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County Ecosystem Health Assessment Based on the VORS Model: A Case Study of 183 Counties in Sichuan Province, China

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Abstract: The scientific assessment of the health level of county ecosystems is the basis for formulating county-based sustainable development strategies. In this paper, we take the county areas of Sichuan Province as the evaluation objects and combine the SDGs (the Sustainable Development Goals) to establish a county ecosystem health evaluation index system based on the VORS (Vigor–Organization–Resilience–Service) model. On this basis, we used the entropy weight method, the Moran index method, and the obstacle degree model to analyze the ecosystem health level, spatial distribution characteristics, and obstacles of 183 counties in Sichuan Province. The main results were as follows: (1) A total of 80.87% of the counties in Sichuan Province were at sub-healthy and healthy levels, concentrated in the southeastern part of Sichuan, and 19.13% of the counties were at an unhealthy level, mainly in the Aba, Ganzi, and Liangshan areas. (2) The health levels of county ecosystems in Sichuan Province had high spatial autocorrelation characteristics. The H–H (High–High) agglomeration area and the L–L (Low–Low) agglomeration area had significant agglomeration characteristics, which were distributed in the Cheng–Mian area and the northwestern Sichuan area, respectively. (3) The key indicators restricting the healthy development of urban ecosystems in Sichuan counties are economic vitality, economic resilience, and quality of life, all of which belong to the economic subsystems, with obstacles reaching 17.25%, 16.68%, and 13.52%, respectively. This study can provide theoretical and methodological support for research into ecosystem health evaluations at the county level, and provide a decision-making basis for promoting the health of county ecosystems and coordinating regional development in Sichuan Province.

Keywords: VORS model; ecosystem health assessment; spatial heterogeneity; barrier degree; county level



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1. Introduction

Urban ecosystem health is a major requisite for human survival and development, the basis for regional sustainable development, and necessary for human health [1]. In recent years, the continuous increase in the urbanization level and the accelerated development of urban construction have had certain impacts on the health of urban ecosystems, and have even threatened human health. Scholars are now paying more attention to the health of urban ecosystems [2,3].

The county seat is the main body of urban development in China [4], the most basic administrative unit in China, and the basic platform for national governance [5,6]. Its

ecosystem health level is directly related to the sustainable development of a region [7]. In addition to its characteristics of complexity, vulnerability, and vulnerability to external interference, each county's ecosystem is also affected by a number of problems such as air pollution and water pollution caused by rapid economic and social development. The deterioration of health status directly reduces the level of well-being derived from the ecological services enjoyed by residents [7]. Therefore, scientifically evaluating the health level of county ecosystems and exploring the healthy development path of differentiated ecosystems suitable for each county have important theoretical and practical significance for promoting coordinated regional development and implementing the Sustainable Development Goals (SDGs).

Most scholars construct the index system from the perspective of the operation mechanism of the urban ecosystem. For example, Zhang [8], Zhu [9], Costanza [10], and others constructed ecosystem health evaluations from three aspects: ecological force, organizational structure, and resilience. Li [11], Liu [12], and others constructed ecosystem health evaluations based on four elements (urban vitality, organizational structure, resilience, and service function maintenance or function maintenance). Pan [13], Wang [14], Guan [15], Zhao [16], Chen [17], Guo [18], Su [19], and others used five aspects (urban ecosystem vitality, organizational structure, resilience, ecosystem services, and human health) to build an assessment model system. Some scholars have applied PSR (pressure–state–response) and its series of derived models to evaluate urban ecosystem health from an operational process, such as Ning [20], Lu [21], Xu [22], Wei [23], Corvalan [24], and others using PSR models, Lu [25], Liu [26], and others using DPSIR (driver–pressure–state–impact–response) models, and Jerry [27] et al. using the DPSEE (driving–force–pressure–state–exposure–effect–response) model. In addition, Zhao [28], Zhang [29], and others constructed an index system for the health evaluation of urban ecosystems from the perspectives of society, the economy, and the environment. The above evaluation frameworks have their advantages and disadvantages. The existing research has the following shortcomings: (1) In the evaluation process, it is difficult to emphasize the operation mechanism of the urban ecosystem or the entire operation process, while considering the influence of social, economic, and environmental factors. (2) Due to incomplete county-level statistical data in China, the evaluation scales have focused on provinces, cities, or key areas, which cannot reflect the heterogeneity of development within regions. (3) The selection of the indicator system relies on the traditional evaluation framework, and no reference indicators for international evaluation are selected, which is not conducive to the comparison of evaluation results.

Sichuan Province is an important water source conservation area in the upper reaches of the Yangtze and Yellow Rivers and a key node in the construction of the “Belt and Road” and the development of the Yangtze River Economic Belt. Therefore, it is known as the “frontier” of China's inland development and opening up and the “guardian” of China's ecological security [30]. In this study, the SDG indicators were connected, and the VORS (Vigor–Organization–Resilience–Service) function model was used to construct an ecosystem Health Evaluation Index System in county areas. On this basis, 183 county-level units in Sichuan Province were used as samples to analyze the health level, spatial differentiation characteristics, and obstacles of county ecosystems. This study provides a reference for other experts and scholars to study similar fields.

2. Study Area

Sichuan Province is situated between 97°21′–108°33′ east longitude and 26°03′–34°19′ north latitude. It is located in the southwest hinterland of mainland China, (with an area of 486,000 square kilometers, ranking fifth in China and administering 21 cities (states) and 183 counties (county-level cities, districts). Sichuan Province borders seven provinces (autonomous regions and municipalities), including Chongqing, Guizhou, Yunnan, Tibet, Qinghai, Gansu, and Shaanxi, and has the largest inhabited area of Yi people, the second-largest inhabited area of Tibetan people, and the only area inhabited by Qiang people.

The landform of Sichuan Province is complex and diverse, with differences between the east and west. The terrain is high in the west and low in the east. It is composed of mountains, hills, plain basins, and plateaus. Sichuan province belongs to three climates; the subtropical humid climate in the Sichuan Basin, the subtropical semi-humid climate in the mountainous areas of Southwest Sichuan, and the alpine and plateau alpine climate in Northwest Sichuan [31]. There are significant differences in regional climate performance. The east is warm in winter, dry in spring, hot in summer, and rainy in autumn, with cloud, fog, less sunshine than other regions, and a long growing season. In contrast, the west is cold, and has a long winter but basically no summer; it receives sufficient sunshine, with concentrated precipitation and distinct dry and rainy seasons. There are many kinds of meteorological disasters, with high frequency and a wide range, consisting of mainly drought and rainstorms.

Sichuan Province is rich in natural resources, with three natural World Heritage Sites, one cultural World Heritage Site, and one mixed World Heritage Site (both natural and cultural). Sichuan Province has 145 wild animals under Special State Protection, ranking first in the country, including 1387 wild giant pandas. The forest volume of Sichuan Province is 1.897 billion cubic meters, ranking third in the country. The forest coverage rate of Sichuan Province is 39.6%, and the comprehensive vegetation coverage of grassland is 85.6%. Sichuan Province is also one of 36 biodiversity hotspots in the world with its mountains in Southwest China [32], and its ecological status is important, shown as Figures 1 and 2.

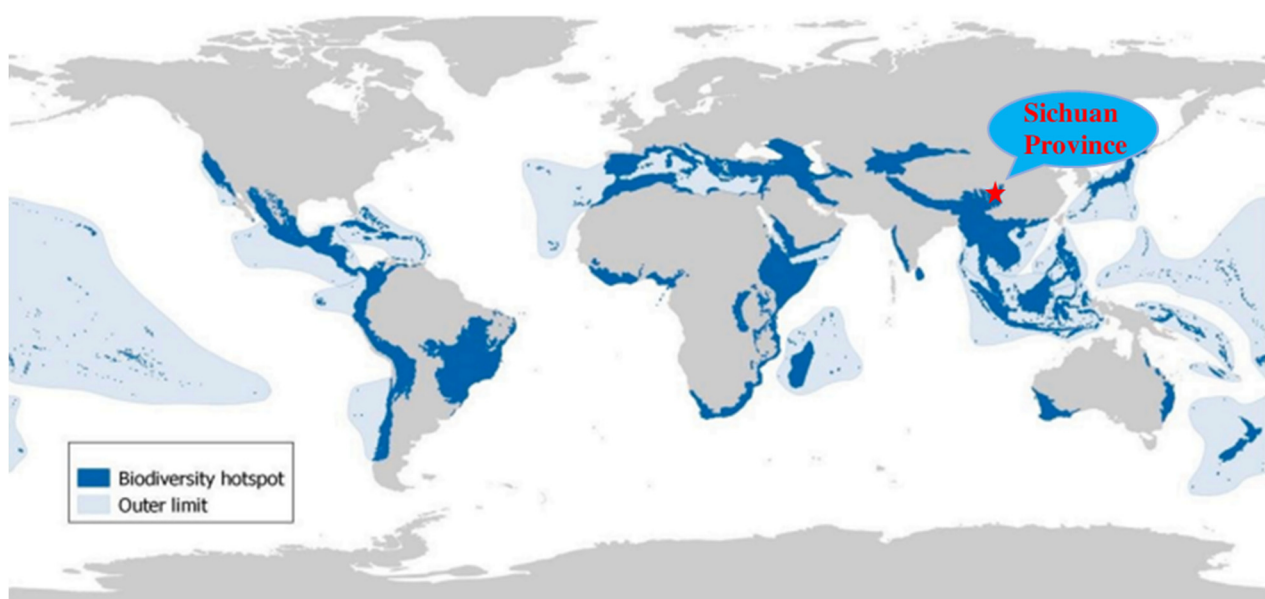


Figure 1. Location of Sichuan Province in Biodiversity Hotspots [32].

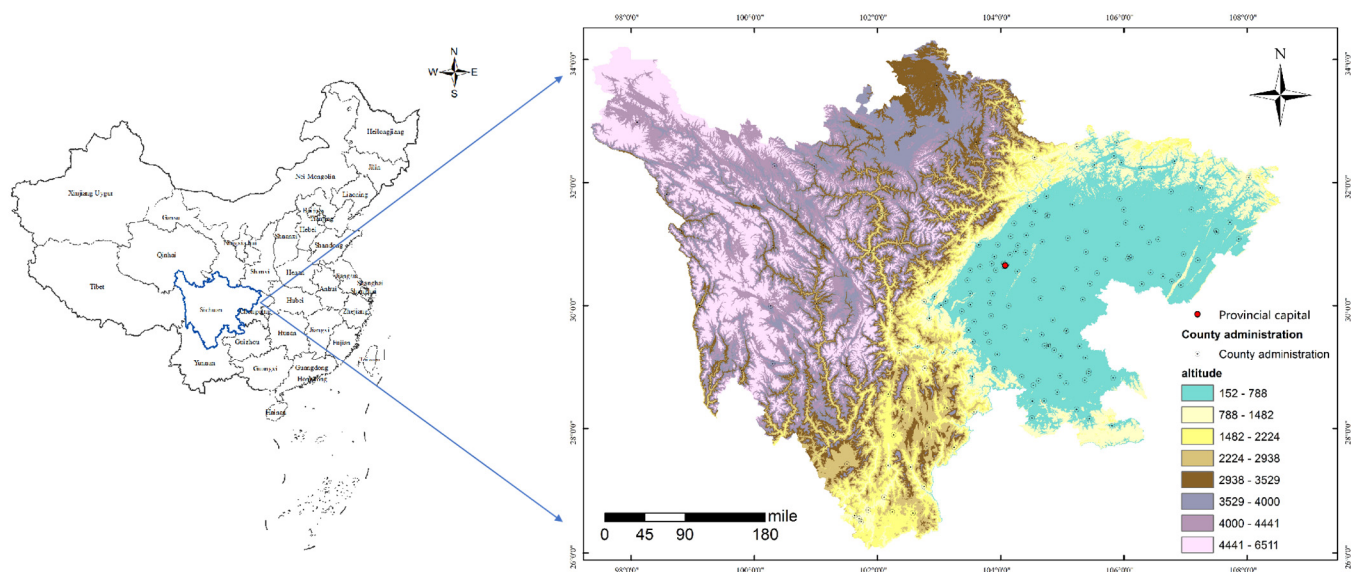


Figure 2. Study area.

3. Materials and Methods

3.1. The Construction Method of the Index System

Rapport first proposed and demonstrated ecosystem health, considering that ecosystem health refers to the ability of an ecosystem to maintain its original organizational structure, self-regulation, and recovery when under external coercion, and is expressed by vitality, organization, and resilience. Since then, many scholars have had different views on ecosystem health, but there is no unified urban ecosystem health indicator system [33,34]. Costanza proposed the VOR model, which described ecosystem health as a comprehensive, multiscale measure of system vigor, organization, and resilience [10]. This study extends the ecosystem health model to urban ecosystem health evaluation, enriches and expands the “Vitality–Organizational-structure–Resilience” model, and constructs a “Vitality–Organizational-structure–Resilience–Service-function” assessment framework centered on the coordinated development of the environmental, economic, and social systems. Compared with other models, the VORS model can better characterize the operation mechanism and the entire operation process of the urban ecosystem.

According to the requirements of the VORS model, following the principles of data science, measurability, comparability, and availability, the evaluation index system was divided into four levels by top-down and layer-by-layer decomposition. The first layer was the target layer, which took the ecosystem health level as the comprehensive evaluation target and was the final result calculated; the second layer was the criterion layer, including the vitality, organizational structure, resilience, and service functions. The third layer was the category layer, which was mainly related to the logical framework of the evaluation. According to its effect on the healthy development of the ecosystem, the category layer was constructed from the perspectives of the environment, economy, and society [6,35,36]. The fourth layer was the indicator layer. To facilitate the comparison of evaluation results, we selected specific indicators in an internationally recognized context, such as the SDGs [37]. For some indicators that were unsuitable or incompatible with the Chinese context, we selected and replaced the indicators with the same domestic equivalent, using reliable data sources and high retrieval frequency. Finally, a county ecosystem health evaluation index system including 32 specific indicators was constructed, as shown in Figure 3.

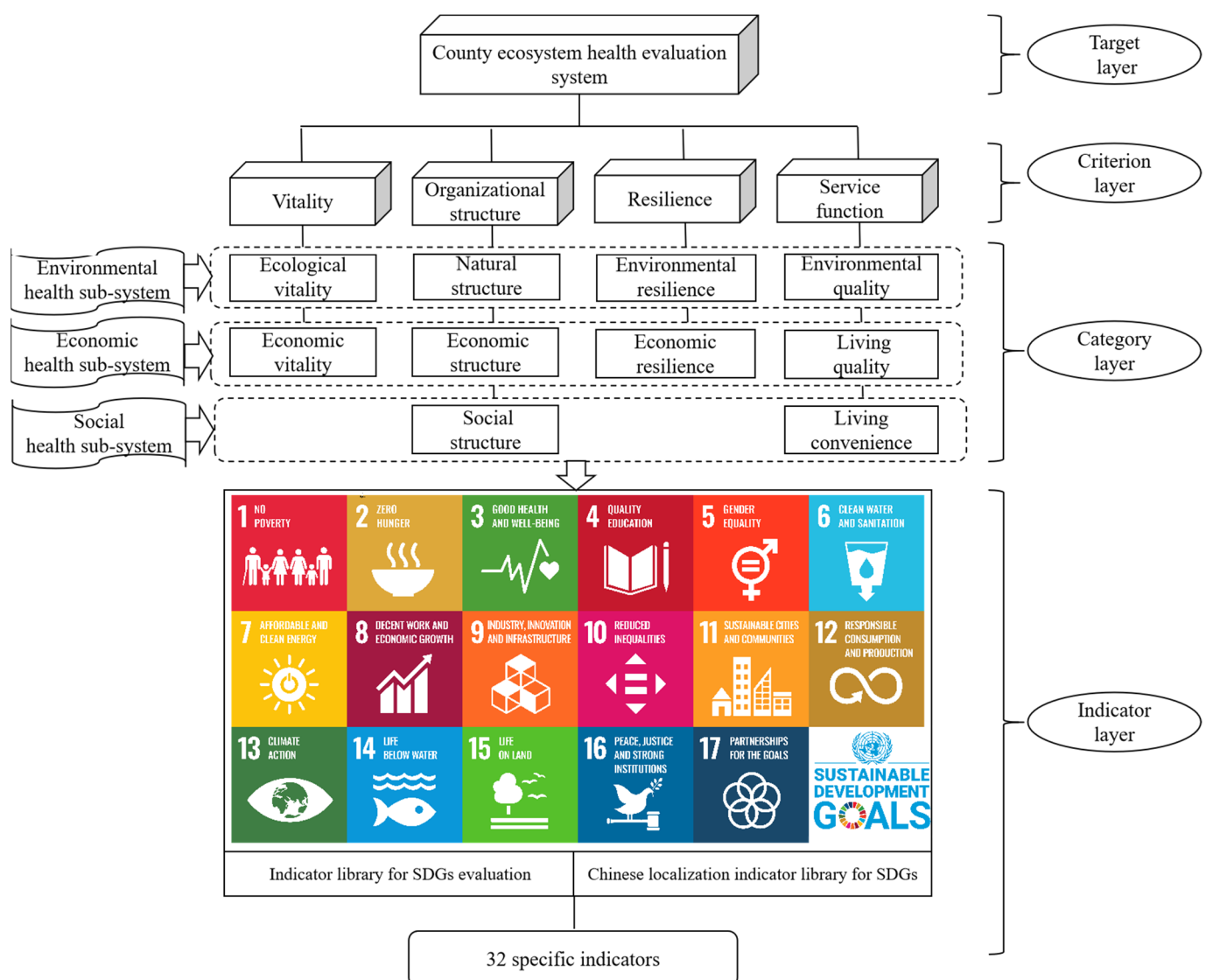


Figure 3. County ecosystem health assessment framework based on the VORS Model.

In the health assessment framework of county-level urban ecosystems, the vitality factor referred to the activity of the county-level urban ecosystem, including economic vitality and ecological vitality. The higher the vitality factor index, the faster the urban ecosystem obtained more nutrients. The organizational structure of the urban ecosystem mainly included three parts: the economic structure, the social structure, and the natural structure. The more complex the organizational structure was, the more reasonable it was, indicating that the urban ecosystem was healthier. Resilience referred to the ability of a city to self-regulate and self-repair when the environment and economic subsystems were damaged. Generally, many manual interventions are required to complete the self-repair function of the urban system. Service function elements mainly referred to the functions of the urban environment, economic, and social systems serving human society, which was reflected in three aspects: the convenience of living, the quality of the environment, and the quality of life. The final construction of the county-level urban ecosystem health evaluation system is shown in Table 1.

Table 1. Index system of county ecosystem health assessment in Sichuan Province.

Criterion Layer	Category Layer	Indicator Layer	Indicator Attributes	Corresponding SDG Goals	Weight
Vitality (V)	Ecological vitality (V1)	Biological richness index (V11)	Positive	SDG15	0.031
		Vegetation coverage index (V12)	Positive	SDG15	0.025
		Water network denseness index (V13)	Positive	SDG15	0.025
		Land stress index (V14)	Positive	SDG15	0.025
		Pollution load index (V15)	Positive	SDG15	0.019
	Economic vitality (V2)	GDP per capita (V21)	Positive	SDG8	0.031
		Growth rate of GDP per capita (V22)	Positive	SDG8	0.031
		Growth rate of GDP (V23)	Positive	SDG8	0.032
		The growth rate of fixed asset investment in the whole society (V24)	Positive	SDG8	0.031
Organizational structure (O)	Natural structure (O1)	Per capita green area of parks (O11)	Positive	SDG15	0.041
		Green coverage in built-up areas (O12)	Positive	SDG15	0.042
	Economic structure (O2)	The share of secondary industry in GDP (O21)	Positive	SDG9	0.041
		The share of tertiary industry in GDP (O22)	Positive	SDG9, SDG8	0.042
	Social structure (O3)	Population density (O31)	Negative	SDG11	0.028
		Urban–rural income ratio (O32)	Negative	SDG10	0.028
		Urbanization rate (O33)	Positive	SDG11	0.027
Resilience (R)	Environmental resilience (R1)	Sewage treatment rate (R11)	Positive	SDG6	0.042
		Domestic waste disposal rate (R12)	Positive	sdg12	0.042
		Park green space service radius coverage (R13)	Positive	SDG11	0.042
	Economic resilience (R2)	Growth rate of industrial added value above designated size (R21)	Positive	SDG9	0.061
		The rate of change in the proportion of tertiary production (R22)	Positive	SDG9	0.063
Service function (S)	Environmental quality (S1)	Intensity of fertilizer use (S11)	Negative	SDG12	0.017
		Concentration of PM _{2.5} (S12)	Negative	SDG11	0.016
		Percentage of days with good air quality (S13)	Positive	SDG11	0.017
		Proportion of monitoring sections with good water quality (S21)	Positive	SDG6	0.017
		Average concentration of O ₃ (S22)	Negative	SDG11	0.017
	Living quality (S2)	Urban per capita disposable income (S23)	Positive	SDG8	0.027
		Rural per capita disposable income (S24)	Positive	SDG8	0.028
	Living convenience (S3)	Road area rate in built-up area (S31)	Positive	SDG11	0.021
		Gas penetration rate (S32)	Positive	SDG7	0.021
		Water penetration rate (S33)	Positive	SDG6	0.021
		Public water supply penetration rate (S34)	Positive	SDG6	0.021

3.2. Evaluation Model

3.2.1. Standardization of Indicators

Due to the differences in the types, dimensions, and trends of indicators in the evaluation system, we used Formula 1 and Formula 2 to convert the index values into relative values ranging from 0 to 100 points.

Positive indicator:

$$d_{ij} = \frac{D_{ij} - d_{\min}}{d_{\max} - d_{\min}} \times 100 \quad (1)$$

Negative indicator:

$$d_{ij} = \frac{D_{ij} - d_{\max}}{d_{\min} - d_{\max}} \times 100 \quad (2)$$

where d_{ij} represents the standardized value of the j th indicator of the i th county unit; D_{ij} represents the statistical value of the j th indicator of the i th county unit; $d_{\min}$ represents the minimum value of the indicator statistics; and $d_{\max}$ represents the maximum value of the indicator statistics.

3.2.2. Weight Calculation

Based on the theoretical level analysis, we used the entropy weight method [38–40] to obtain the weight of specific indicators. The calculation method is as follows:

For a data set with n indicators and m samples, we calculated the entropy E_j of the j th evaluation indicator of each dimension according to Formula (3):

$$p_{ij} = \frac{d_{ij}}{\sum_{i=1}^m d_{ij}} \quad (3)$$

$$E_j = (\ln m)^{-1} \sum_{i=1}^m p_{ij} \ln p_{ij} \quad (4)$$

If $p_{ij} = 0$, we define $\lim_{p_{ij} \rightarrow 0} p_{ij} \ln p_{ij} = 0$.

The formula for calculating the objective weight w_j of each index using entropy is as follows:

$$w_j = \frac{1 - E_j}{n - \sum_{j=1}^n E_j} \quad (5)$$

3.2.3. Weighted Method to Measure Ecosystem Health Level

We weighted and summed the standardized specific indicators according to the weights and calculated the scores of each criterion indicator and ecosystem health level. For easy characterization and analysis, we converted each subgoal score of the criterion layer into a relative value between 0 and 100 points. The sub-target index F_{ik} of each region is:

$$F_{ik} = \frac{\sum_{j=1}^n W_j d_{ij} \times 100}{w_k} \quad (k = 1, 2, 3) \quad (6)$$

where w_k is the weight of the criterion indicator.

The formula for calculating the ecosystem health level in each region is:

$$E_i = \sum_{j=1}^n W_j d_{ij} \quad (7)$$

After calculating the ecosystem health level of each county unit, the natural breaking point method (implemented by ArcGIS 10.6 software) was used to divide the ecosystem health level of 183 county units in Sichuan Province into the categories of unhealthy level, sub-healthy level, and healthy level.

3.3. Spatial Correlation Analysis Model

The spatial correlation analysis method [41–44] revealed the spatial heterogeneity of ecosystem health levels in 183 counties in Sichuan Province, including global spatial correlation and local spatial correlation.

3.3.1. Global Spatial Correlation Analysis

Global spatial autocorrelation was used to analyze the spatial distribution characteristics of a certain attribute in the research range. We mainly used Moran's I index to reflect the similarity, dissimilarity, and correlation deconstruction pattern of elements in the study area. The global spatial autocorrelation Moran index can be expressed as:

$$I = \frac{m \sum_{a=1}^m \sum_{b=1}^m \omega_{ab} (x_a - \bar{x})(x_b - \bar{x})}{\sum_{a=1}^m \sum_{b=1}^m \omega_{ab} (x_a - \bar{x})^2} \quad (8)$$

where x_a and x_b are the ecosystem health levels of county a and county b , respectively (the index health level of the criterion layer); $\bar{x}$ represents the mean value of the ecosystem health level of 183 county units; and ω_{ab} represents the spatial weight. The global Moran's I index has a strict limit $[-1, 1]$. When the value is positive, it means that it has a positive spatial correlation, or it has a negative spatial correlation. The global Moran's I index significance test is usually tested by the Z-score and p value to judge whether the null hypothesis can be rejected.

3.3.2. Local Spatial Correlation Analysis

The local spatial correlation index was used to reveal the high-value clusters and low-value clusters at different spatial locations, that is, the spatial distribution law of hot and cold areas. We used the Local Moran's I statistic to reflect the spatial correlation and heterogeneity of spatial elements in an adjacent area of the measurement unit. Its calculation formula can be expressed as:

$$I_a = \frac{m^2}{\sum_{a=1}^m \sum_{b=1}^m \omega_{ab}} \times \frac{(x_a - \bar{x}) \sum_{b=1}^m (x_b - \bar{x})}{\sum_{a=1}^m (x_a - \bar{x})^2} \quad (9)$$

In the formula: I_a is the local correlation index of unit a , indicating the degree of association with other fields.

3.4. Diagnostic Models of Obstacle Factors

To further clarify the improvement direction of the healthy and coordinated development of county-level ecosystems, we used the obstacle degree model to diagnose the obstacles to the healthy development of county-level unit ecosystems. The model structure is as follows [45,46]:

$$Q_{ij} = \frac{(100 - d_{ij}) \times W_j \times 100\%}{\sum (100 - d_{ij}) \times W_j} \quad (10)$$

$$Q_i = \sum Q_{ij} \quad (11)$$

In the formula, Q_{ij} represents the obstacle degree of a single index to the ecosystem health, and Q_i is the obstacle degree of the category layer to the county ecosystem health.

3.5. Data Sources

The data involved in this study mainly include socioeconomic–environmental attribute data and map data. The socioeconomic–environmental attribute data come from (1) various databases, including the National Bureau of Statistics and the EPS database; (2) statistical data, including provincial and city (state) statistical yearbooks, national economic and social development statistical bulletins, and ecological environment conditions communiqués, etc.; and (3) government agencies, including the Sichuan Provincial People's Government,

the Sichuan Provincial Department of Ecology and Environment, etc. In the map data, the distribution map of biodiversity hotspots comes from the literature, and the rest of the maps are from the 2017 1:1 million national basic geographic databases published on the official website of the China Geographic Information Resource Catalog Service System.

This study took the county as the research unit, and the research scope was 183 county-level administrative units in Sichuan Province in 2020.

4. Results

4.1. Measurement Results and Spatial Feature Analysis

We calculated through ArcGIS software that there were 35 county-level units at the unhealthy level ($x_i \leq 47.83$), 79 county-level units at the sub-healthy level ($47.83 < x_i \leq 54.57$), and 69 county-level units at the healthy level ($x_i > 54.57$). We statistically calculated the ecosystem health level of 183 administrative units, and the average value was 52.43, which was generally in the sub-healthy level, reflecting that the overall county ecosystem health level in Sichuan Province was at a moderately low level. The standard deviation was 5.19, and the coefficient of variation was 0.099. The standard deviation and the coefficient of variation were small, indicating that the difference in the health levels of the ecosystem among the county-level administrative units in Sichuan Province was small and relatively balanced.

From the perspective of spatial distribution (Figure 4), the healthy counties were located in the southeastern region of Sichuan Province, with Ya'an-Chengdu as the center point and along the northeast direction (the Chengdu–Deyang–Mianyang–Nanchong–Guangyuan line) and the southeast (the Ya'an–Leshan–Yibin line), forming an L-shaped linear distribution, in addition to the economically developed Dazhou, Panzhihua, and other places with block distribution. Sub-healthy counties and healthy counties were consistent in the spatial pattern distribution and were distributed in the southeastern Sichuan region. The clustering distribution of unhealthy counties was obvious, mainly in Aba, Ganzi, and Liangshan in the northwest.

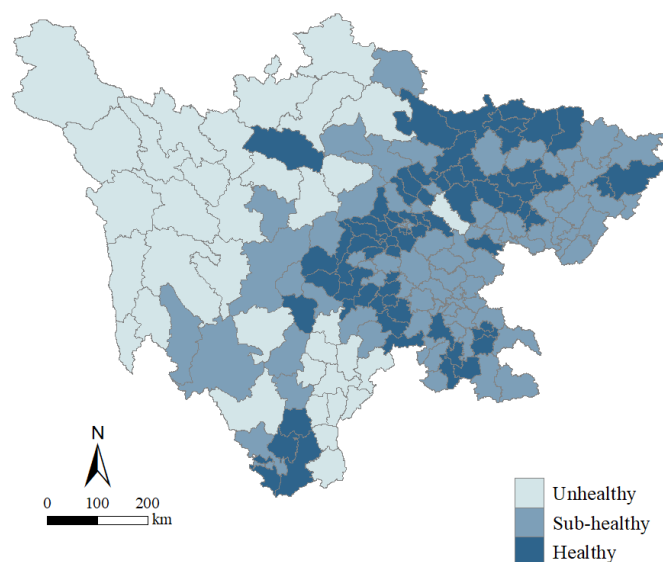


Figure 4. Health level distribution of ecosystems in the counties of Sichuan Province.

The urban ecosystem is a complex system, and its health level is affected by many factors. We found that the counties at a healthy level could be divided into two categories: (1) Chengdu, Mianyang, Yibin, Nanchong, Dazhou, and other economically and socially developed regions are the core components of the fourth pole of China's economy (the Chengdu–Chongqing economic circle), and their GDP accounts for more than two-thirds of the whole province in Sichuan. In addition, the degree of ecological organization and green management level of these cities are at the forefront of the province, and their social

and economic vitality and quality are overwhelming, making up for their deficiencies in atmospheric, ecological, and other environmental qualities, and the overall health of the ecosystem is good. (2) Ya'an, Panzhihua, Guangyuan, and other regions have obvious ecological advantages and good environmental quality. Taking Ya'an as an example, the city's forest coverage rate exceeds 69%, ranking first in the province, and its air and water quality at the exit section rank among the top in China. In addition, Ya'an is rich in biodiversity, and has a reputation as an "animal and plant gene bank" and as "the lungs of heaven". The favorable natural ecological background conditions play a role in promoting the health of the region's ecosystems. Except for Zhongjiang County (Deyang), all counties with unhealthy levels were distributed in the tri-state area, which is a minority area with "few people, remote location, mountainous area, and poverty". The topography of these counties is complex and diverse, the level of social and economic development has been lagging for a long time, and the infrastructure construction is far behind that of other areas in the province, so the health of the ecosystem is far behind other counties. However, at the same time, they are an ecological barrier for Sichuan Province and even China, and there is room for maneuver for Sichuan's economic development; thus, the health of their county ecosystems is crucial.

The average score of the four criterion-level indicators had a few differences (Figure 5). The vitality score was 44.98, the organizational structure score was 51.00, the resilience score was 54.85, and the service function score was 58.88. The service function was the highest, reflecting the overall good service function of the county seat in Sichuan Province, and people were more likely to have more satisfaction and happiness. For example, Chengdu, Panzhihua, and other regions have been rated as "China's happiest cities" for many years. The vitality score was low, and it is still necessary to further strengthen the vitality advantage areas, and actively make up for the shortcomings in vitality. From the perspective of spatial distribution, the spatial distribution of the health level of the four criterion indicators had very significant clustering characteristics. The vitality of counties (Figure 6a) and service functions (Figure 6b) were mostly at healthy and sub-healthy levels, and the number of unhealthy counties and urban areas was small. The counties with organizational structure (Figure 6c) and resilience (Figure 6d) at healthy and sub-healthy levels were concentrated in southeastern Sichuan, and counties with unhealthy levels were concentrated in the tri-state area. The spatial distribution of criterion indicators showed that the vitality, organizational structure, resilience, and service functions of the same county unit were not completely synchronized.

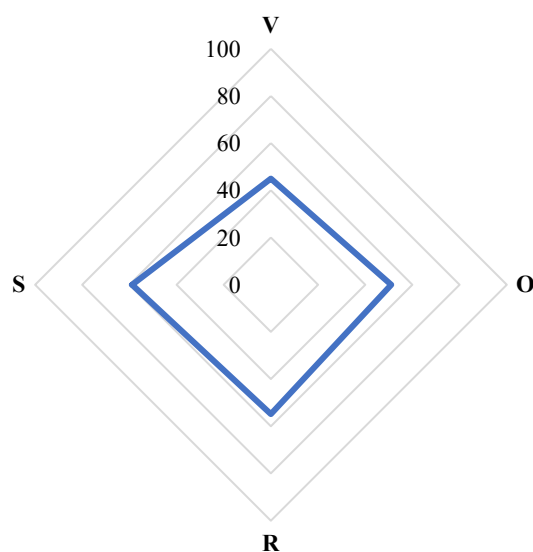


Figure 5. Radar map of county ecosystem health score in Sichuan Province.

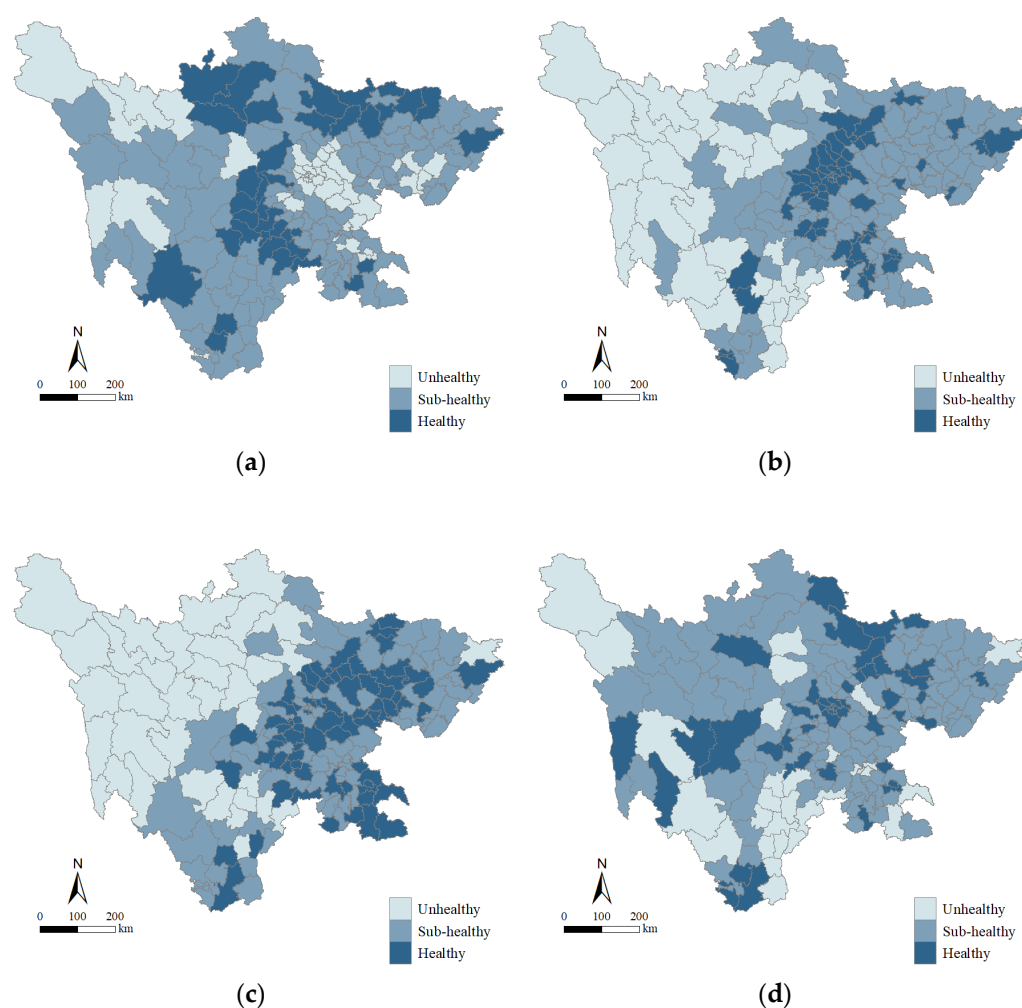


Figure 6. (a) Health level of vitality; (b) health level of organizational structure; (c) health level of resilience; (d) health level of service function.

4.2. Spatial Heterogeneity Analysis

To analyze the spatial correlation characteristics of ecosystem health levels, we calculated the global Moran's I value of each county in Sichuan Province and tested its significance (Table 2). The LISA agglomeration map of the health level of urban ecosystems in the counties (Figure 7) divided the counties into high–high (H–H), high–low (H–L), low–high (L–H), and low–low (L–L) types.

Table 2. Regional correlation test of county ecosystem health in Sichuan Province.

Project	Moran's I	Z-Value	p-Value
Vitality (V)	0.59	12.88	0
Organizational structure (O)	0.60	13.20	0
Resilience (R)	0.56	12.23	0
Service function (S)	0.46	10.24	0
Ecosystem health (E)	0.52	11.48	0

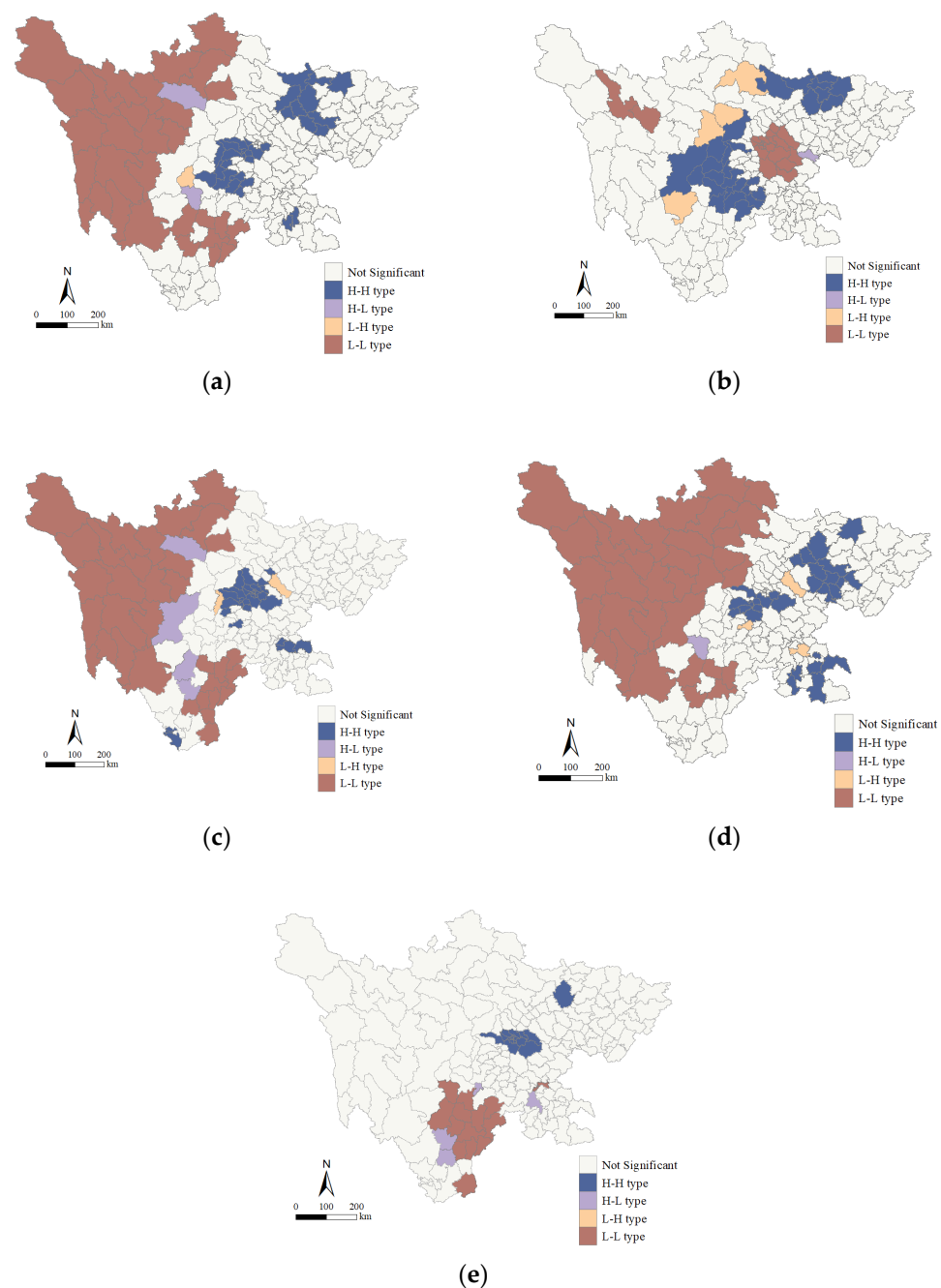


Figure 7. (a) Local autocorrelation spatial distribution of ecosystem health level; (b) local autocorrelation spatial distribution of vitality health level; (c) local autocorrelation spatial distribution of organizational structure health level; (d) local autocorrelation spatial distribution of resilience health level; (e) local autocorrelation spatial distribution of service function health level.

It can be seen from Table 2 that the ecosystem health level passed the significance test with a confidence level of 99%, and the global Moran's I index was positive and reached 0.59, indicating that there was a positive spatial correlation between the ecosystem health levels among the counties in Sichuan Province, and the correlation relationship was strong. Among the sub-criteria indicators, all the criteria indicators passed the significance test with a confidence level of 99%, and the Moran's I index was positive and all >0.4 , indicating that the four criteria indicators had strong agglomeration in the spatial distribution.

For the local spatial autocorrelation, only the H-H and L-L agglomeration areas had significant agglomeration characteristics in the ecosystem health level. The H-H

agglomeration area included 29 counties such as Chongzhou, Jiangyou, etc., accounting for 15.85% of the total counties in the province. These counties had a relatively high level of ecosystem health and were positively affected by surrounding counties. They were mainly located in Chengdu and Mianyang areas. The L–L agglomeration area included 30 counties (Hongyuan, Litang, etc.). These counties accounted for 16.39% of the total counties in the province. The ecosystem health level of these counties and adjacent counties was relatively low, showing a low-level correlation state, mainly distributed in Northwest Sichuan. The counties in the H–H agglomeration area should further exert their highly coordinated radiation and spillover effects, play their exemplary and leading role, and drive the coordinated development of the counties in the L–L agglomeration area. Although there were certain spatial differences in the clustering types of indicators at each criterion level, they were also synchronized. For example, organizational structure and resilience showed an L–L agglomeration in the northwestern Sichuan region, and all criterion level indicators showed an H–H agglomeration in the central Chengdu Plain.

4.3. Obstacle Model

We used the obstacle degree model to diagnose the main obstacle factors for the healthy development of the Sichuan county ecosystem in 2020. The results are shown in Figure 8. Counties that were higher than others are marked in the figure.

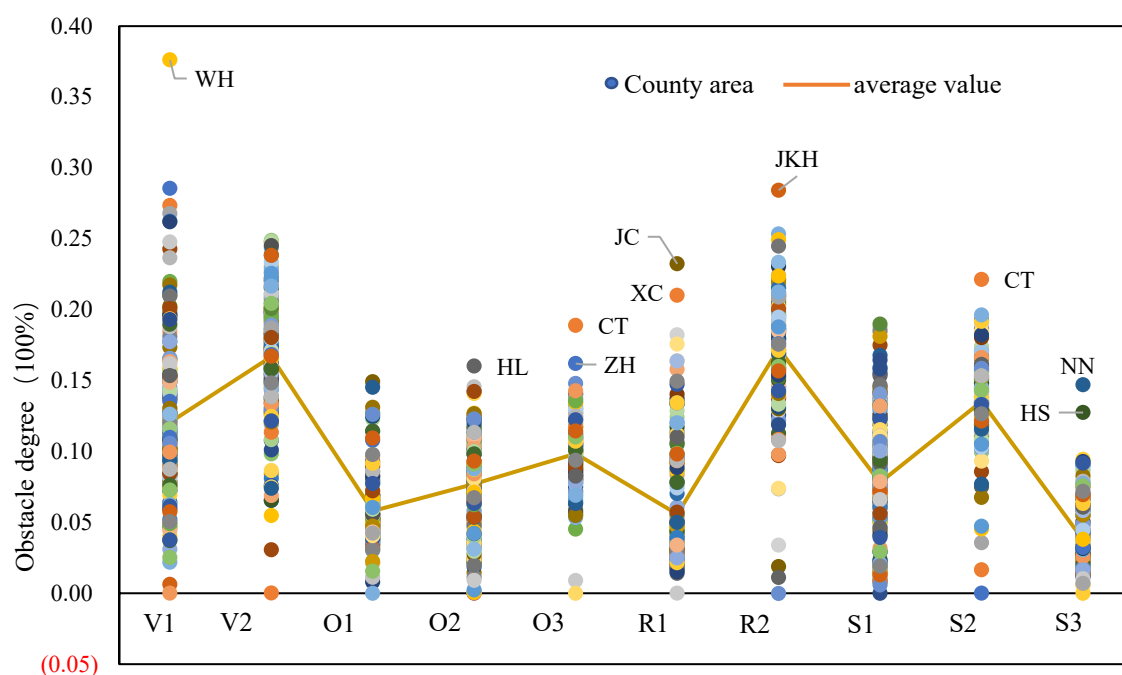


Figure 8. Obstacle degree to the health of county ecosystems in Sichuan Province.

The order of the obstacle degree of the category-level indicators was economic resilience (R2) > economic vitality (V2) > life quality (S2) > ecological vitality (V1) > social structure (O3) > environmental quality (S1) > economic structure (O2) > natural structure (O1) > environmental resilience (R1) > life convenience (S3), and the average obstacle degree was 17.25%, 16.68%, 13.52%, 12.06%, 9.84%, 7.81%, 7.71%, 5.80%, 5.57%, and 3.77%, respectively. It can be seen that (1) Insufficient economic resilience was the main obstacle restricting the healthy development of county ecosystems in Sichuan Province, especially the Jinkou River, where the degree of economic resilience obstacle reached 28.42%, which was significantly higher than that of other counties. Jinkouhe District is dominated by low-end industrial industries such as smelting and mining, which are highly dependent on resources and energy, and this district has been greatly affected by the impact of the COVID-19 epidemic, which restricted its economic recovery. (2) The top three obstacles belonged

to the economic system. From the perspective of the economic–social–environmental system, economic development was still a weakness for the healthy development of county ecosystems in Sichuan. With the construction of the Chengdu–Chongqing economic circle, the county economy in Chengdu Plain has developed rapidly, and people’s quality of life, economic vitality, and economic resilience have been significantly improved. However, there is a large gap in economic scale between counties; most counties are still in the stage of extreme economic backwardness, and Sichuan is still an economically underdeveloped region in China, which will not change in the short term. (3) Ecological vitality has always been considered to be the most significant advantage of Sichuan, but the analysis results show that it has become one of the main obstacles, which needs to be attended to.

5. Discussion

In this study, we constructed a county ecosystem health evaluation index system including 32 specific indicators based on the VORS model. On this basis, we comprehensively evaluated the ecosystem health level of 183 counties in Sichuan Province using the entropy weight method, Moran index, and obstacle degree model. The research results and prospects are as follows:

- (a) The county ecosystems in Sichuan Province are generally at the sub-health level. The ecosystem health levels differ little among the counties and have significant spatial distribution characteristics. The healthy and sub-healthy counties are mainly distributed in the southeast of Sichuan, and the unhealthy counties in the northwest Sichuan. When improving the health of county-level urban ecosystems, Sichuan Province needs to pay special attention to the urban vitality of county-level cities, and take measures to expedite the economic and ecological vitality of county-level cities. In particular, in the southeastern region, the government should strive to improve the ecological vitality and environmental resilience of county-level cities and make up for the shortcomings of the healthy development of urban ecosystems. In the northwest, while maintaining environmental quality, the government should strive to increase the economic vitality required for the health of the urban ecosystem, continuously improve the quality of life of the people, and optimize the social and economic structure of the county seat.
- (b) The ecosystem health level and the four criterion indicators have strong agglomeration in the spatial distribution, the correlation between counties is strong, and the global Moran’s I index is positive, with all > 0.4 . The analysis of the LISA index showed that the local correlation between the health levels of ecosystems in each county in Sichuan was obvious, the H–H agglomeration area was distributed in the Chengdu–Mianyang area, and the L–L agglomeration area in the northwest Sichuan area. Almost all the criteria layer indicators showed different degrees of H–H agglomeration in the Chengdu plain and L–L in the northwestern Sichuan region. It is necessary to seize opportunities for coordinated regional development such as the construction of the Chengdu–Chongqing economic circle, strengthen the radiation and driving effect of counties with relatively healthy ecosystems such as Chengdu–Mianyang, and generate positive spillover effects with the help of spatial autocorrelation.
- (c) The analysis of obstacles shows that economic development is still a shortcoming for the healthy development of ecosystems in Sichuan counties, and economic vitality, economic resilience, and quality of life are the largest obstacles. The ecological environment quality of most county units is out of sync with the social and economic quality. The counties with relatively developed social economies often lack consideration of environmental protection while developing the economy. Governments at all levels should actively take measures to effectively narrow the development gap between the ecological environment and social economy in each county, promote the decoupling of economic growth and environmental costs, explore differentiated and characteristic development paths according to local conditions, strengthen re-

source complementarity and functional integration, and achieve the organic unity of ecological benefits.

- (d) The Obstacle degree discussed in this article also help indicate where counties should work in the future. Counties with low levels of ecosystem health such as Xiangtang, Shiqu, Seda, and Meigu should focus on indicators with higher barriers, improve the treatment level of urban sewage and domestic waste, and increase the per capita disposable income of residents in order to promote the resilience and service function of the urban ecosystem. Counties need to take action to improve performance on indicators with higher barriers. For example, Wuhou should reduce its levels of pollution emissions, increase the density of its vegetation coverage and biological abundance, and effectively improve the ecological vitality of the region.

The evaluation index system constructed in this paper is significant for promoting the health level of the county ecosystem in Sichuan Province. However, limited by factors such as the difficulty of collecting county data, we need to further improve the indicator system. In the follow-up research, we suggest that the National Bureau of Statistics accelerate the construction of a county-level urban ecosystem health monitoring system, and further refine the statistical caliber of county-level related data. It is necessary to strengthen the monitoring and statistics of indicators such as ecology, social vitality, and social resilience factors at the county scale, and support comprehensive research on the health of county-level urban ecosystems.

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References

1. Yi, Q.Y.; Zhang, Y.F.; Ding, M.H. Assessment of urban ecosystem health based on information entropy method. *J. Nanning Norm. Univ. (Nat. Sci. Ed.)* **2021**, *38*, 122–128. [\[CrossRef\]](#)
2. Su, M.; Yang, Z.; Chen, B.; Liu, G.; Zhang, Y.; Zhang, L.; Xu, L.; Zhao, Y. Urban Ecosystem Health Assessment and Its Application in Management: A Multi-Scale Perspective. *Entropy* **2012**, *15*, 1–9. [\[CrossRef\]](#)
3. Qin, Q.; Dai, W.; Chen, Z.X. Review of researches on the evaluation of urban ecosystem health in China. *Saf. Environ. Eng.* **2014**, *21*, 106.
4. Tao, D.K.; Yang, C.; Lv, J.; Wang, X.J. Development path of new urbanization in county-level units under the background of territorial planning. *City Plan. Rev.* **2022**, *46*, 76.
5. Li, X.L. Research on the Adjustment of Administrative Division to Adapt to the Future Urbanization Development. *Reg. Econ. Rev.* **2021**, *32*, 116–124. [\[CrossRef\]](#)
6. Zhang, R.B.; Zhong, C.B. Smart city pilot projects, nearby pollution transfer, and green and low-carbon development. *China Resour. Environ.* **2022**, *32*, 91–104.
7. Qian, J.; Li, J.Y. Coordinated Development between Regional Economy and Environment under the Ecosystem Health System. *Ecol. Econ.* **2017**, *33*, 179.
8. Zhang, N.; Dou, S.Q.; Xu, Y.; Jing, J.L.; Zhang, H.B. Temporal spatial changes of ecosystem health in Guangxi in the past 14 years. *J. Guilin Univ. Technol.* **2021**, *41*, 370–378.

9. Zhu, J.Y.; Lu, H.T.; Wang, H.F.; Yan, Y.; Tang, L.N. Ecosystem health assessment of the Wenchuan earthquake hard-hit disaster areas during the recovery period. *Acta Ecol. Sin.* **2018**, *38*, 9001–9011.
10. Costanza, R. Toward an operational definition of health. *Ecosyst. Health* **1992**, *6*, 239–256.
11. Li, H.; Huang, M.S.; Yao, L.; Chen, S.J. Dynamic assessment of urban ecosystem health in Hefei City based on emergy analysis. *Chin. J. Ecol.* **2011**, *30*, 183–188. [\[CrossRef\]](#)
12. Liu, G.; Yang, Z.; Chen, B.; Zhang, Y.; Zhang, L.; Zhao, Y.; Jiang, M. Emergy-based urban ecosystem health assessment: A case study of Baotou, China. *Commun. Nonlinear Sci. Numer. Simul.* **2009**, *14*, 972–981. [\[CrossRef\]](#)
13. Pan, Z.; He, J.; Liu, D.; Wang, J.; Guo, X. Ecosystem health assessment based on ecological integrity and ecosystem services demand in the Middle Reaches of the Yangtze River Economic Belt, China. *Sci. Total Environ.* **2021**, *774*, 144837. [\[CrossRef\]](#)
14. Wang, Q.; Liu, M.; Tian, S.; Yuan, X.; Ma, Q.; Hao, H. Evaluation and improvement path of ecosystem health for resource-based city: A case study in China-Science Direct. *Ecol. Indic.* **2021**, *128*, 107852. [\[CrossRef\]](#)
15. Guan, D.J.; Su, Y.; He, Z.C. Dynamic evaluation on urban ecosystem health based on fuzzy mathematics model. *Res. Soil Water Conserv.* **2014**, *21*, 150–156. [\[CrossRef\]](#)
16. Zhao, S.; Chai, L.H.; Li, P.F.; Chen, H.X. Urban ecosystem health assessment model and its application: A case study of Tianjin. *Acta Sci. Circumstantiae* **2013**, *33*, 1173–1179. [\[CrossRef\]](#)
17. Chen, K.L.; Su, M.X.; Li, S.C.; Lu, J.; Chen, Y.; Zhang, F.; Liu, Z. The health assessment of the urban ecosystem of Xining city. *Geogr. Res.* **2010**, *29*, 214–222.
18. Guo, R.L.; Zheng, Q.Y.; Liu, J.; Li, M.R. Ecosystem health assessment of Chongqing City based on entropy and GM (1, 1) model. *China Environ. Sci.* **2012**, *32*, 1148–1152.
19. Su, M.R.; Yang, Z.F.; Chen, B. Ecosystem health assessment of urban clusters: Method and application. *Procedia Environ. Sci.* **2012**, *13*, 1134–1142. [\[CrossRef\]](#)
20. Ning, L.X.; Liang, X.Y.; Cheng, C.X. Spatiotemporal variations of ecosystem health of Jing-Jin-Ji region based on the PSR model. *Ecol. Sci.* **2021**, *40*, 1–12.
21. Lu, Y.S.; Han, R.; Shi, Y.; Guo, Y. Ecosystem health assessment of Qiandongnan Miao and Dong Autonomous Prefecture. *Acta Ecol. Sin.* **2021**, *41*, 5557–5569.
22. Xu, Z.Y. Spatial—Temporal dynamics of ecosystem health in Sichuan Province based on PSR model. *Remote Sens. Land Resour.* **2020**, *32*, 251–258.
23. Yang, W.; Zhang, Z.; Sun, T.; Liu, H.; Shao, D. Marine ecological and environmental health assessment using the pressure-state-response framework at different spatial scales, China. *Ecol. Indic.* **2021**, *121*, 106965. [\[CrossRef\]](#)
24. Corvalan, C.; Briggs, D.; Zielhuis, G.D. *Decision-Making in Environment Health*; E&FNSPON: London, UK, 2000; pp. 58–75.
25. Lu, W.; Xu, C.; Wu, J.; Cheng, S. Ecological effect assessment based on the DPSIR model of a polluted urban river during restoration: A case study of the Nanfei River, China. *Ecol. Indic.* **2019**, *96*, 146–152. [\[CrossRef\]](#)
26. Liu, Y.; Yang, C.; Tan, S.; Zhou, H.; Zeng, W. An approach to assess spatio-temporal heterogeneity of rural ecosystem health: A case study in Chongqing mountainous area, China. *Ecol. Indic.* **2022**, *136*, 108644. [\[CrossRef\]](#)
27. Spiegel, J.M.; Bonet, M.; Yassi, A.; Molina, E.; Concepcion, M.; Mast, P. Developing Ecosystem Health Indicators in Centro Habana: A Community-based Approach. *Ecosyst. Health* **2001**, *7*, 15–26. [\[CrossRef\]](#)
28. Zhao, R.; Shao, C.; He, R. Spatiotemporal Evolution of Ecosystem Health of China's Provinces based on SDGs. *Int. J. Environ. Res. Public Health* **2021**, *18*, 10569. [\[CrossRef\]](#)
29. Zhang, Y.; Yang, Z.; Li, W. Analyses of urban ecosystem based on information entropy. *Ecol. Model.* **2006**, *197*, 1–12. [\[CrossRef\]](#)
30. Zhu, L.; Wang, T.L.; Xia, D. The identification of county-level rural territorial function types and research on rural revitalization path in Sichuan province. *Trop. Geogr.* **2021**, *41*, 870–880. [\[CrossRef\]](#)
31. Wang, D.; Yang, T.; Li, Y.; Deng, F.; Dong, S.; Li, W.; He, Y.; Zhang, J.; Zou, L. Light Intensity-A Key Factor Affecting Flavonoid Content and Expression of Key Enzyme Genes of Flavonoid Synthesis in Tartary Buckwheat. *Plants* **2022**, *11*, 2165. [\[CrossRef\]](#)
32. Holly, V.; David, H.; Nigel, M. Congruence between global crop wild relative hotspots and biodiversity hotspots. *Biol. Conserv.* **2022**, *265*, 109432.
33. Rapport, D.J. Ecosystem health: Exploring the territory. *Ecosyst. Health* **1995**, *1*, 5–13.
34. Rapport, D.J.; Costanza, R.; Mcmichar, A.J. Assessing ecosystem health. *Trends Ecol. Evol.* **1998**, *13*, 397–402. [\[CrossRef\]](#)
35. Hancock, T. Urban Ecosystem and a Human Health: A paper prepared for the Seminar on CIID-IDRC and urban development in Latin America, Montevideo, Uruguay. *Ecol. Model.* **2000**, *4*, 143–150.
36. Farber, S.C.; Costanza, R.; Wilson, M.A. Economic and ecological concepts for valuing ecosystem services. *Ecol. Econ.* **2002**, *41*, 375–392. [\[CrossRef\]](#)
37. United Nations. *SDG Indicators: Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development*; United Nations: New York, NY, USA, 2015; pp. 34–45.
38. Qiao, C.; Wang, Y.; Li, C.; Yan, B. Application of Extension Theory Based on Improved Entropy Weight Method to Rock Slope Analysis in Cold Regions. *Geotech. Geol. Eng.* **2021**, *39*, 4315–4327. [\[CrossRef\]](#)
39. Yi, X.; Jue, W.; Huan, H. Does economic development bring more livability? Evidence from Jiangsu Province, China. *J. Clean. Prod.* **2021**, *293*, 126187. [\[CrossRef\]](#)
40. Ye, Y.; Qiu, H. Environmental and social benefits, and their coupling coordination in urban wetland parks. *Urban For. Urban Green.* **2021**, *60*, 127043. [\[CrossRef\]](#)

41. Gao, J.L.; Shao, C.F.; Chen, S.H.; Wei, Z.Z. Evaluation of sustainable development of tourism cities based on SDGs and tourism competitiveness index: Analysis of 221 prefecture-level cities in China. *Sustainability* **2021**, *13*, 12338. [[CrossRef](#)]
42. Feng, Y.; Chen, X.; Gao, F.; Liu, Y. Impacts of changing scale on Getis-Ord Gi* hotspots of CPUE: A case study of the neon flying squid (*Ommastrephes bartramii*) in the northwest Pacific ocean. *Acta Oceanol. Sin.* **2018**, *37*, 67–76. [[CrossRef](#)]
43. Namayande, M.S.; Nejadkoorki, F.; Namayande, S.M.; Dehghan, H. Spatial hotspot analysis of acute myocardial infarction events in an urban population: A correlation study of health problems and industrial installation. *Iran. J. Public Health* **2016**, *45*, 94–101. [[PubMed](#)]
44. Wang, Z.; Yang, Y.; Wang, Y.J.; Yang, R.L. Analysis of the Pattern of cold Hot spots in Urban space Expansion based on the least-resistance Model-a case study of Suzhou-Xichang Region. *Econ. Geogr.* **2016**, *36*, 57–64.
45. Zhao, A.Z.; Wang, D.L.; Wang, J.J.; Hu, X.F. Coupling Coordination Degree and Obstacle Factor Diagnosis of Urbanization Tourism Ecological Environment in Beijing Tianjin Hebei Urban Agglomeration. *Soil Water Conserv. Res.* **2021**, *28*, 333–341.
46. Serrano-Gómez, V.; García-García, Ó.; Pinasa, V.G.I.; Fernández-Liporace, M.; Hernández-Mendo, A.; Rial-Boubeta, A. Measuring Perceived Service Quality and Its Impact on Golf Courses Performance According to Types of Facilities and User Profile. *Sustainability* **2020**, *12*, 5746. [[CrossRef](#)]