J. Geogr. Sci. 2021, 31(7): 1015-1038
DOI: https://doi.org/10.1007/s11442-021-1883-3

Evaluation of ontological value of regional tourism resources:
A case study of Hainan Island, China

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Abstract: Evaluation of tourism resources is necessary for tourism regionalization and planning and for the development of tourism destinations. Furthermore, the scientific evaluation of the status of existing tourism resources is important for optimally combining and rationally developing regional tourism resources. In this study, a conceptual model for estimating the ontological value of tourism resources was developed and an evaluation indicator system was designed for the ontological value. On the basis of the quantitative and spatial characteristics of regional tourism resources, six indicators were constructed: quantitative density, richness, dominance, combination, aggregation, and accessibility. Furthermore, spatial differentiation characteristics of the ontological value indicators of county-level tourism resources on Hainan Island were analyzed, and the ontological value of the tourism resources was comprehensively evaluated and ranked by using a fuzzy clustering evaluation method. Finally, the evaluation results were verified on the basis of the quantity, quality, and accessibility of regional tourism resources by using an expert scoring method. The results showed that the test results were consistent with the inferences drawn from the ontological value, indicating that the evaluation indicator system is scientific and reliable and that it is an effective alternative to existing evaluation indexes of regional tourism resources, which are inconsistent. The fuzzy clustering evaluation method overcomes the subjectivity in the evaluation process and is practical for the quantitative evaluation of regional tourism resources. The evaluation indicator system for regional tourism resources designed in this study can provide a reference for the evaluation of the tourism resource development value on a regional scale, and the evaluation results can facilitate informed policymaking for the rational development of regional tourism resources.

Keywords: ontological value; indicator system; evaluation of regional tourism resources; Hainan Island; China

Received: 2020-09-30 **Accepted:** 2021-03-10
Foundation: The Project of Hainan Province Tourism Resources Survey and Planning Information, No.2018Y88M2001AL
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1 Introduction

Tourism resources are at the core of tourism development, and they encompass all types of things and factors in nature and human society that can attract tourists, that can help develop tourism, and that can be used to derive economic, social, and environmental benefits (Guo *et al.*, 2000). Tourism development in a region mainly depends on the richness and value of resources. Therefore, the scientific evaluation of tourism resources is important for the development of regional tourism (He and Wang, 2011). The essence of tourism resource evaluation is the evaluation of the development value of tourism resources, which is related to the development process, development scale, and development direction of the tourism resources and to tourism regionalization and planning. Its purpose is to determine the quality of tourism resources and to evaluate the status of existing tourism resources for the development of tourism destinations (He and Wang, 2011). Some scholars have defined the concept of evaluation of regional tourism resources by comparing and judging the development, utilization, and value of tourism resources from the perspective of tourism development (He and Wang, 2011). From the evaluation content, including the determined characteristics of the resources, resource environment, and tourism development conditions, scholars have identified three factors influencing the evaluation of regional tourism resources: characteristics of tourism resources (density, capacity, value, function, and regional combination characteristics and properties), conditions required for the development and utilization of tourism resources (location, regional economic development level, tourist market, and construction conditions), and tourism development order (Chen, 1991). Four additional factors influencing the evaluation have also been identified: market factors (object and distance), quality factors (attractiveness of resources), scenic spot scale, environmental factors (scenic spot environment and nature protection), and socioeconomic factors (economy, development conditions, and policies) (Xi and Wang, 1987).

However, some scholars hold that the above-mentioned evaluation content is not derived from a strict evaluation of tourism resources, but from a qualitative evaluation rather than an attraction-based evaluation, and that tourism resources themselves should be evaluated for determining the tourism potential of a place (Yang and Yan, 1999). According to them, the evaluation of tourism resources themselves should exclude the evaluation of purely developmental environmental factors such as traffic conditions and the regional economic development level (Yin and Song, 1995; Yang and Yan, 1999). Some other scholars have analyzed the contents of tourism resource evaluation, made a conceptual distinction between tourism resources' own value and external development conditions, and proposed a conceptual model that assumes that the tourism resource development value is the sum of tourism resources' own value and the value of external development conditions. This model divides the evaluation of the tourism resource development value into the evaluation of tourism resources' own value and the subsequent evaluation of development conditions, but it only evaluates the development conditions (Qi, 2018; Wang *et al*., 2020). Using the conceptual model, we expand the concept of tourism resource development value and discuss the expanded concept in detail.

In the indicator system used for evaluating regional tourism resources, tourism resources exist as tourism resource groups, which are characterized by quantity, space, and time (Xi *et al*., 2004). By considering group of the tourism resources, we can analyze the effect of an

agglomeration of tourism resources and determine the advantages of the agglomeration. The development value of an agglomeration is obtained by considering not only the numerous tourism resource values, but also the spatial combination characteristics of tourism resources within a cluster (Yao and Hu, 2012). Tourism resource groups with a high tourism resource value may not attain a certain size. Only when the tourism resources are concentrated in a certain area and the layout and combination of various types of tourism resources are coordinated, the group can show a certain scale of development and have a high development value (Priskin, 2001; Choong and Sang, 2002; He and Wang, 2011). The regional tourism resource value is determined by using different indicators. Some scholars have selected indicators such as the total amount of tourism resources, monomer density, type of abundance, reserve abundance, average quality, and number of excellent monomers to comprehensively evaluate the level of tourism resources (Fang *et al*., 2007; Wang, 2007; Ma, 2009; Zhang and Fan, 2009; Sun, 2012). The main features of the proposed method reflect quantitative statistical characteristics of the average state in an area, and the results do not adequately reflect the spatial differences. On the other hand，some scholars have chosen the resource value, combination conditions, and comprehensive quality to evaluate combinations of tourism resources (Ye, 2014). Some other scholars have chosen indexes of aggregation, superiority, and scale to evaluate the development potential of tourism resource groups (Xu and Su, 2007; Zhang *et al*., 2011; Tian and Chen, 2013; Lu *et al*., 2017), while still others have evaluated the spatial structure of tourism using aggregate fractal theory (Yang, 2013; Wang, 2008). These studies have investigated the evaluation of the spatial structure of tourism resources. However, most of the evaluation processes provide qualitative descriptions and lack quantitative evaluation models.

To assess spatial differences between tourism resources, we propose an ontology-based conceptual model of tourism resource ontological value. The origin of ontology can be traced back to Aristotle, an ancient Greek philosopher who lived in 300 BC. Aristotle tried to classify things in the world. The philosophical definition of the term is “a systematic description of the existence of the objective world,” and it refers to an explanation of objective existence and the abstractness of objects (Liu, 2017). The theory of ontology has been used to standardize a conceptual system (Gruber, 1993) and to construct a conceptual model of an arid valley ontology by using a geographical ontology (Yang, 2014). Some scholars have combined a geographical ontology with tourism and constructed a tourism geographical ontology with geographical location, tourism space, tourism resources, tourism participants, and tourism behavior as the core, and the tourism geographical ontology is used for in-depth mining and knowledge discovery of geographic information about tourism resources (Moreno *et al*., 2013; Sparks *et al*., 2013; Vicient *et al.*, 2013; Hong *et al*., 2016). Ontology has also been used in tourism geography. The application of ontology to the evaluation of tourism resource value is mainly confined to the determination of the scale effect of tourism resources and the spatial relationship between tourism resources. The assessment of regional tourism resources involves the consideration of the scale effect. Different spatial scales, such as provincial area, county area, township, or tourist area, correspond to different landscape quality and spatial characteristics of tourism resources. Therefore, the evaluation of tourism resources at different spatial scales involves different factors. Ontology helps to abstract and unify scale effects in concepts, entities, and relationships, which eliminates inconsistency

among evaluation factors of tourism resource quality caused by scale effects. On the other hand, tourism resource groups constitute a complete geographical complex in terms of spatial semantic relations, and ontology can better describe the spatial relations of tourism resources (Almeida, 2009; Chantrapornchai and Choksuchat, 2016).

The above research indicates that the evaluation of the regional tourism resource value has mainly been based on the quantitative characteristics of tourism resource groups, with little consideration for their spatial characteristics such as combination, connectivity, and aggregation, and a unified regional evaluation indicator system has not been developed. Furthermore, most of the studies have focused on conceptual ontology, and few studies have pertained to the application of a domain ontology. Accordingly, this study attempted to use ontology for the following purposes:

1) to describe the characteristics of tourism resource groups on a certain regional scale,

2) to develop a conceptual model for estimating the ontological value of tourism resources from the perspective of quantitative and spatial characteristics of tourism resource groups,

3) to construct an indicator system for the tourism resource ontological value, and

4) to evaluate county-level tourism resources by using a fuzzy clustering evaluation method. The results of this study are expected to provide decision support to government organizations for the development of tourism resources.

The evaluation indicator system provides a new perspective for and facilitates the evaluation of regional tourism resources for tourism planning. It evaluates the quality from the tourism resource value, and it has certain universality and is suitable for large-scale geographical spatial units with a regional nature, such as administrative regions, watersheds, coastal zones, geomorphic units, and other natural or artificial areas. The method can provide a reference for the rational development of tourism resources in similar areas and thereby help optimize the integration of tourism resources and promote the joint development of tourism products.

2 Ontological value evaluation methods

2.1 Definition of ontological value concept for tourism resources

In order to analyze the effect of clustering tourism resources, it is necessary to determine the overall advantages of the tourism resources. Their development value should be determined by considering not only the value of the tourism resources, but also the characteristics of spatial combinations and agglomerations of tourism resources in the cluster. Tourism resources with a higher self-value may not necessarily form a scale, being concentrated in a certain area, and the coordinated layout and combination of multiple resources can form a certain scale of development with greater development value. The tourism resources in a region have different spatial characteristics, and the spatial characteristics of tourism resources in different regions are determined by the development and environmental conditions in those regions. In order to solve the problem of different evaluation factors of tourism resource quality caused by the scale effect, this study introduces the concept of ontology, unifies and abstracts the values of tourism resources, and considers it as the value of ontology, so as to better represent the spatial differences between tourism resources in a region. Quantitative characteristics can indicate only the average situation of a region, and evalua-

tion results cannot reflect regional spatial differences. The ontological value of tourism resources proposed in this paper is essentially an evaluation of the quantitative and spatial characteristics of the tourism resources, and it can be used for the spatial difference evaluation of regional tourism resources (Figure 1).

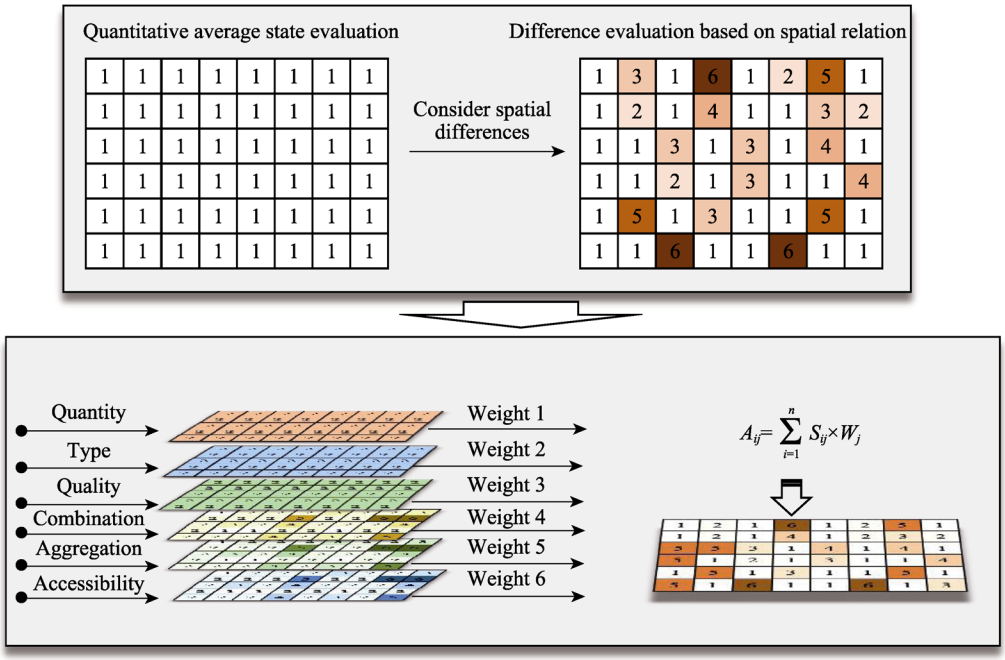

Figure 1 Principle of tourism resource evaluation on the basis of spatial differences

The concept of ontology can be understood as the formalization and explicit specification of a shared conceptual model in a domain; the model can be used to acquire knowledge in a domain of interest (Jing, 2005). Geographical ontology refers to the theory and method of abstracting relevant geoscience knowledge, information, and data obtained from the objective world into objects or entities with consensus, forming a system of entities in which the relationship between entities is known, conceptualizing and defining the system clearly, and finally expressing it formally (Yi *et al*., 2009). The essence of ontology is a set of relationships, and the relationship between tourism resources in a region can be represented by various spatial relationships in geographical space (Figure 2). The features considered for evaluating the quality of regional tourism resources are as follows: large quantity, multiple types, high quality, reasonable combination, high agglomeration and strong interconnection.

In this study, the concept of ontology was concretized, and it can be interpreted as the relationship between geographical entities with a certain spatial structure and functions. Geographical elements can be combined into a unit with specific attributes, structures, and functions on a certain spatial unit scale, while tourism resources can be integrated into a certain geographical space, with a specific spatial scale and structure, and can be characterized on the basis of their clustering, combination, closure, and connectivity in space. Therefore, tourism resource ontology is defined as follows: in a certain area, on the basis of their geographical locations, advantages and disadvantages of different types, and grades, several resource units are combined into a single unit that shows high dependence on the land-

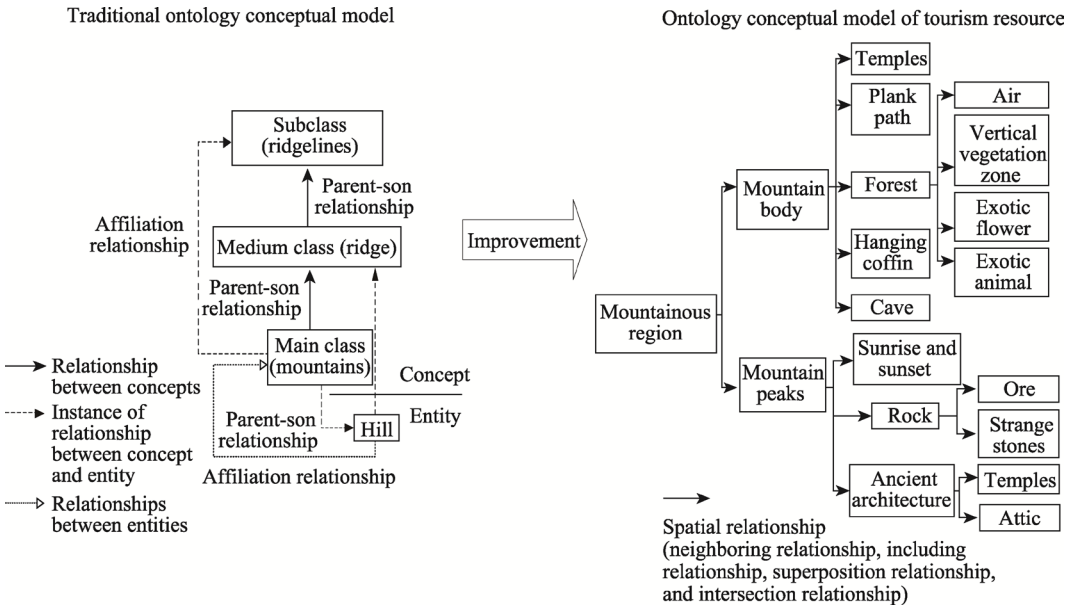

Figure 2 Contrast between traditional ontology and tourism resource ontology

scape's structure, function, and overall attractiveness. The quality of tourism resource ontology depends mainly on the degree of spatial association between different tourism resources. When they form a tight and orderly unit, a tourism resource group will have an ontological value of 1 plus 1, which is greater than 2. Therefore, the geographical locations, grades (superior or inferior), and combined features of resources will influence and restrict the integrity of tourism resources. This paper describes the regional tourism resource ontological value by considering two aspects: quantitative and spatial characteristics (Figure 3).

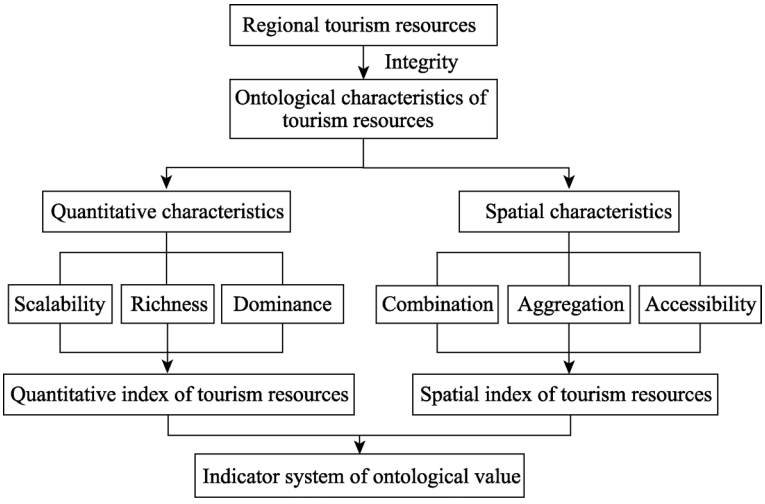

Figure 3 Conceptual model for estimating the ontological value of regional tourism resources

2.1.1 Quantitative characteristics

(1) Scalability

Scalability refers to the amount of tourism resources present in a certain space. When the

amount of tourism resources in a certain area is large, the scale of tourism resources is large and the tourism resource value is high.

(2) Richness

Richness refers to the diversity of tourism resources in a region, and it reflects sightseeing opportunities for tourists. Therefore, the more abundant the variety of tourism resources in a region, the more diverse and abundant is its tourism landscape.

(3) Dominance

Dominance refers to the rank of excellent tourism resources in an area and within a tourism resource group. It indicates how dominant such tourism resources are in the tourism resource group and among regional tourism resources. The better the tourism resources in a region, the better the advantages and the greater the amount of tourism resources.

2.1.2 Spatial characteristics

(1) Combination

Combination refers to a highly interdependent and inseparable combination of tourism resources formed by several individual resources with similar geographical positions and different resource levels according to a certain landscape's structure and function, and the resource level includes the type and quality level of resources and the regional space where they are located. A higher combination degree results in a higher level allocation, a larger number of tourism resource types, a more harmonious proportion of tourism resources in the region, closer links between tourism resources, and greater attraction to tourists. Therefore, a combination of tourism resources is not the simple addition of individual tourism resources, but the individual tourism resources attract, constrain, and influence each other and finally form a structure with characteristics that individual tourism resources cannot have. The structure formed belongs to the "ten fingers interlocking mode" (Li, 2010).

(2) Aggregation

Aggregation reflects the degree of spatial distribution and aggregation of individual tourism resources and is an important indicator of the degree of association of individual tourism resources. It is an important index that can be used to measure the degree of shielding effect produced by a vertical layout of individual tourism resources. The denser the spatial distribution of tourism resources, the better the tourist experience and the more attractive the tourism resource group system is to foreign tourism. Agglomeration effect is the external effect of the spatial agglomeration of many similar tourism resources. Therefore, the larger the quantity and scale of agglomeration, the greater the agglomeration effect. For regional tourism resources, the greater the aggregation degree, the stronger the correlation between tourism resources and the greater the tourism resource ontological value.

(3) Accessibility

The accessibility between tourism resources indicates the transportation in the region and the convenience of accessing one resource from another. The denser the spatial distribution of tourism resources, the better the tourist experience, the stronger the advantages, and the stronger the agglomeration effect. Transportation spatially connects tourism resources, compensates for the shortage of spatial distance to some extent, and promotes the combination of tourism resources into a single unit. The better the connectivity between tourism resources in a region, the greater the tourism resource value.

2.2 Indicator system development

The above-mentioned tourism resource value indicates that regional tourism resources have two characteristics: quantitative (scale, richness, and superiority of tourism resources) and spatial characteristics (agglomeration, combination, and accessibility). Therefore, the evaluation of the tourism resource ontological value mainly involves these two aspects, and the evaluation of the number of tourism resource groups requires the evaluation of the amount of individual tourism resources in the tourism resource groups, the evaluation of the level and grade of tourism resources, and the evaluation of resource diversity. The evaluation of tourism resources' ontological value space requires the evaluation of the resource combination degree, resource aggregation degree, and traffic connectivity. On the basis of the conceptual model proposed for estimating the ontological value of tourism resources, indicator factors that reflected the quantitative and spatial relationships were identified.

2.2.1 Indicators of quantitative relationship

The quantity, type, and quality of tourism resources reflect the scale, richness, and superiority of the tourism resources, and the quantitative density, type abundance, and dominance were considered as the evaluation indexes of tourism resources (Xi *et al*., 2004). The meanings and calculation formulas of specific indicators are as follows (Table 1).

Table 1 Quantitative-relationship-based evaluation indicator system for tourism resources

Evaluation factor	Quantitative characteristics indicator	Calculation method	Method description
Quantity	Scalability	$S_r = m / A$	The quantity of tourism resources per unit area in a region (district, county, and city). In the formula, S_r is the quantitative density, m is the total quantity of regional tourism resources, and A is the area.
Type	Richness	$R_r = n/N$	The proportion of fundamental types of tourism resources in cities and counties. In the formula, R_r is the type abundance, n is the number of fundamental types in the region, and N is the total number of fundamental types in the province.
Quality	Dominance	$D_r = \sum_{i=1}^{5} w_i \times m_i / m$	The proportion of tourism resources at all levels in the region. In the formula, D_r is the quality proportion, i is the level of tourism resources, w_i is the weight of level i (level 5 is 1.0, level 4 is 0.7, level 3 is 0.5, level 2 is 0.2, and level 1 is 0.1), m_i is the quantity of tourism resources of level i, and m is the total quantity of regional tourism resources.

Notes: *In the last row, the weight of each level is determined through expert scoring.

2.2.2 Indicators of spatial relationship

From the spatial relations of combination, aggregation, and accessibility, the combination degree, aggregation degree, and accessibility degree were chosen as the evaluation indicators of a tourism resource's ontological value. The meanings and calculation formulas of specific indicators are as follows.

(1) Combination index

This index of regional tourism resource combination reflects the coordination degree of a tourism resource combination for a certain distance threshold. This study mainly considered the combination relationship between different types of tourism resources, expressed by a network in graph theory. The calculation method includes the following three steps.

First, a multiscale analysis method was used to calculate the distance threshold of the provincial scale on Hainan Island (Ripley, 1977). Second, the total amount of different types of tourism resources under the distance threshold was determined. Third, we used the connectivity of complex networks as the reference to calculate the accessibility (Ou, 2017). For a certain distance threshold, the tourism resources of different major categories were expressed as a binary group G = (V, E), where V is the collection of tourism resource points and E is the collection of connecting edges of tourism resources of different main types; each edge was formed by connecting two points in V. The formula for the index is as follows:

$$G_r = \frac{2 \mid E_d \mid}{\mid V \mid (\mid V \mid -1)} \tag{1}$$

where G_r is the combination degree of resources, E_d is the number of connecting edges for threshold distance d, which is the median of the nearest distances between tourism resources in a certain area, and V is the number of edges in the network. The larger the G_r value, the more coordinated the tourism resources are in the regional distribution.

(2) Aggregation index

The aggregation index of regional tourism resources reflects the spatial distribution and aggregation degree of individual tourism resources, which is an important indicator of the agglomeration degree of individual tourism resources. It is an important index to measure the shielding effect caused by the vertical arrangement of tourism resource groups. We used the average nearest-neighbor index as the reference to indicate the aggregation degree (Ni and Ma, 2018), and modified the average distance in the aggregation degree index model to the median distance, thus eliminating the influence of the maximum and minimum distance values. The formula for the index is as follows:

$$C_r = \frac{\overline{r_i}}{\overline{r_e}} = \frac{\overline{r_i}}{2\sqrt{\frac{n}{A}}} = 2\sqrt{D} * \overline{r_i} \tag{2}$$

where C_r is the aggregation index of a point set, $\overline{r}$ is the median of the distance between each point and its nearest neighbor, $\overline{r_e}$ is the theoretical nearest-neighbor distance, A is the study area, N is the number of calculated points, and D is the density of points. The larger the C_r value, the more concentrated the tourism resources are in the regional distribution.

(3) Accessibility index

The accessibility index of regional tourism resources is a measure of the difficulty in moving between nodes in the geographic network, that is, the smoothness between nodes, and the speed of the connection between tourism resources. The accessibility model is based on a network structure comprising combination relations, and we used the number of shortest-distance connections in the network to further modify the connectivity of the network. In this study, we considered the influence of only regional internal environmental factors and the development condition on the connectivity. The accessibility index can be expressed as the average distance of the shortest paths from one vertex to all other vertices in the network. The formula for the index is as follows:

$$A_r = \frac{\sum_{j=1}^{n}\sum_{i=1}^{n} D_{ij}}{2n^2} \tag{3}$$

where A_r is the accessibility index of the network, D_{ij} is the shortest distance from vertex i to vertex j, the cumulative sum is the distance from vertex i to all vertices. The larger the value of A_r, the higher the network accessibility.

2.3 Fuzzy clustering evaluation method

The mathematical foundation of fuzzy theory is the set theory of classical mathematics. In 1965, American cybernetics expert Chad founded a new branch of mathematics, namely, fuzzy mathematics, which pertains to fuzzy phenomena and concepts. Cluster analysis is a multivariate analysis method in mathematical statistics, and it involves the use of mathematics to quantitatively determine the genetic relationship between research objects for their objective classification (Ling, 2013). It is used to divide a dataset into several different subclasses according to their internal structure. This results in samples in the same class being as similar as possible, while the samples in different classes are as different as possible. The introduction of fuzzy mathematics into clustering analysis can result in cluster analysis adapting better to the fuzziness of the objective world, and also effectively cluster datasets with a mixture of classes (Fu, 2003).

In this study, the Euclidean distance method was used to determine the similarity coefficient between ontological value indexes, and a reflective and symmetrical fuzzy similarity matrix was obtained. Subsequently, a fuzzy equivalent matrix was obtained through the transitive closure operation. Finally, fuzzy equivalent matrices with different confidence levels were clustered. The mathematical model was as follows:

$$r_{ij} = 1 - c\sqrt{\sum_{k=1}^{m}\left(x_{ik} - x_j k\right)^2} \tag{4}$$

$$R = \begin{bmatrix} r_{11} & & & \\ r_{21} & r_{22} & & \\ \cdots & \cdots & \cdots & \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \tag{5}$$

$$r_{ij}^{(k)} = \bigvee_{k=1}^{m}(r_{ik} \bigwedge r_{jk}) \tag{6}$$

$$r_{ij}^{*}(\omega) = \begin{cases} 0, r_{ij} < \lambda \\ 1, r_{ij} > \lambda \end{cases} \tag{7}$$

In equation (4), $\sqrt{\sum_{k=1}^{m}(x_{ik} - x_j k)^2}$ is the Euclidean distance d_{ij}; c is a constant that ensures r_{ij} is in the interval [0,1], and it is given by $c = 1/d_{max(ij)}$ in calculations. In equation (5), R represents a fuzzy relation matrix, and in equation (6), $r^{(k)}$ represents the fuzzy equivalent matrix. In equation (7), r^{*}_{λ} represents a cluster-intercepted matrix, and λ forms a dynamic cluster pedigree graph that could be large or small.

3 Evaluation of tourism resources on the basis of ontological value on Hainan Island

3.1 Study area and data source

Hainan Island, which is one of the excellent island tourism cities in Hainan Province, China, is famous for its coastal tourism, tropical rain forest, and national historical culture. It is located in the southernmost part of China and is the second largest island in China after Taiwan Island, with an area of 33,900 km^2. Hainan Island has a unique coastal zone landscape, mountains, rare tropical and subtropical forest resources, rich flora and fauna, high-quality climate and environmental resources, biodiversity, rich cultural tourism resources, and rural ethnic characteristics, and it is rich in tourism resources. The tourism resources in the northern, southern, and central regions feature volcanic landscapes and theme parks, coastal resorts, and tropical rain forests, respectively, and the east coast is better than the west coast. Hainan, as an independent island, has rich and unique tourism resources, but there are obvious differences in the type and quality of tourism resources in different areas on the island. In order to bring out the spatial differences in the quality of tourism resources in different regions and the availability of data, we selected 18 administrative districts in Hainan Island as the spatial research units for the comparison of the quality of regional tourism resources. The 18 municipal administrative units covered in the study area include three prefecture-level cities (Haikou, Sanya, and Danzhou), five county-level cities (Wuzhishan, Wenchang, Qionghai, Wanning, and Dongfang), four counties (Ding'an County, Tunchang County, Chengmai County, and Lingao County), and six autonomous counties (Baisha Li Nationality) (Figure 4). Sansha was not included because it had no data on tourism resources. Although there are differences at the administrative level among the 18 administrative units, they are all under the jurisdiction of Hainan Province. Both Hainan Provincial Department of Culture and Tourism and Statistics Bureau manage scenic tourism spots and tourism economic statistics in parallel with 18 counties and cities, and most other tourism-related studies on Hainan have also analyzed the 18 counties and cities in parallel. As relatively single and complete geographical units, they are ideal places for testing the applicability of ontological analysis. According to the statistics of the 18 administrative regions, the average value of the area is 1892 km^2, the standard deviation is 629, and the probability that the area distribution of each region is within the range of two standard deviations is 95%. Thus, the difference between the areas of the different regions is small and does not affect the comparison between regions.

Data on tourism resources on Hainan Island were acquired from four sources: tropical forest tourism planning documents of Hainan Province, the database of the second census of geographical names, high-resolution remote sensing images, the official tourism website of Hainan Province, and a field survey. The survey period was two months, June–August 2018. The field investigation was conducted by researchers from the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences, Hainan Normal University, and the 18 county-level tourism administrations of Hainan. On the basis of the regional characteristics and research efficiency, the researchers were divided into three groups to study the northern, central, and southern parts of Hainan Island. The field survey covered the entire island and 10,260 spatial data were collected, including 3696 physical

geographical tourism resources and 6564 human geographical tourism resources (Figure 5). The survey provided the location, type, nature, and characteristics of the tourism resources, the surrounding environment, and attribute information on protection and development conditions. Among the investigated attributes, only the type and value attributes of tourism resources were used in this study. According to China's national standard, specified in

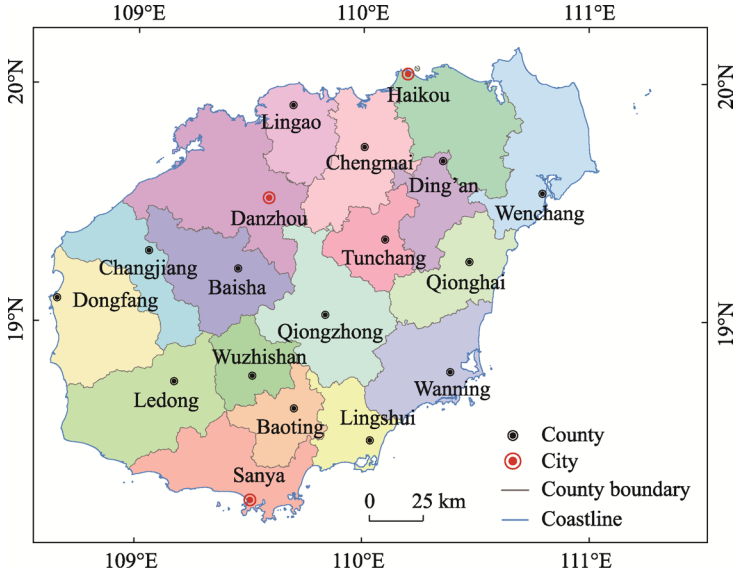

Figure 4 Location of the Hainan Island

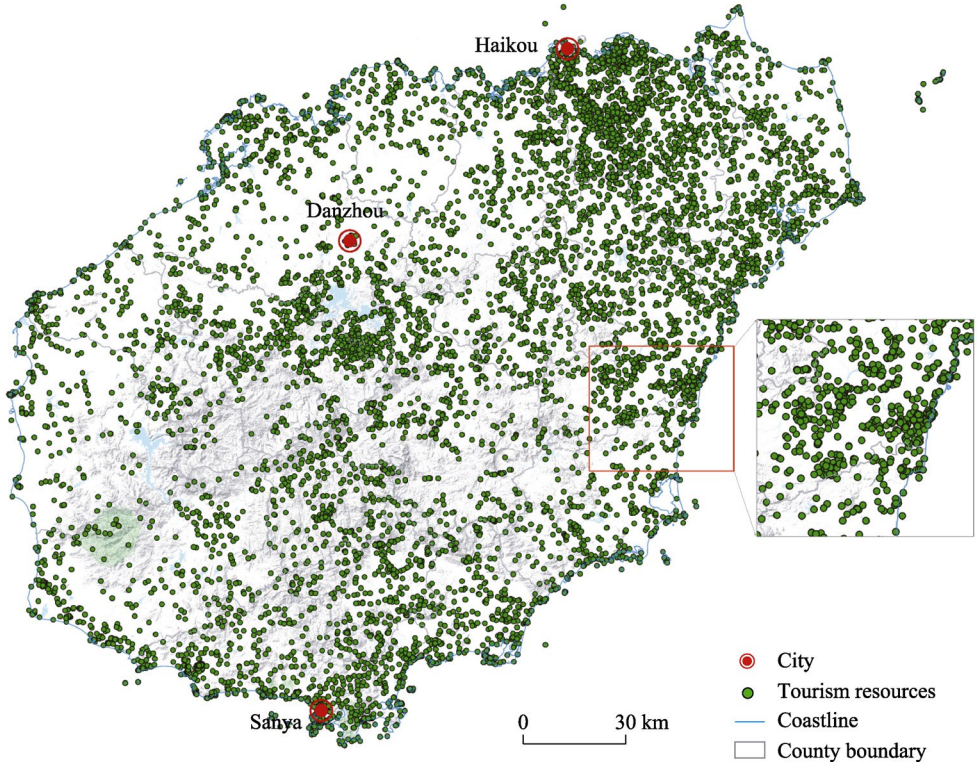

Figure 5 Spatial distribution of tourism resources on Hainan Island

"Classification, Investigation and Evaluation of Tourism Resources" (GBT 18972-2017), and on the basis of Hainan's natural environmental characteristics, tourism resources are divided into nine categories: geographical landscapes, water landscapes, biological landscapes, astronomical phenomena and meteorological landscapes, buildings and facilities, ruins and remains, human activities, tourism commodities, and ocean and coastal landscapes. These categories can be further divided into 25 subtypes and 112 fundamental types (Table 2). Tourism experts, geography experts, and government officials participated in the evaluation of the value of tourism resources. The assessment was divided into five levels (Table 3).

Table 2 Classification of tourism resources on Hainan Island

Main type	Subtype
Geographical landscapes	Natural landscape complex
	Geographical and structural features
	Surface morphology
	Natural markers and natural phenomena
Water landscapes	River system
	Lake marsh
	Groundwater
	Sea surface
	River or lake
Biological landscapes	Vegetation landscape
	Wildlife habitat
Astronomical phenomena and meteorological landscapes	Astronomical phenomena
	Weather and climate phenomena
Buildings and facilities	Human landscape complex
	Practical buildings and core facilities
	Landscape and sketch architecture
Ruins and remains	Material cultural relics
	Intangible cultural remains
Tourism commodities	Agricultural products
	Industrial products
	Handmade crafts
Human activities	Personnel activity record
	Season
Ocean and coastal landscapes	Coastal landscape
	Marine landscape

Notes: The above classification is based on China's national standard, which is specified in "Classification, Investigation and Evaluation of Tourism Resources" (GBT 18972–2017).

3.2 Comprehensive evaluation of regional tourism resource ontological value

3.2.1 Regional differences in indicator values based on ontological values

By using the conceptual model proposed for estimating the tourism resource ontological value, this study integrated the tourism resource development value on Hainan Island with a quantitative relation index (quantitative density, richness, and dominance) and a spatial relation index (combination degree, aggregation degree, and accessibility degree) and obtained the value of the ontological value index. The results of each index were classified by Jenks' natural fracture method to ensure consistency in the classification standards of different regions and to analyze the spatial differentiation characteristics of each index value (Figure 6).

As evident in Figure 6, the spatial patterns of the quantitative density index and richness

Table 3 Evaluation grades of tourism resources

Score interval	Grade of tourism resources
⩾90	Level five
75–89	Level four
60–74	Level three
45–59	Level two
30–44	Level one

Notes: The above grading is based on China's national standard, which is specified in "Classification, Investigation and Evaluation of Tourism Resources" (GBT 18972-2017).

index on Hainan Island showed different characteristics. In particular, they showed clear different patterns between the high-value area and the low-value area. By contrast, there was no apparent difference in the distribution pattern of the dominance index. In Figure 6a, the highest-value area of the quantitative density index is distributed in Haikou, Wenchang, Qionghai, Tunchang, and Ding'an in the north and in Sanya, Baoting, and Lingshui in the south. The second-highest-value area is distributed in Baisha, Wuzhishan, and Qiongzhong in the central region and in Danzhou and Lingao on the northwest coast. The low-value areas are distributed in the east and in Ledong and Changjiang in the southwest. The richness index patterns of the high-value and low-value areas are similar but different. While the highest-value area is distributed in most cities from the north to the central region, and to the west and south, Ding'an County in the north belongs to a low-value area and the distribution here is not dense. The second-highest-value areas are located in Chengmai, Lingao, and Tunchang to the northwest of Hainan Island, and in Baisha and Changjiang in the middle. The low-value areas are distributed in the east and in Ledong on the southeast coast, in Wuzhishan in the central region, and Ding'an in the north (Figure 6b). There is no clear difference between the high-value and low-value regions of the dominance index, but this index shows a difference between the north and the south. The high-value area is mainly distributed in most cities in the south, and the low-value area is mainly distributed in the north (Figure 6c).

The spatial patterns of the county agglomeration index, composition index, and accessibility index showed clear different characteristics, and the patterns in the high-value and low-value areas could be clearly differentiated. The highest-value area of the aggregation index was distributed in Haikou, Wenchang, Qionghai, Tunchang, and Ding'an in the north and in Sanya, Baoting, Lingshui, and Ledong in the south. The second-highest-value area was distributed in Baisha in the central region and Danzhou on the northwest coast, and the low-value area was distributed in Changjiang on the southwest coast and in Qiongzhong in the central region (Figure 6d). There were differences in the combination index between the high-value and the low-value areas. The first-high-value area was distributed on the west and east coasts, the second-highest-value area was distributed in Baisha and Qiongzhong in the central region, and the low-value area was distributed in Haikou in the north and Sanya in the south (Figure 6e). There were apparent differences in the accessibility index between the high-value area and the low-value area, and the index showed a central-peripheral pattern. The high-value areas were mainly distributed in most plains and coastal cities, while the low-value areas were mainly distributed in the hilly area of the central region (Figure 6f).

To summarize, as far as the quantitative distribution is concerned, the tourism resources on Hainan Island are located mostly in the north and southeast and are less in the southwest.

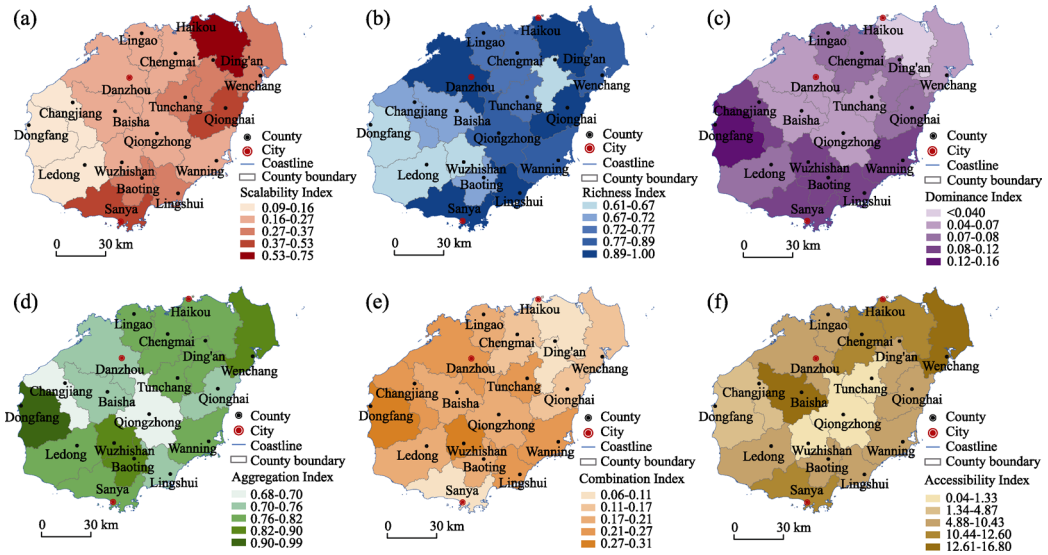

Figure 6 Spatial distributions of the (a) scalability index, (b) richness index, (c) dominance index, (d) aggregation index, (e) combination index, and (f) accessibility index of tourism resources

The quantity distribution in the north and southwest shows apparent agglomeration characteristics. With regard to the distribution of types, the north and southeast regions are rich and show different distributions, while the southwest region has a single type and shows an apparent clustering distribution. In terms of quality distribution, the tourism resources in the south are superior to those in the north. Furthermore, the high-quality resources in the southwest and the general resources in the south are clustered and distributed. The tourism resources in the north and southeast of Hainan Island are apparently clustered and distributed on the spatial distribution maps. The combination of tourism resources on the west coast and east coast is good. By contrast, the northern region is poor in tourism resources, but the traffic accessibility is better. The central hilly region is also poor in tourism resources.

3.2.2 Fuzzy clustering evaluation of regional tourism resources

(1) Normalization of indicator values

As evident from the above values, different evaluation indicators often have different dimensions, and the differences between their values may be very large, which may affect the results of data analysis. Therefore, it is necessary to standardize the data, subject them to linear transformation using min-max normalization, and confine them to a specific area for performing a comprehensive analysis, to eliminate the effect of different dimensions or value ranges between indicators. In this study, min-max normalization was used for standardizing data. This involves the linear transformation of the original data, resulting in the data having values between zero and one (Table 4). For the quantitative density index, Haikou scored the highest, followed by Sanya; Dongfang scored the least. For the wealth index, Sanya scored the highest, followed by Haikou; Wuzhishan scored the least. For the dominance index, Dongfang scored the highest and Wanning was next, and Haikou scored the least. On the basis of the spatial relationship index, Dongfang had the highest aggregation index, followed by Wuzhishan; Changjiang had the lowest score. Wuzhishan had the highest

combination index and Dongfang was next, and Haikou had the lowest score. Wenchang had the highest accessibility index, followed by Baisha and Wuzhishan. To summarize, high scores were mainly found in Haikou, Sanya, Dongfang, and Wuzhishan. Among these cities, Haikou had higher quantitative density and richness but lower dominance and combination degree; Sanya had high quantitative density, high richness, and high accessibility, but low combination degree; and Dongfang had low quantitative density, low richness, and low accessibility, but high dominance, high aggregation, and high combination. The richness and accessibility of Wuzhishan were low, but the aggregation and combination degrees were high.

Table 4 Standardization of the ontological value index of tourism resources on Hainan Island

Name	Scalability	Richness	Dominance	Aggregation	Combination	Accessibility
Wuzhishan City	0.27	0.00	0.56	0.73	1.00	0.00
Tunchang County	0.31	0.31	0.28	0.33	0.79	0.01
Chengmai County	0.23	0.34	0.35	0.35	0.38	0.75
Baisha County	0.24	0.21	0.28	0.26	0.56	0.99
Changjiang County	0.11	0.24	0.58	0.00	0.83	0.29
Baoting County	0.36	0.28	0.47	0.56	0.53	0.47
Qiongzhong County	0.18	0.72	0.24	0.06	0.59	0.08
Dongfang City	0.00	0.07	1.00	1.00	0.93	0.26
Qionghai City	0.59	0.93	0.35	0.23	0.39	0.62
Wanning City	0.26	0.62	0.70	0.37	0.76	0.60
Lingao County	0.21	0.41	0.32	0.35	0.57	0.53
Ledong County	0.06	0.10	0.34	0.42	0.54	0.52
Lingshui County	0.43	0.79	0.48	0.26	0.82	0.47
Danzhou City	0.22	0.79	0.21	0.16	0.70	0.54
Sanya City	0.66	1.00	0.61	0.37	0.17	0.75
Ding'an County	0.39	0.14	0.39	0.40	0.18	0.58
Wengchang City	0.42	0.55	0.26	0.56	0.43	1.00
Haikou City	1.00	0.90	0.00	0.45	0.00	0.73

Low value High value; Low value High value

(2) Fuzzy clustering evaluation

A fuzzy clustering evaluation method was used to comprehensively evaluate the tourism resource ontological value on Hainan Island. The fuzzy clustering pedigree map of Hainan Island was obtained through fuzzy clustering calculations (Figure 7). The greater the distance intercept between cities and counties, the more apparent was the difference in the ontological value and the more reliable were the clustering evaluation results. On the basis of the evaluation results, the quantity of tourism resources on Hainan Island can be divided into four levels. The higher the tourism resource ontological value in the first-level cluster cities, the greater their development potential, and the lower the tourism resource ontological value in the fourth-level cluster cities, the lower their development potential.

- First-level cluster cities: Chengmai, Lingao, Baoting, Ledong, Ding'an, Baisha, and

Wenchang

- Second-level cluster cities: Tunchang, Changjiang, Wanning, Lingshui, Qiongzhong, and Danzhou
- Third-level cluster cities: Dongfang and Wuzhishan
- Fourth-level cluster cities: Haikou, Sanya, and Qionghai

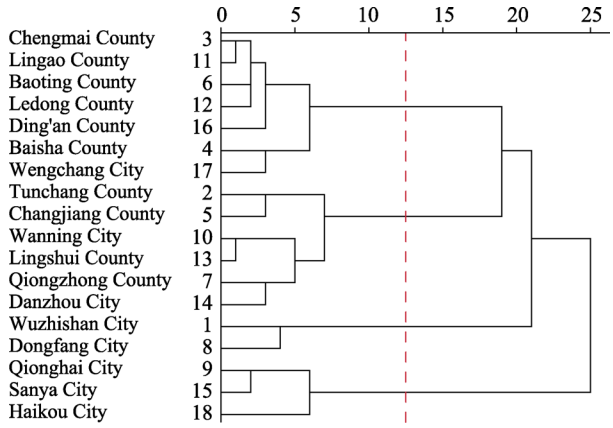

Figure 7 Fuzzy clustering pedigree of tourism resources on Hainan Island

(3) Clustering result analysis

From an overall evaluation of Hainan Island's tourism resources, we could gage the present situation of all counties and cities on the island, and the evaluation results were in accord with the objective reality. On the basis of the clustering result of regional tourism resources, Hainan Island's tourism resources can be divided into four categories (Figure 8). There are seven first-level cluster cities, among which the northern, central, and southern regions cover a large area, and there are spatial differences in the resource value between the cities. While Wenchang, Ding'an, Lingao, Chengmai, and other places in the north are endowed with good tourism resources, there are many cultural tourism resources at these places, and these places have high scores on all characteristics except resource combination. Baisha County scored low in dominance and aggregation, and high in other characteristics, while Ledong County and Baoting County scored low in richness. On the whole, the tourism resources in the first-level cluster cities have high potential for development, and they should be accorded priority. Government departments should adopt different development strategies for different regions. There are five cities in the secondary cluster, which are concentrated in the hilly region. While these areas have good resource endowment and resource combinations, the traffic conditions are a major problem, resulting in a low score for the accessibility index. Government departments should improve the regional traffic situation, which will increase the development potential of tourism resources. There are two third-level cluster cities. Although Dongfang and Wuzhishan scored low in quantity, type, and connectivity, they are poor in tourism resources and their development potential is not high. There are three four-level cluster cities that have become mature tourism destinations, and they have excellent well-developed natural tourism resources. Haikou, as the capital of Hainan Province, is a famous tourism hub. While Sanya and Qionghai are also rich in coastal tourism resources and endowed with high-quality tourism resources and convenient

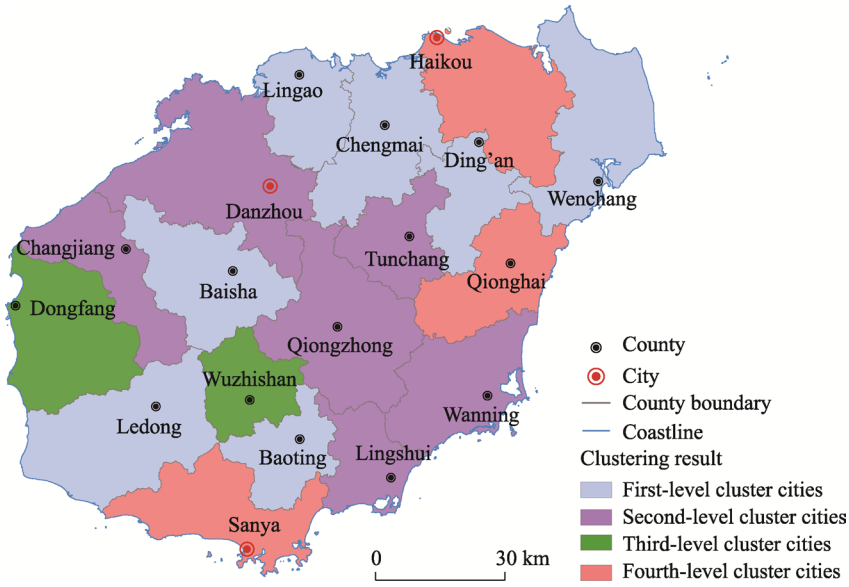

Figure 8 Cluster distribution of the tourism resource ontological value for Hainan Island

transportation, they have been developed to a high degree. Priority should be accorded to the development of the first-level and second-level cluster cities with high development potential.

3.3 Verification of evaluation results

In order to test the accuracy of the tourism resource ontological value index and the reliability of the fuzzy clustering evaluation method, this study used the Delphi method. Tourism experts, geography experts, and local government tourism managers were invited, and selected values of the tourism resource value, scale, characteristics, and accessibility were used to evaluate the tourism resource development value of the 18 counties and cities (Table 5). We invited 6 tourism experts, 6 geography experts, 18 tourism managers, and 30 census personnel to score the 18 counties and cities in terms of the value (ornamental value, recreational value, cultural value and historical value), scarcity, scale, and accessibility of tourism resources according to China's national standard. This study compared and analyzed the results scored according to China's national standard with those obtained in this study, and a significant correlation was observed between the two scoring systems (Figure 9a). We used the D'Agostino and Pearson Omnibus Normality method to test the distribution normality of the two scoring results. The results showed that China's national standard scores deviated from the normal distribution ($K2 = 21.03$, $p < 0.01$) (Figure 9c), while the scores of this study were consistent with the normal distribution ($K2 = 0.514$, $p = 0.786$) (Figure 9b). The Wilcoxon signed rank test was used to test the deviation between median and mean, and similar results were obtained ($p = 0.0252$ for scoring according to China's national standard; $p = 0.899$ for the scoring result of this study).

From an evaluation perspective, the results of testing were compared with the ontological value used in this study. The conclusion of the expert evaluation was close to the result of the ontological value evaluation in this study (Figure 10). This showed that the ontological

Table 5 Standardization of the ontological value index of tourism resources on Hainan Island

Panel composition	Number of participants	Weight
Tourism experts	6	0.4
Geography experts	6	0.3
Local government tourism managers	18	0.2
Census enumerators	30	0.1

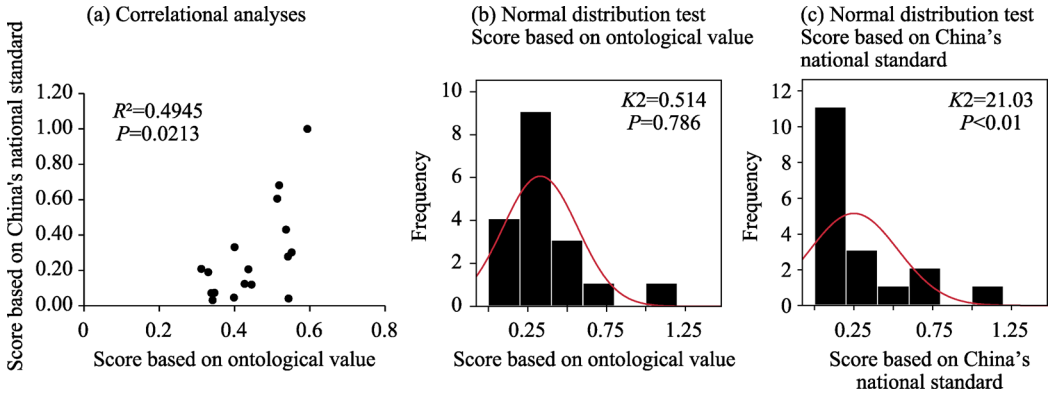

Figure 9 Correlational analyses and normal distribution test

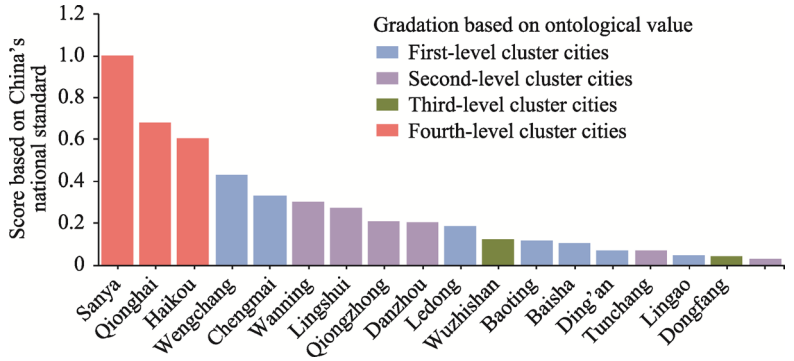

Figure 10 Comparison and contrast between China's National Standard and ontological value

value index system was scientific and reliable for regional tourism resource evaluation; importantly, it solved the inconsistency problem faced with traditional indexes. The evaluation index system and method are universal and can provide a reference for other regions. The statistical results based on China's national standard scores showed strong subjectivity. The clustering method adopted in this study avoids subjective scores and improves objectivity, and therefore, it is advantageous for performing scientific evaluations.

4 Discussion

Tourism development planning is based on an evaluation of tourism resources. Scientific evaluation of existing tourism resources in a region is important for the development and construction of the region, and it is useful for achieving an optimal combination of tourism resources and for rational development planning. Tourism resources exist as independent

individual entities in space, while tourism resources in a region comprise tourism resource groups. The spatial combination and agglomeration characteristics of tourism resource groups render them a complex tourism resource with ontological characteristics reflected in quantity and space (Xi *et al*., 2004). However, this ontological feature is difficult to perceive and quantify subjectively, unlike the ornamental value or recreational value. Therefore, the ontological value of regional tourism resources has received little attention, and few scholars have evaluated and studied the spatial relationship between tourism resources. The main use of the ontological value of tourism resources presented in this study is in the evaluation of the quantitative and spatial characteristics of tourism resources in regional space, namely, the combination, agglomeration, and connectivity of tourism resources.

For the regional evaluation of tourism resources in Hainan, some scholars have used the analytic hierarchy process (AHP) to evaluate the quality, scale, and regional combination of tourism resources (Wang, 1996; Chen and Luo, 2011; Wang *et al*., 2018). However, in these studies, the evaluation of regional combination factors was subjective, and it was dependent on expert judgment rather than model quantification, resulting in too subjective evaluation results. The advantage of this study is the large number of samples, namely, the tourism resource data collected through field research. The data can comprehensively reflect the type of tourism resources, provide accurate spatial positioning information, and fully describe the spatial characteristics of tourism resources, such as combinatorial relations and aggregation characteristics.

For the spatial characteristic index, the results of the present study are substantially different from those of previous studies. For example, Ni and Ma (2018) described a combination of tourism resources from three aspects, namely, aggregation effect, shielding effect, and substitution effect, and calculated the aggregation degree by using the proximity ratio index. The calculation method of the researcher was similar to that of the aggregation index used in the current study, but the distance parameters were different. Furthermore, one similarity in clustering was related to the distance between tourism resources, the quantity of resources, and the area. The difference was laid in the calculation of the average distance. The average distance in previous studies was a fixed value, while the random average distance in this study is the median distance at different scales. Few scholars have quantitatively determined the characteristics of tourism resource combination for tourism resource evaluation. The calculation of the combination index is one of the significant contributions of this study, with a graph network structure being used to express the combination relationship between different types of tourism resources. In the combination index calculation model, we introduced the spatial distance and used graph connectivity to calculate the combination index. Because of the large sample size of the tourism resource data, the combination of different types of tourism resources formed a complex network. We constructed an accessibility index model based on the shortest distance in complex networks and quantitatively described the connectivity of tourism resource combination networks. Some scholars have calculated the accessibility between scenic spots on the basis of geographical network accessibility (Zhu *et al*., 2018). The main feature of this method is a small sample size, which is quite different from the connectivity in this study. This study attempted to assess regional tourism resources on the basis of the tourism resource ontological value. The presence of tourism resources in large quantities and of high quality does not guarantee high

development potential. The index system of tourism resource ontological values is systematic and comprehensive, and it can facilitate decision-making for determining the development timing for tourism destinations. In the evaluation of the tourism resource value, due consideration should be provided from a systematic viewpoint to not only the quantitative characteristics of regional tourism resources but also the spatial relationship between tourism resources. This study attempted to use an innovative evaluation index for the tourism resource value, apply ontology to determine the value of regional tourism resources, obtain the ontological characteristics of regional tourism resources, and construct an ontological value index system from quantitative and spatial characteristics of regional tourism resources, to solve the problem of inconsistency in existing evaluation index systems for regional tourism resources.

AHP is a widely used evaluation method (Zhang, 2018; Zhao *et al*., 2019). The main feature of this method is the determination of multilevel evaluation factors, and the weight of each evaluation factor should be determined. The weight determination process is subjective. To solve this problem, we should ensure that the spatial characteristics of regional tourism resources are quantitatively and objectively described. The spatial characteristics of the ontological value indicators were analyzed, and a fuzzy clustering evaluation method was used to comprehensively evaluate and rank the ontological value. The evaluation process and results showed that the selection of the tourism resource ontological value index system was scientific and reasonable, and that the application of fuzzy clustering to the tourism resource ontological value evaluation was valid. Obtaining the regional tourism resource value for tourism development in China is not only of universal guiding significance but also has reference significance for the rational development of tourism resources in similar regions.

In short, the research of this paper has the following scientific value:

First, this study defined regional tourism resources from the viewpoint of ontology. It defined regional tourism resources as tourism resource ontology, in which the most fundamental feature is a set of spatial relations. By constructing a conceptual model for estimating the tourism resource ontological value, the long-standing difficult problem of not being able to quantitatively evaluate regional tourism resources was solved. Using the conceptual model, this study constructed a value index system for regional tourism resources, especially reconstructing a spatial characteristic index for tourism resources, devising a way to evaluate spatial relations quantitatively, and overcoming the problem of evaluation indexes being nonuniform. Compared with the results of many experts, the results of the two methods were basically the same, which showed that the method has strong operability.

Some aspects of this study should be improved, such as the selection of evaluation methods, determination of index weights, and identification of a reasonable sample size. We will continue to determine ways to evaluate the tourism resource value under different development conditions with the objective of realizing a practical evaluation method.

5 Conclusions

The ontological characteristics and value definition of regional tourism resources indicate that the regional tourism resource ontological value depends on the quantitative and spatial relationships between tourism resources. This study systematically examined the current

related contents and main methods of tourism resource evaluation, and developed a tourism resource evaluation scheme based on an ontological value. Furthermore, an evaluation index system was designed for the quantitative relationship (density, richness, dominance) and spatial relationship (combination, aggregation, accessibility) between tourism resources, and an evaluation model was constructed for Hainan Island's tourism resources.

The salient features of this study are as follows:

(1) Evaluation indexes of tourism resources were constructed, namely, scalability, superiority, richness, quantitative density, type, and abundance. From the spatial relations of combination, aggregation, and accessibility, the combination degree, aggregation degree, and accessibility degree were identified as the evaluation indicators of the tourism resource ontological value.

(2) The tourism resource fuzzy clustering pedigree diagram was constructed using a fuzzy clustering method, and the tourism resource ontological value was comprehensively evaluated.

(3) From the perspective of county scale, the spatial pattern of quantitative indicators and spatial relationship indicators for Hainan Island showed apparent different characteristics. In particular, they showed apparent differentiation patterns for high-value and low-value areas. On the basis of a fuzzy clustering evaluation method, comprehensive evaluation results obtained for the ontological value were divided into four grades: Chengmai, Lingao, Baoting, Ledong, Ding'an, Baisha, and Wenchang were the first-level cluster cities; Tunchang, Changjiang, Wanning, Lingshui, Qiongzhong, and Danzhou were the second-level cluster cities; Dongfang and Wuzhishan were the third-level cluster cities; and Haikou, Sanya, and Qionghai were the fourth-level tourism resource areas.

The evaluation model adopted in this study considers the spatial characteristics of tourism resources. It evaluated the development potential of Hainan's tourism resources on the basis of their quantitative and spatial characteristics. A comparison between the research results and traditional expert scoring evaluation results showed that both results were similar. In particular, the obtained data on tourism resources rendered the evaluation of regional tourism resources on Hainan Island more quantitative. The proposed evaluation index system provides an innovative and improved way to identify development opportunities for regional tourism resources.

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