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Research Article

Dynamic Evaluation of Urban Sustainability Based on ELECTRE: A Case Study from China

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Sustainable urban evaluation is an important management tool to grasp the status of urban development in real time and to make policy adjustments. In this study, the evaluation indicator system is constructed from the three dimensions of economy, society, and environment. The ELECTRE (elimination et choice translation reality) model based on information entropy weighting is employed to evaluate urban sustainability. The model applies three-dimensional data to explore the dynamics of sustainable urban development. The spatial measurement model is used to explore the spatial effects of cities. Finally, 17 cities in Henan Province from 2013 to 2017 are used as case studies for urban sustainable development evaluation. The results show that, in 2013–2017, the sustainability of cities such as Zhengzhou, Luoyang, and Sanmenxia was stable at a high level, while the sustainability levels of Kaifeng, Luohe, and Xinyang showed a fluctuating downward trend, and the sustainability levels of Puyang, Nanyang, and Xinxiang showed a fluctuating upward trend. Among the 17 cities, Zhengzhou has the highest sustainability level and its economic and social sustainability levels are significantly better than other cities. Zhoukou is the city with the lowest level of sustainability. In addition, from 2013 to 2016, the level of urban sustainability was not spatially correlated but gradually presented positive spatial correlation and the characteristics of clustering distribution in 2017. The cities such as Zhengzhou, Luoyang, and Jiaozuo are mainly represented by "high-high (H-H)" agglomeration. In contrast, Shangqiu, Zhoukou, and Zhumadian are mainly represented by "low-low (L-L)" agglomeration. This research provides suggestions and decision-making support for promoting urban sustainability.

1. Introduction

As a carrier of human habitation, cities are closely related to people's daily lives. It is estimated that, by 2050, 67% of the population in the world will live in cities [1]. Since the reform and opening up in the late 1970s, China has experienced rapid urbanization. Especially, in the past 30 years, China has significantly accelerated urbanization and achieved a massive rural population transferring to cities. The urbanization rate in China increased from 17.4% in 1978 to 59.58% in 2018 [2]. However, with the acceleration of urbanization, while promoting local economic prosperity and improving people's living standards, which also brings severe ecological and social problems [3]. For example, a series of problems have appeared, such as severe air pollution, water quality degradation, energy consumption, resource scarcity, significantly increased temperature difference between urban and suburban areas, and decreased local plant species [4]. Therefore, how to maximize the resource utilization rate of urban socioeconomic activities, minimize the negative impact on the environment in the process of urban development and solve the problem of sustainable and coordinated development between economy, society, and environment in the process of urbanization are the critical research topics in the world today.

In 2015, the United Nations launched the 2030 Agenda for Sustainable Development, which called on countries to take action towards the achievement of 17 sustainable development goals over the next 15 years. Among them, Goal 11 is "to build an inclusive, safe, resilient sustainable city and human settlements". As a significant concentration of population, the sustainable development of cities has become a top priority. In the processes of sustainable urban construction, the policy decision-makers need to resort to evaluation indicators and methods to assess the status of sustainable urban development and make a comparison against other cities. They can recognize the strengths and weaknesses from perspectives of society, economics, and environment after one period, which supports them in making the development planning and correct policy interventions to guarantee the goal of sustainable urban development [5]. Therefore, the evaluation of urban sustainability is an important aspect and plays a crucial role in sustainable urban development. Many scholars have conducted extensive research on urban sustainability evaluation [5–10]. However, most of these studies adopt a single comprehensive evaluation method for static evaluation, which cannot understand the dynamic status of sustainable urban development. Therefore, to compare the level of sustainable development of each city in different periods, it is necessary to carry out the dynamic evaluation.

Realistic urban evaluation of sustainability require the followings: (1) the integration of diverse information concerning economic, social, environmental, and other objectives; (2) the handling of conflicting aspects of these objectives as a function of the views and opinions of the individuals involved in the evaluation process. The evaluation of urban sustainability is, therefore, increasingly regarded as a typical decision-making problem that could be handled by multicriteria decision aid (MCDA) methods. ELECTRE (elimination et choice translation reality) is a multicriteria decision-making tool. The basic idea is to eliminate the inferior schemes by constructing a series of weak dominance relations to gradually reduce the scheme set until the decision-maker can select the most satisfactory scheme from them. ELECTRE is a solution to deal with the multicriteria decision making for finite schemes. Because of its easy understanding principle, concise and straightforward logic, and good interactivity, it has been widely used in many areas [11, 12]. Kaya and Kahraman [13] combined the AHP (analytic hierarchy process) and ELECTRE methods for environmental impact assessment. Hatami-Marbini et al. [14] evaluated the safety and health of hazardous waste recycling facilities using the fuzzy group ELECTRE method. Comanita et al. [15] employed the ELECTRE method to assess the economic and environmental performance of bioplastics. In the ELECTRE method set, ELECTRE II focuses on the problem of ranking solutions with explicit decision-making data. Gao and Chen [16] proposed a simplified ELECTRE II ranking model. This model not only avoided the significant differences caused by the subjectivity of the threshold in the traditional ELECTRE method but also facilitated the ranking results based on the obtaining net superiority index value. Therefore, it avoided the complicated process of ranking solutions based on the strength/weakness relationship diagram and subjectively setting multiple thresholds. Besides, the traditional ELECTRE method is suitable for the static evaluation of two-dimensional data and cannot compare the overall level of multiple systems at different periods. This study builds an urban sustainability evaluation index system, whose data are expressed by three-dimensional data. A dynamic evaluation method based on ELECTRE is proposed to evaluate the urban sustainability of 17 prefecture-level cities in Henan Province from 2013 to 2017. The method can get the evaluation result of each period for objects and the overall evaluation value and the ranking results in a certain period for objects.

Henan is a typical landlocked province in China, with a large population and few resources, and rapid urbanization in recent years, highlighting the urban sustainability. Its pattern of development and the problems it encounters in the process of development is very representative of China. Therefore, it is typical to study the urban sustainability in Henan Province. The research methods and findings are typical of the nation.

The remainder of the paper is organized as follows: Section 2 provides a literature review of urban sustainability and evaluation methods. Section 3 constructs the urban sustainability evaluation indicator system from three dimensions: economy, society, and environment. Section 4 introduces the material and methods. Section 5 describes the result and discussion of this paper. Section 6 presents the research conclusion, limitations, and future research of this paper.

2. Literature Review

2.1. Urban Sustainability. Since the early 1990s, the concepts of sustainability and sustainable development have been applied to urban planning and design [17], leading to the emergence of urban sustainability and sustainable urban development. United Nations Centre for Human Settlements defines a sustainable city as that has achieved sustainable development in social, economic, and physical aspects and that possesses the natural resources on which sustainable development depends. Camagni [18] defined sustainable urban development as a process of synergistic integration and co-evolution between the various subsystems (economic, social, natural, and environmental) that make up a city. It is necessary to ensure that the local population's long-term health does not decline, does not damage the surrounding area's development potential, and reduces the harmful effects of development on the biosphere. Hamilton et al. [19] believed that urban sustainability refers to "the process of developing a built environment that meets people's needs while avoiding unacceptable social or environmental impacts". Zhao [20] argued that a sustainable city can maintain and improve urban ecosystem services and provide sustainable welfare to its inhabitants. Bibri and

Krogstie [21] believed that urban sustainable development strategies long-term goals, including environmental protection and integration, economic development and regeneration, and urban social equity and justice. In other words, sustainable urban development should improve the quality of life, reduce resource demand, and environmental impacts by providing healthy, livable, and prosperous human settlements to avoid burdening future generations with potential environmental degradation or ecological deficiencies. Wu et al. [22] defined urban sustainability as an adaptive process that promoted and maintained a virtual cycle between ecosystem services and human well-being by coordinating ecological, economic, and social actions to respond to changes inside and outside the city. Dias et al. [23] argued that urban sustainability was the coordinated development of three critical systems of environment, economy, and society, which provided goals, foundations, and conditions for sustainable urban development. Yang et al. [3] believed that sustainable urban development meant dividing urban systems from ecological inputs, social and economic benefits. It also included adjusting the dynamic balance between ecological investment and urban social, economic and environmental benefits, seeking maximize social, economic and environmental benefits, and pursuing the sustainable development of the city in time and space. In general, urban sustainability aims to improve long-term human well-being by balancing three aspects of sustainability: minimizing resource consumption and environmental damage, maximizing resource efficiency, and ensuring fairness and democracy [24].

2.2. Evaluation of Urban Sustainability. Sustainable development has gradually become a concept that governments, organizations, and industries are eager to adhere to. Evaluating sustainability quantitatively is an essential part of sustainability science research [22]. Agenda 21, adopted at the first Earth Summit in Rio DE Janeiro, Brazil, in 1992, called for the assessment methodologies of sustainable development. In the following years, many studies on sustainable development assessment have emerged [25–28].

Urban sustainability evaluation can help city managers to clearly understand the current level of sustainable urban development to make reasonable development plans [29]. Simultaneously, the evaluation of urban sustainability is a complex process with a strict system, an extended period, and a broad spatial scale. Therefore, scholars have developed many models and methods for assessing urban sustainability. Dijk and Zhang [30] adopted the Urban Sustainable Development Index to measure the sustainability of four medium-sized cities in China from three aspects: urban status, urban coordination, and urban potential. Ding et al. [31] proposed an inclusive framework for sustainable city assessment in developing countries, entitled "trinity of cities sustainability from spatial, logical and time dimensions". Zinatizadeh et al. [32] evaluated and predicted urban sustainability in different areas of Kermanshah city of Iran from three aspects of social welfare progress, economic growth, and environmental protection. Yi et al. [29] evaluated the sustainability of 17 cities in Shandong Province from three aspects of the economy, society, and environment using the deviation maximization method.

In addition, multicriterion decision-making analysis (MCDA) is considered an appropriate tool for sustainability assessment by considering different sustainability perspectives, including stakeholders, values, uncertainties, and intergenerational and internal considerations [33]. MCDA consists of a set of methods that allow for the explicit consideration of multiple criteria to support individuals or groups in the ranking, selecting, and/or comparing different alternatives (e.g., products, technologies, and strategies) [34]. The most commonly used MCDA methods include AHP (analytic hierarchy process), TOPSIS (technique for order preference by similarity to an ideal solution), ELECTRE (elimination et choice translation reality), and PROMETHEE (preference ranking organization method for enrichment evaluation) [35–38]. The MCDA methods are grouped based on three underlying theories: utility function, outranking relation, and decision rules [39, 40]. Among them, theory-based utility approaches (especially, multi-attribute utility theory and AHP) and outranking relation-based approaches (especially ELECTRE and PROMETHEE) are considered the most widely used MCDA tools in sustainability research [41]. In terms of urban sustainability, an increasing number of studies are beginning to evaluate the level of urban sustainability using the MCDA methodology. Ding et al. [7] used the TOPSIS-Entropy method to quantitatively evaluate the sustainable development level of 287 cities in China from three aspects of society, economy, and environment. Lu et al. [38] applied the TOPSIS method to measure and rank the sustainability of the selected 15 typical resource-based cities in northeast China. Liang et al. [8] developed a principal component analysis (PCA) and Grey TOPSIS methodology to measure urban sustainability for 13 cities in Jiangsu province from five aspects: environmental capacity, government supports, cultural entertainment, social security, and economic development. Tang et al. [5]proposed a modified TOPSIS model based on grey relational analysis to assess the sustainability of cities in three dimensions: economic, social, and ecological.

From the above literature, it can be seen that the urban sustainability evaluation method based on the indicator system has been extensively studied. At the same time, since urban sustainability evaluation is a multicriteria decision problem, the MCDA approach has been widely used. However, there is a lack of dynamic assessment and spatial agglomeration analysis to test the effects of sustainable policy implementation in cities.

3. Urban Sustainability Evaluation Indicator System

It is difficult to evaluate the sustainable development level of a city because we cannot fully grasp its development situation. However, we can have a detailed understanding of the macro situation through some micro and operable fragments of information in the system. The index system construction decomposes a complex and abstract problem into several concrete operable subsystems [29]. Based on the literature review, this study constructs an urban sustainability evaluation index system covering three dimensions of economy, society, and environment. Specific indicators are shown in Table 1.

3.1. Economic Indicators. Economic indicators reflect the economic development of a city. Economic development is the core issue of sustainable development for a city, which is the fundamental guarantee for social development, environmental improvement, and people's material and cultural life quality. At the same time, economic sustainability is also a guarantee for the sustainable development of cities [29, 43]. Therefore, in this study, GDP per capita, per capita investment in fixed asset, actually per capita of foreign capital utilized, the proportion of GDP contributed by tertiary industry, total import and export volume, retail sales of consumer goods, and urbanization rate are selected as the indicators to measure the sustainable development of the urban economy.

3.2. Social Indicators. Social sustainability considers both the basic needs of the present and the development of future generations [29]. It is the ultimate goal of urban sustainable development [43]. Social sustainability aims to promote the continuous improvement of people's quality of life and social spiritual civilization and provide people with a safe and comfortable living environment, good education opportunities, and social security [46]. Therefore, the establishment of social sustainability indicators should be people-oriented [5]. In this study, per capita disposable income of urban residents, urban unemployment rate, natural population growth rate, beds of medical institutions for per 10,000 people, number of buses for per 10,000 persons, per capita green area, per capita water resource, the coverage rate of old-age insurance, the proportion of government budgetary expenditure in education, and the proportion of government budgetary expenditure in science and technology are selected as the indicators to measure the sustainable social development of urban.

3.3. Environmental Indicators. Environmental sustainability is the foundation for urban sustainable development [43]. The low environments not only constrain the healthy development of the economy but also harm human health. Environmentally sustainable cities show a strong awareness and action for environmental protection, urban greening construction, pollution control, and treatment [29]. Therefore, in this study, the comprehensive utilization rate of industrial solid waste, industrial soot and dust emissions, industrial wastewater emissions, green coverage rate of built-up areas, annual average concentration of PM2.5, centralized sewage treatment rate, and household waste treatment rate is selected as environmental sustainability evaluation indicators.

4. Materials and Methods

4.1. Evaluation Framework. The evaluation process represents the flow and combination of information between indicators and alternatives, as well as the integration of information between subject and objective. Its goal is to provide an evaluation value, selection, and ranking. In most cases, it is ranking from the best to the least optimal option [47]. The basic procedure to solve the evaluation problem includes clarifying the purpose of evaluation, identifying relevant indicators and alternatives, obtaining indicator weights, selecting or constructing aggregation models, and calculating and ranking evaluation values. Based on this procedure, the urban sustainability evaluation processes are shown in Figure 1.

4.2. Research Area and Data Source. In this section, 17 cities in Henan Province are taken as the specific research area based on the economic-social-environmental framework. Based on various indices data of each city, the current situation of sustainable urban development in Henan Province is studied, which can provide a reference for the sustainable construction of each city. The distribution of cities is shown in Figure 2.

The rapid urbanization process of Henan Province has not only resulted in a vast increase in the demand for natural resources but also generates environmental problems. Exploring the dynamic development process of urban sustainability is crucial to improve environmental quality during the urbanization process and resultant urban development of these fast-growing regions. For this reason, Henan Province is seen as an appropriate study area to uncover the dynamic process of urban sustainability.

The data of the indicators in this study were collected from the Henan Province Statistical Yearbook (2014–2018) and China City Statistical Yearbook (2014–2018). The indicator data of the 17 cities in Henan Province from 2013 to 2017 were derived.

4.3. The Indicator Weight Determining Method—Entropy Method. The entropy method was first developed in thermodynamics and was further introduced to measure information or uncertainty in information theory [48]. This particular approach was gradually used in social science for determining the weights in evaluating performance and sustainability [32, 48, 49]. The basic logic behind such an approach is that when the index data contains more effective information, the entropy value is smaller, and the weight would be more extensive. The specific steps of this method are as follows:

Step 1. Constructing decision-making matrix: this evaluation system has m cities and n indicators. Let $X = (x_{ij})m \times n$ be the decision-making matrix and x_{ij} ($i = 1, 2, 3, \ldots, m$, $j = 1, 2, 3, \ldots, n$) be the index value.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}. \tag{1}$$

Table 1: Urban sustainability evaluation indicator system.

Dimension	Code	Indicator	Unit	Property	References
Economy	C1	GDP per capita	Yuan	Benefit	Yi et al. [29]; Tang et al. [5]; Zhang et al. [10]; Ding et al. [7]; Lu et al. [38]; Xu et al. [9]; Yi et al. [42];
	C2	Per capita investment in fixed asset	Yuan	Benefit	Yi et al. [29]; Yi et al. [42]; Lu et al. [38]; Li et al. [43];
	C3	Amount of foreign capital utilized actually per capita	Dollar	Benefit	Yi et al. [29]; Yi et al. [42]; Li et al. [43];
	C4	Proportion of GDP contributed by tertiary industry	%	Benefit	Yi et al. [29]; Zhang et al. [10]; Ding et al. [7];Liang et al. [8]; Lu et al. [38]; Xu et al. [9]; Yi et al. [42];
	C5	Total import and export volume	10000 Dollar	Benefit	Tang et al. [5]; Lu et al. [38];
	C6	Retail sales of consumer goods	10000 Yuan	Benefit	Tang et al. [5]; Zhang et al. [10]; Lu et al. [38];Xu et al. [9]; Yi et al. [42];
	C7	Urbanization rate	%	Benefit	Yi et al. [29];
Society	C8	Per capita disposable income of urban residents	Yuan	Benefit	Tang et al. [5]; Ding et al. [7]; Lu et al. [38]; Yi et al. [42];
	C9	Urban unemployment rate	%	Cost	Yi et al. [29]; Tang et al. [5]; Zhang et al. [10]; Ding et al. [7]; Lu et al. [38]; Xu et al. [9]; Yi et al. [42];
	C10	Natural population growth rate	‰	Benefit	Lu et al. [38]; Yi et al. [42];
	C11	Beds of medical institutions for per 10,000 people	Unit	Benefit	Yi et al. [29]; Liang et al. [8]; Xu et al. [9]; Yi et al. [42];Zhang et al. [10];
	C12	Number of buses for per 10,000 people	Vehicle	Benefit	Ding et al. [7]; Xu et al. [9];
	C13	Per capita green area	㎡	Benefit	Yi et al. [29]; Lu et al. [38]; Zhang et al. [10];
	C14	Per capita of water resource	m3	Benefit	Yi et al. [29]; Tang et al. [5]; Zhang et al. [10];
	C15	Coverage rate of old-age insurance	%	Benefit	Yi et al. [29]; Liang et al. [8];
	C16	Proportion of government budgetary expenditure in education	%	Benefit	Yi et al. [29]; Ding et al. [7]; Liang et al. [8]; Lu et al. [38]; Xu et al. [9];
	C17	Proportion of government budgetary expenditure in science and technology	%	Benefit	Yi et al. [29]; Ding et al. [7]; Lu et al. [38]; Xu et al. [9];
Environment	C18	Comprehensive utilization rate of industrial solid wastes	%	Benefit	Yi et al. [29]; Tang et al. [5]; Zhang et al. [10]; Ding et al. [7]; Liang et al. [8]; Yi et al. [42]
	C19	Industrial soot and dust emissions	Ton	Cost	Yi et al. [29]; Zhang et al. [10]; Lu et al. [38]; Yi et al. [42];
	C20	Industrial waste water emissions	10,000 Ton	Cost	Yi et al. [29]; Tang et al. [5]; Zhang et al. [10]; Lu et al. [38]; Yi et al. [42];
	C21	Green coverage rate of built-up areas	%	Benefit	Tang et al. [5]; Zhang et al. [10]; Ding et al. [7]; Liang et al. [8]; Lu et al. [38]; Xu et al. [9];
	C22	Annual average concentration of PM2.5	Ug/m³	Cost	Ding et al. [7];Han et al. [44];He et al. [45]; Xu et al. [9];
	C23	Centralized sewage treatment rate	%	Benefit	Ding et al. [7]; Liang et al. [8]; Xu et al. [9];
	C24	Household waste treatment rate	%	Benefit	Ding et al. [7]; Liang et al. [8];

Step 2. Standardizing the decision matrix: the decision matrix $X = (x_{ij})m \times n$ is standardized according to the 0-1transformation, as matrix $Y = (y_{ij})_{m\times n}$. The indicators are divided into benefit and cost types.

$$\text{benefit indices } y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}, \tag{2}$$

$$\text{cost indices } y_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}. \tag{3}$$

Step 3. Calculate the entropy value e_j of each indicator:

$$e_j = -k \sum_{i=1}^{m} \left(p_{ij} \ln\, p_{ij} \right). \tag{4}$$

In equation (4), $k = 1/\ln m$ and $p_{ij} = (y_{ij}/\sum_{i=1}^{m} y_{ij})$, $(i = 1, 2, 3, \ldots, m, j = 1, 2, 3, \ldots, n)$. When $p_{ij} = 0$, $\lim_{p_{ij} \longrightarrow 0} p_{ij} \ln\, p_{ij} = 0$.

Calculate the coefficient of variation h_j of each index. For one index, the larger the coefficient of variation h is, the smaller the e_j is. The greater the impact of the index on urban sustainability is, and the larger the corresponding weight coefficient is [50]. The formula for calculating the coefficient of variation h_j is as follows:

$$h_j = 1 - e_j. \tag{5}$$

Determine the weight value w_j of each evaluation index.

$$w_j = \frac{h_j}{\sum_{j=1}^{n} h_j}, \tag{6}$$

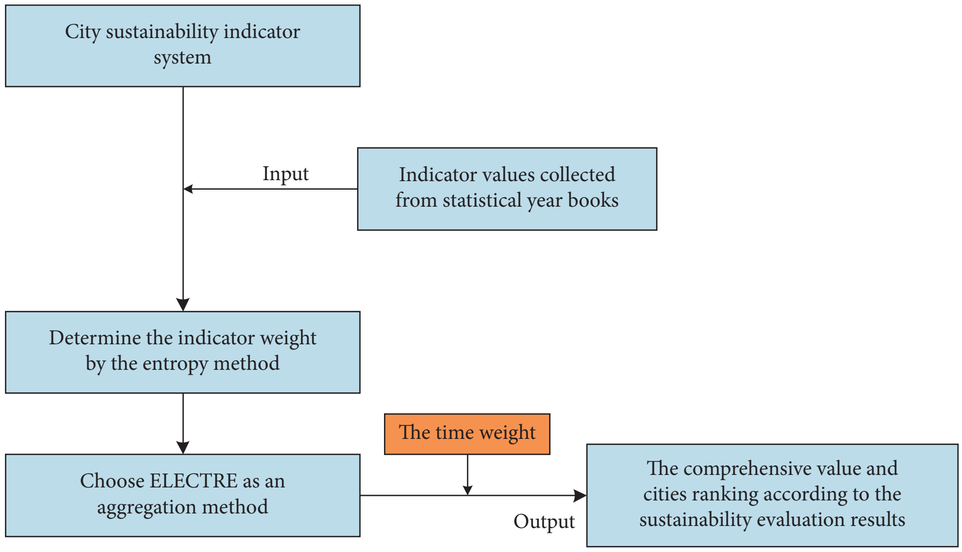

FIGURE 1: Urban sustainability evaluation processes.

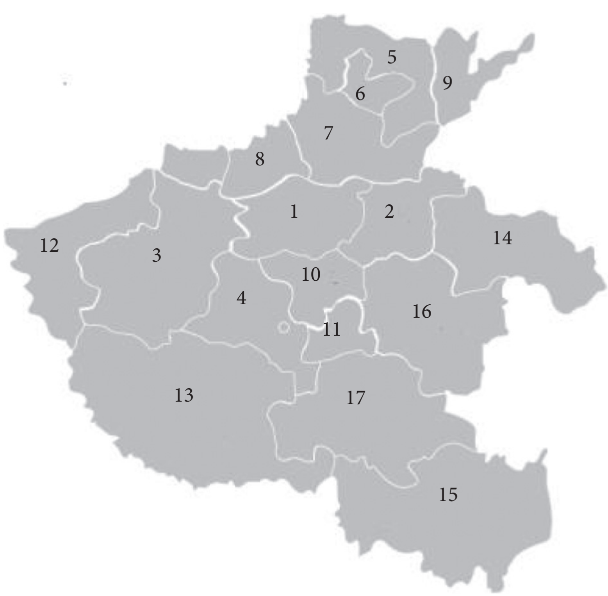

FIGURE 2: Urban distribution map of Henan Province.

where $0 \leq w_j \leq 1$, $(j = 1, 2, 3, \ldots, n)$ and $\sum_{j=1}^{n} w_j = 1$.

4.4. Dynamic Evaluation of Urban Sustainability with ELECTRE Method. The evaluation of urban sustainability was carried out using the ELECTRE method, which employs the three-dimensional time-series data to present the dynamic process of the urban sustainability. The specific steps are as follows.

It is assumed that there are m alternatives, and each alternative is measured by n indicators. The evaluation value of the j th evaluation indicator of the i th alternative obtained in chronological order is $x_{ij}(t_k)$ $(i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, N)$.

(1) Constructing the original evaluation indicator value matrix $X(t_k)$.

$$X(t_k) = \left(x_{ij}(t_k)\right)_{m\times n} = \begin{pmatrix} x_{11}(t_k) & x_{12}(t_k) & \cdots & x_{1n}(t_k) \\ x_{21}(t_k) & x_{22}(t_k) & \cdots & x_{2n}(t_k) \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}(t_k) & x_{m2}(t_k) & \cdots & x_{mn}(t_k) \end{pmatrix}. \tag{7}$$

(2) Normalizing value matrix. The original evaluation indicator value matrix is normalized to obtain a normalized decision matrix X'.

$$X'(t_k) = \left(x'_{ij}(t_k)\right)_{m\times n} = \begin{pmatrix} x'_{11}(t_k) & x'_{12}(t_k) & \cdots & x'_{1n}(t_k) \\ x'_{21}(t_k) & x'_{22}(t_k) & \cdots & x'_{2n}(t_k) \\ \vdots & \vdots & \ddots & \vdots \\ x'_{m1}(t_k) & x'_{m2}(t_k) & \cdots & x'_{mn}(t_k) \end{pmatrix},$$

$$\text{Benefit indices } x'_{ij}(t_k) = \frac{x_{ij}(t_k) - \min x_{ij}(t_k)}{\max x_{ij}(t_k) - \min x_{ij}(t_k)},$$

$$\text{Cost indices } x'_{ij}(t_k) = \frac{\max x_{ij}(t_k) - x_{ij}(t_k)}{\max x_{ij}(t_k) - \min x_{ij}(t_k)}. \tag{8}$$

(3) Calculating the weighted normalized decision matrix. A weighted normalized decision-making matrix is computed by multiplying the normalized decision-making matrix X' with the weights

$w_j(t_k)$ $(j = 1, 2, \ldots, n)$. The weighted normalized decision-making matrix $Y(t_k)$ is shown as follows:

$$Y(t_k) = \left(y_{ij}(t_k)\right)_{m\times n} = x_{ij}'(t_k)\cdot w_j(t_k)$$
$$= \begin{pmatrix} x_{11}'(t_k) & x_{12}'(t_k) & \cdots & x_{1n}'(t_k) \\ x_{21}'(t_k) & x_{22}'(t_k) & \cdots & x_{2n}'(t_k) \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}'(t_k) & x_{m2}'(t_k) & \cdots & x_{mn}'(t_k) \end{pmatrix} \begin{pmatrix} w_1(t_k) & 0 & \cdots & 0 \\ 0 & w_2(t_k) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & w_n(t_k) \end{pmatrix}$$
$$= \begin{pmatrix} x_{11}'(t_k)w_1(t_k) & x_{12}'(t_k)w_2(t_k) & \cdots & x_{1n}'(t_k)w_n(t_k) \\ x_{21}'(t_k)w_1(t_k) & x_{22}'(t_k)w_2(t_k) & \cdots & x_{2n}'(t_k)w_n(t_k) \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}'(t_k)w_1(t_k) & x_{m2}'(t_k)w_2(t_k) & \cdots & x_{mn}'(t_k)w_n(t_k) \end{pmatrix} \quad (9)$$
$$= \begin{pmatrix} y_{11}(t_k) & y_{12}(t_k) & \cdots & y_{1n}(t_k) \\ y_{21}(t_k) & y_{22}(t_k) & \cdots & y_{2n}(t_k) \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1}(t_k) & y_{m2}(t_k) & \cdots & y_{mn}(t_k) \end{pmatrix}.$$

(4) Determining the concordance matrix $C(t_k)$ and discordance matrix $D(t_k)$.

4.4.1. Determining the Concordance Set and the Discordance Set. Any two different rows are compared in the weighted normalized decision-making matrix Y. If the value of y in the i th row and j th column is higher than the value of y in l th row, the indicator represented by j th column would be classified into the concordance set; otherwise, it would be classified into the discordance set.

4.4.2. Calculating the Concordance Matrix. The concordance matrix $C(t_k)$ can be obtained by adding the weights of the indicators in each consistency set.

$$C(t_k) = \left(c_{il}(t_k)\right)_{m\times m}, \quad (i = 1, 2, \ldots, m; l = 1, 2, \ldots, m; k = 1, 2, \ldots, N),$$
$$c_{il}(t_k) = \frac{\sum_{j\in C_{il}'(t_k)} w_j + 0.5\sum_{j\in C_{il}''(t_k)} w_j}{\sum_{j=1}^{n} w_j}, \quad j = 1, 2, \ldots, n. \quad (10)$$

In equation (10), $c_{il}(t_k)$ $(i = 1, 2, \ldots, m; l = 1, 2, \ldots, m; k = 1, 2, \ldots, N)$ represents the relative advantage index of alternative i over alternative l at t_k moment. $C_{il}'(t_k) = \left\{j|y_{ij}(t_k) > y_{lj}(t_k)\right\}$ $(j = 1, 2, \ldots, n; k = 1, 2, \ldots, N)$ means that the value of y in the i th row and the j th column has a higher preference than the value of y in the l th row. $C_{il}''(t_k) = \left\{j|y_{ij}(t_k) = y_{lj}(t_k)\right\}$ $(j = 1, 2, \ldots, n; k = 1, 2, (t_k), N)$ represents that the preference of y in the i th row and the j th column is equal to the preference of y in the l row.

4.4.3. Determining the Discordance Matrix $D(t_k)$. The relative disadvantage index of the two alternatives is as follows:

$$D(t_k) = \left(d_{il}(t_k)\right)_{m\times m}, \quad (i = 1, 2, \ldots, m; l = 1, 2, \ldots, m; k = 1, 2, \ldots, N),$$
$$d_{il}(t_k) = \frac{\max_{j\in D_{il}'(t_k)}\left|y_{ij}(t_k) - y_{lj}(t_k)\right|}{\max_{l\in S}\left|y_{ij}(t_k) - y_{lj}(t_k)\right|}, \quad j = 1, 2, \ldots, n,$$
$$D_{il}'(t_k) = \left\{j|y_{ij}(t_k) < y_{lj}(t_k)\right\},$$
$$S = \{1, 2, \ldots, n\}. \quad (11)$$

In equation (11), $d_{il}(t_k)$ $(i = 1, 2, \ldots, m;\ l = 1, 2, \ldots, m;\ k = 1, 2, \ldots, N)$ represents the relative disadvantage index of alternative i over the alternative l at t_k moment. Comparing with $c_{il}(t_k)$ that which only contains the indicator weight information. $d_{il}(t_k)$ represents the difference between the weighted indicator values, which not only contains the weight information but also contains the information of the indicator value itself. Therefore, there is no complementarity between the relative advantage index and the relative disadvantage index. The greater the value of $d_{il}(t_k)$ is, the more likely i is to be inferior to l.

4.4.4. Revising the Discordance Matrix. According to the idea proposed by Sun [51], the discordance matrix $D'(t_k)$is revised and shown in the following equation:

$$\begin{aligned} D'(t_k) &= \left(d'_{il}(t_k)\right)_{m\times m} \\ d'_{il}(t_k) &= 1 - d_{il}(t_k). \end{aligned} \tag{12}$$

The larger $d'_{il}(t_k)$ means that the alternative i may be more inferior to alternative l at $t_k$moment.

4.4.5. Calculating the Revised Weighted Aggregation Matrix $E(t_k)$. The elements in the revised discordance matrix are the same as the elements in the concordance matrix. The higher the value is, the higher the degree of preference is. Therefore, the revised weighted aggregate matrix $E(t_k)$ can be obtained by multiplying the elements in the corresponding positions of the concordance matrix. The revised discordance matrix [16] is as follows:

$$\begin{aligned} E(t_k) &= \left(e_{il}(t_k)\right)_{m\times m}, \quad (i = 1, 2, \ldots, m; l = 1, 2, \ldots, m; k = 1, 2, \ldots, N), \\ e_{il}(t_k) &= c_{il}(t_k) \cdot d'_{il}(t_k). \end{aligned} \tag{13}$$

4.4.6. Calculating the Comprehensive Evaluation Value $u_i(t_k)$. This study applies the concept of net advantage value as follows [52]:

$$u_i(t_k) = \sum_{\substack{l=1 \\ l\neq i}}^{m} e_{il}(t_k) - \sum_{\substack{l=1 \\ l\neq i}}^{m} e_{li}(t_k), \quad i = 1, 2, \ldots, m. \tag{14}$$

The net advantage value u_i is the difference between the sum of the advantage indexes of alternative X_i to other schemes and the sum of the advantage indexes of other alternatives to X_i, which reflects the degree of the advantage of X_i in the alternative set. The larger the u_i is, the more advantageous alternatives the X_i will be.

4.4.7. Ranking the Alternatives. The alternatives are ranked according to the overall evaluation value of $u_i(t_k)$, with the greater the $u_i(t_k)$ meaning of the higher rank.

This study determines time weights using the method that the closer to the present, the more important the weight; conversely, the further from the present, the smaller is the weight. Within the time interval $[t_1, t_N]$, the time weight at t_k moment is w_k.

$$\begin{aligned} w_k &= \frac{k}{\sum_{k=1}^{N} k}, \\ \sum_{k=1}^{N} w_k &= 1, \quad w_k > 0. \end{aligned} \tag{15}$$

The comprehensive evaluation value of alternative i in the time interval $[t_1, t_N]$ is g_i.

$$g_i = \sum_{k=1}^{N} w_k u_i(t_k). \tag{16}$$

Finally, the alternatives are ranked according to g_i.

4.5. The Spatial Econometric Model. In this study, the spatial autocorrelation model is used to study the spatial dependence or spatial correlation between the sustainability level and the geographical location of cities. The spatial autocorrelation model can be divided into global spatial autocorrelation and local spatial autocorrelation. Global spatial autocorrelation adopts the global Moran index I to test whether there is an interaction between the sustainability levels of cities in a particular area.

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}(x_i - \overline{x})^2}. \tag{17}$$

The value of the global Moran index I is between −1 and 1. $I > 0$ represents the positive spatial correlation; $I < 0$ represents the negative spatial correlation; $I = 0$ represents spatial randomness. n is the number of cities in Henan Province. x_i and x_j are the sustainability value of each city. $\overline{x}$ is the mean value; w_{ij} is the spatial weight matrix. If the two spatial units are adjacent to each other, the spatial weight value is 1; otherwise, it is 0.

Since the global Moran index can only test whether there is a spatial correlation between all cities in a region, and the specific spatial correlation between cities cannot be obtained [53]. Therefore, the local Moran spatial autocorrelation index I_i is calculated on the basis of the global Moran index.

$$I_i = \frac{n(x_i - \overline{x})\sum_{j=1}^{n} w_{ij}(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2}. \tag{18}$$

The local spatial autocorrelation is represented by the local Moran scatterplot to verify the existence of spatial clustering characteristics. The local Moran spatial autocorrelation index $I_i > 0$ indicates a high-high or low-low spatial clustering around the spatial unit; and the local Moran spatial autocorrelation index $I_i < 0$ indicates a high-low or low-high spatial clustering around the spatial unit.

5. Results

The sustainability of the 17 cities in Henan Province from 2013 to 2017 is evaluated using the mathematical model established in this study.

5.1. Calculating the Weight of Each Indicator. According to equations (1)–(3), the decision matrix A is established and normalized. Then, the entropy value e_j and weight w_j of each indicator are calculated by using equations (4)–(6). The specific calculation results of 2017 are shown in Table 2. Due to limited space, the data of other years are omitted.

5.2. Dynamic Evaluation of Urban Sustainability Based on ELECTRE. The dynamic evaluation value and ranking of sustainable urban development in Henan Province from 2013 to 2017 can be obtained by implementing the methods shown in Section 4, as shown in Table 3. According to equation (15), the time weight w can be calculated as follows:

$$w = (0.0667,\ 0.1333,\ 0.2000,\ 0.2667,\ 0.3333). \tag{19}$$

The comprehensive evaluation value is calculated by considering the time weight. Therefore, the ranking of the sustainability of 17 cities in Henan Province is shown in Figure 3.

Similarly, the results s can be obtained for 17 cities in Henan Province in the economic, social, and environmental dimensions of sustainable development, as shown in the Tables 4–6.

5.3. Ranking of Urban Sustainability. Figure 3 can directly reflect the level of sustainability of cities in Henan Province. Zhengzhou is the city with the highest score in Henan Province, that is, the city with the highest level of sustainability. Luoyang is ranked second place; Zhoukou has the lowest level of sustainability, followed by Shangqiu. Zhengzhou, the capital city of Henan Province, has invested much money in economic, social construction, and environmental protection in recent years to achieve great success. So its sustainability level is significantly higher than other cities in terms of actual development. Luoyang, as a sub–center city in Henan Province and a member of the Zheng–Luo–Xin National Independent Innovation Demonstration Zone, has developed rapidly in recent years to get a high level of sustainability. Zhoukou, Shangqiu, and Zhumadian are located in the regions with relatively concentrated cultivated land in Henan Province. Limited by the red line of agricultural land, it is challenging to develop the industry. The task of grain production restricts the economic development of the cities to some extent, which leads to the relatively backward economic level of these regions. Secondly, the permanent resident population of Zhoukou, Shangqiu, and Zhumadian is ranked in the third, fourth, and fifth place in the province, respectively. Due to the low economic level and large population, as well as the lack of corresponding science and education innovation resources and infrastructure, the level of urban sustainability of this region lags behind that of other cities in Henan Province.

Table 2: The weight of each indicator.

Indicator	e_j	w_j
C1	0.9284	0.0378
C2	0.8873	0.0595
C3	0.8139	0.0983
C4	0.9480	0.0275
C5	0.9127	0.0461
C6	0.8823	0.0621
C7	0.8851	0.0607
C8	0.9703	0.0157
C9	0.9096	0.0477
C10	0.9250	0.0396
C11	0.8787	0.0641
C12	0.8805	0.0631
C13	0.9478	0.0276
C14	0.9662	0.0179
C15	0.9220	0.0412
C16	0.8778	0.0645
C17	0.8328	0.0883
C18	0.9681	0.0168
C19	0.9681	0.0169
C20	0.9542	0.0242
C21	0.9440	0.0296
C22	0.9604	0.0209
C23	0.9711	0.0153
C24	0.9720	0.0148

Figure 4 shows the ranking of the sustainability levels of 17 cities in Henan Province in 2013–2017. It can be seen that Zhengzhou, Luoyang, and Sanmenxia were stable at higher levels during 2013–2017; Kaifeng, Luohe, and Xinyang show downward fluctuations; and Puyang, Nanyang, and Xinxiang show fluctuations upward. From 2013 to 2017, most of the cities are ranked relatively stable in terms of the sustainability level.

5.4. Spatial Autocorrelation Analysis

5.4.1. Global Spatial Autocorrelation. The purpose of spatial autocorrelation analysis is to explore whether the urban sustainability level is spatially correlated. If it appears that the closer the geographic location of the city, the more similar the level of urban sustainability is, which means that the urban sustainability level is positively correlated. If it appears that the closer the geographic location of the city, the more different the level of urban sustainability is, which means that the urban sustainability level is negatively correlated. If the urban sustainability level does not appear to be spatially correlated, it shows spatial stochasticity. The adjacency spatial weight matrix is employed to calculate the global Moran index using Data 13.0 software. The global

Table 3: The dynamic evaluation value and ranking of urban sustainable development in Henan Province from 2013 to 2017.

City	Abbreviation	Value					Ranking				
		2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
Zhengzhou	ZZ	12.228	12.191	12.139	12.274	11.936	1	1	1	1	1
Kaifeng	KF	−1.840	0.701	4.013	−4.591	−5.265	11	9	3	15	16
Luoyang	LY	5.670	6.671	5.095	4.383	6.518	2	2	2	3	2
Pingdingshan	PDS	−1.844	−3.114	−2.350	−2.478	−2.470	12	14	11	11	12
Anyang	AY	−0.557	−1.800	−2.033	−3.375	−1.693	9	11	10	14	11
Hebi	HB	2.893	2.945	2.619	3.743	3.008	4	5	6	4	4
Xinxiang	XX	−1.357	−2.576	−3.144	−3.110	2.477	10	13	14	13	5
Jiaozuo	JZ	1.068	1.509	0.154	−0.477	1.557	7	7	8	8	6
Puyang	PY	−3.514	−4.005	−2.780	−0.521	−1.602	14	15	13	9	10
Xuchang	XC	0.093	0.837	−0.104	0.828	1.179	8	8	9	7	7
Luohe	LH	1.573	2.819	1.382	2.184	−1.046	6	6	7	6	9
Sanmenxia	SMX	5.091	5.938	3.985	4.759	6.148	3	3	4	2	3
Nanyang	NY	−2.524	−2.370	−2.355	−2.002	0.898	13	12	12	10	8
Shangqiu	SQ	−7.007	−7.127	−7.953	−6.670	−4.960	17	16	17	17	14
Xinyang	XY	1.664	3.787	2.681	3.316	−4.124	5	4	5	5	13
Zhoukou	ZK	−6.781	−7.277	−6.456	−5.487	−7.214	16	17	16	16	17
Zhumadian	ZMD	−4.856	−1.128	−4.893	−2.775	−5.059	15	10	15	12	15

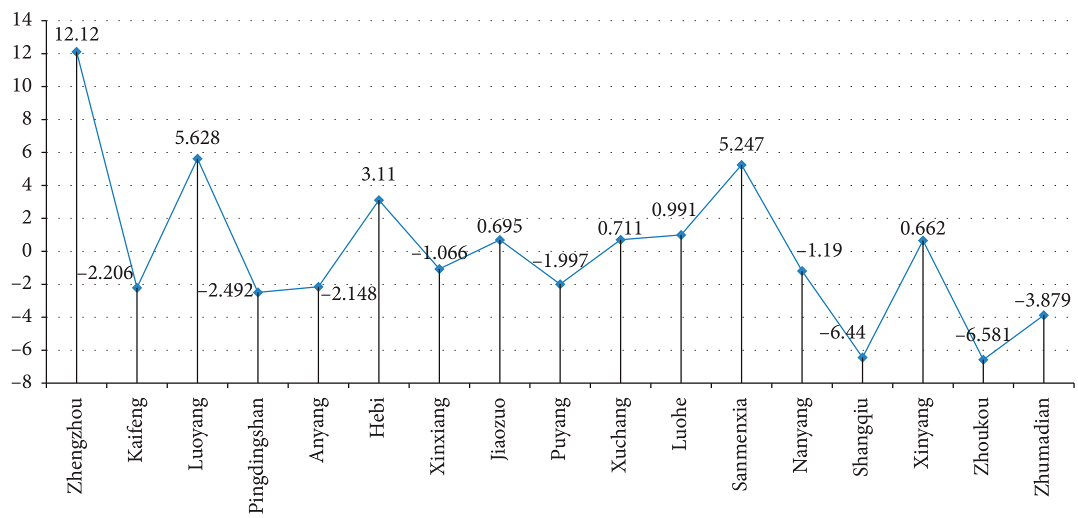

Figure 3: The comparison of the sustainability of cities in Henan Province.

Table 4: The sustainability evaluation value and ranking of each city in the economic dimension.

City	Value					Ranking					Consider the time weighting	
	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017	Value	Ranking
Zhengzhou	16.000	16.000	16.000	16.000	15.959	1	1	1	1	1	15.986	1
Kaifeng	−1.722	−4.115	−2.655	−6.713	−3.365	12	12	12	14	13	−4.106	13
Luoyang	10.667	10.949	11.680	11.141	10.974	2	2	2	2	2	11.136	2
Pingdingshan	−1.305	−2.573	−2.613	−4.858	−2.866	11	11	11	12	11	−3.204	11
Anyang	0.567	1.173	1.136	−1.014	−3.286	8	9	9	10	12	−0.944	10
Hebi	1.619	1.928	2.246	1.494	2.039	6	6	6	7	6	1.892	6
Xinxiang	2.503	0.566	2.338	2.196	3.442	5	10	5	6	5	2.443	5
Jiaozuo	5.057	6.057	5.594	5.761	6.771	3	3	3	4	4	6.057	4
Puyang	−7.474	−5.833	−4.440	−2.913	−2.607	14	14	13	11	10	−3.810	12
Xuchang	0.094	2.994	1.439	2.473	1.255	10	5	8	5	7	1.771	7
Luohe	0.319	1.879	1.443	1.070	0.040	9	7	7	9	9	0.859	9
Sanmenxia	4.351	3.397	3.898	8.164	8.552	4	4	4	3	3	6.551	3
Nanyang	1.333	1.195	0.573	1.337	0.523	7	8	10	8	8	0.894	8
Shangqiu	−10.104	−9.632	−10.755	−10.827	−11.735	17	17	17	17	17	−10.908	17
Xinyang	−3.771	−5.783	−7.850	−5.760	−6.960	13	13	14	13	14	−6.449	14
Zhoukou	−8.326	−8.680	−8.482	−8.539	−7.668	15	15	15	15	15	−8.242	15
Zhumadian	−9.810	−9.523	−9.551	−9.011	−11.070	16	16	16	16	16	−9.927	16

Table 5: The sustainability evaluation value and ranking of each city in the social dimension.

City	Value					Ranking					Consider the time weighting	
	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017	Value	Ranking
Zhengzhou	8.074	7.312	8.107	8.271	2.705	1	2	1	1	5	6.242	1
Kaifeng	−0.838	2.838	6.503	−0.852	−4.791	12	5	2	13	16	−0.201	11
Luoyang	3.042	3.820	3.678	1.049	5.433	4	3	5	5	1	3.539	3
Pingdingshan	0.783	−1.131	−0.286	−0.772	0.368	8	12	8	12	9	−0.239	12
Anyang	0.992	0.282	−1.338	0.838	1.332	6	11	12	6	7	0.504	7
Hebi	3.560	1.333	1.432	5.679	0.305	3	6	6	2	10	2.317	4
Xinxiang	−1.270	−2.590	−2.936	−0.273	4.619	13	14	14	9	4	0.450	8
Jiaozuo	0.537	0.711	−0.767	−0.387	0.876	9	7	9	10	8	0.166	10
Puyang	−3.349	−5.590	−2.745	0.385	−1.443	14	15	13	7	11	−1.896	14
Xuchang	−0.364	0.371	−0.909	−0.973	1.918	10	10	10	14	6	0.223	9
Luohe	0.871	0.561	0.666	0.371	−2.470	7	8	7	8	12	−0.458	13
Sanmenxia	7.168	8.236	5.521	2.190	4.761	2	1	3	4	3	4.851	2
Nanyang	−0.811	−1.249	−1.315	−2.166	5.000	11	13	11	15	2	0.605	6
Shangqiu	−7.298	−9.654	−9.157	−7.946	−4.523	16	17	17	16	15	−7.232	16
Xinyang	2.505	3.720	4.589	5.075	−2.739	5	4	4	3	13	2.021	5
Zhoukou	−8.832	−9.383	−7.247	−9.988	−7.741	17	16	16	17	17	−8.533	17
Zhumadian	−4.770	0.414	−3.798	−0.499	−3.610	15	9	15	11	14	−2.359	15

Table 6: The sustainability evaluation value and ranking of each city in the environmental dimension.

City	Value					Ranking					Consider the time weighting	
	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017	Value	Ranking
Zhengzhou	−6.494	−5.929	−4.561	−1.585	−6.498	17	15	13	12	17	−4.724	15
Kaifeng	−5.587	−4.822	4.919	−2.492	−2.705	15	14	3	13	12	−1.598	11
Luoyang	−2.226	4.410	2.159	−3.411	1.011	9	6	7	15	7	0.299	10
Pingdingshan	−4.919	−3.656	−1.983	4.905	1.658	13	12	9	3	6	0.649	7
Anyang	−4.959	−3.571	−4.043	−3.391	−3.610	14	11	12	14	14	−3.723	14
Hebi	7.784	−0.217	7.778	−0.069	3.740	2	9	2	10	4	3.274	4
Xinxiang	−4.319	−3.979	−4.632	−7.228	−6.055	11	13	14	16	16	−5.690	16
Jiaozuo	−4.807	−5.987	−5.305	−9.704	−4.292	12	16	16	17	15	−6.198	17
Puyang	3.326	5.915	−2.015	−0.108	0.116	6	4	10	11	10	0.617	8
Xuchang	5.323	6.148	4.547	3.069	3.800	4	3	4	4	3	4.169	3
Luohe	12.037	6.484	8.818	5.618	3.605	1	2	1	2	5	6.131	2
Sanmenxia	−2.473	0.228	−5.507	1.083	−2.656	10	8	17	8	11	−1.832	12
Nanyang	−5.617	−8.620	−4.759	1.154	−2.854	16	17	15	7	13	−3.119	13
Shangqiu	−0.866	4.863	2.710	0.149	4.675	8	5	6	9	2	2.731	5
Xinyang	6.534	7.356	0.310	2.125	0.123	3	1	8	6	9	2.086	6
Zhoukou	2.261	−0.542	−2.749	3.064	0.462	7	10	11	5	8	0.500	9
Zhumadian	5.003	1.919	4.312	6.819	9.478	5	7	5	1	1	6.429	1

Moran index is shown in Table 7, and the Moran scatter plot is shown in Figure 5. As showing in Table 7, the Moran index of urban sustainability level from 2013 to 2016 is not significant. It means that there is no significant spatial correlation between cities from 2013 to 2016. It may be because these cities are in the stage of development transformation. These cities develop independently and are not closely related. The Moran index in 2017 is positive and passes the significance test ($Z > 1.65$, $p < 0.1$), indicating a positive correlation between the urban sustainability level in 2017.

5.4.2. Local Spatial Autocorrelation. The local spatial autocorrelation in 2017 is analyzed with the Moran scatter plot in Figure 5.

The numbers in the figure are labeled according to the order of cities in Table 3: 1 representing Zhengzhou, 2 representing Kaifeng, and 17 representing Zhumadian. The figure shows that most cities are clustered in the first quadrant (high−high, H−H) and the third quadrant (low−low, L−L), while a few cities are in the second quadrant (low−high, L−H) and the fourth quadrant (high−low, H−L). The result indicates that, in 2017, most cities in Henan Province are in the high−high and low−low clustering, and few are in the low−high and high−low clustering. That is, these cities with higher levels of sustainable development are clustered together, and cities with lower levels of sustainable development are clustered together. Among them, Zhengzhou, Luoyang, Jiaozuo, and Sanmenxia are in the high−high clustering. Shangqiu, Zhoukou, and Zhumadian

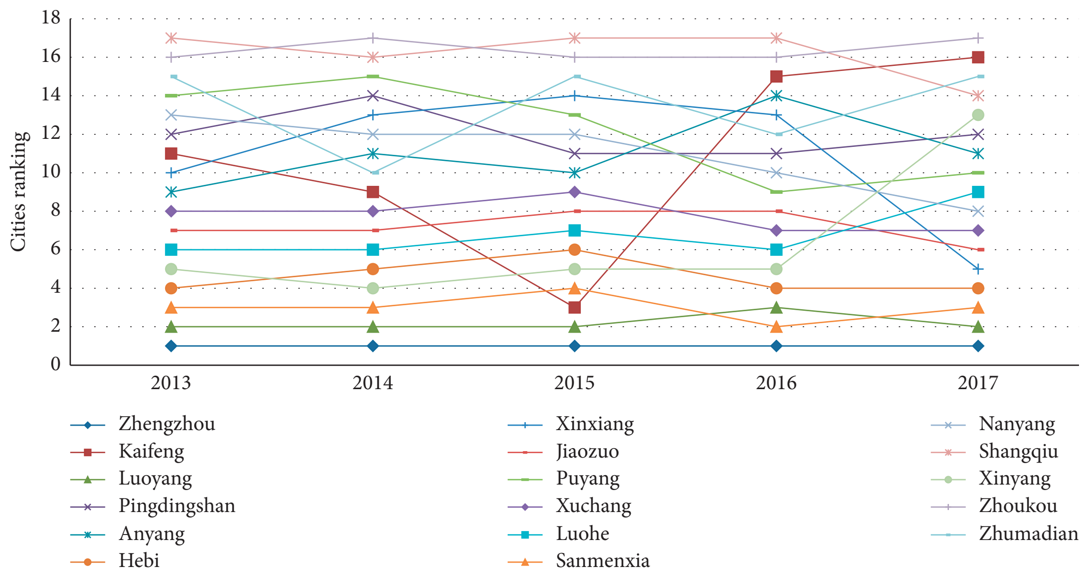

Figure 4: Ranking of urban sustainability in Henan Province from 2013 to 2017.

Table 7: Global Moran index of the urban sustainability level.

years	I	Z	p
2013	0.145	1.328	0.074
2014	0.116	1.164	0.122
2015	0.056	0.786	0.216
2016	0.047	0.735	0.231
2017	0.337	2.608	0.005

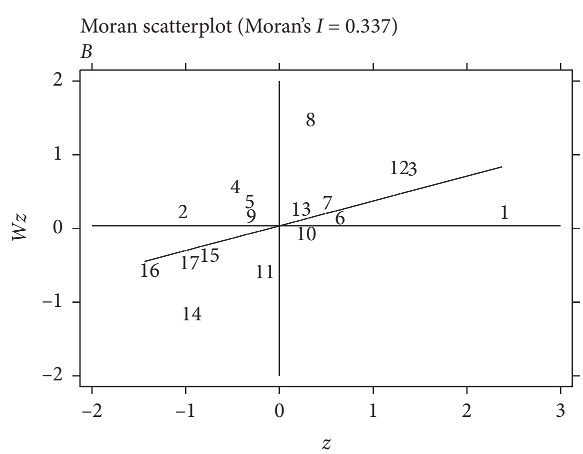

Figure 5: Moran scatter plot of urban sustainability level in 2017.

are in the low–low clustering. The results indicate that the high–high clustering cities are mainly concentrated around Zhengzhou and Luoyang, and the low–low clustering cities are mainly concentrated in the southeast of Henan.

6. Discussion

6.1. Economic Dimension. During the period 2013–2017, as showing in Figure 6, Zhengzhou has been ranked first in economic sustainability. As the capital city of Henan Province, Zhengzhou is a political, economic, cultural, and transportation center with the best resources in the province and plays a leading role in the development process. The economic sustainability of Luoyang, Sanmenxia, Jiaozuo, Xinxiang, Hebi, and Xuchang has also been maintained at a relatively high level. As cities bordering Zhengzhou, Luoyang, Jiaozuo, Xinxiang, and Xuchang have advantages in transportation, technology, and markets, thus making their economic development more dynamic. Especially in recent years, driven by the strategies of aerodrome economy, Zhengzhou-Europe Shuttle Train, and national central city development, the economy of Zhengzhou is significantly more potent than other regions. As a deputy central city in Henan Province and a member of The National Independent Innovation demonstration zone of Zhengzhou-Luoyang-Xinxiang, Luoyang has experienced rapid economic development in recent years. Xuchang is close to the aviation port area and has experienced remarkable economic growth in recent years. The excellent business environment has brought opportunities for the development of private enterprises in Xuchang. Jiaozuo, as a representative of the successful transformation of a resource–depleted city, is now focusing its economic development on commerce trade and tourism. The rapid development of sunrise industries has made per capita GDP and the proportion of tertiary industry in the national economy perform well. Cities in the eastern and southern regions, such as Shangqiu, Zhumadian, Zhoukou, and Xinyang have limited economic drive and relatively weak industrial manufacturing due to their predominantly agricultural farming areas.

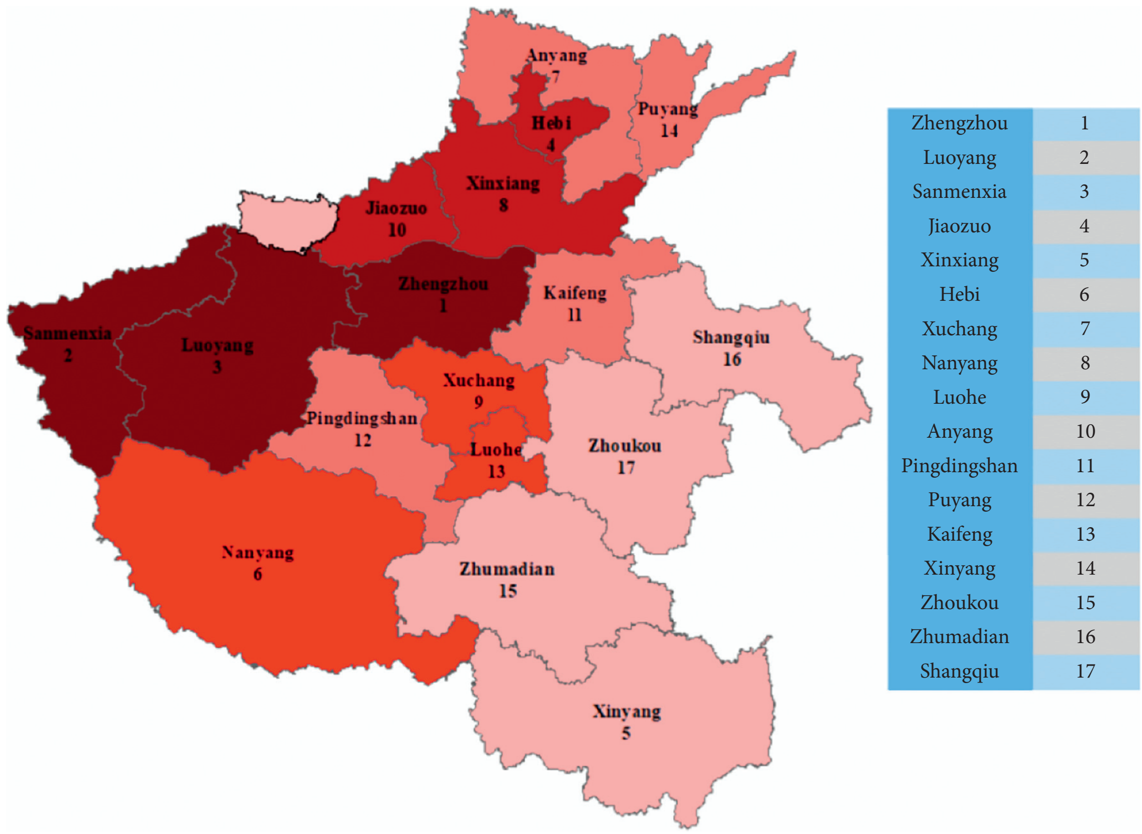

Figure 6: A comprehensive ranking of the sustainable development of cities in Henan Province in the economic dimension.

Simultaneously, due to the low concentration of high technology and limited market scope, the economic sustainability ranking is significantly lower. A comparative analysis of the indicators of the economic dimension shows that, in order to improve the sustainability of the city, it is necessary to improve the overall economic level [5]. For these cities, the government should focus on providing more policy and financial support, including strengthening investment attraction, creating a favorable market atmosphere and emphasizing the development of the tertiary sector and modern agriculturalization.

6.2. Social Dimension. In the social dimension, as showing in Figure 7, the highest level of sustainability is still Zhengzhou, the capital of Henan Province. At the same time, its social sustainability level has remained stable at a high level during 2013–2017. In addition, cities such as Sanmenxia, Luoyang, Hebi, Xinyang, and Anyang have relatively high levels of social sustainability. These cities have well-developed public infrastructures and relatively high investment of public resources. From specific indicators, it can be found that these cities have higher expenditures on education, science and technology and medical care, as well as higher pension insurance coverage rates and a more comprehensive social security system. In the southeastern region, social sustainability is at a low level due to a small economy and a large population, and insufficient investment in people's livelihoods. In particular, cities such as Zhoukou, Shangqiu, and Zhumadian have low per capita disposable income for urban residents and inadequate pension insurance coverage. Financial investment in science and technology, medical care, and other areas is also relatively low. At the same time, the urban registered unemployment rate is high. Therefore, the level of social sustainability is the worst. For these cities, the social security system needs to be further strengthened in the later development process to promote "people-oriented" sustainable development.

6.3. Environmental Dimension. From 2013 to 2017, as showing in Figure 8, the cities with high environmental sustainability levels in Henan Province include Zhumadian, Luohe, Xuchang, Hebi, and Shangqiu. Luohe, Xuchang, and Hebi have relatively good environmental quality due to their excellent environmental foundation and specific economic strength for environmental governance. For cities like Zhumadian and Shangqiu, due to their low industrialization level, the emission of industrial soot and dust and industrial wastewater is less. Cities with poor environmental quality include Jiaozuo, Xinxiang, Zhengzhou, Anyang. Jiaozuo has steel, coal, building materials, textile, and other traditional industries. Most of these industries are raw materials and high energy consumption. Therefore, Jiaozuo's industrial wastewater emissions and the annual average concentration of MP2.5 are relatively high. In addition, Jiaozuo's comprehensive utilization rate of industrial solid wastes, the ratio of wastewater centralized treated, and the green coverage

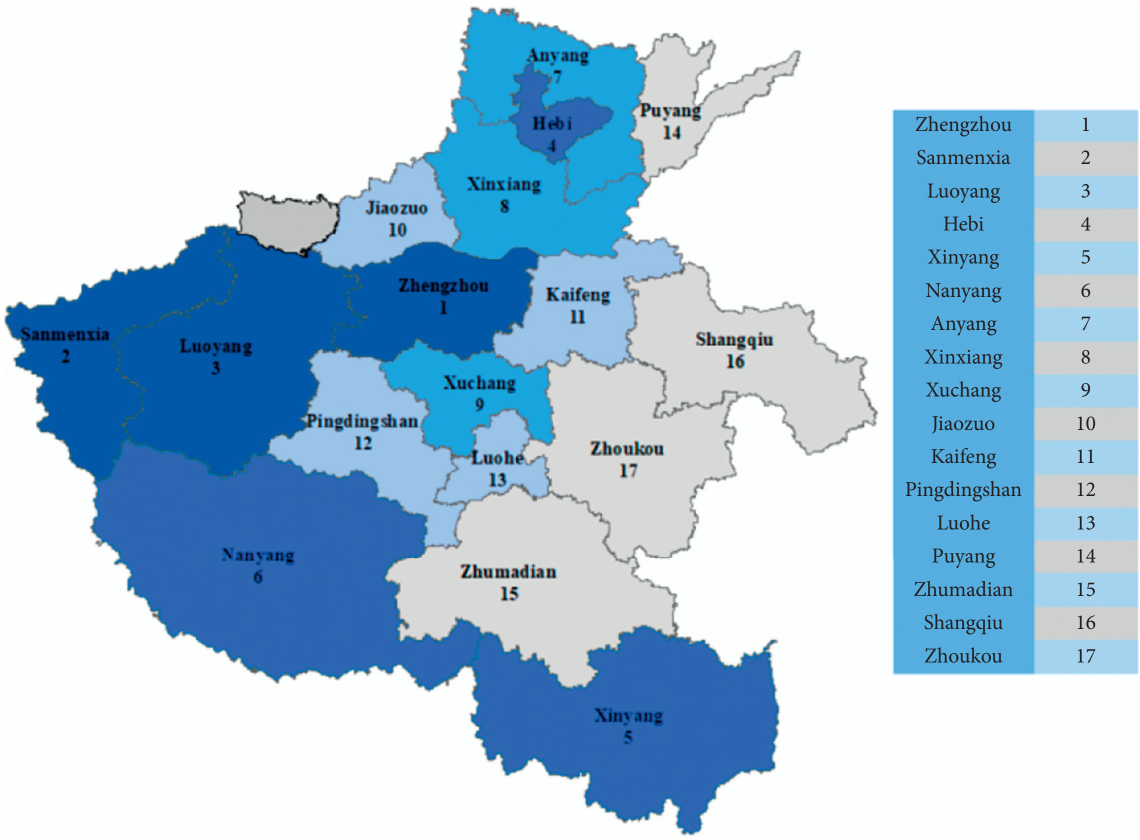

Figure 7: The comprehensive ranking of the sustainable development of cities in Henan Province in the social dimension.

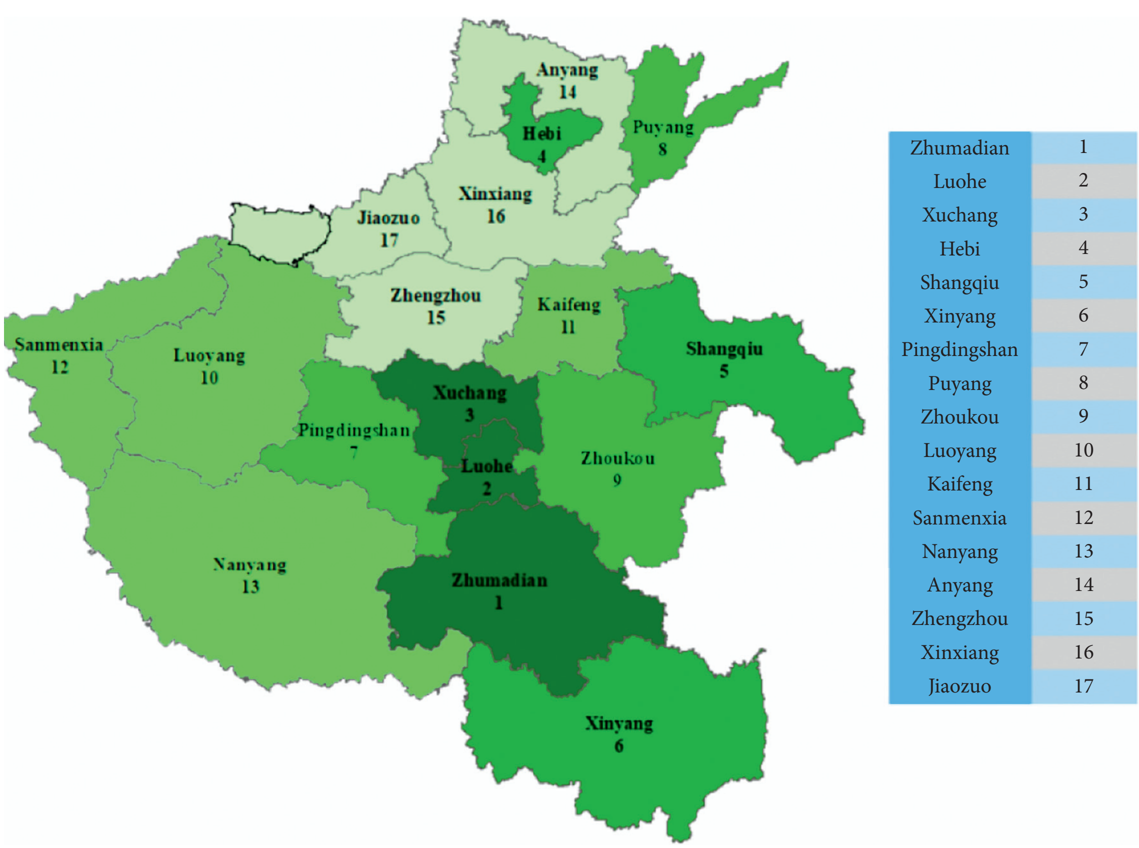

Figure 8: The comprehensive ranking of the sustainable development of cities in Henan Province in the environmental dimension.

rate of built–up areas are low. Therefore, it has always been at the bottom place of urban environmental sustainability in Henan Province from 2013 to 2017. Cities like Xinxiang and Anyang have many heavy industries, such as machinery manufacturing, building materials, and energy. Urban heavy industry has a significant negative impact on environmental sustainability. For example, in the past five years, the average industrial wastewater emissions in Xinxiang ranked first place among 17 cities in Henan. The annual average concentration of PM2.5 ranked third. Anyang has the highest average industrial soot and dust emissions in the past five years, and the annual average concentration of PM2.5 ranks second, after Zhengzhou. With the rapid economic development of Zhengzhou, people's living standards have been greatly improved. Zhengzhou is the city with the largest number of public vehicles per capita among the 17 cities. As a result, its annual average concentration of PM2.5 is the highest. In addition, the industrial wastewater emissions, industrial soot, and dust emissions of Zhengzhou are also relatively high. Therefore, Zhengzhou has been ranked at the last place of the environmental sustainability level during the period 2013–2017. Research has found that the low level of environmental sustainability in some cities has a great deal to do with their rapid economic development. Therefore, a balance should be struck between economic, social, and environmental sustainable development, avoiding the old path of "pollute first, cure later". In addition, in the process of urban development, the construction of ecological civilization should be integrated into all areas of society. The "greening" strategy should be used to promote the transformation and upgrading of industries and to realize green industrial production with high technology, high efficiency, low pollution, and low consumption.

6.4. Spatial Autocorrelation Analysis. The results of global spatial autocorrelation analysis show that the spatial correlation between cities in Henan Province from 2013 to 2016 is not significant. This is largely due to the fact that these cities are in a stage of development and transformation. Cities develop independently of each other without close ties. At the end of 2016, the National Development and Reform Commission issued the Development Plan for Central Plains City Clusters, Zhengzhou as the capital of Henan Province, becoming the center to lead the development of Central Plains City Clusters. Under the background of this policy, there is a positive correlation between the level of urban sustainability in Henan Province from 2017.

And the local spatial autocorrelation analysis shows that cities with higher levels of sustainable development in Henan Province clustered together in 2017, while cities with lower levels of sustainable development are clustered together. Among them, the high-high clustering cities are mainly concentrated around Zhengzhou and Luoyang, and the low-low clustering cities are mainly concentrated in the southeast of Henan Province. As the capital of Henan Province and the central city of the Central Plains Economic Zone, Zhengzhou ranks first in the Central Plains Economic Zone in terms of urban comprehensive strength, which has a strong attraction to the surrounding areas, prompting the concentration of population, resources and other factors in the surrounding cities to it, strengthening the connection between Zhengzhou and other cities. Zhenzhou has a strong external radiation capacity, driving the development of the surrounding cities. The eastern and southern regions of Henan Province are mainly agricultural, with limited economic capacity, relatively weak industrial manufacturing, and no obvious resource advantages or core industries. Therefore, the overall level of sustainability is relatively weak.

7. Conclusions

Urban sustainability evaluation plays a crucial role in sustainable urban development, and the evaluation results can provide support for stakeholders and decision-makers to formulate urban development plans and correct policy interventions. This study constructs an urban sustainability evaluation indicator system from the three dimensions of economy, society, and environment. The two-dimensional data with time-series data is extended to three-dimensional data. A dynamic evaluation model based on ELECTRE is employed to evaluate the sustainable development of 17 cities in Henan Province from 2013 to 2017. The research results show that, from 2013 to 2017, cities such as Zhengzhou, Luoyang, and Sanmenxia remained stable at a relatively high level, while the sustainability levels of cities such as Kaifeng, Luohe, and Xinyang showed a trend of downward fluctuations. The cities such as Puyang, Nanyang, and Xinxiang showed a trend of upward fluctuations. The results based on the spatial measurement model showed no spatial correlation in the sustainability level among cities in Henan Province from 2013 to 2016. However, the correlation between urban sustainability began to emerge in 2017. The cities showing high-high clustering are mainly concentrated around Zhengzhou and Luoyang, while those showing low-low clustering are mainly concentrated in the southeastern part of Henan. Specifically, Zhengzhou is the city with the highest level of sustainability among the 17 cities. Its economic and social sustainability levels are significantly higher than any other city. Zhoukou is the city with the lowest level of sustainability among the 17 cities. In the economic dimension, Zhengzhou has the highest sustainability level, and Shangqiu has the lowest level. In the social dimension, Zhengzhou ranks first, and Zhoukou ranks the lowest place. In the environmental dimension, Zhumadian has the highest sustainability level, and Jiaozuo has the lowest.

According to the evaluation results, this paper puts forward specific suggestions. Firstly, cities such as Shangqiu and Zhoukou are economically and socially underdeveloped. The government should provide them with more financial and policy support, including strengthening investment attraction, creating a favorable market environment, and emphasizing the development of the tertiary sector and modern agriculture. In addition, the social security system needs to be further strengthened to promote "people-oriented" sustainable development. Secondly, cities such as Zhengzhou, Xinxiang, and Jiaozuo have high economic sustainability levels but low levels of environmental sustainability. In the process of development, a balance should be struck between the economy, society, and the environment. The construction of ecological civilization should be integrated into all areas of society. The "greening" strategy should be used to promote the transformation and upgrading of industries, to achieve high-technology, high-efficiency, low-pollution, and low-consumption green industrial production and to promote the high-quality development of cities.

Based on the classic triple bottom line framework of sustainable development theory, this paper considers the characteristics of urban development and constructs an urban sustainability evaluation index system from economic, social, and environmental dimensions. And the ELECTRE method is used to dynamically evaluate urban sustainability based on three-dimensional data. The index system constructed and the research method adopted in this paper provide tools for measuring the sustainability status of a city (not only Henan but also other cities), which has certain theoretical and practical significance.

The research contributions of this study are manifested in three aspects. Firstly, the ELECTRE method is used to evaluate the urban sustainability level, and the time weights are considered to obtain the dynamic sustainability level of each city in annual, overall, as well as in the three dimensions of economy, society, and environment. Secondly, a spatial measurement model is used to identify the difference and clustering in the spatial distribution of urban sustainability levels. Finally, the research results provide a useful reference for city managers to clarify the current sustainability level of cities and to formulate reasonable development plans to promote sustainable development further.

At the same time, this study also has certain limitations. In the evaluation process, the method used to calculate the weighting system ignored the existence of interaction among indicators. Urban sustainability is a complex system affected by economic, social, and environmental dimensions, with the existence of interaction and conflict among factors. For example, many studies have concluded that there is an inverted "*U*" relationship between economic growth and environmental pollution in China. Therefore, in the future, we will continue to improve the calculation method of weights and pay more attention to the interaction among indicators.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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