

Classification and Improvement Strategies for Rural Landscapes Based on Dominant Ecosystem Services

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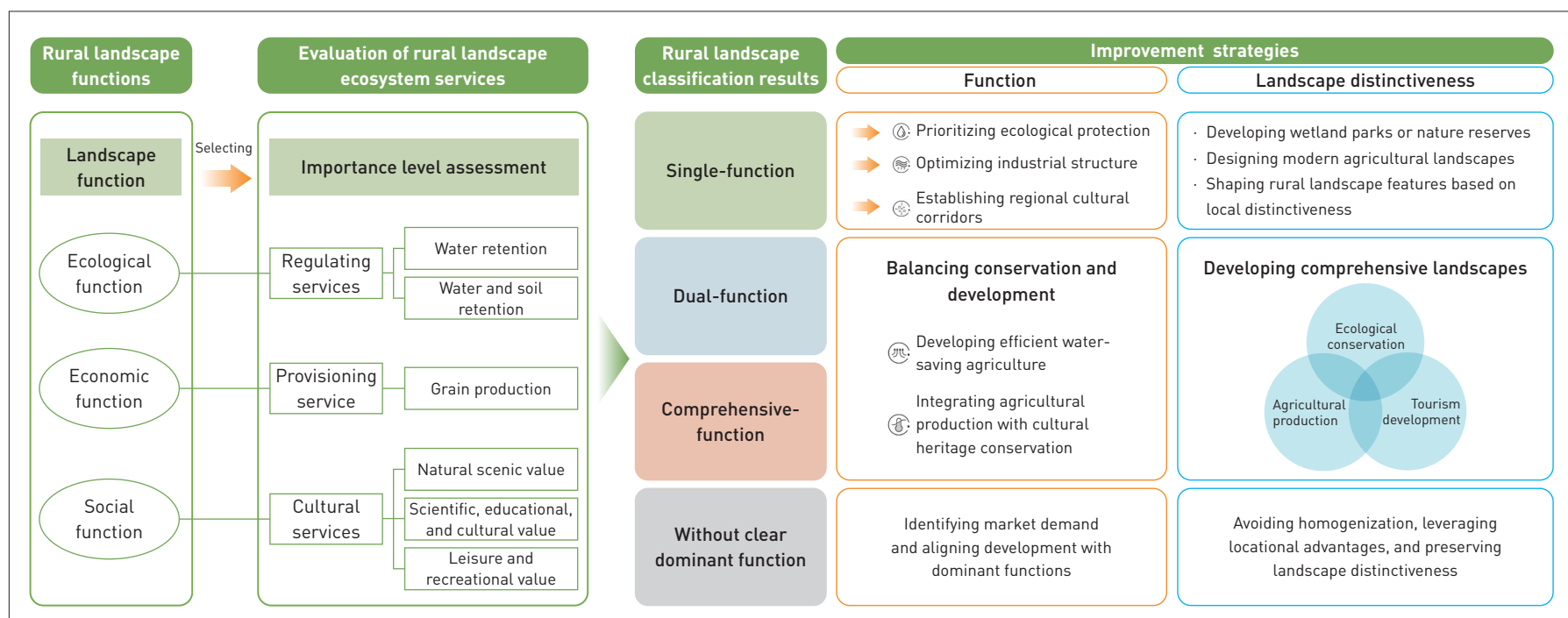
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GRAPHICAL ABSTRACT



ABSTRACT

As carriers of rural ecological and cultural systems, rural landscapes provide essential ecosystem services. Using Wuhan, China as a case study, this study explores rural landscape classification and enhancement strategies based on dominant ecosystem services. Six ecosystem services—water retention, water and soil conservation (regulating services), grain production (provisioning service), natural scenic value, scientific, educational, and cultural value, and leisure and recreational value (cultural services)—were evaluated. The cumulative proportion method was applied to classify the results, identifying dominant ecosystem services at the administrative village level.

The findings reveal significant spatial variations, with regulating services more prominent in the north and south of the study area, provisioning services in the south, and cultural services in the north. Based on these patterns, rural landscapes of the study area were classified into four major types and eight subcategories, each exhibiting distinct spatial clustering. Finally, improvement strategies were proposed from the perspectives of optimizing functions and landscape distinctiveness development, emphasizing a balance between ecological conservation and economic growth. Recommendations include optimizing industrial structures, preserving cultural heritage, and promoting

green agriculture and tourism to strengthen the capacity, vitality, and appeal of rural landscapes. This study provides a new approach to rural landscape classification and offers theoretical and practical insights for rural revitalization.

KEYWORDS

Rural Landscape; Ecosystem Service; Dominant Function; Landscape Classification; Rural Revitalization; Landscape Enhancement Strategies

HIGHLIGHTS

- Proposes a rural landscape classification method based on dominant ecosystem services
- Improves cultural service evaluation by integrating the MaxEnt model with POI data
- Develops rural landscape enhancement strategies from functional optimization and distinctiveness

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1 Introduction

Rural ecological revitalization is key to rural revitalization, and creating a high-quality rural ecological environment serves as an effective pathway and critical measure to achieve this goal^[1]. Rural landscapes, as critical carriers of rural ecological and cultural systems, require systemic classification to support structural and functional studies. This process underpins landscape pattern analysis, planning and design, and construction management while

providing a pivotal interface between landscape ecology theory and practical implementation^[2]. All these aspects are essential for comprehending rural landscapes, building ecologically livable rural areas, and advancing rural ecological revitalization.

Research on rural landscape classification initially emerged in geographical land classification and later extended to human impacts and landscape functional morphology^[3]. By natural and cultural attributes, rural landscapes were categorized into settlement and non-settlement landscapes^[4]. They can also be classified into natural, managed, and artificial landscapes by human disturbance levels^[5]. Functionally, they might be divided into landscape regions, classes, subclasses, and units^[6]. Besides, a four-tier system comprising landscape groups, regions, classes, and elements was proposed, integrating rural landscapes' physical types and subjective perceptions^[7]. In Poland, rural landscapes were categorized into geomorphological units and subunits such as hills, plains, basins, and valleys according to natural, cultural, and visual characteristics^[8].

While existing studies primarily focus on physical morphological features, rural landscapes are not only visual entities but also integral components of rural ecosystems, delivering a variety of ecosystem services^[9]. Rapid urbanization, however, has gradually weakened these critical ecosystem services^[10]. Ecological processes, material flows, and energy transfer within rural landscapes are closely linked to their services. Thus, identifying dominant ecosystem services can deepen understanding of the key roles of rural landscapes in maintaining ecological balance, delivering ecosystem services, and enhancing human well-being.

Functional dominance is defined by the spatial hierarchy of landscape functions, where one or a few dominant functions represent the overall landscape^[11]. This concept has been widely applied in landscape classification and the identification of production, living, and ecological spaces. For example, some studies identified the dominant functions of land parcels by analyzing and evaluating their natural agricultural suitability and geographical locations; based on functional differences, agricultural landscapes were further classified into production, service facility, recreational, and ecological types^[12]. Other scholars identified the dominant, secondary, and auxiliary functions of different land-use types by assessing their ecological, productive, and living functional values, thereby refining spatial classification^[13]. In a research about Beijing, the points of interest (POI) and land-use data were used to quantify ecosystem service contributions by various land-use types within village buffers, enabling dominant service identification and rural landscape resource classification^[10].

On the whole, current studies that conducted ecosystem service assessments to identify dominant ecosystem services for rural landscape classification are scarce and often lack granularity, making it difficult to provide precise guidances for rural landscape enhancement. Precise landscape classification is fundamental to conservation, development, and optimization. Focusing on Wuhan, this study evaluates its rural ecosystem services, identifies the dominant services at the administrative village level, and establishes a rural landscape classification system based on dominant ecosystem services. The findings aim to provide technical guidances for enhancing rural landscapes and theoretical support for rural revitalization.

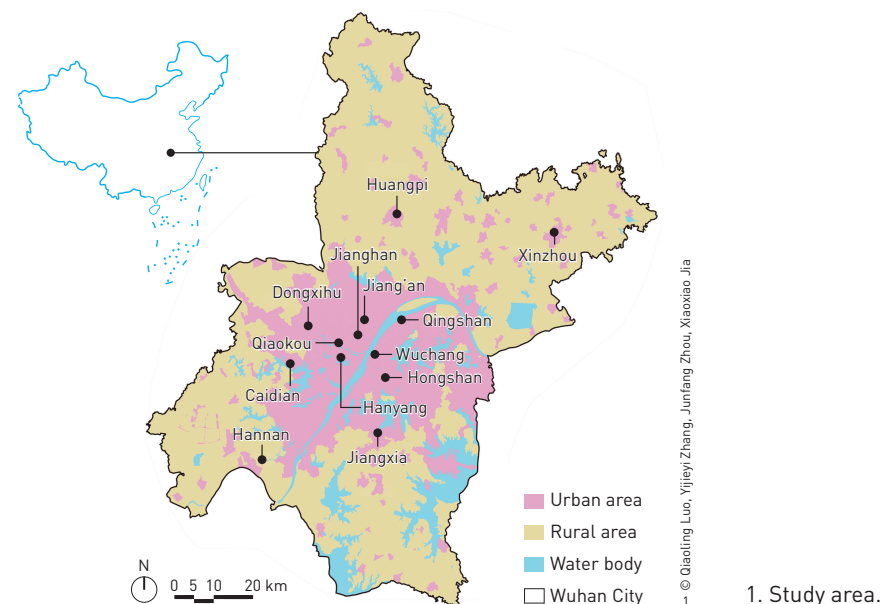
2 Study Area and Research Methods

2.1 Study Area

Wuhan is located in eastern Hubei Province in China at the confluence of the Yangtze River and the Hanjiang River. Its rural areas encompass diverse ecosystems such as lakes, wetlands, forests, and farmlands, with rich natural and cultural resources. As of 2022, the rural population stood at 2.3052 million (24.4% of the city's total), and the gross output of agriculture, forestry, animal husbandry, and fishery reached 83.672 billion yuan^[14]. Rapid socio-economic development has driven urban expansion into peripheral zones, subjecting rural landscapes to dual pressures from urbanization and rural development. These pressures have triggered ecological degradation, such as water pollution and soil erosion. Against this backdrop, this study selected administrative villages in Wuhan's rural areas as study units (Fig. 1) to explore landscape classification methods and improvement strategies based on the dominant ecosystem services.

2.2 Research Roadmap

Rural landscapes, as relatively pristine spatial systems, provide irreplaceable ecological, economic, and social functions distinct from urban areas.^[15] They play a vital role in maintaining ecological balance, supporting agricultural production, and offering recreational resources.^[16] This study first identified the ecological, economic, and social functions of rural landscapes, integrating these with Wuhan's rural characteristics to establish an ecosystem service evaluation and classification framework. Based on the evaluation results, rural landscapes were categorized according to the dominant ecosystem services identified at the village level. Finally, tailored improvement strategies were developed for different rural landscape types, focusing on functional optimization



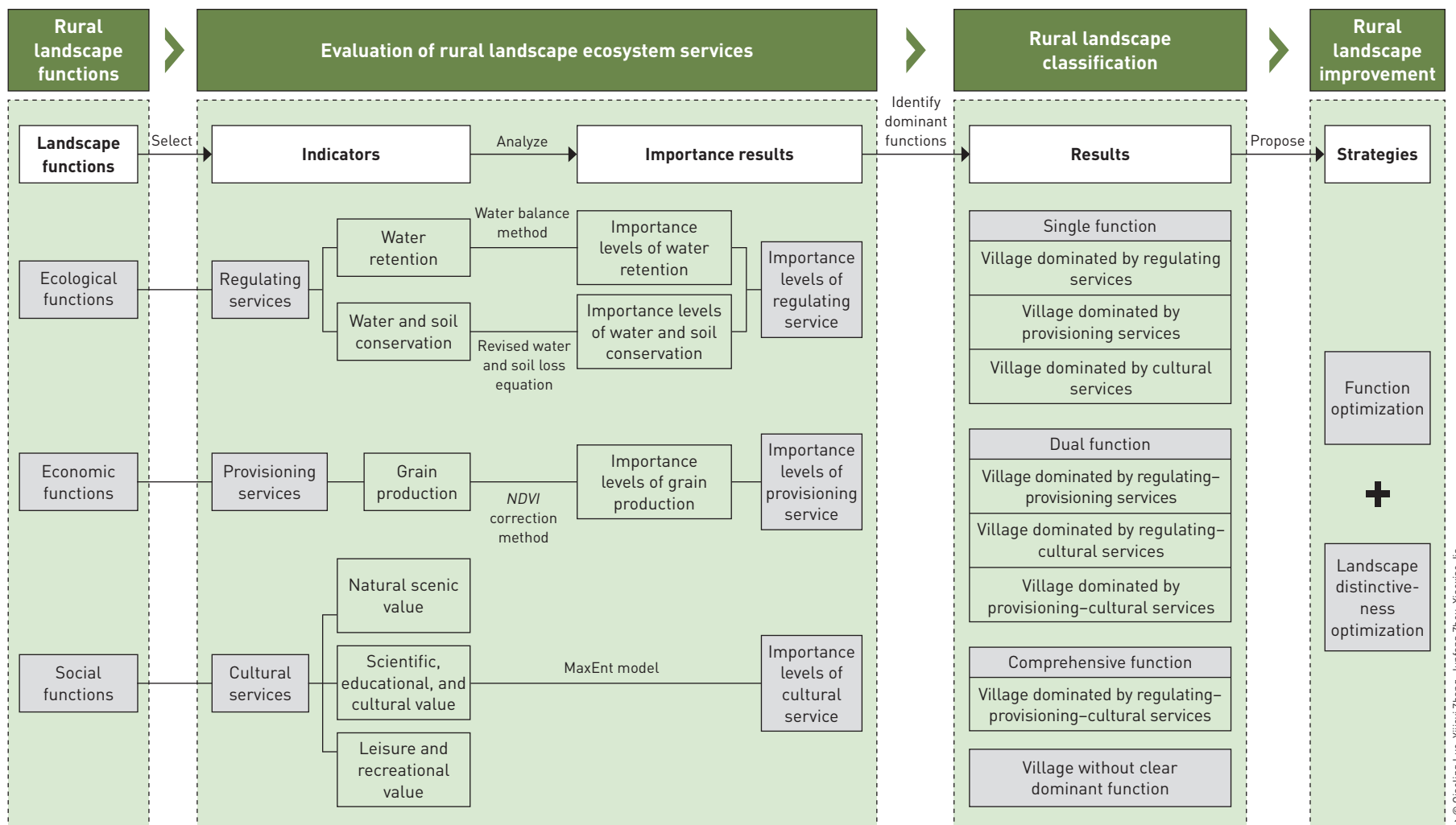
1. Study area.

and distinctiveness, providing actionable guidances for rural revitalization (Fig. 2).

2.3 Data and Methods

2.3.1 Data Sources and Processing

The data used in this study and their sources are detailed in Table 1. Village boundary data were obtained from Map World and the rural areas were delineated based on the compilation regulations for statistical zoning code and urban-rural classification code by the National Bureau of Statistics of China (selecting regions where the first digit of the urban-rural classification code is "2"). The study area encompasses 1,690 village-level administrative units, including administrative villages, forest farms, agricultural farms, tea plantations, aquaculture farms, fishery farms, and agricultural research institutes. The land use and land cover data, from China Land Cover Dataset (2000 ~ 2020), was retrieved from Zenodo and reclassified into 8 categories: farmland, grassland, forest, shrubland, wetland, water body, bare land, and built-up land. The precipitation and evapotranspiration data were spatially interpolated using Kriging methods in ArcGIS after linking tabular data to corresponding meteorological stations, generating raster datasets that represent their spatial distribution. The POI data were obtained from Amap. Those data of POIs with cultural service value were categorized into three categories based on the POI Classification Code from Amap Open Platform: tourist attraction, science/culture & education service, and sports & recreation, encompassing 22 subcategories and 76 subtypes. The POI data for Wuhan's rural areas were then clipped by the boundaries of the 1,690



2. Research framework.

village units in ArcGIS, yielding spatial distribution data of the rural POIs within the study area. Additional datasets, such as soil composition, normalized difference vegetation index (*NDVI*), digital elevation model (*DEM*), road, water body, historical cultural village, and famous tourist village, were downloaded from corresponding open data platforms. These datasets were standardized and projected to the *WGS_1984_UTM_Zone_49N* coordinate system, with raster data resampled to a resolution of 30 m and analyses conducted using 2020 as the temporal benchmark.

2.3.2 Ecosystem Service Evaluation Methods

(1) Selection of ecosystem service evaluation indicators

Ecosystem services refer to the environmental conditions and benefits provided by ecosystems that are essential for human survival and development^[17]. The *Millennium Ecosystem Assessment* categorizes them into regulating, provisioning, cultural, and supporting services^[18].

China's rural revitalization strategies emphasize the ecological functions of rural landscapes, such as climate regulation and environment improvement, to ensure ecological security. These align with the regulating services of ecosystems. Wuhan is prone to flooding and soil erosion due to its hydrogeological conditions, though it is well known for its abundant water resources. Therefore, water retention and water and soil conservation were selected as evaluation indicators for regulating services.

The primary productive function of rural areas, i.e. generating agricultural products, corresponds to the provisioning services. Wuhan, situated in the middle and lower Yangtze River Plain, benefits from abundant arable land and favorable agricultural conditions. Thus, grain production, the core metric for economic functions of rural landscapes, was chosen as the evaluation indicator for provisioning services.

Rural landscapes also hold significant natural and historical cultural values, corresponding to cultural services. Wuhan's rural

Table 1: Research data and sources

Name	Format	Source	Description
Village boundary in Wuhan	Vector	Map World (National Platform for Common GeoSpatial Information Services of China)	Extracted a total of 1,690 villages
Land use and land cover	Raster	Zenodo	Resolution of 30 m × 30 m
Precipitation and evapotranspiration	—	Resource and Environmental Science Data Platform, Chinese Academy of Sciences	Daily precipitation and evapotranspiration data from national meteorological stations of China
Soil composition	Raster	National Tibetan Plateau Data Center of China	Resolution of 1 km × 1 km
NDVI	Raster	National Ecosystem Science Data Center of China	Resolution of 30 m × 30 m
DEM	Raster	Geospatial Data Cloud	Resolution of 30 m × 30 m
Road	Vector	BIGEMAP	Major roads (national, provincial, expressways), secondary roads (urban arterials), and other roads (streets, country roads)
Water body	Vector	BIGEMAP	Rivers and lakes, including the Yangtze River, Hanjiang River, Liangzi Lake, and Mulan Lake
POI geographic data	Vector	Amap Open Platform	Categories including “tourist attraction,” “science/culture & education service,” and “sports & recreation”
Lists of historical and cultural village and famous tourist village	Vector	Wuhan Municipal Bureau of Culture and Tourism	Including 1 national-level historical and cultural village, 9 city-level historical and cultural villages, and 6 city-level famous tourist villages

areas feature interconnected rivers and lakes, along with rich historical and cultural heritages and a long history of traditional agricultural practices. With the rise of rural tourism, these landscapes increasingly serve as venues for leisure and cultural experiences. Cultural services are “nonmaterial benefits people obtained from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences,” including spiritual and religious, educational, and aesthetic values^[18]. Based on visual communication, spiritual conveyance, and place usage, this study refined the classification of cultural services to reflect the ecological value of rural landscapes, categorizing them into 1) natural scenic value, 2) scientific, educational, and cultural value, and 3) leisure and recreational value^[19].

Supporting services, which underpin the other three types of services to ensure ecosystem stability and health (e.g., nutrient cycling essential for life on Earth), were not a focus of this research.

(2) Regulating service evaluation

Water retention capacity, measured as water retention volume, was used as the evaluation indicator, considering factors such as river source areas, climate, land cover, and topography. The calculation formula is as follows^[20]:

$$TQ = \sum_i^j (P_i - R_i - ET_i) \times A_i \times 10^3, \quad (1)$$

where TQ is the water retention volume (m^3), representing the total retained water in a specific area over a given time; i represents the land use type and j represents the total number of land use types in the study area; P_i is for the precipitation (mm), R_i is for the runoff (mm), ET_i is for the evapotranspiration (mm), and A_i is for the area (km^2) of land use type i .

Water and soil conservation was evaluated based on the difference between potential and actual soil erosion, calculated

using the Revised Universal Soil Loss Equation (RUSLE)^[20]:

$$A = R \times K \times L \times S \times (1 - C), \quad (2)$$

where A represents the amount of soil conserved ($\text{t}/\text{hm}^2 \cdot \text{a}$); R is the rainfall erosivity ($\text{MJ} \cdot \text{mm}/\text{hm}^2 \cdot \text{h} \cdot \text{a}$) reflecting the energy and intensity of rainfall, with higher values indicating greater soil erosion potential; K is the soil erodibility ($\text{t} \cdot \text{hm}^2 \cdot \text{h}/\text{hm}^2 \cdot \text{MJ} \cdot \text{mm}$), representing the susceptibility of specific soil types to erosion under given conditions; L and S are topographic factors— L represents the slope length (longer slopes are associated with higher erosion risk), while S represents the slope steepness (steeper slopes correspond to higher erosion rates); C is the vegetation cover factor, representing vegetation's ability to suppress soil erosion (lower values indicate higher vegetation cover, stronger suppression, and lower erosion rates).

(3) Provisioning service evaluation

Grain production was evaluated using cropland as the target area, with the $NDVI$ correction method applied to redistribute the total grain yield across grid cells within the study area^[21]. The calculation formula is as follows:

$$G_i = G_{sum} \times \frac{NDVI_i}{NDVI_{sum}}, \quad (3)$$

where G_i is the grain yield (kg/hm^2) allocated to cropland grid i ; G_{sum} is the total grain yield of major crops in the study area (kg); $NDVI_i$

and $NDVI_{sum}$ are the $NDVI$ value of cropland grid i and the total $NDVI$ value of cropland within the study area, respectively.

(4) Cultural service evaluation

This study used the MaxEnt model combined with POI data to evaluate cultural services. The MaxEnt model, based on the maximum entropy theory, uses known incomplete information to infer the probability distribution of unknown information. Initially developed for predicting species distribution in ecology, it has since been applied to evaluate cultural services due to its spatial visualization capabilities^{[22][23]}. The model allows for the quantitative evaluation of the impacts of environmental variables on cultural services. The evaluation included the following 5 steps.

1) POI data classification. Based on the subtype standards of the POI Classification Code from Amap Open Platform, POI data related to cultural services were selected and categorized into natural scenic value, scientific, educational, and cultural value, and leisure and recreational value (Table 2). This classification generated spatial distribution points for each value category.

2) Selection of environmental variables. Referring to previous studies, the selected environmental variables included land use and land cover, slope, elevation, distance to water bodies, distance to roads, and $NDVI$ ^{[24][25]}. The Shapiro-Wilk test showed that p -values for all variables were much less than 0.05, indicating non-normal distributions. Consequently, Spearman's correlation coefficient

Table 2: Cultural service value types and corresponding POI subtypes from Amap

Cultural service value category	Number of POIs	POI subcategory from Amap
Natural scenic value	314	Tourist attraction related, scenery spot, world heritage, national view spot, provincial view spot, beach
Scientific, educational, and cultural value	1,082	Memorial hall, Buddhist & Taoist temple, church, mosque, science & education cultural place, museum, Audi museum, Mercedes-Benzes museum, exhibition hall, convention & exhibition center, art gallery, library, science & technology museum, planetarium, cultural palace, archives hall, arts organization, media organization
Leisure and recreational value	755	Sports & recreation places, sports places, sports center, bowling hall, tennis court, basketball stadium, football field, ski field, skating rink, outdoor gym facility, public beach, natatorium, gym center, table tennis hall, pool room, squash court, horse riding club, race track, rugby court, badminton court, taekwondo venue, golf related, golf course, golf training course, recreation center, night club, KTV, disco, pub, game center, card & chess room, lottery center, internet bar, holiday & nursing resort, resort, nursing home, recreation place, amusement park, fishing spot, plucking park, camping site, water sports center, theater and cinema related, cinema, concert hall, theater, park & square, park, zoo, botanical garden, aquarium, city plaza

NOTE

The repetition of POI classification names does not impact the results of this study.

was employed to quantify the association between the variables. Multicollinearity test results revealed that the correlation coefficients between variables were all less than 0.75, variance inflation factors (VIF) were all less than 10, and tolerances were all greater than 0.2, indicating weak correlations^[26] and no multicollinearity issues^[27]. Therefore, all variables were retained for modeling.

3) MaxEnt model analysis. The three types of cultural service value distribution points and environmental variables were input into the MaxEnt model to generate spatial distribution maps for each value category.

4) Spatial distribution result adjustment. Using the information of historical and tourist villages within the study area, the spatial distribution maps of the scientific, educational, and cultural value and leisure and recreational value were normalized. Specifically, the scientific, educational, and cultural value results of the national-level historical and cultural village and city-level historical and cultural villages (10 in total) were adjusted to the maximum value of 1. Similarly, the leisure and recreational value results of 6 city-level famous tourist villages of Wuhan with rich tourism resources and well-developed infrastructure were adjusted to the maximum value of 1.

5) Generation of cultural service evaluation results. The normalized maps of the three cultural service values were assigned equal weights and overlaid to obtain the final distribution results of rural landscape in cultural service values.

2.3.3 Classification Standards for Ecosystem Service

The classification of ecosystem services should reduce the fragmentation of the highest-level categories and facilitate comparison^[28]. Common classification methods include the natural breaks method^[29], the quantile method^[30], and the cumulative proportion method^[31]. Studies have shown that the cumulative proportion method outperforms others in terms of classification quality, distinctiveness, and applicability. This method has relatively fixed cumulative values at each level, providing strong comparability^[28]. Specifically, with this method, the values of individual ecosystem service, corresponding to each grid cell, were ranked in descending order, and cumulative service values were calculated. Following the Guidelines on Delimitation of Ecological Protection Red Line, the grid values corresponding to a cumulative service value that accounts for 50% and 80% of the total ecosystem service value were used as thresholds. Using ArcGIS reclassification tools, the importance of each ecosystem service type was divided into three levels: very important (top 50%), important (50% ~ 80%), and moderate (80% ~ 100%). For regulating services, the importance

level was determined by the highest level from the classifications of water retention and water and soil conservation.

2.3.4 Classification Standards for Rural Landscapes

Classifying rural landscapes at the administrative village level helps clarify the dominant ecosystem service of individual villages, providing guidances for targeted improvement strategies and future development of rural areas. This study determined the dominance based on the area proportion of each ecosystem service^[10]. Referring to related research, an ecosystem service was considered dominant if the area of its very important zone exceeded 33% of the administrative village's total area^[10]. Given the equal importance of regulating, provisioning, and cultural services for rural landscapes, this study adopted 33% as the baseline. Based on the dominant ecosystem services, rural landscapes can be categorized into 4 major types: single function, dual functions, comprehensive functions, and no clear dominant function. These further formed 8 combinations (Table 3).

3 Results

3.1 Spatial Distribution Characteristics of Regulating Service

The importance levels of water retention showed a general spatial trend of being higher in the north and south and lower in the center (Fig. 3-1). Very important areas accounted for 26.54%, mainly distributed in the northwest, northeast, and southern parts of the study area. Important areas accounted for 43.02%, concentrated in the central region. Moderate areas accounted for 30.43%, primarily located in the northern and central regions. This spatial distribution was closely related to vegetation cover and terrain, with the northwest and eastern areas characterized by high mountains and forests and the south dominated by cropland and water bodies.

The importance levels of water and soil conservation were generally low across the region, though with a few clusters of high-value villages (Fig. 3-2). Very important areas accounted for 3.55%, mainly located in the northwest and northeast, overlapping with the higher-importance-level areas for water retention. Important areas accounted for 6.84%, mainly surrounding the very important areas of water and soil conservation. Moderate areas accounted for 89.61%, widely distributed across the rural areas.

The spatial distribution of regulating service importance levels reflected the combined ecosystem services of water retention and water and soil conservation, aligning closely with the distribution of water retention (26.98%, 45.10%, and 27.91% for very important, important, and moderate areas, respectively) (Fig. 3-3).

Table 3: Classification of rural landscapes based on the dominant ecosystem services

Category	Dominant function type	Regulating service	Provisioning service	Cultural service
Single function	Village dominated by regulating services	$A \geq 33\%$	$B < 33\%$	$C < 33\%$
	Village dominated by provisioning services	$A < 33\%$	$B \geq 33\%$	$C < 33\%$
	Village dominated by cultural services	$A < 33\%$	$B < 33\%$	$C \geq 33\%$
Dual functions	Village dominated by regulating–provisioning services	$A \geq 33\%$	$B \geq 33\%$	$C < 33\%$
	Village dominated by regulating–cultural services	$A \geq 33\%$	$B < 33\%$	$C \geq 33\%$
	Village dominated by provisioning–cultural services	$A < 33\%$	$B \geq 33\%$	$C \geq 33\%$
Comprehensive functions	Village dominated by regulating–provisioning–cultural services	$A \geq 33\%$	$B \geq 33\%$	$C \geq 33\%$
Without clear dominant function	Village with no clear dominant function	$A < 33\%$	$B < 33\%$	$C < 33\%$

NOTE

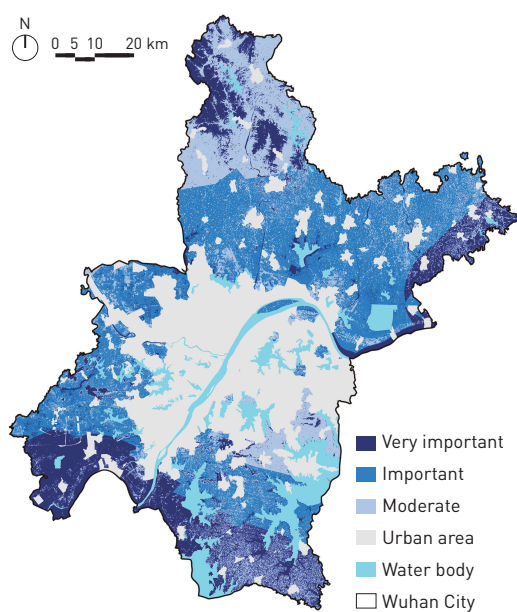
“A” represents the area proportion of regulating service in a village identified as very important; similarly, “B” for provisioning service, and “C” for cultural service.

3.2 Spatial Distribution Characteristics of Provisioning Service

The spatial distribution of provisioning service importance levels exhibited a general pattern of being higher in the south and lower in the northwest (Fig. 4). Very important areas accounted for 29.38%, concentrated in the southeast, dominated by cropland

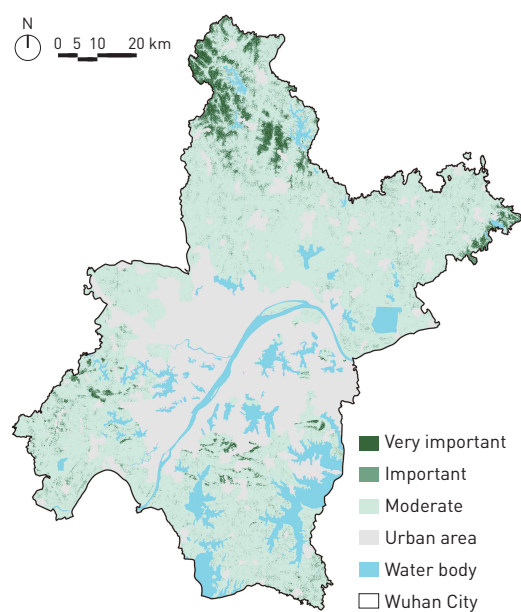
with high *NDVI* values and forming contiguous clusters. Important areas accounted for 24.12%, mainly in the north, also dominated by cropland. Moderate areas accounted for 46.50%, primarily in the northwest, southwest, and areas around central urban regions, dominated by forests, built-up land, and water bodies. The overall

3. Importance levels of regulating service of Wuhan’s rural landscapes.



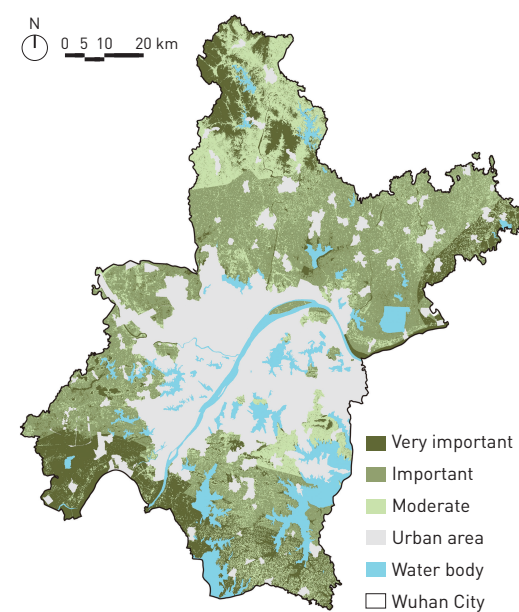
Importance levels of water source conservation

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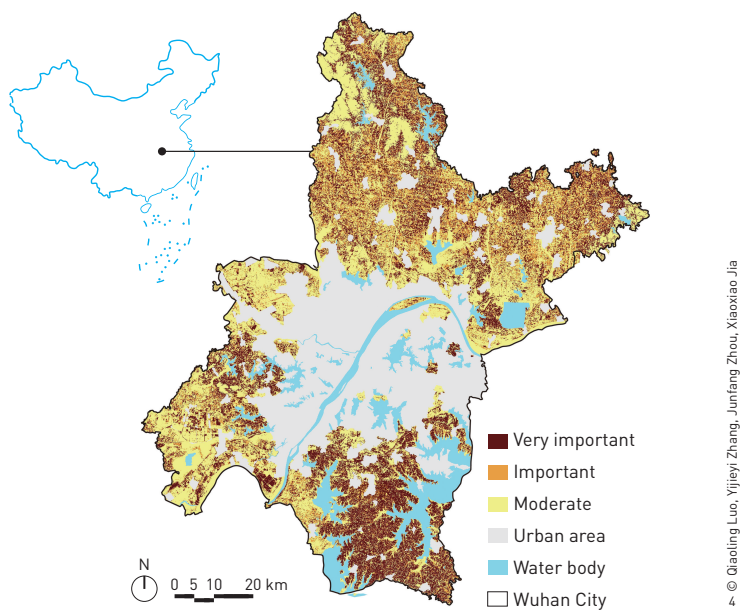
Importance levels of water and soil conservation

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Importance levels of regulating service

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4. Importance levels of provisioning service of Wuhan's rural landscapes.

result showed that the total proportion of very important and important areas was relatively high, underscoring the significance of rural landscapes in grain production.

3.3 Spatial Distribution Characteristics of Cultural Service

The spatial distribution of cultural service importance levels reflected the combined value of the three categories. The MaxEnt model employed in this study used the jackknife method to measure the contribution of each environmental factor to model construction. Results showed that the natural scenic value was higher in the north and lower in the south, which was strongly correlated with elevation and slope (Fig. 5-1). The high-value areas of scientific, educational, and cultural value were concentrated in areas around central urban regions and historical and cultural villages. Land use and land cover and *NDVI* were the main influencing factors, suggesting that this value was closely related to land use type and vegetation cover (Fig. 5-2). The leisure and recreational value showed a linear spatial distribution, with distance to roads and land use and land cover as the primary influencing factors (Fig. 5-3). Overall, very important areas of the cultural services accounted for 23.26%, mainly in the northern region and surrounding urban built-up areas, where it found abundant natural and historical cultural resources, convenient transportation, and comprehensive public services; important areas accounted for 29.17%, primarily located around very important areas; and moderate areas accounted for 47.58%, distributed in the

southern region, dominated by cropland with a lack of distinctive natural and historical cultural resources (Fig. 5-4).

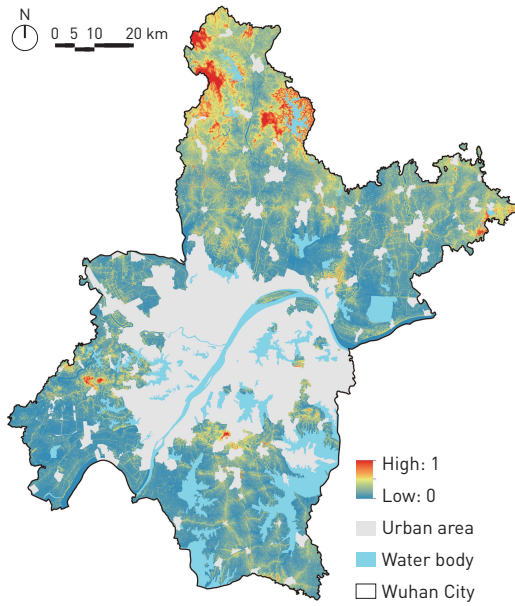
3.4 Rural Landscape Classification Results

The classification results for rural landscapes in Wuhan based on the dominant ecosystem services are shown in Fig. 6. Single-function villages (46.80%) consisted of 202 villages dominated by regulating services, 362 by provisioning services, and 227 by cultural services. Dual-function villages (19.70%) included 142 villages dominated by regulating–provisioning services, 56 by regulating–cultural services, and 135 by provisioning–cultural services. The number of comprehensive-function villages was 20 (1.18%). Villages with no clear dominant function numbered 546 (32.31%).

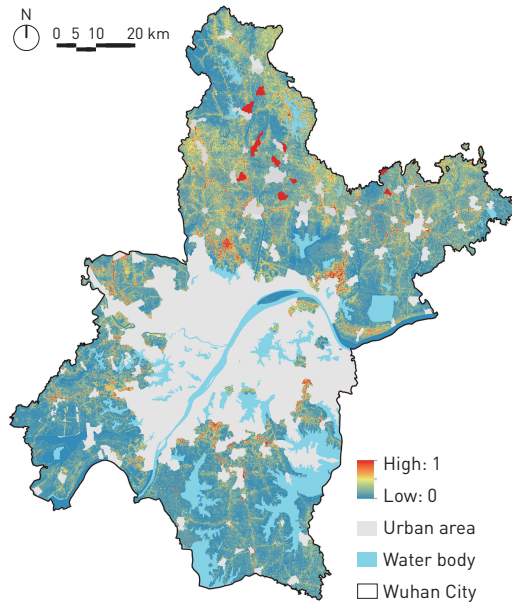
Different types of rural landscapes within the study area showed evident spatial clustering. Villages dominated by regulating services were distributed around high mountain forest areas and water-dense regions; those dominated by provisioning services were concentrated in the north and south, dominated by cropland in flat terrains; and villages dominated by cultural services were located in areas with abundant natural and historical cultural resources, convenient transportation, and comprehensive public services in the north. Moreover, villages dominated by regulating–provisioning services were found in the south, leveraging cropland and water resources; those dominated by regulating–cultural services were mainly in areas around high mountain forests and water bodies, characterized by distinctive natural scenery and ecological conditions; and those dominated by provisioning–cultural services were located around villages dominated by provisioning and cultural services, enjoying agricultural and cultural tourism resources. In addition, villages with dominant regulating–provisioning–cultural services were distributed in the northeast, where natural, ecological, and cultural resources are prominent; while villages with no clear dominant function were primarily around urban built-up areas, impacted by development and lacking distinct ecosystem service.

4 Strategies for Improving Rural Landscapes

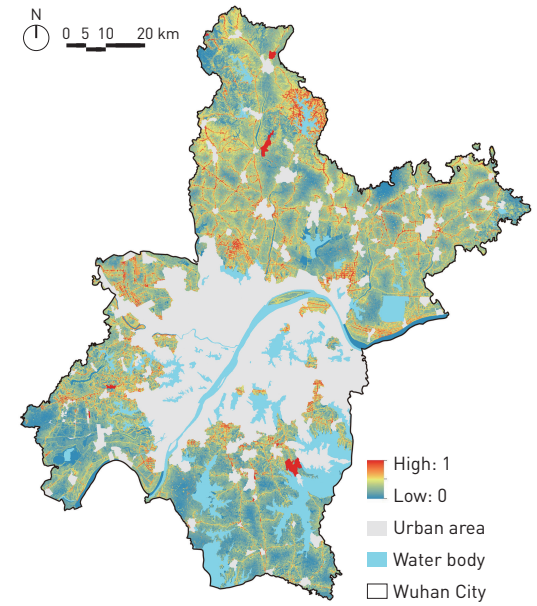
Rural landscapes, as vital components of rural ecosystems, form a complex ecological–economic–social system^[32]. This study evaluated rural landscapes based on regulating, provisioning, and cultural services of ecosystems, taking administrative villages as units and classifying landscapes based on dominant ecosystem services. Improvement strategies from the perspectives of function



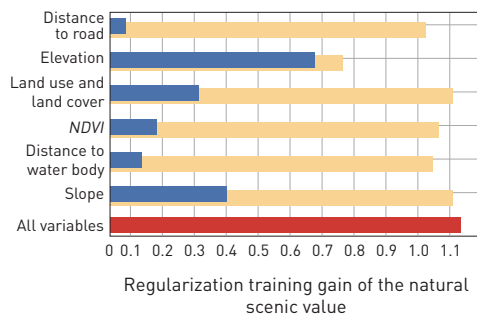
Natural scenic value



Scientific, educational, and cultural value



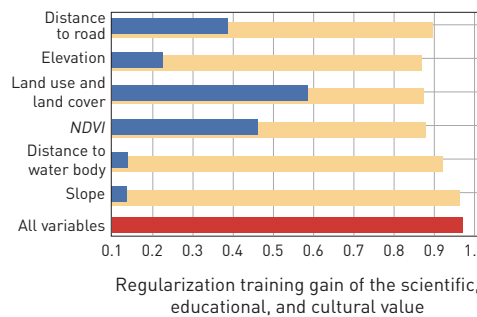
Leisure and recreational value



Without certain variable Only certain variable Including all variables

Analysis of the environmental factor importance in the natural scenic value

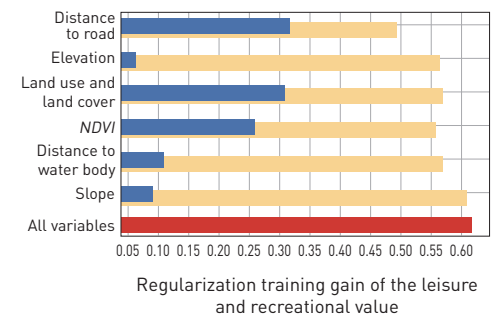
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Analysis of the environmental factor importance in the scientific, educational, and cultural value

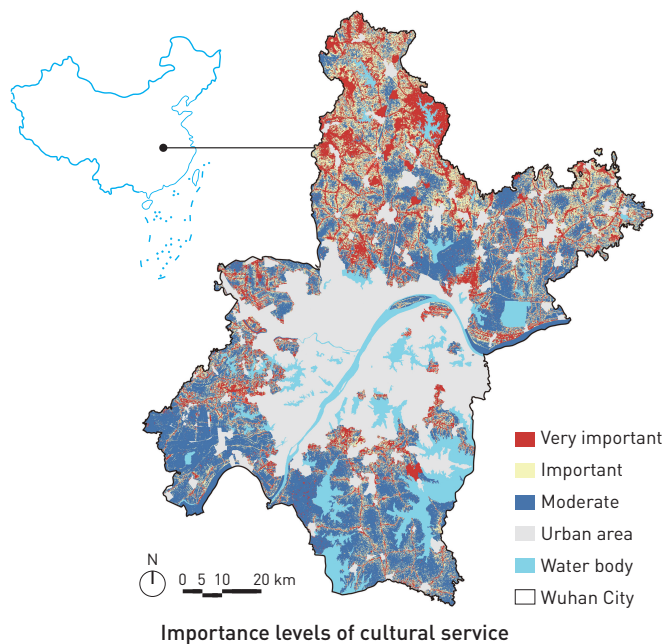
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Without certain variable Only certain variable Including all variables

Analysis of the environmental factor importance in the leisure and recreational value

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Importance levels of cultural service

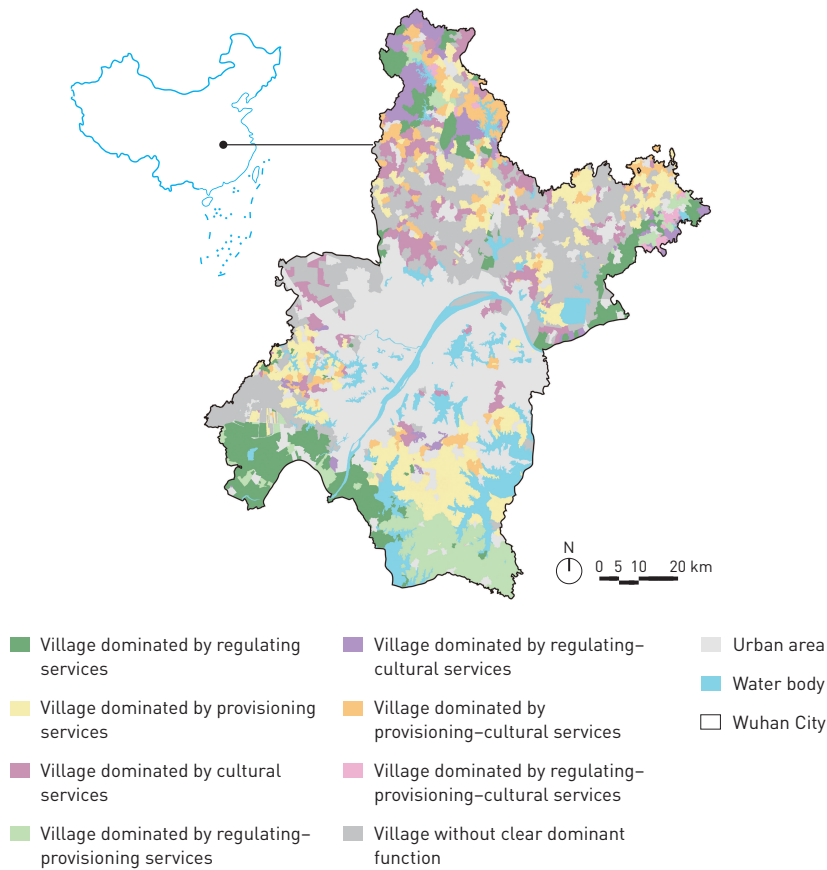
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and landscape distinctiveness to improve rural landscapes were proposed.

4.1 Strengthening Functions to Balance Protection and Development

The capacity, vitality, and attraction of rural landscapes^[33] reflect their ecological, economic, and social functions. Enhancing rural landscapes requires addressing these three functions to achieve integrated development of rural ecosystems. Generally, based on ecological functions, it is essential to strengthen the maintenance and management of rural landscape resources to enhance their carrying capacity; driven by economic functions, wise planning

5. Importance levels of cultural services of Wuhan's rural landscapes.



6. Classification results of Wuhan's rural landscape.

of rural industrial layouts should be implemented to foster sustainable economic development and vitality; highlighting by social functions, the creation of regional rural cultural landscapes should be prioritized to enhance attractiveness^[33]. According to the classification results of rural landscapes in Wuhan, the functional guidance strategies are proposed as follows.

Regarding single-function villages, those dominated by regulating services are critical for climate regulation and water retention, where ecological protection should be prioritized. For northern mountain forest areas, measures of protecting forest ecosystems, restoring water retention functions, and implementing water quality management should be taken. In the southern water-rich regions, emphasis should be placed on preserving wetland ecosystems and enhancing flood management and water resource utilization. Villages dominated by provisioning or cultural services should focus on development. Villages dominated by provisioning services, often with flat terrain and rich cropland resources, should optimize industrial structures, develop green agriculture, and promote specialized industries to enhance economic benefits while maintaining food security. Villages dominated by cultural

services, the second most abundant in quantity, should strengthen historical site and natural heritage protection while avoiding over-commercialization. Establishing regional cultural corridors and enhancing linkages among cultural landscapes are essential.

Dual-function and comprehensive-function villages should balance ecological protection and agricultural development. For instance, villages dominated by regulating-provisioning services should promote efficient water-saving agriculture and protect aquatic ecosystems. Villages dominated by provisioning-cultural services should integrate agricultural production with cultural heritage to develop diversified tourism industries such as agritourism, farming experiences, and rural retreats.

Villages with no clear dominant function require on-site investigations and market research to understand resource endowments and market demands better. Development should be guided towards establishing a dominant function while avoiding resource wastage by aligning with locational and market conditions.

4.2 Differentiated Strategies to Create Distinctive Rural Landscape Features

This study further selected representative villages from various rural landscape types, and based on their landscape characteristics, explores how to leverage their resource endowments to create rural landscape features.

Villages dominated by regulating services can leverage abundant forests, waterways, lakes, and wetlands to create wetland parks or nature reserves. For example, Pingfeng Village in the northwest of the study area has strong water retention, water and soil conservation, and climate regulation functions. Key measures include preserving natural mountain and water features by designating critical ecological areas (water retention forests, wildlife habitats, etc.) to restrict human activities and incorporating ecological principles into rural landscape planning and design (green roofs, rain gardens, eco-friendly parking lots, etc.) to minimize environmental impacts.

Villages dominated by provisioning services can showcase traditional agricultural landscapes like rice paddies, rapeseed flower fields, and tea gardens, combined with modern agricultural modes such as greenhouses and agricultural science parks. For instance, Leiling Village in the southern study area has favorable farming and irrigation conditions. Local agricultural enterprises have introduced advanced farming techniques and management practices, enhancing production efficiency and yield. Strategies for the village include creating large-scale agricultural landscapes aligned with natural topography and promoting high-value crop

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cultivation and eco-friendly farming to improve economic benefits while maintaining the traditional rural aesthetic.

Villages dominated by cultural services should emphasize the creation of landscapes that reflect the local cultural heritage. For example, Qiupi Village in the northern study area, a historical and cultural village of Wuhan, should restore and maintain local traditional residences as a priority, and adapt and reinterpret architectural styles and elements, such as those from vernacular dwellings, for public spaces like roads, bridges, squares, and parks, creating a distinctive architectural and cultural landscape.

Dual-function and comprehensive-function villages can integrate ecological conservation, agricultural production, and tourism development to form multifunctional landscapes. For example, Lamei Village in the northern low hills region, characterized by cropland, forest land, and proximity to a reservoir, enjoys abundant natural resources and numerous tourist attractions. Future strategies include strengthening ecological conservation efforts, developing organic agriculture and specialty products, and integrating regional cultural and tourism resources to boost economic growth by leveraging the village's landscape appeal.

Villages with no clear dominant function have weaker ecosystem services and should avoid homogenized urban development. Instead, they can retain and protect unique rural landscape features, leveraging locational advantages to create a new countryside charm with urban civilization. For example, Yueming Village in the northwest of the study area could develop into an eco-education base and a family-friendly farm or multifunctional recreational space appealing to urban residents, acting as a “backyard” complementing the city.

5 Conclusions

Existing rural landscape classification methods are often based on land classification, human impact levels, and landscape functional forms. Taking Wuhan as a case study, this research explores a rural landscape classification method grounded in dominant ecosystem services. Six representative ecosystem services—water retention, water and soil conservation (regulating services); grain production (provisioning services); and natural scenic value, scientific, educational, and cultural value, and leisure and recreational value (cultural services)—were evaluated. The results revealed significant spatial differences in the distribution of these functions within Wuhan's rural landscapes. Specifically, regulating service showed higher importance levels in the southern and northern parts of the study area, with lower values in the central region.

Provisioning services were more prominent in the south. Cultural services were particularly concentrated in the north. Based on these findings, a cumulative proportion method was employed to classify the evaluation results, identifying dominant ecosystem services by analyzing the proportion of the very important areas within each administrative village unit. The classification resulted in 8 rural landscape types—three for single-function villages, three for dual-function villages, as well as comprehensive-function villages, and villages without clear dominant function—each exhibiting notable spatial clustering patterns. Strategies for improving rural landscapes were then proposed from the perspectives of function and landscape distinctiveness based on the spatial distribution of ecosystem services and the classification results.

The proposed classification method for rural landscapes, first, via quantitative assessment, addresses the lack of fine-grained ecosystem service evaluations in previous classifications. Second, it enhances the precision of results in guiding rural landscape development through administrative village-level analysis. Third, by using the MaxEnt model combined with POI data and adjusting the results with listed historical and tourist villages, a more applicable approach for assessing cultural services in rural areas is explored.

While this study introduces methodological and strategic innovations, there were certain limitations. It examines rural landscapes from ecological, economic, and social dimensions, focusing on regulating, provisioning, and cultural services, while only evaluating 6 representative ecosystem services. Future research can expand the range of indicators to measure ecosystem services more comprehensively, enabling more detailed and nuanced classifications of rural landscapes. This would facilitate deeper analyses and provide more targeted strategies for rural landscape development.

ELECTRONIC SUPPLEMENTARY MATERIAL

Supplementary material is available in the online version of this article at <https://doi.org/10.15302/J-LAF-0-020028>.

Competing interests | The authors declare that they have no competing interests.

REFERENCES

- [1] Fan, L., Xu, X., & Liu, Y. (2019). Rural ecological construction planning in southern Jiangsu Province based on rural revitalization. *Planners*, 35(11), 24–31.
- [2] Wang, Y. (1996). A theoretical methodology of landscape eco-classification. *Chinese Journal of Applied Ecology*, 7(S1), 121–126.
- [3] Fan, J., Wei, C., & Li, S. (2009). Concept and development of rural landscape. *Tropical Geography*, 29(3), 285–289, 306.
- [4] Jin, Q., Dong, X., & Zhang, X. (1990). *Rural Geography*. Jiangsu Education Publishing House.
- [5] Xiao, D., & Zhong, L. (1998). Ecological principles of landscape classification and assessment. *Chinese Journal of Applied Ecology*, 9(2), 217–221.
- [6] Li, Z., Liu, L., & Xie, H. (2005). Methodology of rural landscape classification: A case study in Baijiatuan Village, Haidian District, Beijing. *Resources Science*, 27(2), 167–173.
- [7] Zhang, Y., Hao, J., Huang, A., & Zu, J. (2019). Rural landscape classification based on combination of perception elements and remote sensing data. *Transactions of the Chinese Society of Agricultural Engineering*, 35(16), 297–308.
- [8] Górka, A., & Niecikowski, K. (2021). Classification of landscape physiognomies in rural Poland: The case of the municipality of Ciekocyn. *Urban Planning*, 6(4), 80–95.
- [9] Zhang, C., & Fu, R. (2020). The goal setting and realization path of rural ecological revitalization based on ecosystem services. *Rural Economy*, (12), 42–48.
- [10] Ge, Y., & Li, F. (2020). Research on the promotion strategy of rural landscape in Beijing based on the identification of dominant ecosystem service. *Chinese Landscape Architecture*, 36(1), 25–30.
- [11] Liu, Y., & Fu, B. (2019). Landscape multifunctionality: Concept clarification, recent progress, and frontier issues. *Acta Ecologica Sinica*, 39(8), 2645–2654.
- [12] Liang, F., Liu L., & Qu, Y. (2011). Methodology of agricultural landscape classification with rural scale and its application in planning of new rural construction. *Transactions of the CSAE*, 27(11), 330–336.
- [13] Li, G., & Fang, C. (2016). Quantitative function identification and analysis of urban ecological–production–living spaces. *Acta Geographica Sinica*, 71(1), 49–65.
- [14] Wuhan Municipal Bureau of Statistics, & National Bureau of Statistics Survey Office in Wuhan. (2022). *Wuhan Statistical Yearbook*. China Statistics Press.
- [15] Lin, R., & Cai, Y. (2012). Study on rural multifunction and landscape reformulation in the transitional period. *Human Geography*, 27(2), 45–49.
- [16] Xie, H. (2004). Preliminary researches on the functional evaluation of rural landscape. *Acta Ecologica Sinica*, 24(9), 1988–1993.
- [17] Daily, G. C. (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press.
- [18] Millennium Ecosystem Assessment. (2003). *Ecosystems and Human Wellbeing: A Framework for Assessment*. Island Press.
- [19] Mao, H., & Pu, Y. (2022). Study on rural rejuvenation strategy based on cultural ecosystem services: A case study of Longwang Village, Beibei District, Chongqing. *Landscape Architecture Academic Journal*, 39(3), 39–47.
- [20] Ministry of Natural Resources of China. (2019). *Technical guidelines for evaluating resource and environmental carrying capacity and land spatial development suitability (trial)*.
- [21] Jiang, C., Zhang, H., & Zhang, Z. (2018). Spatially explicit assessment of ecosystem services in China's Loess Plateau: Patterns, interactions, drivers, and implications. *Global and Planetary Change*, (161), 41–52.
- [22] He, S., Su, Y., Shahtahmassebi, A. R., Huang, L., Zhou, M., Gan, M., Deng, J., Zhao, G., & Wang, K. (2019). Assessing and mapping cultural ecosystem services supply, demand and flow of farmlands in the Hangzhou metropolitan area, China. *Science of the Total Environment*, (692), 756–768.
- [23] Richards, D. R., & Tunçer, B. (2018). Using image recognition to automate assessment of cultural ecosystem services from social media photographs. *Ecosystem Services*, 31(C), 318–325.
- [24] Huo, S., Huang, L., & Yan, L. (2018). Valuation of cultural ecosystem services based on SolVES: A case study of the South Ecological Park in Wuyi County. *Acta Ecologica Sinica*, 38(10), 3682–3691.
- [25] Zhao, Q., Li, J., Liu, J., Qin, K., & Tian, T. (2018). Assessment and analysis of social values of cultural ecosystem services based on the SolVES model in the Guanzhong–Tianshui Economic Region. *Acta Ecologica Sinica*, 38(10), 3673–3681.
- [26] Chen, W., Liu, X., Li, H., Liu, J., Zhao, X., Yuan, J., Zhao, H., Wang, R., Xing, L., Wang, C., & Luo, X. (2024). Based on MaxEnt model, the change of potential suitable area of cultivated land in Northeast China under the future climate change situation was predicted. *Geological Bulletin of China*, 43(9), 1515–1529.
- [27] Luo, B., Hong, Z., & Wang, J. (2020). Application of multiple linear regression model in prediction of house price. *Computer Era*, (6), 51–54.
- [28] Zhang, D., Wang, X., Zhang, L., & Huang, B. (2021). Research on the classification methods of ecosystem service of soil retention for large-scale choropleth mapping. *Acta Ecologica Sinica*, 41(4), 1391–1401.
- [29] Wang, C., & Pan, D. (2017). Zoning of Hangzhou Bay ecological red line using GIS-based multi-criteria decision analysis. *Ocean & Coastal Management*, (139), 42–50.
- [30] An, J., Xu, M., Sun, K., Tian, Y., & Meng, B. (2018). Research on delineation of three-level ecological conservation system: A case study in Gaoping City, Shanxi Province. *Environmental Science & Technology*, 41(10), 226–232.
- [31] Rao, E., Ouyang, Z., Yu, X., & Xiao, Y. (2014). Spatial patterns and impacts of soil conservation service in China. *Geomorphology*, (207), 64–70.
- [32] Laterra, P., Orúe, M. E., & Booman, G. C. (2012). Spatial complexity and ecosystem services in rural landscapes. *Agriculture, Ecosystems and Environment*, (154), 56–67.
- [33] Liu, B., & Yang, M. (2003). The evaluation quantization model of landscape area and tourism destination—Taking the overall planning of Xuanwu Lake Scenic Area as example. *Chinese Landscape Architecture*, (5), 61–62, 67–68.

基于生态系统服务主导功能的乡村景观分类及提升策略研究

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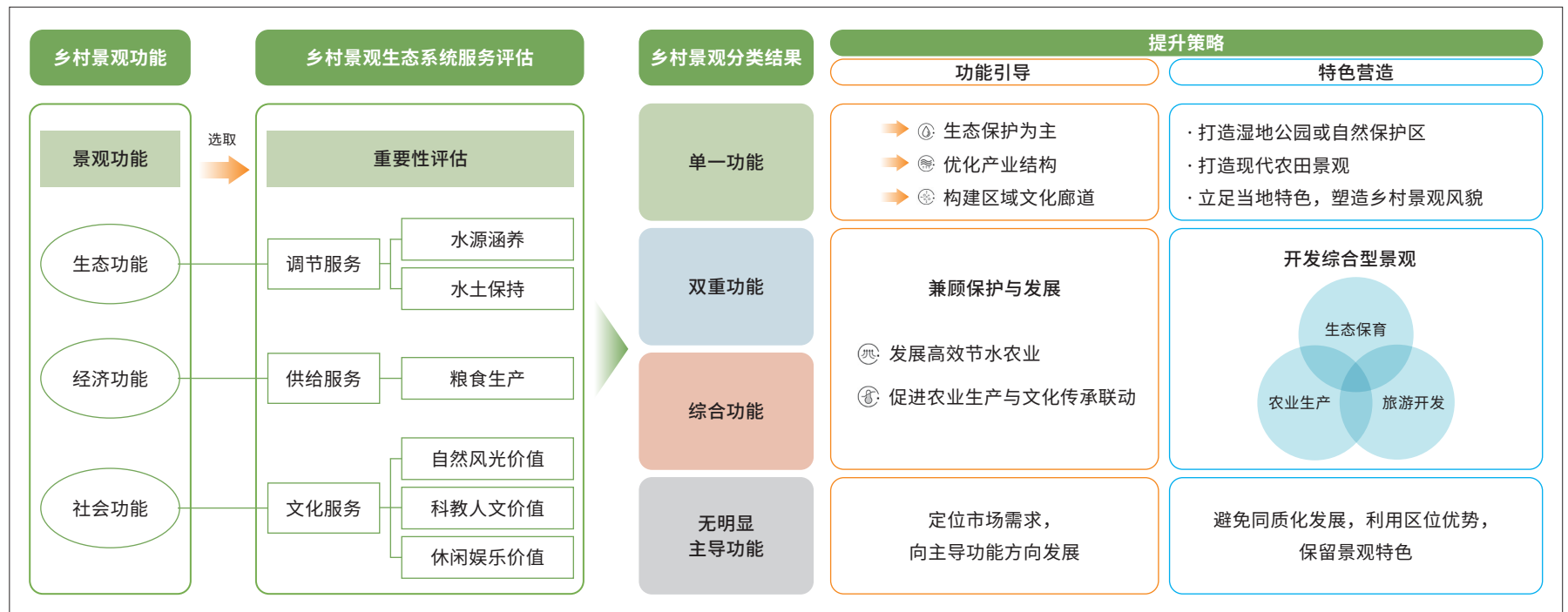
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图文摘要



摘要

乡村景观作为乡村生态系统及文化的重要承载单元, 具有重要的生态系统服务功能。本研究以中国武汉市为例, 探讨了基于生态系统服务主导功能的乡村景观分类及提升策略。研究选取水源涵养、水土保持(调节服务), 粮食生产(供给服务), 以及自然风光价值、科教人文价值和休闲娱乐价值(文化服务)等六项生态系统服务功能进行评估, 采用累积比例法对评估结果进行分级, 并以村级单元为单位识别乡村景观的主导功能。结果表明, 武汉市乡村景观的生态系统服务功能空间分布呈现明显的地域差异, 调节服务功能在研究区域内南北部较高, 供给服务功能在南部较高, 文化服务功能在北部突出。基于此, 研究将武汉市乡村景观分为单一功能、双重功能、综合功能和无明显主导功能

四大类, 共八种组合, 各类村庄呈现明显的空间集聚特征。最后, 研究从功能引导和特色营造两方面提出了乡村景观提升策略, 强调生态保护与经济发展的平衡, 建议通过优化产业结构、保护文化遗产、发展绿色农业和旅游产业等方式, 提升乡村景观的承载力、生命力和吸引力。研究为乡村景观分类提供了新的方法, 并为乡村振兴提供了理论支撑和实践指导。

关键词

乡村景观; 生态系统服务; 主导功能; 景观分类; 乡村振兴; 景观提升策略

文章亮点

- 提出基于生态系统服务主导功能的乡村景观分类方法
- 结合MaxEnt模型与POI数据改进文化服务评估
- 从功能引导与特色营造角度提出乡村景观优化策略

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1 引言

乡村生态振兴是乡村振兴的核心内容之一，建设良好的乡村生态环境是实现乡村生态振兴的有效途径与重要抓手^[1]。乡村景观是乡村生态系统及文化的重要承载单元，对其进行科学分类既是乡村景观结构与功能研究的基础，又是开展乡村景观格局分析、规划与设计、建设管理等实践的前提，同时也可促进景观生态学理论与实践的连接^[2]。这对科学认识乡村景观、建设生态宜居乡村及助力乡村生态振兴具有重要意义。

乡村景观的分类研究最早出现在地理学的土地分类领域，随后逐步扩展到人为影响程度、景观功能形态等方面^[3]。基于乡村景观的自然和人文属性，可分为乡村聚落景观和乡村非聚落景观^[4]。根据人类活动对乡村景观的干扰程度，可将其分为自然景观、经营景观和人工景观^[5]。依据景观功能形态，乡村景观又可划分为景观区、景观类、景观亚类和景观单元^[6]。此外，结合物理景观类型与主观感知，有学者构建了包含景观群、景观区、景观类和景观要素的四级乡村景观分类体系^[7]。另有学者通过比较波兰某地乡村景观的自然、文化和视觉特征，将其分类为丘陵、平原、盆地、山谷等景观地貌单元及亚单元^[8]。

上述研究主要关注乡村景观的物质形态，然而乡村景观不仅是视觉感知的对象，更是乡村生态系统的重要组成部分，为人类提供了多种生态系统服务^[9]。但随着城镇化的快速推进，乡村景观承载的重要生态系统服务功能正逐渐减弱^[10]。乡村景观的内部生态过程、物质流动和能量转换都与其功能密切相关。通过识别主导功能，可以更加深入地理解乡村景观在维持生态平衡、提供生态系统服务及促进人类福祉等方面的关键作用。

功能主导性指景观功能在空间中呈现的强弱关系，通常一种或少数几种景观功能能够代表整个景观的特征^[11]。这一概念已被广泛应用于景观分类和“三生”空间识别等研究。例如，有研究根据地块农业生产的自然适宜性及其地理区位，通过综合分析和评价确定其主导功能，并基于功能差异，将农业景观划分为农业生产景观、农业服务设施景观、农业旅游休闲景观和农业生态景观等^[12]。另有学者通过评估不同用地类型的生态、生产和生活功能价值量，识别其主导功能、次级功能和副级功能，进而明确划分空间类型^[13]。此外，有研究以北京市为例，利用POI和土地利用数据，通过计算村庄邻域缓冲区内各类用地类型提供的生态系统服务功能类型占比，识别其主导功能，并对该市乡村景观资源进行分类^[10]。

总体而言，目前基于生态系统服务功能评估来识别主导功能以进行乡村景观分类的研究较少，且分类单元较为粗略，难以为乡村景观提升提供精细化指导。精准的景观分类是保护、开发和提升的前提。本研究以武汉市为例，开展武汉市乡村生态系统服务功能评估，并根据村级单元识别其生态系统服务主导功能，构建基于生态系统服务主导功能的乡村景观分类体系，以期为乡村景观提升提供技术参考，为乡村振兴提供理论支撑。

2 研究区域概况与研究方法

2.1 研究区域概况

武汉市位于中国湖北省东部，地处长江与汉江交汇处。乡村地区地域辽阔，拥有丰富的自然与人文资源，涵盖湖泊、湿地、森林、农田等多种生态系统类型。2022年，武汉市乡村人口为230.52万人，占全市总人口的24.4%；全年实现农林牧渔业总产值836.72亿元^[14]。随着社会经济的发展，武汉市建成区不断向周边扩展，乡村景观受到城市化和农村发展的双重影响，面临水体污染、土壤退化等生态环境问题。在此背景下，本研究选取武汉市乡村地区的村级单元作为研究对象（图1），探讨基于生态系统服务主导功能的乡村景观分类方法与提升策略。

2.2 研究思路

乡村景观是相对原生态的地域空间系统，拥有城市地域所无法替代

的生态、经济和社会等功能^[15]，能够维持生态环境平衡、提供农产品，也是重要的旅游观光资源^[16]。本研究首先从乡村承载的生态、经济和社会功能出发，结合武汉市乡村地域特征，选取相应指标构建乡村生态系统服务评价体系，开展生态系统服务评估与分级；再根据评估结果，以村级单元承载的生态系统服务主导功能为依据，对乡村景观进行分类；最后基于分类结果，从功能及特色两个层面分类制定不同类型的乡村景观提升策略，为乡村振兴提供精细化指导（图2）。

2.3 研究数据与方法

2.3.1 数据来源与处理

本研究使用的数据及其获取来源见表1。武汉市村庄边界数据来源于天地图，依据国家统计局《统计用区划代码和城乡划分代码编制规则》（国统字〔2009〕91号），提取城乡分类代码首位数字为“2”的区域，并划定为乡村范围。研究范围内共有1 690个村级单元，包括行政村、林场、农场、茶场、养殖场、渔场和农业科学研究所等。从Zenodo平台获取2000~2020年的土地利用和土地覆盖数据，并将研究范围内的用地重分类为农田、草地、林地、灌丛、湿地、水体、裸地和建设用地8类。降雨量和蒸散发量表格数据通过ArcGIS平台的关联功能连接至对应气象站点，并采用克里金法进行空间插值，得到降雨量和蒸散发量数

据。此外，POI地理大数据来源于高德地图，依据高德开放平台的《POI分类编码》，首先筛选出“风景名胜”“科教文化服务”“体育休闲服务”三大类（含22中类、76小类）具有文化服务价值的POI数据；随后，以1 690个村级单元为范围，在ArcGIS平台中裁剪武汉市域内的POI空间分布数据，得到全市乡村地区的POI空间分布数据。土壤成分、归一化植被指数（NDVI）、数字高程模型（DEM）、道路、水体，以及历史文化名村、旅游名村名录等其他数据均从相应开放数据平台下载。所有数据统一投影至WGS_1984_UTM_Zone_49N坐标系，栅格数据重采样为30m×30m计算精度，选取年份为2020年。

2.3.2 生态系统服务评估方法

（1）生态系统服务评估指标选择

生态系统服务是生态系统形成并维持人类赖以生存和发展的环境条件和效用^[17]。《千年生态系统评估》将其分为调节、供给、文化及支持四种类型^[18]。

乡村振兴战略强调乡村景观应发挥调节气候、改善环境的生态功能，从而保障人类生态安全，对应生态系统调节服务功能。武汉市水资源丰富但易受洪涝灾害影响，地形多样但面临水土流失压力，因而选取水源涵养和水土保持作为调节服务维度的评估指标。

表 1: 研究数据及来源

数据名称	数据格式	数据来源	数据描述
武汉市村庄边界	矢量	天地图	共提取 1 690 个村级单元
土地利用和土地覆盖	栅格	Zenodo	分辨率为 30m×30m
降雨量和蒸散发量	—	中国科学院资源环境科学数据中心	全国气象站点的逐日降雨量和蒸散发量
土壤成分	栅格	国家青藏高原科学数据中心	分辨率为 1km×1km
NDVI	栅格	国家生态科学数据中心	分辨率为 30m×30m
DEM	栅格	地理空间数据云	分辨率为 30m×30m
道路	矢量	BIGEMAP	主要道路（国道、省道、快速路等）、二级道路（城市主干道等）和其他道路（城镇街道、乡村道路等）
水体	矢量	BIGEMAP	长江、汉江、梁子湖、木兰湖等河流与湖泊
POI 地理数据	矢量	高德开放平台	“风景名胜”“科教文化服务”“体育休闲服务”类 POI 数据
历史文化名村、旅游名村名录	矢量	武汉市文化和旅游局	1 个中国历史文化名村、9 个武汉市历史文化名村和 6 个武汉市旅游名村

提供农产品是乡村的主要生产功能，对应生态系统的供给服务功能。武汉市地处长江中下游平原，拥有丰富的耕地资源和适宜农业生产的条件，而粮食生产能力是衡量乡村景观经济功能的核心指标，因此选取粮食生产作为供给服务维度的评估指标。

乡村景观特有的自然与历史文化资源对应生态系统的文化服务功能。武汉市乡村地区拥有大江大湖、山水相依的独特自然景观，也保留了丰富的历史文化资源和传统农耕文化。随着乡村旅游的发展，乡村景观逐渐成为市民休闲娱乐和文化体验的重要场所。而文化服务是人们通过精神满足、认知发展、思考、消遣和美学体验而从生态系统中获得的非物质收益，包括精神与宗教价值、教育价值、美学价值等^[18]。本研究结合乡村景观生态价值特征，适当调整与合并文化服务的分类，从视觉传达、精神传达和场所使用三个角度^[19]将其划分为自然风光价值、科教人文价值和休闲娱乐价值，作为评估指标。

支持服务主要为前三类功能提供支撑，从而维持生态系统的稳定和健康发展（如地球生命生存环境的养分循环等），故不作为本研究的评估重点。

（2）调节服务评估

水源涵养以水源涵养能力（即水源涵养量）为衡量指标，主要考虑河流源区、气候、地表覆盖及地形等因子。计算公式为^[20]：

$$TQ = \sum_i^j (P_i - R_i - ET_i) \times A_i \times 10^3, \quad (1)$$

式中， TQ 为水源涵养量（ m^3 ），代表一个区域在特定时间内所保持的总水量； i 为研究区域内第 i 类土地利用， j 为研究区域内土地利用类型数； P_i 为第 i 类土地利用的降雨量（ mm ）， R_i 为地表径流量（ mm ）， ET_i 为蒸散发量（ mm ）， A_i 为面积（ km^2 ）。

水土保持以水土保持量（即潜在土壤侵蚀量与实际土壤侵蚀量的差值）作为评价指标，采用修正的水土流失方程（RUSLE）^[20]进行计算：

$$A = R \times K \times L \times S \times (1 - C), \quad (2)$$

式中， A 表示水土保持量（ $t/hm^2 \cdot a$ ）； R 表示降雨侵蚀力因子（ $MJ \cdot mm/hm^2 \cdot h \cdot a$ ），表示降雨的能量和强度，数值越高表明具有越强的侵蚀土壤的能力； K 为土壤可蚀性因子（ $t \cdot hm^2 \cdot h/hm^2 \cdot MJ \cdot mm$ ），指特定土壤类型在给定条件下被侵蚀的难易程度； L 和 S 为地形因子， L 为坡长因子（指斜坡长度对土壤侵蚀的影响，数值越大表示侵蚀的潜在风险越高）， S 为坡度因子（指斜坡陡峭程度对土壤侵蚀的影响，数值越大表示侵蚀率越高）； C 为植被因子，表示植被覆盖对土壤侵蚀的抑制作用——其数值越小，表明植被的覆盖度越高，抑制作用越强，侵蚀率越低。

（3）供给服务评估

评估粮食生产指标时，以耕地为对象，采用 $NDVI$ 校正法将研究范围

内的粮食产量重新分配至栅格尺度^[21]，计算公式如下：

$$G_i = G_{sum} \times \frac{NDVI_i}{NDVI_{sum}}, \quad (3)$$

式中， G_i 为第 i 个耕地栅格分配的粮食产量（ kg/hm^2 ）； G_{sum} 为市域主要粮食作物的总产量（ kg ）； $NDVI_i$ 和 $NDVI_{sum}$ 分别为第 i 个耕地栅格的 $NDVI$ 值和市域耕地 $NDVI$ 值的总和。

（4）文化服务评估

本研究采用MaxEnt模型结合POI数据进行文化服务的评估。MaxEnt模型以最大熵理论为基础，利用已知的不完全信息来推断未知信息的概率分布。最初，该模型主要用于生态学领域的物种分布预测，又因具有空间可视化优势被应用于文化服务的评估中^{[22][23]}——通过量化各环境变量对文化服务的影响来评估生态系统文化服务。具体包含以下5个步骤。

1) POI数据分类。基于高德开放平台《POI分类编码》的“小类”标准，筛选与文化服务相关的POI数据，将其划分为自然风光价值、科教人文价值和休闲娱乐价值三类（表2），再生成各类价值的空间分布点。

2) 选取环境变量。参考以往研究，选取土地利用和土地覆盖、坡度、高程、距水源距离、距道路距离及 $NDVI$ 作为环境变量^{[24][25]}。Shapiro-Wilk检验结果显示，所有变量 p 值均远小于0.05，表明均为非正态分布，因此采用Spearman相关性系数作为统计量。结合多重共线性检验结果，发现各变量间相关系数均小于0.75、方差膨胀因子均小于10，容差均大于0.2，表明相关性较弱^[26]且不存在多重共线性^[27]，因此全部变量皆保留用于建模。

3) MaxEnt模型分析。将三类文化服务价值分布点与环境变量输入MaxEnt模型，生成各类价值的空间分布图。

4) 空间分布结果修正。结合研究范围内的历史文化名村及旅游名村名录等信息，对科教人文价值和休闲娱乐价值的空间分布图进行归一化处理：将中国历史文化名村和武汉市历史文化名村（共10个村庄）的科教人文价值结果修正为最大值1，将旅游资源丰富、基础设施完善的6个武汉市旅游名村的休闲娱乐价值结果修正为最大值1。

5) 生成文化服务评估结果。将修正后的三类文化服务价值地图以相同的权重进行叠加分析，获取最终的乡村景观文化服务价值分布结果。

2.3.3 生态系统服务分级标准

生态系统服务的分级应减少最高级别的破碎程度，并便于比较^[28]。目前常用的分级方法包括自然断点法^[29]、分位数法^[30]和累积比例法^[31]等。有研究表明，累积比例法在分级质量、辨识度及适用性方面优于其他方法，其各级累积量相对固定，可比性强^[28]。因此，本研究采用该方法对各单项生态系统服务进行分级。具体方法是将每一个栅格像元对应的单项生态系统服务值按从高到低的顺序排列，计算累加服务值，参考

表 2: 文化服务价值分类与高德地图 POI 分类对照表

文化服务价值类型	POI 数量 (个)	对应的高德地图 POI 分类
自然风光价值	314	风景名胜相关、风景名胜、世界遗产、国家级景点、省级景点、海滩
科教人文价值	1 082	纪念馆、寺庙道观、教堂、回教寺、科教文化场所、博物馆、奥迪博物馆、梅赛德斯 - 奔驰博物馆、展览馆、会展中心、美术馆、图书馆、科技馆、天文馆、文化宫、档案馆、文艺团体、传媒机构
休闲娱乐价值	755	体育休闲服务场所、运动场所、综合体育馆、保龄球馆、网球场、篮球场、足球场、滑雪场、溜冰场、户外健身场所、海滨浴场、游泳馆、健身中心、乒乓球馆、台球厅、壁球场、马术俱乐部、赛马场、橄榄球场、羽毛球馆、跆拳道馆、高尔夫相关、高尔夫球场、高尔夫练习场、娱乐场所、夜总会、KTV、迪厅、酒吧、游戏厅、棋牌室、博彩中心、网吧、度假疗养场所、度假村、疗养院、休闲场所、游乐场、垂钓园、采摘园、露营地、水上活动中心、影剧院相关、电影院、音乐厅、剧场、公园广场、公园、动物园、植物园、水族馆、城市广场

注

POI 分类名称可能存在重复，但不影响本研究结果。

《生态保护红线划定指南》，将累加服务值占生态系统服务总值50%与80%比例下所对应的栅格值作为分界点，再利用ArcGIS重分类工具将各单项服务功能重要性分为极重要（前50%）、重要（50%~80%）和一般重要（80%~100%）。其中，调节服务的重要性等级取水源涵养和水土保持两个单项分级结果的最高等级予以确定。

2.3.4 乡村景观分类标准

以行政村为单位开展乡村景观分类，有助于明确单个行政村的生态系统服务主导功能，为具体的提升策略及未来乡村建设提供指导。本研究根据各单项生态系统服务面积占比来判断其主导性^[10]。参照相关研究，若某一行政村中某单项生态系统服务的极重要区面积占其总面积比值超过33%，则认为该服务具有较强的功能主导性^[10]。因调节、供给和文化服务功能三者对乡村景观而言同等重要，故本研究选取33%为基准线。据此，基于生态系统服务主导功能，乡村景观可分为单一功能、双重功能、综合功能和无明显主导功能4大类，共8种组合（表3）。

3 研究结果

3.1 调节服务空间分布特征

水源涵养功能重要性在空间分布上整体呈现南北高、中部低趋势（图3-1）。极重要区占比26.54%，主要分布于研究区域西北、东北和南部；重要区占比43.02%，集中于中部；一般重要区占比30.43%，大致汇集在北部和中部。武汉市西北和东侧以高山林地为主，南部多为耕地

表 3: 基于生态系统服务主导功能的乡村景观分类

类别	主导功能类型	调节服务功能	供给服务功能	文化服务功能
单一功能	调节服务主导型	A ≥ 33%	B < 33%	C < 33%
	供给服务主导型	A < 33%	B ≥ 33%	C < 33%
	文化服务主导型	A < 33%	B < 33%	C ≥ 33%
双重功能	调节—供给服务主导型	A ≥ 33%	B ≥ 33%	C < 33%
	调节—文化服务主导型	A ≥ 33%	B < 33%	C ≥ 33%
	供给—文化服务主导型	A < 33%	B ≥ 33%	C ≥ 33%
综合功能	调节—供给—文化服务主导型	A ≥ 33%	B ≥ 33%	C ≥ 33%
无明显主导功能	无明显主导功能型	A < 33%	B < 33%	C < 33%

注

A 为村级单元内调节服务功能极重要区面积占比，B 为村级单元内供给服务功能极重要区面积占比，C 为村级单元内文化服务功能极重要区面积占比。

和水体，其水源涵养功能重要性的空间分布与乡村地区的植被覆盖度和地形地貌较为相关。

水土保持功能重要性的空间分布表现为局部高、整体偏低的特征（图3-2）。极重要区占比3.55%，主要分布于西北和东北，与水源涵养功能高值区有所重叠，反映出高山林地显著的水源涵养和水土保持能力；重要区占比6.84%，主要位于水土保持功能高值区周边；一般重要区占比89.61%，广泛分布于乡村区域。

调节服务功能重要性的空间分布体现了水源涵养和水土保持功能的共同作用，其整体分布与水源涵养功能趋于一致，极重要区、重要区和一般重要区占比分别为26.98%、45.10%、27.91%（图3-3）。

3.2 供给服务空间分布特征

供给服务功能重要性的空间分布呈南部高、西北低的总体特征（图4）。其中，极重要区占比29.38%，集中分布于东南部，以耕地为主，呈集中连片形态，且该区域NDVI值较高；重要区占比24.12%，主要分布在北部，亦以耕地为主；一般重要区占比46.50%，集中于西北、西南及中心城区周边，以林地、建设用水体和为主。整体评价结果显示，重要区和极重要区占比更高，反映出乡村景观在粮食供给方面的重要性。

3.3 文化服务空间分布特征

文化服务功能重要性的空间分布体现了自然风光价值、科教人文价值和休闲娱乐价值的综合结果。本研究使用的MaxEnt模型采用刀切法测度各环境因子对模型构建的贡献度。实验结果显示，自然风光价值呈北高南低的空间分布特征，高程和坡度对模型的贡献度较大，即此类价值空间分布与这两个环境变量相关性较高（图5-1）。科教人文价值的较高值区域集中于中心城区周边及历史文化名村所在地，且以土地利用和NDVI为主要影响因子，表明其空间分布与土地利用类型和植被覆盖度相关性较高（图5-2）。休闲娱乐价值呈线状分布，其中距道路距离和土地利用类型为影响因子（图5-3）。就整体文化服务功能重要性的空间分布而言，极重要区占比23.26%，多分布在研究区域北部及建成区周边，该区域自然和历史文化资源丰富、交通便利，且公共服务设施较齐全；重要区占比29.17%，主要位于极重要区周边；一般重要区占比47.58%，分布于研究区域南部，以耕地为主，缺乏独特的自然历史文化资源（图5-4）。

3.4 乡村景观分类结果

基于生态系统服务主导功能的武汉市乡村景观分类结果如图6所示。其中，单一功能村庄（占比46.80%）包括202个调节服务主导型村庄、362个供给服务功能主导型村庄和227个文化服务主导型村庄；双重功能村庄（占比19.70%）包括142个调节—供给服务主导型村庄、

56个调节—文化服务主导型村庄和135个供给—文化服务主导型村庄；综合功能村庄共20个（占比1.18%）；另有无明显主导功能型村庄546个（占比32.31%）。

整体而言，武汉市乡村景观类型呈现明显的空间集聚特征。调节服务主导型村庄多分布于研究区域四周的高山林地和水网密集地区；供给服务主导型村庄集中在北部和南部，以耕地为主，地势较平缓；文化服务主导型村庄位于北部等自然和历史文化资源丰富、交通便利及公共服务设施较齐全的地区；调节—供给服务主导型村庄分布于南部，依托耕地及水资源优势；调节—文化服务主导型村庄主要位于高山林地和水体周边，此处具有独特的自然风光和优越的生态条件；供给—文化服务主导型村庄集中于供给和文化服务主导型村庄周边，兼具农耕和文旅资源；调节—供给—文化服务主导型村庄主要分布于东北部自然、生态和文化资源较为集中的区域；无明显主导功能空间村庄主要位于城镇建成区周边，受开发影响，未表现出突出的生态系统服务功能。

4 乡村景观提升策略

乡村景观是乡村生态系统的重要组成部分，是一个生态—经济—社会复合生态系统^[32]。本研究选择生态系统调节、供给和文化服务作为评价对象，以行政村为单位，基于生态系统服务主导功能进行乡村景观分类，以期从功能引导和特色营造方面提出乡村景观提升策略。

4.1 强功能——妥善处理保护与发展的关系

乡村景观的承载力、生命力和吸引力^[33]是其生态、经济和社会功能的体现，乡村景观提升应从这三种功能出发，实现乡村生态系统的复合发展。总体原则为：以生态功能为基础，加强乡村景观资源的维护和管理，提升承载力；以经济功能为动力，合理规划乡村产业布局，推动乡村经济可持续发展，提升生命力；以社会功能为特色，营造地域性乡村文化景观，提升吸引力^[33]。基于乡村景观分类结果，武汉市乡村景观的功能引导策略如下。

就单一功能村庄而言，调节服务主导型村庄在气候调节和水源涵养等方面至关重要，应以生态保护为主。研究区域北部的高山林地周边需保护森林生态系统，恢复水源涵养功能，实施水质保护措施；南部水网密集地区需重点保护湿地生态系统，加强洪水管理与水资源利用。供给服务或文化服务主导型村庄应以发展为导向。供给服务主导型村庄地势平坦，耕地资源丰富，可优化产业结构，发展绿色农业和特色产业，提升经济效益；同时继续发挥粮食供给能力，保障粮食安全。文化服务主导型村庄数量仅次于供给服务类，应加强对历史遗迹和自然遗产的保护，避免过度商业化；同时构建区域文化廊道，加强文化景观联动。

双重功能和综合功能村庄需兼顾保护和发展。例如，调节—供给服

务主导型村庄应发展高效节水农业,保护水生态系统;供给—文化服务主导型村庄应结合农业生产与文化遗产,发展农业观光、农耕体验和田园度假等多元旅游产业。

针对无明显主导功能村庄,需开展实地考察与市场调研,深入了解资源禀赋和市场需求。在明确发展方向、避免资源浪费的同时,综合区位条件和市场需求,引导其逐步向主导功能方向发展。

4.2 分类型——营造乡村景观特色风貌

本研究进一步从不同类型的乡村景观中选取代表性村庄,基于其景观特征,探讨如何利用自身资源禀赋营造乡村景观特色。

调节服务主导型村庄可依托丰富的山林、水系、湖泊和湿地资源,打造湿地公园或自然保护区。例如,位于研究区域西北部的平峰村具有较强的水源涵养、水土保持和气候调节功能。首先,应保护其自然山水格局,通过划定水源涵养林、野生动植物栖息地等重要生态区域,限制人类活动。其次,将生态原则融入乡村景观规划和设计中,充分考虑引入绿色屋顶、雨水花园和生态停车场等绿色基础设施,以减少对自然环境的影响。

供给服务主导型村庄可打造连片的农田景观(如水稻田、油菜花田、茶园等),展现传统农耕风貌;融入温室大棚、农业科技园等,展示现代农业技术与景观。例如,地处研究区域南部的雷岭村适宜耕作且灌溉条件良好,同时当地的现代农业企业通过引入先进种植技术和管理方法,提高了农业生产效率和产量,使其具有较强的供给服务功能。于该村而言,不仅可结合自然地形打造农田大地景观,还可推广高附加值种植和生态养殖,在提升经济效益的同时,保留传统的乡村风貌。

文化服务主导型村庄可营建具有当地文化特色的乡村景观风貌。例如,邱皮村位于研究区域北部,是武汉市历史文化名村。其发展应先修复、维护当地特色民居;而后借鉴、提取耿家大湾民居的建筑风格和元素,转译应用于道路、桥梁、广场和公园等公共空间设计中,形成独特的建筑景观风貌。

双重功能和综合功能村庄可融合生态保育、农业生产和旅游开发于一体,开发复合型景观。例如,研究区域北部的腊梅村地处低山丘陵地带,以耕地和林地为主,西临水库,周边自然景观资源丰富、旅游景点众多。其未来可通过加强生态保护,发展有机农业和特色农产品,并整合区域文旅资源来提升其景观和经济价值。

无明显主导功能村庄的生态系统服务功能较弱,应注意避免与周边城镇景观的同质化发展,保留乡村景观特色,利用区位优势,形成郊野风光与城市文明共融的乡村景观。以研究区域西北部的月明村为例,可发展生态教育基地、亲子农场等城市居民向往的多功能休闲空间,构建城市“后花园”。

5 结论

现有的乡村景观分类方法多基于土地分类、人为干扰程度及景观功能形态等维度展开。本研究以武汉市为例,探索了一种基于生态系统服务主导功能的乡村景观分类方法。研究选取水源涵养、水土保持(调节服务),粮食生产(供给服务),以及自然风光价值、科教人文价值和休闲娱乐价值(文化服务)等生态系统服务功能进行评估。结果表明,武汉市乡村景观的上述功能空间分布呈现明显的地域差异。其中,调节服务功能重要性在研究区域南、北部较高,中部较低;供给服务功能重要性在南部较高;文化服务功能重要性则在北部表现突出。以此为基础,通过累积比例法对生态系统服务评估结果分级,比较各行政村单元内极重要区的面积占比,进而识别乡村景观的主导功能。结果显示,武汉市乡村景观共分为8类——3类单一功能村庄、3类双重功能村庄,以及综合功能村庄和无明显主导功能型村庄,各自呈现较为明显的空间集聚特征。最后,依据各生态系统服务功能的空间分布特征及乡村景观分类结果,从功能引导和特色营造两方面提出乡村景观提升策略。

本研究提出的乡村景观分类方法具有如下特点:1)通过量化评估,弥补了以往乡村景观分类方法在乡村生态系统服务精细化评估方面的不足。2)以行政村为研究单元,提高了研究结果对乡村景观建设的指导精度。3)采用MaxEnt模型并结合POI数据进行文化服务评估,并结合历史文化名村和旅游名村名录对结果进行修正,探索了更适用于乡村地区的文化服务评估方法。

尽管本研究在方法和策略上有所创新,但亦存在不足之处。本研究从乡村景观的生态、经济和社会功能出发,对应调节、供给和文化服务三个维度,但仅选取了6项代表性生态系统服务进行评估。未来研究可进一步增加指标,以更全面地衡量乡村生态系统服务功能,对乡村景观进行更细致和具体的分类,从而深入分析和探讨乡村的景观特征与发展策略。

补充材料

可通过<https://doi.org/10.15302/J-LAF-0-020028>查看本文补充材料。

图 1. 研究范围

图 2. 研究思路

图 3. 武汉市乡村景观调节服务功能重要性

图 4. 武汉市乡村景观供给服务功能重要性

图 5. 武汉市乡村景观文化服务功能重要性

图 6. 武汉市乡村景观分类结果