	0.2480	–0.2480	–0.6240	–0.8120	Ideal livable	Ideal livable	Critical livability
$K_j(x_8)$	–0.4600	–0.1514	0.2650	–0.3311	Critical livability	Not livable	Critical livability
$K_j(x_9)$	0.1333	–0.8667	–0.9200	–0.9429	Ideal livable	Critical livability	Critical livability
$K_j(x_{10})$	0.0667	–0.9333	–0.9556	–0.9667	Ideal livable	More livable	Critical livability
$K_j(x_{11})$	0.2685	–0.7315	–0.8658	–0.9105	Ideal livable	Critical livability	More livable
$K_j(x_{12})$	–0.2899	0.3100	–0.1550	–0.5171	More livable	More livable	Critical livability
$K_j(x_{13})$	0.2857	–0.2857	–0.6154	–0.7368	Ideal livable	Ideal livable	Ideal livable
$K_j(x_{14})$	–0.5933	0.2200	–0.1528	–0.3900	More livable	More livable	More livable
$K_j(x_{15})$	–0.3813	0.0167	–0.0100	–0.3734	More livable	Critical livability	Critical livability
$K_j(x_{16})$	–0.1819	0.1430	–0.5713	–0.7428	More livable	Ideal livable	Ideal livable
$K_j(x_{17})$	0.3840	–0.6160	–0.8903	–0.9360	Ideal livable	More livable	Not livable
$K_j(x_{18})$	0.0180	–0.0180	–0.6727	–0.8036	Ideal livable	Ideal livable	Critical livability
$K_j(x_{19})$	–0.8372	–0.7965	–0.5930	0.4070	Not livable	Not livable	Not livable
$K_j(x_{20})$	–0.8343	–0.7100	–0.4200	0.4200	Not livable	Not livable	Critical livability
$K_j(x_{21})$	0.4759	–0.5241	–0.7026	–0.7837	Ideal livable	More livable	Not livable
$K_j(x_{22})$	0.1029	–0.8971	–0.9520	–0.9640	Ideal livable	More livable	More livable
$K_j(x_{23})$	–0.3548	0.4584	–0.3939	–0.6667	More livable	More livable	More livable
$K_j(x_{24})$	0.3800	–0.3800	–0.5867	–0.6900	Ideal livable	Ideal livable	More livable
$K_j(x_{25})$	0.1560	–0.8440	–0.9220	–0.9480	Ideal livable	More livable	More livable

Table 4. Ecological livable degree evaluation results of Guiyang

Comprehensive correlation degree	N_1	N_2	N_3	N_4	Grade
$K_j(N_{2005})$	–0.5613	–0.3690	–0.2913	–0.1057	Not livable
$K_j(N_{2006})$	–0.5212	–0.3039	–0.2036	–0.1114	Not livable
$K_j(N_{2007})$	–0.4729	–0.2360	–0.1530	0.1550	Critical livability
$K_j(N_{2008})$	–0.4588	–0.2437	–0.2239	–0.1681	Not livable
$K_j(N_{2009})$	–0.3863	–0.2392	–0.2347	–0.2545	Critical livability
$K_j(N_{2010})$	–0.3200	–0.1624	–0.2268	–0.3308	More livable
$K_j(N_{2011})$	–0.2758	–0.1599	–0.2759	–0.3359	More livable
$K_j(N_{2012})$	–0.2102	–0.1410	–0.3329	–0.4106	More livable
$K_j(N_{2013})$	–0.0592	–0.1519	–0.3756	–0.5557	Ideal livable
$K_j(N_{2014})$	–0.0436	–0.3055	–0.4852	–0.5933	Ideal livable
$K_j(N_{2015})$	–0.0011	–0.4149	–0.5802	–0.6530	Ideal livable

4.2. Analysis of comprehensive evaluation results of ecological livability in Guiyang

It can be seen from **Table 4** that the ecological livable level of Guiyang City from 2005 to 2006 and 2008 was "not livable", 2007 and 2009 were "critical livable", 2010 to 2012 were "more livable", and 2013 to 2015 were "ideal livable". Although the grade change fluctuated from 2007 to 2009, generally speaking, the ecological livability of Guiyang showed a leap from "not livable" to "ideal livable" from 2005 to 2015. The comprehensive correlation values from 2005 to 2015 are all in [1,0], indicating that the evaluation grade does not fully meet the standard requirements but has the conditions for transformation.

From the change process, $K_4(N_{2005}) > K_4(N_{2006})$ shows that although the ecological livable level of Guiyang was not livable from 2005 to 2006, the situation of not livable" has improved. From 2007 to 2009, the grade began to improve, but showed a fluctuating change of" critical livability is not livable, critical livability", indicating that the ecological livable grade of Guiyang is relatively unstable, and the urban ecological livable construction is vulnerable to the influence of relevant factors. The grade of more livable" has not changed from 2010 to 2012, but $K_2(N_{2012}) > K_2(N_{2011}) > K_2(N_{2010})$, reflecting the increase of urban ecological livability year by year. From 2013 to 2015, it reached the ideal livable" level, but the comprehensive correlation value is less than 0, which does not meet the standard requirements, indicating that there are weak links in the development of ecological livable in Guiyang. The above analysis shows that in the past 10 years, Guiyang has continuously explored the ecological development mode and actively promoted the construction of ecological civilization city, which has played a role in promoting the improvement of urban ecological livability. However, there are still some deficiencies in the construction of an ecological livable city that need to be further improved.

4.3. Analysis of single index evaluation results of ecological livability in Guiyang

According to the differentiation information provided by a single evaluation index, from 2005 to 2015, many indexes in Guiyang showed different degrees of grade rise, and 17 indexes reached the level of ideal and livable (**Table 3**). Among them, per capita GDP, per capita general local financial income, energy consumption per unit GDP, water consumption per unit GDP, water penetration rate, urban domestic sewage treatment rate, per capita disposable income, and other indicators have realized the transformation from "not livable" to "ideal livable", which has made an important contribution to the improvement of ecological livability in Guiyang. Research findings: since 2005, the economy of Guiyang has developed rapidly, the income level of residents has been continuously improved, and the awareness of urban sustainable development has been strengthened. Continuously optimize and upgrade the industrial structure, actively develop the circular economy, and strive to reduce energy and resource consumption. Continue to strengthen urban infrastructure construction, strengthen urban environmental improvement, effectively improve residents' production and living conditions, and make important contributions to the construction of an ecologically livable city.

Among the indicators that fail to meet the "ideal livable", the per capita urban road area, the comprehensive utilization rate of industrial solid waste, the proportion of environmental protection investment in GDP, and other indicators have decreased or are at a low level, which has become an important factor restricting the development of eco livable cities in Guiyang. Although Guiyang has been committed to urban road construction, due to the limitations of natural and geographical conditions in mountainous areas, the construction of transportation infrastructure is difficult and the development is slow. In 2015, the per capita urban road area of Guiyang was only 9.94 m^2[12], far lower than the national per capita of 15.06 m^2[14]. We also need to strengthen the construction and improve the urban road traffic environment. With the acceleration of urbanization, the pressure on the urban ecological environment is increasing, while the proportion of environmental protection investment in GDP in Guiyang is decreasing, from 1.18% in 2005 to 0.58% in 2015[13]. The investment in environmental protection is inconsistent with the speed of economic development, affecting the sustainable development of the city. In addition, the comprehensive utilization rate of industrial solid waste has been maintained at about 50%[12] for a long time, which is not conducive to the development of an urban circular economy.

5. Conclusions and discussions

From 2005 to 2015, the ecological livability of Guiyang City significantly improved, and the livable level jumped from not livable to ideal livable, but the correlation of the "ideal livable" level in 2015 was very weak. Lagging urban road construction, poor reuse of industrial solid waste, and insufficient capital investment in ecological and environmental protection are the main factors limiting the further improvement of ecological livability in Guiyang. Therefore, improving the urban road network system, promoting the innovation of solid waste treatment technology, and reforming the investment and financing system of environmental protection are the key points of the construction of eco livable city in Guiyang in the future.

In traditional evaluation methods, the evaluation results cannot show the grade subordination and change information of a single index, while the matter-element model can not only obtain the comprehensive evaluation results of urban ecological livability but also determine the livable grade of a single index, which is convenient for accurate analysis of the problems and deficiencies existing in the construction of ecological livable city.

As a research method, the research attempts to apply the matter-element model to the evaluation of ecologically livable cities, and basically achieve the expected purpose. As there is no unified standard for the scope of the classical domain and festival domain and the availability of data is limited, the improvement of the urban ecological livability evaluation index system and the threshold definition of the classical domain and festival domain need to be further studied.

Conflict of interest

The authors declare no conflict of interest.

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