A Study on the Evaluation and Spatial Variation of Urban Living Environment Quality in Hubei Province

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Abstract: Scientific evaluation of urban living environment quality is an important foundation for promoting new urbanization. This paper takes 13 prefecture-level cities (states) in Hubei Province as the research object, and constructs a living environment quality evaluation system with 28 secondary indicators from four dimensions: natural ecology, social culture, production and life, and green and low carbon. The entropy weight TOPSIS method is used to comprehensively measure the living environment quality of each city in 2024, and the spatial differentiation pattern and driving type are analyzed by natural breakpoint method and K-means clustering. The study found that: (1) The urban living environment quality in Hubei Province presents a spatial pattern of "multi-polar leadership and clear gradient". Shiyan and Wuhan ranked first in comprehensive score (0.462), while Suizhou ranked last (0.248); (2) The social culture dimension has the highest weight (0.382) and is the primary factor causing the difference in living environment quality among cities; (3) The 13 cities can be divided into three levels: high quality (5), medium quality (6) and need to be improved (2), as well as three development models: ecological driving, economic and livelihood driving and balanced development. Differentiated optimization recommendations are proposed.

Keywords: Human Living Environment Quality; Entropy-Weighted TOPSIS; Spatial Differentiation; Cluster Analysis; Hubei Province

1. Introduction

The human settlement environment is the fundamental space for human survival and development, and its quality directly affects residents' well-being. In 2001, Wu [1] published An Introduction to the Science of Human Settlements, which systematically laid the theoretical foundation for research in this field. Since then, Chinese scholars have conducted extensive empirical studies on urban human settlement quality. Li et al. [2] built an evaluation system with four primary indicators—socioeconomic environment, residential environment, infrastructure and public service environment, and ecological environment—and 28 secondary indicators, using the entropy method to analyze spatiotemporal variations across 286 cities in China. Li et al. [3] focused on five prefecture-level cities in Ningxia, constructing an indicator system with ecological, social, cultural, and economic layers, and determined weights through a combination of analytic hierarchy process (AHP) and entropy weighting. Li et al. [4] selected 16 indicators across economic, social, cultural, and ecological dimensions for the Central-Southern Liaoning Urban Cluster and applied the entropy-weighted technique for order preference by similarity to ideal solution (TOPSIS) method. Yang et al. [5] adopted a "three-life space" perspective, used the entropy-weighted TOPSIS method to assess the human living environment in 11 prefecture-level cities in Hebei Province, and identified constraining factors with a barrier factor diagnostic model.

Research trends indicate that evaluation methods are gradually shifting from subjective weighting methods such as the analytic hierarchy process (AHP) to objective evaluation methods such as entropy weighting and TOPSIS. Evaluation scales are also expanding from national and provincial levels to city clusters and individual cities. However, existing research still has shortcomings in comprehensive horizontal comparisons of cities within provinces, particularly in the need for a more in-depth systematic evaluation of the 13 prefecture-level cities (states) in Hubei Province. Furthermore, typological analysis based on objective clustering results is relatively weak.

Hubei Province is located in the middle reaches of the Yangtze River and is an important strategic fulcrum for the rise of the central region. During the "14th Five-Year Plan" period, the province has made remarkable achievements in the construction of urban and rural living environment, and Yichang City was awarded the 2023 China Human Settlements Award [1]. In April 2026, the "Outline of the 15th Five-Year Plan for National Economic and Social Development of Hubei Province" was officially released, which clearly proposed to "improve the level of livability and comfort" and deployed a series of key tasks around urban renewal, ecological protection, green and low-carbon transformation [6]. From the end of the "14th Five-Year Plan" to the beginning of the "15th Five-Year Plan", scientifically assessing the current status and shortcomings of the living environment quality of cities in the province is of great practical significance for promoting the improvement of living environment in a classified manner. Based on this, this paper takes 13 prefecture-level cities (states) in Hubei Province as the research object, constructs an evaluation index system covering four dimensions: natural ecology, social culture, production and life, and green and low-carbon, adopts the entropy weight TOPSIS method for comprehensive measurement, and reveals the spatial differentiation law of urban living environment quality through cluster analysis, in order to provide a reference for the differentiated living environment improvement strategy of Hubei Province.

2. Overview of the Study Area and Indicator System

2.1 Overview of the Study Area

Hubei Province administers 12 prefecture-level cities and 1 autonomous prefecture, covering a total area of approximately 185,900 square kilometers. At the end of 2024, the province's permanent resident population was 58,388,700, and its GDP reached 6,001.27 billion yuan. Hubei's terrain is complex and diverse, with the Qinling-Bashan and Wuling Mountains in the west, the Jianghan Plain in the central region, and the Eastern Hubei Hills in the east, resulting in significant differences in its ecological environment. In recent years, Hubei Province has achieved positive results in improving its living environment. Yichang City was awarded the 2023 China Human Settlements Award and several cities have set examples in areas such as the renovation of old residential areas and ecological restoration.

2.2 Construction of the Evaluation Indicator System

Drawing on previous studies, and taking into account Hubei Province’s local conditions and data availability, we built an evaluation system for living environment quality. The system has four dimensions—natural ecology, social humanities, production and living, and green low-carbon—with 28 sub-indicators (see Table 1). In this framework, the natural ecology dimension focuses on the environmental baseline and green coverage. The social humanities and production-living dimensions are mainly about social development and economic vitality. The green low-carbon dimension measures how efficiently resources are used and how effective environmental management has been.

Table 1. Evaluation Index System for Urban Living Environment Quality in Hubei Province

Primary Indicator	Secondary Indicator	Unit	Attribute
A Natural Ecology	A1 Proportion of days with good air quality	%	Positive
	A2 Annual average PM2.5 concentration	μg/m³	Negative
	A3 Proportion of surface water bodies meeting or exceeding Class III standards	%	Positive
	A4 Green coverage rate in built-up areas	%	Positive
	A5 Per capita park green space area	m²/person	Positive
	A6 Forest coverage rate	%	Positive
	A7 Total water resources	billion m³	Positive
B Social and Cultural	B1 Permanent resident population	10^4 persons	Neutral
	B2 Urbanization rate	%	Positive
	B3 Population density	persons/km²	Negative
	B4 Number of hospital beds per 10,000 persons	beds/10^4 persons	Positive

	B5 Public library holdings per million persons	thousand volumes/ million persons	Positive
	B6 Share of education expenditure in total government expenditure	%	Positive
	B7 Registered urban unemployment rate	%	Negative
	B8 Per capita disposable income of urban and rural residents	yuan	Positive
C Production and Living	C1 Per capita GDP	yuan	Positive
	C2 Share of tertiary sector in GDP	%	Positive
	C3 Per capita retail sales of consumer goods	yuan/person	Positive
	C4 Per capita urban road area	m²/person	Positive
	C5 Water access rate	%	Positive
	C6 Gas access rate	%	Positive
	C7 Daily per capita domestic water consumption	L/person·day	Positive
D Green and Low-Carbon	D1 Water consumption per 10,000 yuan of industrial value added	$m^3/10^4$ yuan	Negative
	D2 Water consumption per 10,000 yuan of GDP	$m^3/10^4$ yuan	Negative
	D3 Sewage treatment rate	%	Positive
	D4 Domestic waste harmless treatment rate	%	Positive
	D5 Comprehensive utilization rate of industrial solid waste	%	Positive
	D6 Number of public vehicles per 10,000 persons	units/10^4 persons	Positive
	D7 Share of fiscal expenditure on energy conservation and environmental protection	%	Positive

2.3 Data Sources

The data for the 28 indicators come from official channels: (1) Air quality indicators (A1, A2) are from the "Ranking of Ambient Air Quality in Cities and Counties of Hubei Province for December 2025 and January–December 2025" issued by the Hubei Provincial Department of Ecology and Environment in February 2026. Surface water quality (A3) is based on the Provincial Ecological and Environmental Conditions Bulletin [7]. The comprehensive utilization rate of industrial solid waste (D5) comes from the 2024 Information Announcements on the Prevention and Control of Environmental Pollution by Solid Waste published by each city. (2) Socioeconomic indicators (B1–B8, C1–C3) primarily come from the Hubei Statistical Yearbook 2025 [8] and the 2024 statistical bulletins of each city; for cities with released 2025 bulletins, preliminary 2025 data are used. (3) Urban construction indicators (A4, A5, C4–C7, D3, D4, D6) are from the China Urban Construction Statistical Yearbook 2024 [9]. Since the 2025 edition is not yet available, 2024 data serve as a temporary substitute. (4) Water resources indicators (A7, D1, D2) come from the Hubei Provincial Water Resources Bulletin [10]. (5) The proportion of energy conservation and environmental protection expenditure in fiscal expenditure (D7) is calculated from the Hubei Statistical Yearbook 2025 [8] using each city's energy conservation and environmental protection expenditure divided by general public budget expenditure. (6) Forest coverage rate (A6) comes from the latest forest resource census data released by local forestry departments.

The data years vary slightly across indicators, but all are taken from the most recent available release of the same statistical source. The definitions are consistent across cities, so the indicators are comparable horizontally. For urban construction indicators, year-to-year changes are typically less than 0.5%. That means replacing missing values with 2024 data has only a limited effect on the overall evaluation. For B7 (the urban registered unemployment rate), the statistical definition changed. As a result, some cities reported the rate as a range. In this paper, we took the upper bound of that range as the input value.

3. Research Methodology

3.1 Entropy Weighting Method

The entropy weight method, based on the principle of information entropy, objectively determines weights through the degree of variation in indicator data. The greater the variation in an indicator, the lower the information entropy, and the higher its weight in the comprehensive evaluation; conversely, the closer the values of various evaluation objects are on a certain indicator, the weaker their distinguishing ability, and the lower their weight. Specific steps include: data standardization, calculating the proportion of each indicator value, calculating the information entropy value and the coefficient of variation, and determining the weight of each indicator.

3.2 TOPSIS Comprehensive Evaluation Method

The TOPSIS method determines the ranking of each evaluation object by calculating its relative distance to the positive and negative ideal solutions. The positive ideal solution consists of the optimal values of each indicator, and the negative ideal solution consists of the worst values of each indicator. The closer an evaluation object is to the positive ideal solution and the farther it is from the negative ideal solution, the higher its comprehensive evaluation value. The calculation steps include: constructing a weighted standardization matrix, determining the positive and negative ideal solutions, calculating the distance of each evaluation object to the positive and negative ideal solutions, and calculating and ranking the relative proximity.

3.3 Spatial Differentiation Analysis Methods

This paper uses two methods to conduct spatial differentiation analysis on the evaluation results: (1) Natural Discontinuity Method, which uses the distribution characteristics of the comprehensive score values to find data discontinuities for hierarchical division; (2) K-means Clustering Method, which uses the proximity scores of the four primary indicators as input variables and iteratively optimizes the cities into several types to reveal different development driving modes.

4. Results and Analysis

4.1 Analysis of Indicator Weights

The entropy weight method calculation results (Table 2) show that the weights of the four primary indicators are as follows: Social and Humanistic (0.382) > Natural Ecology (0.256) > Production and Living (0.234) > Green and Low-Carbon (0.129). The Social and Humanistic dimension has the highest weight, reflecting the differences in residents' income levels, urbanization rates, and medical and educational resource allocation among cities in Hubei Province, which is the primary factor leading to the differentiation of the quality of the living environment. The Natural Ecology dimension has the second highest weight, indicating that there are also significant differences in ecological background conditions such as air quality, water resource endowment, and forest coverage among cities. The green and low-carbon dimension has the lowest weight because all 13 cities have a 100% rate for D4 (harmless treatment rate of domestic waste), resulting in zero information entropy and no distinguishing ability. Other indicators, such as water consumption per 10,000 yuan of GDP and comprehensive utilization rate of industrial solid waste, while showing some inter-city differences, generally exhibit lower variability than the core indicators of the socio-cultural and natural ecological dimensions.

Table 2. Entropy Weights of the Four Primary Indicators

Primary Indicator	Weight
A Natural Ecology	0.256
B Social and Cultural	0.382
C Production and Living	0.234
D Green and Low-Carbon	0.129

4.2 Composite Scores and Rankings

Overall Score and Ranking The TOPSIS proximity scores of each city across the four dimensions were weighted and summed to obtain the overall score and ranking (Table 3). The overall scores show the following characteristics: (1) Shiyan and Wuhan tied for first place (0.462), with Shiyan, which scored the highest, demonstrating balanced development in natural ecology and socio-cultural dimensions, reflecting the comprehensive advantages of its living environment quality; (2) Enshi (0.453) and Yichang (0.450) followed closely behind, with a difference of less than 0.012 points from the top, both belonging to the first tier; (3) Suizhou (0.248) scored the lowest, with a difference of 0.214 points from the top, indicating a significant gradient difference in the quality of urban living environment in Hubei Province.

4.3 Analysis of Scores across Four Dimensions

To further analyze the internal structure of the quality of living environment in each city, the scores of the four dimensions were compared horizontally.

Natural Ecology Dimension: Enshi scored the highest (0.890), the only city close to "perfect ecological score," with a forest coverage rate of 68.75% and an air quality good day ratio of 92.9%, both the best in the province. Jingzhou (0.529) and Xianning (0.520) ranked second and third respectively, demonstrating outstanding performance in total water resources and surface water quality. Wuhan (0.266) and Jingmen (0.170) ranked lower, mainly due to their low forest coverage and relatively poor air quality.

In the socio-cultural dimension: Wuhan and Shiyan tied for first place (0.539). The former far surpassed the others in urban and rural residents' income (62,530 yuan) and urbanization rate (85.22%), while the latter ranked first in the province in the number of medical beds per 10,000 people (105.6 beds). Suizhou (0.133) and Enshi (0.138) scored the lowest, with significant gaps in urbanization rate (60.07% and 50.82%) and residents' income level (34,783 yuan and 29,401 yuan) compared to the leading cities.

In terms of production and daily life: Yichang (0.565) ranks first, with its per capita GDP (164,489 yuan) and the proportion of the tertiary industry (49.72%) both ranking among the top in the province. Wuhan (0.553) follows closely behind, with active retail sales of consumer goods. Suizhou(0.179) and Huanggang (0.199) scored relatively low, indicating room for improvement in economic development and urban infrastructure.

In the green and low-carbon dimension, Ezhou (0.626) performed best, showing significant achievements in wastewater treatment rate and comprehensive utilization of industrial solid waste. Jingmen (0.605) ranked second. Yichang (0.324) and Huangshi (0.381) ranked lower, with room for improvement in water consumption per 10,000 yuan of GDP and industrial water efficiency.

4.4 Spatial Differentiation and Typology

Using the natural discontinuity method, the comprehensive scores of the 13 cities were divided into three levels (Table 4).

Table 3. Comprehensive Scores and Rankings of Living Environment Quality in 13 Cities of Hubei Province

Rank	City	Comprehensive Score	Natural Ecology	Social and Cultural	Production and Living	Green and Low-Carbon
1	Shiyan	0.462	0.454	0.539	0.377	0.404
1	Wuhan	0.462	0.266	0.539	0.553	0.458
3	Enshi	0.453	0.890	0.138	0.427	0.562
4	Yichang	0.450	0.481	0.401	0.565	0.324
5	Ezhou	0.439	0.330	0.481	0.384	0.626
6	Xianning	0.401	0.520	0.298	0.364	0.534
7	Jingzhou	0.377	0.529	0.158	0.494	0.505
8	Huanggang	0.340	0.429	0.319	0.199	0.482
9	Xiaogan	0.344	0.239	0.241	0.518	0.539
9	Xiangyang	0.344	0.264	0.321	0.418	0.435
11	Huangshi	0.338	0.328	0.323	0.351	0.381
12	Jingmen	0.285	0.170	0.210	0.357	0.605
13	Suizhou	0.248	0.327	0.133	0.179	0.549

Table 4. Classification of Urban Living Environment Quality in Hubei Province

Tier	City	Comprehensive Score Range
High Quality	Shiyan, Wuhan, Enshi, Yichang, Ezhou	0.439–0.462
Medium Quality	Xianning, Jingzhou, Huanggang, Xiaogan, Xiangyang, Huangshi	0.338–0.401
Needs Improvement	Jingmen, Suizhou	0.248–0.285

High-quality cities have a leading comparative advantage in natural ecology or socio-economic development within the province. Shiyan and Yichang, relying on the ecological barrier of the Qinling-Bashan Mountains, have outstanding endowments in forest coverage and water conservation, while their socio-economic development is relatively balanced. Wuhan and Ezhou, with their high level of economic development and public service capabilities, compensate for their relative shortcomings in the natural ecology dimension. Enshi, with its excellent ecological foundation, ranks among the top.

Cities of medium quality are at the mid-level in the province across various indicators, but exhibit varying degrees of shortcomings in different dimensions. Jingzhou ranks second in the natural ecology dimension, but only 11th in the socio-cultural dimension; Huanggang and Xiangyang have relatively balanced scores across dimensions, but lack a prominent comparative advantage.

Cities requiring improvement are at the bottom of the province in most dimensions. Suizhou ranks last in both the socio-cultural and production/living dimensions; Jingmen is at the bottom in the natural ecology dimension, and although it performs well in the green and low-carbon dimension, its low weight makes it difficult to reverse its overall lagging position.

To further identify the driving types of urban living environment quality, K-means clustering was performed based on the TOPSIS proximity of the four dimensions. The optimal cluster size K=3 was determined, dividing the 13 cities into three driving types (Table 5).

Table 5. K-Means Clustering Results and Centroid Values

Type	Eco-driven	Economy and Livelihood-Driven	Balanced Development
City	Enshi, Xianning, Yichang, Shiyan, Jingzhou, Huanggang	Wuhan, Ezhou	Xiangyang, Huangshi, Jingmen, Xiaogan, Suizhou
A Center	0.517	0.298	0.269
B Center	0.289	0.510	0.257
C Center	0.391	0.468	0.363
D Center	0.442	0.542	0.477

Six cities are classified as ecology-driven, covering major cities in the western Hubei mountainous region and the southern Hubei hilly region. The cluster center for the natural ecology dimension (0.517) of this type of city is significantly higher than the other two types, but the cluster center for the socio-cultural dimension (0.289) is lower than that of the economy and livelihood-driven type. The economic and livelihood-driven model includes only two cities, Wuhan and Ezhou, both core members of the Wuhan metropolitan area, possessing absolute advantages in economic development level, urbanization process, and residents' income. The balanced development model comprises five cities, whose cluster center values across all four dimensions are not prominent, mostly ranking in the middle to lower levels of the province, lacking a clear comparative advantage.

5. Conclusions and Recommendations

5.1 Main Conclusions

This paper takes 13 prefecture-level cities (states) in Hubei Province as the research object, constructing an evaluation index system covering four dimensions: natural ecology, socio-cultural aspects, production and living conditions, and green and low-carbon development. The entropy-weighted TOPSIS method was used for comprehensive measurement, and the natural breakpoint method and cluster analysis were employed to reveal spatial differentiation characteristics. The main conclusions are as follows:

Firstly, in terms of index weights, the socio-cultural dimension has the highest weight (0.382) among the four dimensions, indicating that the differences in the quality of the living environment among cities in Hubei Province mainly stem from the differentiation in socio-economic development levels, rather than the natural ecological background. This finding reminds policymakers that while focusing on improving the ecological environment, they should also pay more attention to the equalization of public services and the improvement of residents' income levels.

Secondly, in terms of overall ranking, Shiyan and Wuhan tied for first place, followed by Enshi and Yichang, with Suizhou ranking last. The overall scores show a pattern of "multi-polar leadership and clear gradients," with a score range of 0.248-0.462, indicating significant differences between different levels. The asymmetrical pattern of Wuhan's "strong economy, weak ecology" and Enshi's "strong ecology, weak economy" constitutes a typical characteristic of spatial differentiation in the quality of the living environment in Hubei Province.

Thirdly, in terms of driving force type, the 13 cities can be categorized into three models: ecologically driven, economic and livelihood-driven, and balanced development. Ecologically driven cities need to focus on addressing shortcomings in socio-economic development;

economic and livelihood-driven cities should strengthen ecological protection and environmental governance; and balanced development cities need to identify their comparative advantages and achieve key breakthroughs.

5.2 Policy Recommendations

Based on the differentiated characteristics of the three types of cities, the following recommendations are proposed

For ecologically driven cities, under the premise of protecting green mountains and clear waters, they should accelerate the cultivation of green industries and transform ecological advantages into economic development momentum. Support the development of ecotourism and health and wellness industries in Enshi, Shiyan, and other areas; explore mechanisms for realizing the value of ecological products; and enhance the supply capacity of public services through horizontal ecological compensation and other means.

For cities driven by economic and livelihood development, investment in ecological and environmental governance should be increased to alleviate the resource and environmental pressures brought about by economic development. Wuhan should continuously improve the greening level and air quality of its built-up areas, while Ezhou should consolidate its advantages in the green and low-carbon field and build an ecologically livable demonstration zone in the Wuhan metropolitan area.

For cities pursuing balanced development, it is essential to scientifically assess their comparative advantages and avoid homogeneous competition. Xiangyang should leverage its location as a sub-provincial center while Suizhou and Jingmen should strengthen coordination with the Wuhan metropolitan area to enhance infrastructure and public service sharing.

5.3 Research Limitations

This paper has the following limitations: First, due to the limitations of the statistical yearbook's publication cycle, some indicators use 2024 data instead of 2025 data, which may not fully reflect the latest situation; second, the availability of data for some secondary indicators in the indicator system (such as the B7 urban registered unemployment rate) is limited due to adjustments in the statistical caliber; third, due to data acquisition limitations, subjective evaluation indicators such as public satisfaction could not be included. Future research could, based on updated data, introduce questionnaire surveys and spatial econometric models to further deepen the exploration of the mechanisms affecting the quality of the human settlement environment.

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