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RESEARCH ARTICLE

Assessment of the Sustainable Development Potential of Traditional Villages in Sichuan

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ABSTRACT - This study examines traditional villages in Sichuan Province, focusing on the challenges posed by modernization and urbanization—such as population outflow, inadequate infrastructure, and ecological degradation. A comprehensive evaluation system was developed, encompassing three dimensions: natural environment, socio-economic conditions, and development potential. The research employs the Analytic Hierarchy Process, GIS spatial analysis to assess the sustainable development potential of traditional villages across different regions of Sichuan. The results reveal a significant spatial gradient in sustainable development, with higher scores observed in areas characterized by stronger economic development, favorable ecological conditions, and greater development potential. In contrast, regions with scarce natural resources and weak infrastructure scored lower. Further analysis highlights those natural environmental factors—such as elevation, slope, and green coverage rate—are key determinants of village livability. Socio-economic factors, including population density and income growth rate, influence development vitality, while development potential is significantly affected by spatial agglomeration, tourism resources, and national honors. The study also proposes region-specific development strategies, emphasizing the promotion of green industries and technological innovation in high-scoring areas, while focusing on strengthening infrastructure, diversifying industries, and improving ecological management in medium- and low-scoring regions.

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1. INTRODUCTION

Sichuan Province, located in southwestern China, features a complex and diverse geographical environment characterized by the interwoven distribution of mountains, hills, and basins. This varied natural landscape has provided a rich foundation for the formation and development of traditional villages. Sichuan's traditional villages have a long history and profound cultural heritage, shaped by the interaction of diverse ethnic cultures and Central Plains culture. This fusion has given rise to distinctive folk customs and architectural styles [1]. Since the development of the region during the Qin and Han dynasties, Sichuan has gradually become a vital agricultural hub in southwestern China, with village forms evolving alongside social progress. In addition, distinct village types reflect the region's history of multi-ethnic coexistence and integration. Clan culture is particularly prominent in villages of eastern and southern Sichuan, where ancestral halls and family temples serve as important spaces for maintaining familial identity, fostering a strong sense of local cultural cohesion.

In terms of economic development, traditional villages in Sichuan have long been predominantly agriculture-based, relying on specialized industries such as rice cultivation, tea production, and sericulture, thereby forming livelihood patterns that harmonize with the natural environment [2]. The Chengdu Plain in western Sichuan is known for its advanced rice agriculture, while the hilly regions of southern Sichuan are renowned for tea cultivation. In the mountainous areas of northern Sichuan, forestry and the cultivation of medicinal herbs have developed based on the region's abundant forest resources [3]. Traditional villages in Sichuan are facing mounting challenges under the pressures of modernization and urbanization. Population outflow, especially among the youth, has led to village hollowing, labor shortages, and aging, weakening traditional practices and innovation. Urban expansion and industrial development have disrupted rural spatial patterns and ecosystems, while cultural erosion and excessive commercialization have diminished intangible heritage and local identity. Ecological issues such as land overuse and pollution further hinder sustainability. Balancing economic growth with cultural and ecological preservation is thus essential for rural revitalization.

Within the framework of the Sustainable Development Goals (SDGs), the conservation and development of traditional villages are central to coordinated urban-rural development and cultural heritage protection. Sichuan, with its abundance of traditional villages, plays a key role in this process. However, problems such as population decline, industrial stagnation, and ecological degradation persist. A scientifically grounded, multi-dimensional evaluation system is needed to assess the development status and challenges of these villages. Such a system should integrate economic, social,

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ecological, and cultural dimensions while incorporating technologies like GIS, remote sensing, and big data to enhance precision and effectiveness.

Globally, village sustainability research has grown rapidly, with emphasis on land optimization, ecological protection, and cultural preservation. Policies in various countries, including China's Rural Revitalization Promotion Law, advocate integrated development strategies supported by financial and technical tools to boost local resilience. Technological applications such as spatial analysis and smart agriculture are increasingly used to optimize land use and promote low-carbon, eco-friendly development models [4]. However, existing evaluation frameworks often fail to address Sichuan's specific conditions. Many villages are located in mountainous or ecologically sensitive areas, where issues like land carrying capacity and ecological suitability are overlooked. In addition, digital technologies remain underutilized in sustainability assessments [5]. This study seeks to address these gaps by constructing a regionally adaptive evaluation system that combines localized indicators with digital tools [6]. The goal is to support evidence-based policymaking and promote sustainable, resilient development in Sichuan's traditional villages.

2. MATERIALS AND METHODS

2.1 Data Collection

In the study of traditional villages' sustainable development, data acquisition and integration are essential for understanding their natural environment, socio-economic conditions, and cultural resources [7]. Multi-source data analysis helps identify spatial distribution, ecological suitability, and development potential, offering a solid basis for decision-making. This study uses three main types of data: raster data, geographic data, and directory information [8]. Raster data, sourced from platforms such as the Geospatial Data Cloud and the Resource and Environment Science Data Center, include the Digital Elevation Model (DEM, 30m), GDP and population distribution grids (1,000m), the Normalized Difference Vegetation Index (NDVI), and climate variables (annual precipitation and temperature). DEM provides terrain features like elevation, slope, and aspect, which influence village location and accessibility. GDP and population grids indicate economic activity and population density. NDVI reflects vegetation cover and ecological conditions. Climate data help evaluate agricultural viability and liveability. These high-resolution datasets, combined with GIS, enable integrated analysis of terrain suitability, environmental quality, and accessibility.

Table 1. Data sources

Data Type	Data Name	Data Source
Raster Data	DEM (30m)	Geospatial Data Cloud Platform (https://www.gscloud.cn/)
	GDP Spatial Distribution Grid Data (1000m)	Resources and Environmental Sciences Data Platform (https://www.resdc.cn/)
	Population Spatial Distribution Grid Data (1000m)	Resources and Environmental Sciences Data Platform (https://www.resdc.cn/)
	Normalized Difference Vegetation Index	Resources and Environmental Sciences Data Platform (https://www.resdc.cn/)
	Annual Precipitation	Geospatial Data Cloud Platform (https://www.gscloud.cn/)
	Annual Temperature	Geospatial Data Cloud Platform (https://www.gscloud.cn/)
Geographical Data	Sichuan Province City and County Divisions	Amap Data Platform (https://lbs.amap.com/)
	Sichuan Province County Government Locations	Amap Data Platform (https://lbs.amap.com/)
	Sichuan Province Roads	Amap Data Platform (https://lbs.amap.com/)
	Sichuan Province Water System	Amap Data Platform (https://lbs.amap.com/)
	Sichuan Province A-Level Scenic Spots	Amap Data Platform (https://lbs.amap.com/)
Directory Information	Chinese Traditional Villages	Amap Data Platform (https://lbs.amap.com/)
	China Historical and Cultural Villages	Ministry of Housing and Urban-Rural Development of China
	Sichuan Province Historical and Cultural Villages	Sichuan Provincial Department of Housing and Urban-Rural Development
	China Rural Tourism Key Villages	Ministry of Housing and Urban-Rural Development of China
	Sichuan Province Rural Tourism Key Villages	Sichuan Provincial Department of Culture and Tourism
	Sichuan Province A-Level Scenic Spots	Sichuan Provincial Department of Culture and Tourism

Geographic data, obtained from the Amap Data Platform, include administrative boundaries, county seats, road networks, water systems, and A-level scenic spots in Sichuan. Administrative data define the study area and units of analysis. Proximity to county seats reflects access to public services and governance. Road networks indicate transportation accessibility, crucial for market connectivity and development. Water system data provide insights into ecological conditions and agricultural support. Locations of scenic spots help assess tourism potential, as proximity to attractions often correlates with visitor flows and investment interest.

Directory information is gathered from the Ministry of Housing and Urban-Rural Development and Sichuan's housing and tourism departments [9]. It includes lists of traditional villages, historical and cultural villages, and key rural tourism villages. These records reflect a village's historical and cultural value, development recognition, and tourism potential. Comparing key tourism villages with others across economic, social, and ecological indicators helps reveal how rural tourism contributes to sustainability. Data on A-level scenic spots, appearing in both geographic and directory sources, underscore the role of resource value and graded tourism management in shaping development outcomes. Table 1 summarizes the key data sources used in this study, including raster data for terrain and vegetation, geographic data for accessibility and administrative boundaries, and directory information on traditional villages and tourism resources.

2.2 Research Method

In studying the sustainable development of traditional villages, robust evaluation methods are essential for identifying key factors and guiding strategic planning. Commonly used methods include the Analytic Hierarchy Process (AHP), GIS spatial analysis, and regression analysis [10], which together offer insights into village distribution, development potential, and influencing variables. AHP combines expert judgment with quantitative analysis to assign weights in multi-criteria evaluations [11]. It builds a hierarchical structure—typically covering natural environment, socio-economic factors, and development potential—and calculates the relative importance of indicators through expert scoring and consistency checks. This approach enhances objectivity and reduces bias compared to purely subjective assessments.

GIS spatial analysis supports village research through spatial distribution, kernel density, and accessibility analyses [12]. It reveals village clustering patterns, identifies high-density zones with stronger socio-economic connections, and highlights low-density areas at risk of decline. Accessibility analysis measures connectivity to towns and infrastructure, which affects development opportunities. Villages with better access are more likely to integrate into regional economies, while remote one's face limitations. GIS offers strong spatial visualization and quantitative support for planning and conservation [13].

3. CONSTRUCTION OF THE EVALUATION SYSTEM

3.1 Indicator System

The comprehensive evaluation system for the living environment of traditional villages is built around three core dimensions: the natural environment, socio-economic conditions, and development potential [14]. The natural environment forms the basis for village livability and sustainability [15]. Key indicators include elevation, slope, green coverage, and precipitation. Elevation affects climate and agricultural patterns; higher altitudes may suffer from low oxygen and temperature extremes, while lower areas can be prone to floods. Slope influences land use—steeper slopes limit arable land, while gentle terrain supports settlements and farming [16]. Green coverage reflects ecological quality, impacting air temperature, aesthetics, and overall environmental health. Precipitation affects water availability and agricultural productivity, with insufficient rainfall posing drought risks. Additional factors like temperature, proximity to water sources, and distance from roads or county centers affect ecological suitability and access to markets and services.

Socio-economic conditions reflect development vitality [17]. Key indicators include population density, population growth rate, and income growth rate. Balanced population density supports social and economic stability; overly high or low densities can cause strain or stagnation. Population growth signals a village's attractiveness in terms of jobs and services, while decline may indicate labor loss or poor living conditions. Income growth measures improvements in livelihoods and economic dynamism—higher rates suggest economic vitality, while stagnation points to weak competitiveness and structural challenges.

Development potential assesses future sustainability, including spatial agglomeration, tourism resources, and honorary titles. Villages with strong spatial agglomeration benefit from better resource sharing and regional cooperation. Rich tourism resources enhance economic prospects through rural tourism and cultural experiences. Honorary titles—such as "Traditional Village" or "Historic and Cultural Village"—bring recognition, funding, and policy support, boosting a village's visibility and attractiveness [18]. Together, these indicators offer critical insight into a village's long-term development trajectory and support evidence-based planning and policy.

3.2 Weight Determination

The living environment of traditional villages is shaped by multiple interrelated factors. To assess it accurately, we follow the principles of authenticity, operability, and guidance. Based on recent research, we classify the influencing factors into three dimensions: natural environment, socio-economic conditions, and development potential, forming a comprehensive evaluation system for sustainable development. The Analytic Hierarchy Process (AHP) is used to structure

these factors hierarchically and determine their relative importance through pairwise comparisons, enabling the construction of a systematic and objective evaluation model, as shown in the Table 2.

Table 2. Weight determination and evaluation system

Target Layer	Criterion Layer	No.	Indicator Layer	Weight
Evaluation for the sustainable development potential of traditional villages (S)	Natural Environment (N)	X1	Elevation	0.129
		X2	Slope	0.086
		X3	Aspect	0.082
		X4	Distance to Water	0.072
		X5	Distance to Road	0.062
		X6	Distance to County	0.072
		X7	Temperature	0.058
		X8	Precipitation	0.049
		X9	Green Coverage Rate	0.049
	Economic and Social (E)	X10	Population Density	0.089
		X11	Per Capita Income	0.028
		X12	Population Growth Rate	0.056
		X13	Per Capita Income Growth Rate	0.049
	Development Potential (P)	X14	Spatial Kernel Density	0.028
		X15	Distance to Scenic Spot	0.013
		X16	Honorary Titles	0.078

3.3 Scoring Criteria

The evaluation system uses a five-level scoring method for each indicator, assigning scores from 1 to 5 to reflect performance from very poor to excellent. For some qualitative indicators, a simplified three-level scoring (scores 1, 3, 5) is applied [19]. Reverse scoring is used for indicators like distance to tourist attractions, where greater distance results in lower scores.

a) Natural Environmental Factors:

Key indicators include elevation, slope, aspect, distances from water, roads, and counties, temperature, precipitation, and green coverage. Lower elevations (<800m), gentle slopes (<5°), optimal aspect (150-210°), proximity to water (<1km), roads (<5km), and counties (<10km), higher temperatures (>10°C), abundant precipitation (>1200mm), and high green coverage (>77%) receive top scores 5. Conversely, extreme elevations (>3200m), steep slopes (>35°), unfavorable aspects, distant locations, low temperatures (<2°C), low rainfall (<500mm), and poor vegetation (<41%) score the lowest 1.

b) Socio-Economic Factors:

Indicators include population density, per capita income, population growth rate, and income growth rate. Balanced population density (<1000/km²), high income (>10,000 yuan/km²), moderate population growth (1%-2%), and positive income growth (>3%) earn high scores 5. Overcrowding (>12,000/km²), low income (<500 yuan), negative or excessive population growth, and stagnant or declining income receive low scores 1.

c) Development Potential:

Includes kernel density, distance from scenic spots, and honorary titles. High kernel density (>20) indicates strong economic activity and scores 5, while low density (<5) scores 1. Proximity to tourist attractions (<5km) scores 5, remote locations (>45km) score 1. Villages with multiple national honorary titles receive the highest score 5, while those without any recognition score the lowest 1.

Table 3 provides the detailed scoring criteria for each indicator, categorized into five performance levels ranging from 1 (lowest) to 5 (highest). These thresholds are defined based on empirical ranges and spatial characteristics, allowing for a standardized evaluation of village conditions.

Table 3. Scoring criteria for evaluation indicators

No.	Indicator Layer	Criteria	Score	No.	Indicator Layer	Criteria	Score
X1	Elevation (meters)	＜800	5	X9	Green Coverage Rate	≥0.77	5
		800 - 1600	4			0.65-0.77	4
		1600 -2400	3			0.53-0.65	3
		2400 - 3200	2			0.41-0.53	2
		≥3200	1			＜0.41	1
X2	Slope (degrees)	＜5	5	X10	Population Density (people/square km)	＜1000	5
		5-15	4			1000-3000	4
		15-25	3			3000-7000	3
		25-35	2			7000-12000	2
		≥35	1			≥12000	1
X3	Aspect (degrees)	150-210	5	X11	Per Capita Income (10,000 yuan/square km)	≥10000	5
		60-120	4			5000-10000	4
		240-300	3			2000-5000	3
		0-30 and 330-360	2			500-2000	2
		Others	1			＜500	1
X4	Distance from Water (km)	＜1	5	X12	Population Growth Rate (%)	1-2	5
		1-5	4			0-1	4
		5-10	3			2-5	3
		10-15	2			＜0	2
		≥15	1			≥5	1
X5	Distance from road (km))	＜5	5	X13	Per Capita Income Growth Rate (%)	≥3	5
		5-15	4			2-3	4
		15-30	3			1-2	3
		30-50	2			0-1	2
		≥50	1			＜0	1
X6	Distance from County (km)	＜10	5	X14	Kernel Density	≥20	5
		10-30	4			15-20	4
		30-50	3			10-15	3
		50-70	2			5-10	2
		≥70	1			＜5	1
X7	Temperature (Celsius)	≥10	5	X15	Distance from Scenic Spot (km)	＜5	5
		8-10	4			5-15	4
		5-8	3			15-30	3
		2-5	2			30-45	2
		＜2	1			≥45	1
X8	Precipitation (mm)	≥1200	5	X16	Honorary Titles	Received Two or More National Honorary Titles	5
		900-1200	4				
		700-900	3			Received One National Honorary Title	3
		500-700	2				
		＜500	1			Others	1

3.4 Calculation Formula

Within the framework of the Analytic Hierarchy Process (AHP), the weights assigned to each indicator are systematically determined, enabling the calculation of a comprehensive evaluation score for the human settlements in traditional villages. Initially, the evaluation score for each element within the criterion layer is derived. The corresponding calculation formula is expressed as follows:

$$N = \sum_{j=1}^{m} \omega X_j \quad (1)$$

$$E = \sum_{j=1}^{m} \omega X_j \quad (2)$$

$$P = \sum_{j=1}^{m} \omega X_j \quad (3)$$

$$S = N + E + P \quad (4)$$

In the formula: N represents the score for the natural environment; E represents the score for the economic and social environment; P represents the score for development potential; Xj represents the score for indicator j; ω represents the weight value. S represents the sustainable development score.

4. RESULTS AND DISCUSSION

4.1 Score of the Target Layer and Criterion Layer

a) Sustainable Development Score

The sustainable development levels within the study area exhibit significant gradient characteristics based on the spatial distribution of sustainable development scores. These scores integrate three major criterion layers: natural environment, socioeconomic factors, and development potential. The natural breaks classification method is used to divide the samples into three levels—high, medium, and low—revealing regional differences in sustainable development. Figure 1 shows the spatial distribution of sustainable development potential scores for traditional villages across Sichuan.

From a spatial perspective, high-scoring areas are primarily concentrated in regions with relatively advanced economies, favorable ecological conditions, and strong development potential. These areas not only possess a solid natural environmental foundation but also exhibit high population density, elevated per capita income, and stable population growth rates. Moreover, they demonstrate advantages in industrial layout, infrastructure development, and resource utilization efficiency. Such regions exhibit strong sustainable development capacity and are likely to maintain high-quality and stable growth in the future. Medium-scoring areas typically function as transitional zones, with moderate levels of development and mixed performance across key indicators. While they possess a certain foundation in ecological, socioeconomic, and development potential aspects, they may face specific shortcomings. An industrial structure that requires optimization, low resource utilization efficiency, or insufficient population attractiveness. Low-scoring areas are predominantly distributed in regions with weaker ecological environments, lower levels of economic development, or limited development potential. These regions may suffer from low natural resource carrying capacity, underdeveloped infrastructure, and sluggish economic growth, highlighting the urgent need for strategic development optimization.

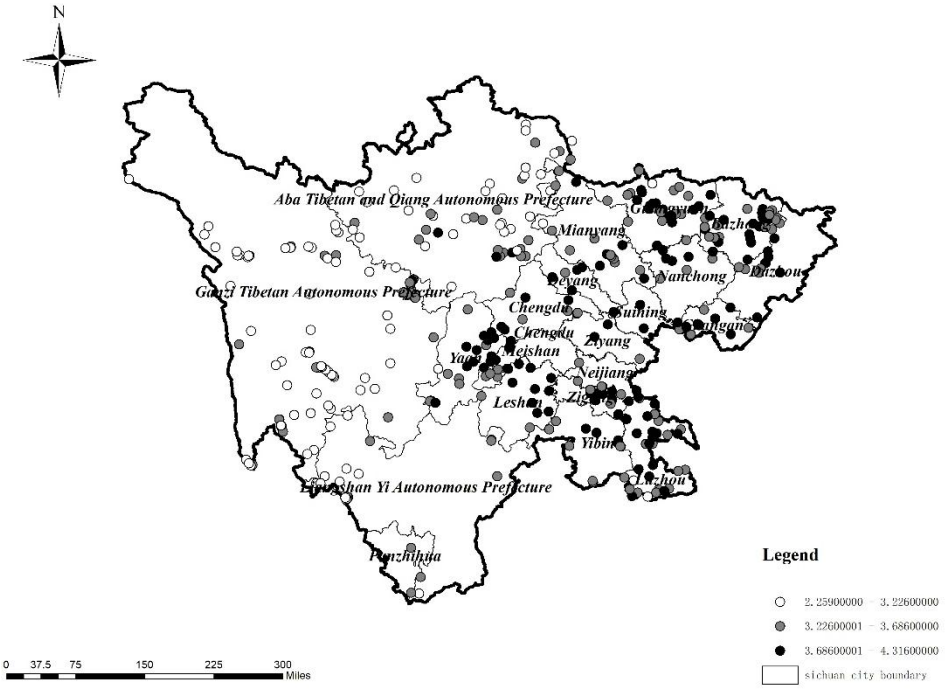

Figure 1. Sustainable development potential scores of traditional villages

In response to this distribution pattern, differentiated development strategies should be adopted to enhance the overall level of sustainable development. For high-scoring areas, efforts should focus on optimizing industrial structures, improving resource utilization efficiency, and promoting green technologies and innovation-driven development to consolidate and enhance their sustainable development advantages. For medium-scoring areas, priority should be given to strengthening infrastructure, optimizing industrial structures, boosting economic vitality, and enhancing ecological protection to facilitate their progression toward high-scoring levels. For low-scoring areas, development strategies should be tailored to their natural endowments and development potential, with a focus on infrastructure investment, guiding

appropriate industrial development, and improving sustainable development conditions through policy support, talent attraction, and public service enhancement.

b) Natural environment score

Based on the comprehensive score analysis of the natural environment criterion layer, the study area exhibits significant spatial differentiation in its overall distribution. This layer is primarily composed of indicators such as elevation, slope, aspect, distance to water, distance to roads, distance to county centers, temperature, precipitation, and green coverage rate. Using the natural breaks classification method, the scores are divided into three levels—high, medium, and low. Figure 2 illustrates the natural environment scores of traditional villages, reflecting variations in terrain, climate, and ecological accessibility.

High-scoring areas generally feature suitable terrain, relatively mild climatic conditions, high green coverage rates, and convenient access to water sources, roads, and county-level administrative centers. These regions clearly benefit from advantageous natural resources and geographic conditions. Medium-scoring areas demonstrate relatively balanced performance across terrain, climate, and accessibility indicators. While these areas possess a certain ecological foundation, there remains a need to enhance the comprehensive management and utilization of natural environmental factors. Low-scoring areas often face more complex terrain conditions or significant limitations in terms of accessibility and water resource utilization. These areas are prone to environmental fragility and tend to exhibit low resource utilization efficiency.

In response to this spatial distribution pattern, differentiated strategies for natural environment management and development should be implemented. For high-scoring areas, efforts should consolidate ecological and geographic advantages through improved resource management and protection. Additionally, new growth opportunities should be explored in green industries and ecotourism to achieve a balance between environmental protection and economic development. For medium-scoring areas, priorities include ecological restoration, infrastructure upgrades, and better environmental monitoring to improve natural conditions. On this basis, the dual objectives of regional economic development and ecological benefits can be pursued. For low-scoring areas, efforts should focus on managing ecologically fragile zones and preventing environmental risks. Improving transportation and water infrastructure, introducing appropriate ecological industries, or implementing ecological compensation schemes can help. Through policy support and external resource investment, the natural environment conditions and sustainable development potential of these regions can be gradually improved.

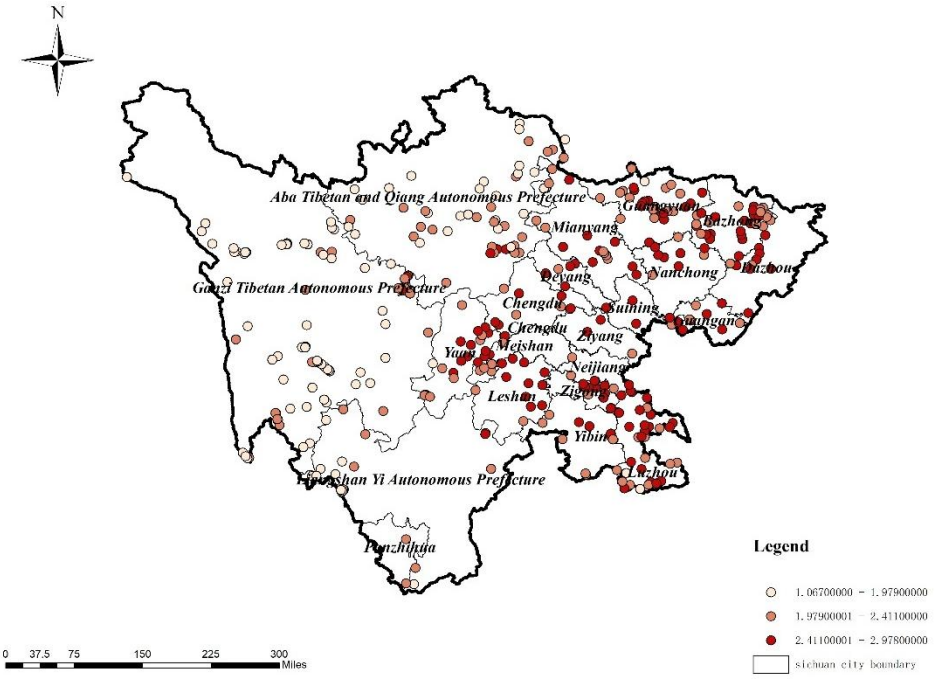

Figure 2. Natural environment development scores of traditional villages

c) Economic and Social Score

Based on the statistical analysis of the socioeconomic criterion layer, this study focuses on four core indicators: population density, per capita income, population growth rate, and per capita income growth rate. Using the natural breaks classification method to segment the overall scores, distinct spatial differences emerge in the distribution. Higher scores typically indicate areas with stronger socioeconomic foundations and greater developmental vitality. This is reflected in the scale effects brought by high population density, improvements in residents' living standards signified by higher per capita income and its growth rate, and a moderately stable population growth rate that highlights demographic structure

balance and regional attractiveness. Figure 3 maps the socio-economic performance of villages based on population density, income levels, and growth rates.

On the map, areas marked in red correspond to high-scoring regions, indicating significant advantages in industrial structure, income levels, and population concentration. These areas often boast well-developed infrastructure and abundant public service resources. Areas marked in orange represent medium scores, suggesting a certain socioeconomic foundation but highlighting the need for further improvements in critical areas such as income growth or population structure optimization. Yellow-marked areas correspond to low scores, signifying weaker socioeconomic conditions, which may include challenges such as low per capita income, unbalanced (either slow or overly rapid) population growth, and underdeveloped infrastructure.

Considering this distribution pattern, differentiated development strategies should be implemented for areas at different scoring levels. For high-scoring regions, efforts should focus on further optimizing industrial structures while enhancing public services and promoting technological innovation to maintain and strengthen their advantages in income levels and population attraction. For medium-scoring areas, the emphasis should be on consolidating existing industrial and demographic strengths while improving public service systems and fostering the development of emerging industries to steadily increase per capita income and its growth rate. For low-scoring areas, priority should be given to improving infrastructure and public services while actively introducing suitable industries to enhance population structure and income levels. At the same time, policy support and targeted resource allocation should be used to gradually boost economic vitality and foster sustainable development in these regions.

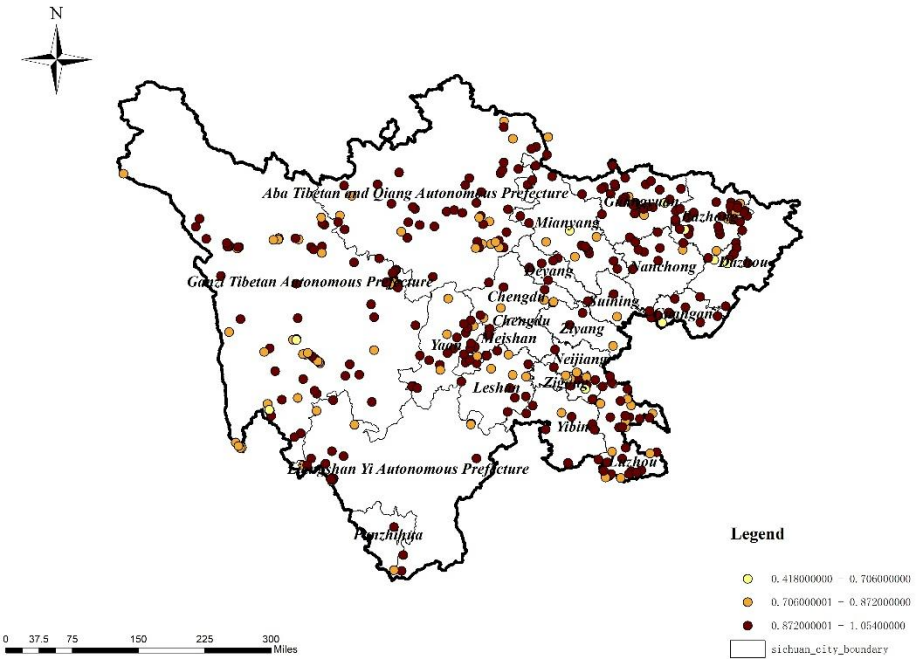

Figure 3. Economic and Social Scores of traditional villages

d) Development Potential Score

Based on the comprehensive score analysis of the development potential criterion layer, the study area exhibits a distinct stratified spatial pattern. This layer is composed of key indicators such as spatial kernel density, distance to scenic spots, and honorary titles. Using the natural breaks classification method, the study area is divided into three levels—high, medium, and low. Figure 4 displays the distribution of development potential scores, derived from spatial agglomeration, proximity to tourist attractions, and national honors.

High-scoring areas generally exhibit high population or functional concentration in geographic space, are relatively close to scenic spots, and have outstanding achievements in honorary titles. These factors collectively indicate significant development potential. Medium-scoring areas show balanced locational advantages and resource endowments but may require further improvement in terms of external attractiveness, cultural branding, or infrastructure development. Low-scoring areas tend to lack spatial concentration, scenic spot influence, or a significant number or level of honorary titles. This limits their ability to leverage external resources and internal advantages, resulting in relatively weak overall development potential.

Given this spatial distribution pattern, differentiated development strategies should be employed to fully unlock regional potential. For high-scoring areas, efforts should focus on consolidating existing locational and resource advantages while enhancing cultural branding and service infrastructure. Attracting more external resources and investments can promote industrial integration and upgrading. For medium-scoring areas, development should focus on strengthening transportation and public service infrastructure, improving the tourism industry and related value chains,

and cultivating regional brands or honorary titles to steadily enhance external influence and long-term sustainability. For low-scoring areas, priority should be given to investing in infrastructure and public services, fostering suitable industries or cultural tourism products, and enhancing external attractiveness and internal growth momentum through policy support and talent recruitment.

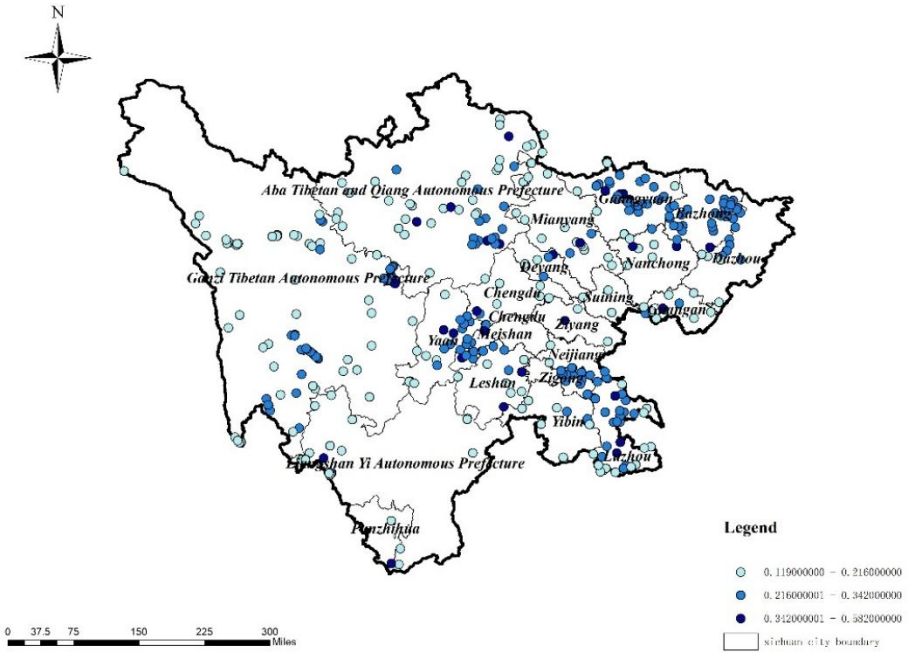

Figure 4. Development Potential Scores of traditional villages

4.2 Sustainable Development Potential Evaluation of Traditional Villages in Each City

a) Sustainable Development Score

Based on the spatial analysis of the average sustainable development scores of traditional villages under the jurisdiction of each city, a distinct stratified pattern emerges across the study area. This sustainable development score integrates three criterion layers: natural environment, socioeconomic factors, and development potential. Using the natural breaks classification method, the scores are divided into three levels—high, medium, and low. Figure 5 presents the average sustainable development scores of traditional villages across different cities in Sichuan.

Darker-colored areas indicate cities where traditional villages enjoy stronger ecological assets, economic vitality, and development potential. Such cities typically possess robust infrastructure and favorable resource endowments. Medium-toned areas demonstrate a certain developmental foundation but still exhibit localized weaknesses, potentially requiring further improvements in industrial structure or public service systems. Lighter-colored areas, with relatively low average scores, suggest that traditional villages in these cities have significant room for improvement across various dimensions, including natural environment, socioeconomic development, and growth potential.

In response to this distribution pattern, differentiated strategies should be adopted to promote regional coordination and sustainable development. For high-scoring cities, efforts should focus on maintaining existing advantages while further optimizing resource utilization in villages, promoting the integration of green industries and cultural tourism, and continuously enhancing economic vitality and ecological protection. For medium-scoring cities, targeted measures should be implemented to address specific weaknesses. This could involve improving public services, introducing emerging industries, and optimizing the industrial structure to enhance the overall competitiveness of villages while ensuring the protection and inheritance of local natural and cultural resources during socioeconomic development. For low-scoring cities, efforts should prioritize addressing infrastructure deficiencies and improving the quality of public services. Additionally, exploring suitable industrial development paths and ecological protection strategies will be essential. Policy guidance and resource investments should be leveraged to cultivate internal growth drivers and gradually raise the level of sustainable development.

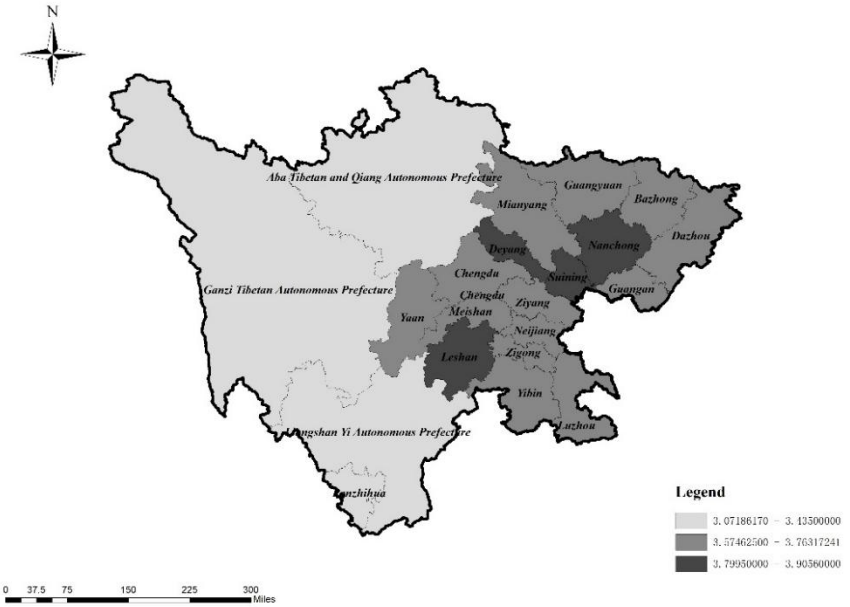

Figure 5. Sustainable development potential scores of traditional villages in each city

b) Natural Environment Score

An analysis of the average natural environment scores of traditional villages under the jurisdiction of each city reveals significant spatial disparities across the study area. This score integrates indicators such as elevation, slope, aspect, distance to water, distance to roads, distance to county centers, temperature, precipitation, and green coverage rate. Using the natural breaks classification method, the scores are divided into three levels—high, medium, and low. Figure 6 compares the average natural environment scores at the city level.

Darker-colored areas represent cities with higher average scores for their natural environment, often benefiting from more favorable terrain conditions, climate suitability, ecological coverage, and better transportation accessibility. Medium-toned areas indicate cities with relatively balanced natural environmental conditions but with some localized weaknesses. Lighter-colored areas, with relatively lower average scores, suggest that traditional villages in these cities face constraints in multiple dimensions, including terrain, ecology, or transportation accessibility. Given this spatial distribution pattern, targeted ecological management and development strategies should be implemented based on the specific conditions of each city. For high-scoring cities, the focus should be on maintaining ecological advantages while strengthening the scientific use and protection of natural resources. Efforts could include optimizing eco-tourism and green industries to enhance economic returns while ensuring sustainable environmental management.

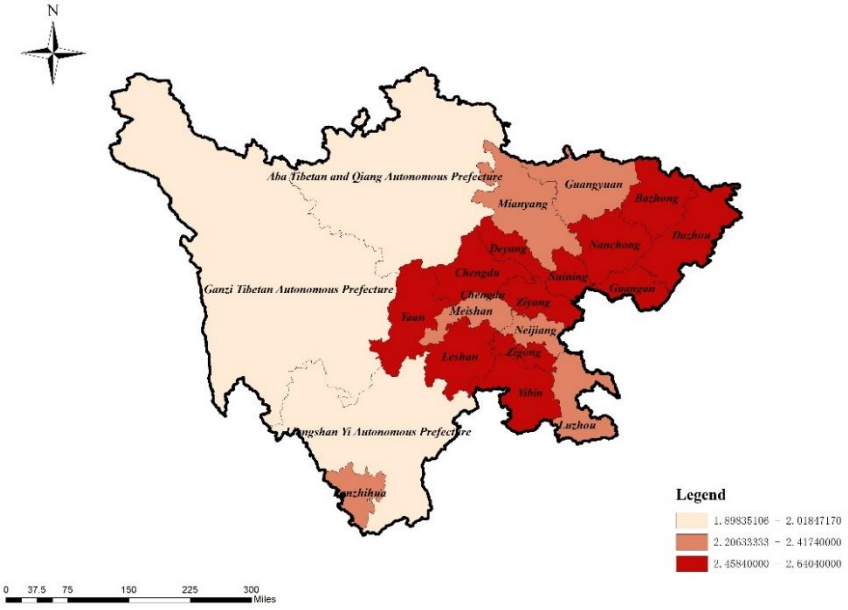

Figure 6. Natural environment scores of traditional villages in each city

For medium-scoring cities, attention should be paid to vulnerable elements of the ecosystem. Infrastructure and transportation networks should be improved, and while maintaining appropriate development levels, efforts should be

made to strengthen soil and water conservation, vegetation restoration, and environmental monitoring to enhance the region's natural environment quality and ecosystem services. For low-scoring cities, greater investments are needed to address ecological infrastructure deficiencies. Priorities should include enhancing water source protection and ecological restoration projects, guiding the development of suitable industries, and gradually improving transportation accessibility and green coverage levels to foster sustainable environmental improvement.

c) Economic and Social Score

An analysis of the average socioeconomic scores of traditional villages under the jurisdiction of each city reveals a clear spatial gradient across the study area. This score integrates key indicators such as population density, per capita income, population growth rate, and per capita income growth rate. Using the natural breaks classification method, the scores are divided into three levels—high, medium, and low. Figure 7 highlights socio-economic differences between cities, based on aggregated data from their respective traditional villages.

Darker-colored areas represent cities with relatively active socioeconomic development, where population concentration, income levels, and growth rates offer notable advantages. Medium-toned areas reflect cities with moderate socioeconomic conditions, indicating room for improvement in income levels and population structure. Lighter-colored areas, with relatively low average scores, suggest that traditional villages in these cities face constraints in economic vitality and social structure, potentially due to limited public services or a narrow industrial base.

In response to this distribution pattern, cities should adopt differentiated development strategies based on their specific conditions. High-scoring areas should focus on further optimizing industrial structures, enhancing public service quality, and strengthening their influence to support lower-scoring regions with technology and resources. For medium-scoring areas, investments in infrastructure and public services should be prioritized, with improvements in transportation, education, and healthcare aimed at attracting more population and industries. Special attention should be given to increasing both per capita income and its growth rate. For low-scoring areas, the focus should be on cultivating distinctive industries, improving social security systems, and enhancing public service infrastructure. Efforts should also target optimizing population structures and developing human resources to build on the existing foundation and achieve sustainable socioeconomic development.

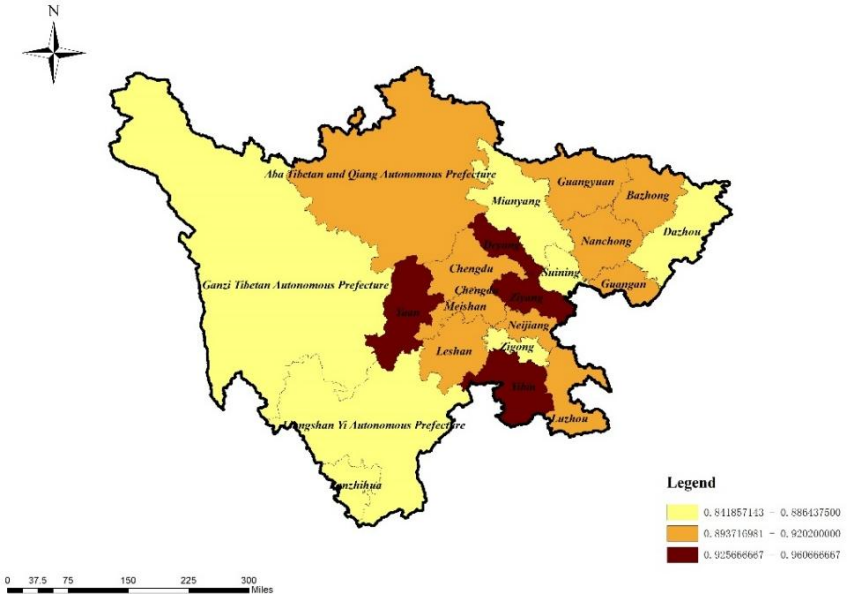

Figure 7. Economic and Social Scores of traditional villages in each city

d) Development Potential Score

An analysis of the average development potential scores of traditional villages under each city's jurisdiction reveals clear spatial differences across the study area. This score is primarily based on indicators such as spatial kernel density, distance to scenic spots, and honorary titles. Using the natural breaks classification method, scores are categorized into high, medium, and low levels. Figure 8 shows the spatial distribution of development potential at the city level.

Darker-colored areas represent cities with relatively high average scores, often characterized by favorable location conditions, proximity to scenic spots, and a significant number of honorary titles (such as model or characteristic villages). These regions exhibit strong overall attractiveness and growth potential. Medium-toned areas demonstrate moderate development potential, indicating a solid foundation in population or functional clustering, tourism resource utilization, and brand-building but still require further enhancement. Lighter-colored areas, with lower average scores, suggest that traditional villages in these cities lack spatial clustering, accessibility to tourism resources, and recognition through honorary titles. These areas urgently need policy support and resource investments to improve their overall competitiveness.

In response to this distribution pattern, differentiated development strategies should be adopted to fully tap into the potential of traditional villages in each region. High-scoring areas should consolidate existing advantages by enhancing regional coordination and resource integration while improving supporting infrastructure and fostering emerging industries to strengthen their influence on surrounding areas. For medium-scoring areas, efforts should focus on improving transportation and public service infrastructure to boost the development and integration of tourism resources. Additionally, building and promoting distinctive cultural brands and earning honorary titles will help enhance external attractiveness. Low-scoring areas should prioritize the in-depth exploration and planning of unique resources, guide the rational layout of industries, and attract skilled talent. Policy incentives and funding can enhance accessibility and service quality, strengthening the foundation for sustainable village development.

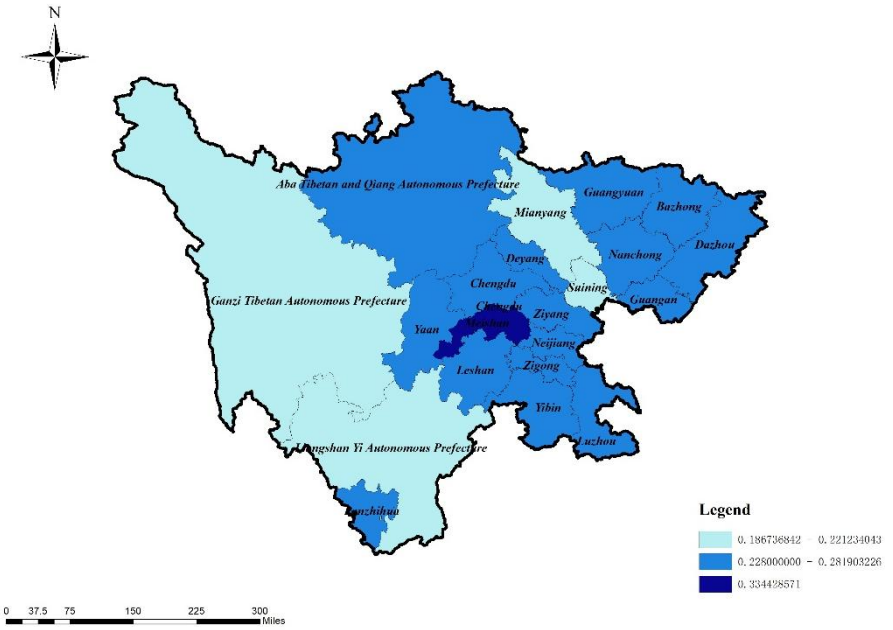

Figure 8. Development Potential Scores of traditional villages in each city

5. CONCLUSION

5.1 Finding

This study reveals a pronounced spatial gradient in the sustainable development levels of traditional villages in Sichuan. High-scoring areas generally possess strong economic foundations, favorable ecological conditions, and significant development potential, manifested in well-developed infrastructure, strong population attraction, and a high degree of industrial diversification. In contrast, low-scoring areas are characterized by ecological fragility, inadequate infrastructure, and sluggish economic growth. The sustainable development capacity of villages is jointly determined by natural environment, socioeconomic factors, and development potential, influenced by variables such as topography, climate, population density, income levels, concentration of tourism resources, and honorary designations. Moreover, policy support mechanisms are currently fragmented, and further field-level insights are needed to ensure targeted development assistance. Accordingly, differentiated development strategies are necessary: high-scoring regions should deepen industrial optimization and green innovation; medium-scoring regions should improve infrastructure and promote industrial diversification; low-scoring regions require increased investment, strengthened services, and enhanced endogenous growth capacity. Future research should focus on improving data acquisition and integrating advanced technologies such as remote sensing and artificial intelligence to establish a more scientific and efficient evaluation framework, thereby providing a robust foundation for policy formulation.

5.2 Limitation

Although this study offers a comprehensive framework for evaluating the sustainable development potential of traditional villages in Sichuan, several limitations remain. First, the study primarily relies on secondary data sources, including GIS datasets and official directories. While these provide valuable insights, they may not fully capture recent changes or local dynamics. Field surveys and community engagement could offer a more nuanced understanding of village-specific challenges and development needs. Second, the evaluation indicators, although grounded in literature and expert input, are subject to weighting subjectivity through the Analytic Hierarchy Process (AHP). Although consistency checks were performed, the results may still reflect certain biases in expert judgment. Third, the spatial analysis focuses on Sichuan Province, and therefore the findings may not be directly generalizable to other regions with different ecological, economic, or cultural contexts. Finally, the current model provides a static evaluation. Longitudinal data and time-series analysis would be beneficial to track sustainability trends and policy impacts over time. Future research should

incorporate dynamic data sources, participatory methods, and comparative regional analysis to enhance model robustness and applicability.

AUTHOR CONTRIBUTIONS

Zhou Zi Hua.: Conceptualization, Methodology, Writing- Original draft preparation.

Omar Jamaludin. Doh Shu Ing.: Supervision.

Tang Xin.: Visualization and Editing.

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DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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