



Ecotourism risk assessment in Yaoluoping Nature Reserve, Anhui, China based on GIS

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Abstract

As tourism development and human disturbance increase, they have been affecting the functional structure distribution, sustainable utilization of resources, and ecological benefits of nature reserves. At the same time, ecological risk has increased significantly. This study proposes ecotourism development patterns for risk areas at each level, to provide a basis for stabilizing and promoting the ecological sustainable development of nature reserves. Yaoluoping National Nature Reserve in China is used as a study case. Based on GaoFen-2 satellite data within the reserve area in 2017, ENVI, Fragstats and ArcGIS10.2 are used for land use classification as well as evaluation indicators selection and analysis. The ecotourism risk assessment model of the reserve is constructed, which is also imbedded with analytic hierarchy process and Ecological Risk Index. The model consists of landscape ecology, topographic hydrology, land use and human activities factors, and it can produce the distribution map at the ecotourism risk level of the reserve. Results show that the high ecotourism risk areas in the reserve are mainly located around rivers and roads, and they are distributed in strips. Overall, the ecotourism risk level in the northern part of the reserve is higher than that in the southern part. Nearly 90% of the regional ecotourism risk is at the middle or low level, implying the reserve in a healthy level overall. However, except for low-risk areas, the proportion of risk areas at all levels in the core zone is higher than that in the buffer zone.

Keywords Ecotourism risk assessments · Nature reserve · Tourism development · GIS · Yaoluoping

Introduction

Ecological risk refers to the risk that an ecosystem suffers from the disturbance of nature or human activities, that is, the adverse effects of accidents or disasters in a certain region on the structure or function of the ecosystem, thereby endangering the safety and health of the ecosystem (Serveiss 2002; Guo et al. 2017; Tang and Ma 2018; Gong et al. 2021). Ecological risk assessment is to organize and analyze existing data, evaluate possible negative Ecological effects, and predict the probability and consequences of

the occurrence of risks (Meng and Zhao 2009; Rohr et al. 2016). The research on ecological risk assessment began in the 1930s. It mainly went through embryonic stage, human health assessment stage, ecological risk assessment stage, and the multiscale comprehensive ecological risk assessment stage from the 1990s to the present (Kapustka 2005; Thomsen et al. 2012; Hua et al. 2017; Xu et al. 2018). In recent years, scholars have extended and improved the study of ecological risk assessment to landscape, region, watershed, and other levels (Detenbeck et al. 2000; Leuven and Poudevigne 2002; Bayliss et al. 2012; Xu et al. 2013; Li et al. 2018; Omar and Cabral 2020).

With the improvement of people's requirements for tourism environment, the ecotourism model of pursuing harmonious coexistence between nature and human has become a hot spot (Salemi et al. 2019; Quoquab et al. 2021). Society is concerned on environmental protection, while local governments also need to consider economic development. Therefore, how to keep the balance between tourism development and resources protection is a key problem of ecotourism research (Wang et al. 2017; Masih et al. 2018; Guerrero

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et al. 2020). Ecotourism risk refers to the potential risk to regional ecosystem in the entire process of tourism development (Wiredu et al. 2020; Sukuryadi et al. 2021). It is necessary to construct the ecological tourism risk evaluation index system scientifically and divide the ecological tourism risk classes by integrating the contribution rate of various resources. It is of great guiding significance for the tourism project planning and ecological environment protection (Mkiramweni et al. 2016; Kan et al. 2018). Ecotourism projects are mostly carried out based on some indicators such as natural environment, infrastructure, historical sites, and distribution of potential tourists. Each indicator has different contribution to ecotourism risks. It is common to evaluate ecotourism risk using Delphi method, fuzzy comprehensive analysis method, and analytic hierarchy process (AHP) (Aliani et al. 2017; Sahani 2019; Fallah and Ocampo 2021). This study of ecotourism risk assessment mainly focuses on nature reserve, scenic spot, forest park, wetland park, and so on. In terms of evaluation scale, ecotourism risk evaluation has gradually shifted from provincial and municipal units to county, village and scenic spots (Yang et al. 2018; Lebrão et al. 2021; Shi et al. 2021).

Nature reserves are with the functions of protecting precious species and maintaining ecological balance. In addition, they have gradually become the main places for ecotourism activities due to their original and unique regional landscapes (Yang et al. 2018; Xue et al. 2019). The existing researches on ecotourism in nature reserves have focused mainly on the evaluation of development potential, status and planning (Pastorok et al. 2003; Aminu et al. 2015; Chaudhary et al. 2021). However, with the continuous increase in tourism development and human disturbance, nature reserves have been facing with severe ecological problems such as resource reduction, ecological function degradation and ecological benefit reduction, and their ecological risks are significantly increased (Van Strien et al. 2016; Wang et al. 2016; Peng et al. 2017; Mondal et al. 2021). Yaoluoping National Nature Reserve in China plays an important role in protecting the representative forest ecosystem in Dabie Mountains, national rare and endangered wildlife, and the water security of Mozitan and Foziling reservoirs in Huaihe River Basin. Therefore, carrying out ecotourism risk assessment, determining the spatial distribution of ecotourism risk levels in the reserve, and discussing and proposing ecotourism development countermeasures tailored to local conditions in the reserve, can provide decision-making basis for the risk management of the reserve as well as the sustainable development of resources and environment (Xu et al. 2015; Zhang et al. 2018; Bai et al. 2021).

Materials and methods

Site description

Yaoluoping National Nature Reserve is located in the junction of three counties (i.e., Yuexi, Huoshan, and Yingshan) in Anhui and Hubei province. It is in the hinterland of the Dabie Mountains with a total area of about 123 km² (Fig. 1). The average altitude of the study area is above 800 m. Its relative altitude difference is 400–1000 m, and its slope is mostly at 40°–60°. The zonal vegetation of the reserve consists of subtropical evergreen broad-leaved forest and warm temperate deciduous broad-leaved forest. The biodiversity of the reserve is extremely rich, preserving a large number of rare and endangered animals as well as ancient relic plants. There is an important species gene bank in Dabie Mountains. There are more than 2000 species of higher vascular plants and more than 200 kinds of terrestrial vertebrates, including more than 40 species of national key protected rare wild animals and plants, such as *Emmenopterys henryi*, *Euptelea pleiospermum*, *Pinus dabeshanensis*, *Andrias davidianus*, and *Moschus moschiferus*. Meanwhile, Yaoluoping Nature Reserve is also the source of some important tributaries of Huaihe River and Yangtze River in Anhui Province, such as Qingtian River, Shisheng River, Dongjia River and Caopan River. It has become the main water conservation area for protecting Huaihe River Basin (Wang et al. 2016).

The Regulations of the People's Republic of China on Nature Reserves require that these concentrated distribution areas where there are the well-preserved natural ecosystems, rare and endangered animals and plants in nature reserves shall be divided into core zones. Any organization and individual are forbidden to enter or engage in scientific research activities in those areas. Buffer zone of a certain area may be delimited outside the core areas, which are only allowed to enter for scientific research and observation activities. The periphery of the buffer zone is divided into experimental zones, which can be used for scientific experiments, teaching practice, visits, tourist activities, and so on. The overall planning of Yaoluoping Nature Reserve has determined the boundaries of three functional zones (core zone, buffer zone, and experimental zone). Its core zone consists of four parts: Chuanshi, Qilingou, Diaoguanjing and Duozhijian. The area ratio of the three functional zones is 17%, 24%, and 59%, respectively. The reserve receives nearly 40,000 tourists annually, mainly relying on natural resources scenery in buffer zones and experimental zones as well as red tourist attractions such as the old military and political site of the Red 28th Army of China.

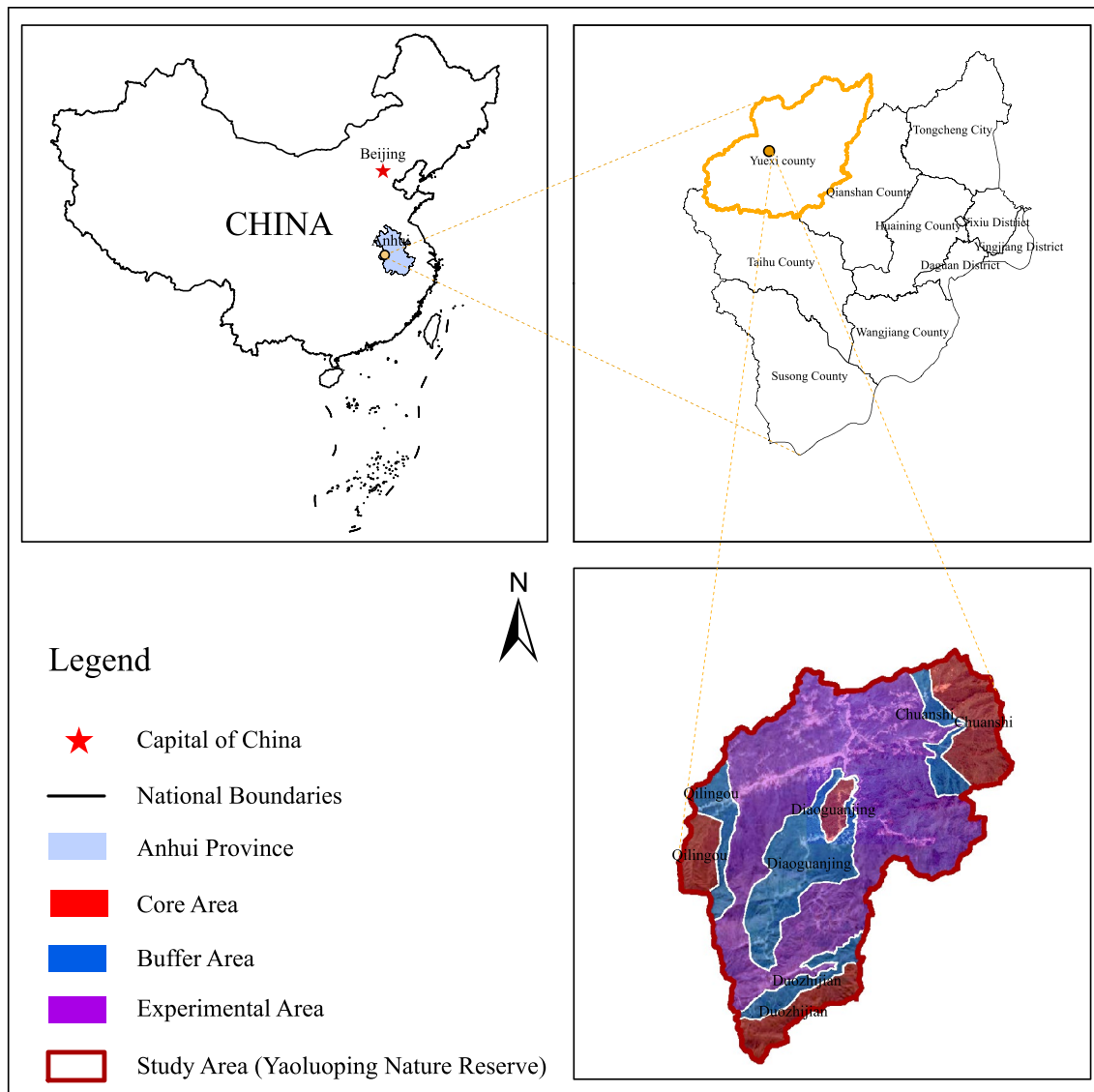


Fig. 1 Location of the study area

Research methods

This study selected the Yaoluoping National Nature Reserve as study object. First, GaoFen-2 (GF-2) satellite data in 2017 were used as image source. ENVI5.3, Fragstats4.2 and ArcGIS10.2 were used for land use classification as well as evaluation indicators selection and analysis. Second, the ecotourism risk assessment model of the reserve was constructed, which was embedded with the AHP and Ecological Risk Index (ERI). Finally, impact factors' weights were estimated, and the distribution map of the ecotourism risk level of the reserve was drawn. The entire research methodology is showed in Fig. 2.

Data pre-processing

GF-2 satellite images (<http://www.sasclouds.com/chinese/home>) on February 10th, 2017 were used in this study. The images include panchromatic band (0.45–0.90 μm) and multispectral bands (0.45–0.52 μm, 0.52–0.59 μm, 0.63–0.69 μm, and 0.77–0.89 μm). The resolution of panchromatic band and multispectral data are 1 m and 4 m, respectively, the cloud amount of image was less than 2%, and imaging quality is good (Wang et al. 2020). The Digital Elevation Model (DEM) data in the study area was ASTER Global Digital Elevation Model V002 (ASTGTM2) (<https://earthexplorer.usgs.gov/>) with a resolution of 30 m.

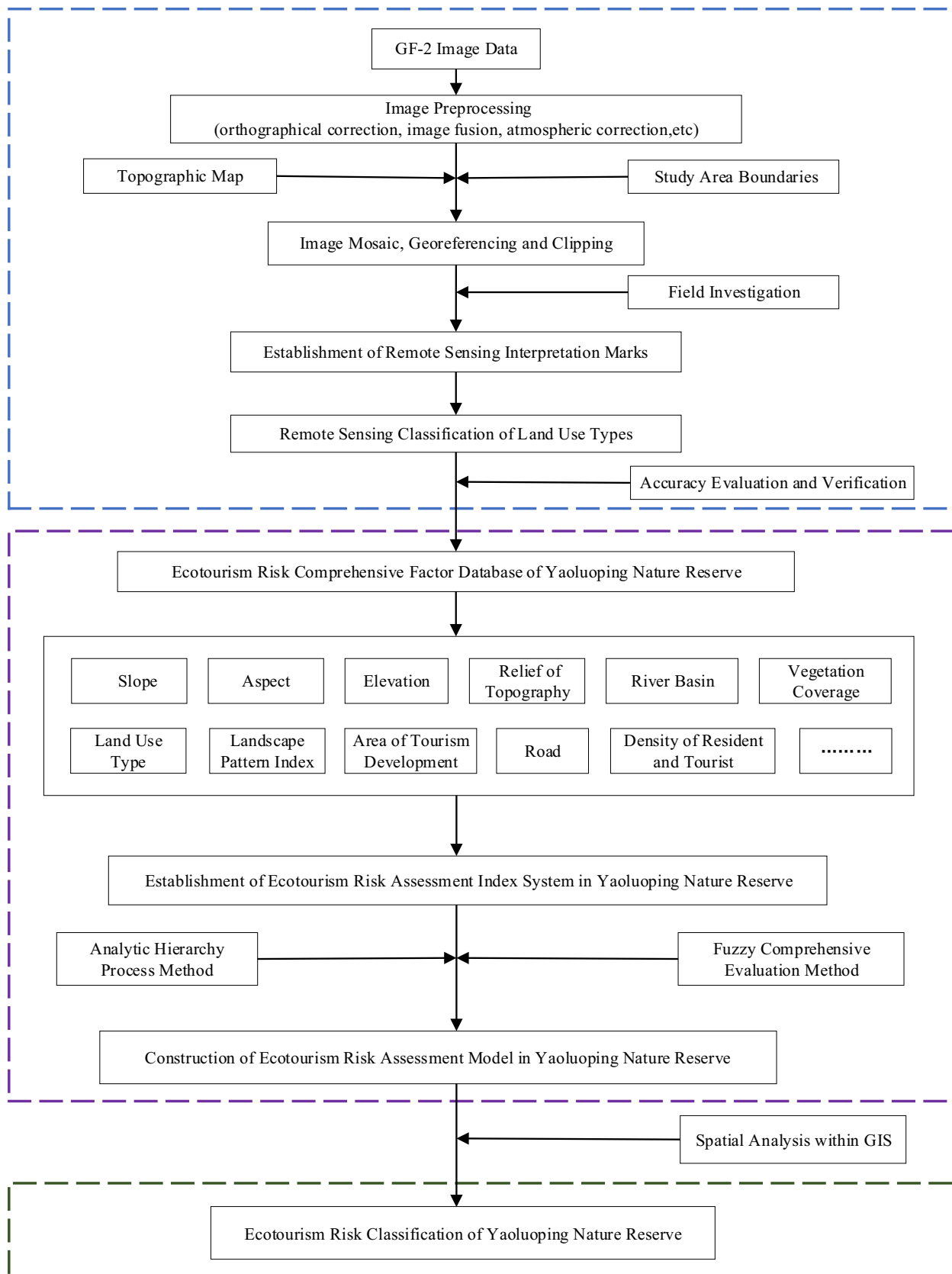


Fig. 2 Road map of the whole research method

Administrative boundaries, regional statistics data and comprehensive planning document of the nature reserve were provided by the Reserve Management Committee.

After the data of GF-2 images were processed by atmosphere correction, orthographical correction and image fusion through ENVI5.3, according to the latest national standard (GB/T 21010-2017) issued in November 2017 for the classification of land use status of the People’s Republic of China, the land types in the study area were divided into six categories by supervised classification. They were forest land, cultivated land, construction land, bare land, water area and road (Fan et al. 2016; Hua et al. 2018; Zhou et al. 2020). Interactive visual interpretations were carried out by being combined with the field investigation and questionnaire survey in October 2017, and results were with the accuracy of 90.4% and Kappa coefficient of 0.84 (Gautam et al. 2021).

Evaluation index selection

A comprehensive index database affected by ecological tourism risk for Yaoluoping Nature Reserve was established, according to the characteristics of land use, the effect of tourism development and the availability of data (Ayre and Landis 2012; Dale and Kline 2013; Liu et al. 2016; Singh and Kumar 2018; Jia et al. 2020). Then, ArcGIS10.2 and Yaahp12.1 were used to analyze and determine the impact factors that can be described and quantified after considering consultative experts’ experience and discussion opinions.

1. *Functional zoning of Yaoluoping Nature Reserve* As species, the quantity and distribution of wild animals and plants, and biodiversity indices date were difficult to be quantified in the risk assessment unit, the functional zoning classification of natural reserve was used to characterize the biological resources factors, which can reflect the importance of ecological red line and government decision-making (Sun et al. 2020). The closer to the core zone of the reserve means the more various resources attracting to the development of ecotourism and the higher ecological risk in the area.

2. *Vegetation coverage* Vegetation coverage is a key parameter to reflect surface vegetation status and ecosystem. It is of significance for water and soil conservation. The wider is the vegetation coverage, the more stable the ecosystem is. This also means the greater ability to resist or self-repair the effects of ecotourism development. Normalized Difference Vegetation Index (NDVI) was used in this study.

$$NDVI = (NIR - R)/(NIR + R), \tag{1}$$

where NIR and R are near infrared band and visible red band of GF-2 image, respectively. The vegetation coverage (F_c) was obtained through statistical range.

$$F_c = (NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min}), \tag{2}$$

where $NDVI_{min}$ and $NDVI_{max}$ are the minimum NDVI and maximum NDVI within the region under the confidence interval of 5% (Peng et al. 2017; Zhan et al. 2020), respectively.

3. *Landscape pattern indicators* Landscape index reflects regional landscape structure change and comprehensively describes landscape ecological pattern. It can be divided into three levels: individual patch level, patch class level, and landscape level (Mörtberg et al. 2007; Hu et al. 2015; Liu et al. 2020). Fragstats4.2 was used to calculate the three class-level indices as landscape pattern metrics based on the landscape fragmentation, separation and dominance (Table 1) (Chmielewski et al. 2014; Gong et al. 2015; Zhang et al. 2016; Fan et al. 2016; Wei et al. 2020), and their weight ratio was assigned to 5:3:2 combined with related studies and expert scoring method (Paukert et al. 2011; Jin et al. 2019; Xie et al. 2021).

4. *Basin area* Basin environment is closely related to its ecosystem. The hydrological analysis module of ArcGIS10.2 was used to develop the river network of the nature reserve from DEM data, and then watershed area is also computed (Jin et al. 2021).

Table 1 Landscape pattern indicator selection

Landscape pattern metrics	Indicator meaning	Plaquetype level index
Landscape fragmentation	The higher fragmentation degree of a landscape type in a given time and nature, the lower the stability of the corresponding landscape ecosystem. The value is inversely proportional to the mean patch area to some extent	AREA_MN (Mean Patch Area)
Landscape separation	The greater the value of the discrete degree of the distribution between patches in a landscape type, the more complex the spatial distribution of the landscape and the higher the degree of fragmentation	SPLIT (Splitting Index)
Landscape dominance	The degree of dominance of a certain landscape type in the overall landscape, the higher the degree, the greater impact of the landscape under the control of that type. Reflect a certain degree of human activity	LPI (Largest Patch Index)

5. *Slope* As one of the sensitive elements that may cause geological disasters, slope is critical to preserve water and soil, and it is also the primary factor in land use planning and control measures (Duan et al. 2020). According to "Technical regulation for inventory for forest management planning and design" (GB/T 26424-2010), slope is divided into four grades: $< 6^\circ$, $6^\circ-15^\circ$, $15^\circ-25^\circ$ and $> 25^\circ$.
6. *Elevation* Since most human disturbance activities are within low-altitude areas, regional ecological risk level decreases as the elevation increases (Kayumba et al. 2021), because temperature drops with increasing elevation. ArcGIS10.2 is used to divide the elevation range from 400 to 1900 m into five grades with the interval of 300 m.
7. *Relief of topography* Relief of topography refers to the difference between the maximum and minimum elevations of all grids in a unit area, and it is widely used in regional soil erosion analysis and ecological environment evaluation. The greater is the value, the greater the possibility of geological disasters is. The study adopted both window analysis method and mean change point analysis method to define the optimum statistical unit of relief of topography. After comparing the statistical results of many grid Windows, the grid of "1000×1000" was selected as the optimum statistical unit. The values of relief of topography were extracted using Neighborhood analysis module of ArcGIS10.2 (Zhang et al. 2021).
8. *Gully density* Gully density refers to the ratio of basin length to basin area per unit area. It is an index to describe the degree of ground broken by water channel, and it can reflect the comprehensive influence of climate, topography, lithology, vegetation and other factors. The greater is the density, the more broken the ground is, the more unstable the surface material is, and the easier surface runoff and aggravate soil erosion occur. Gully density of each functional area was calculated from river network data.
9. Road network density, construction land proportion and agricultural land proportion. To evaluate ecotourism risk of the study area, the basic situation of nature reserve and tourism development status was analyzed. The risk indicators of three land use types (i.e., road network density, construction land proportion and agricultural land proportion) were used to characterize corresponding risk by convenience of tourism transportation, tourism construction projects and production activities by local residents.
10. Tourist distribution proportion and registered population density. On Oct/01/2017, 290 questionnaires were provided to tourists in the reserve. 273 of them were valid, so the questionnaire response rate exceeded 94%.

Combined the main purpose of tourist in the survey results with the geographical location and tourism planning report of the nature reserve, six main scenic spots, including Shifo Temple, Shili Gallery, Yaoluoping Base Scenic Area, the old military and political site of the Red 28th Army, Xiaoqiling and Duozhijian, were selected as the main tourist distribution areas. Their corresponding proportions were determined. Their corresponding registered population densities were obtained through the collected statistical questionnaires from the reserve management committee.

To eliminate the influence from different dimensions, data normalization was used in the evaluation indices. The grid data diagrams with five levels of indicators were obtained using the natural break point grading method of ArcGIS10.2. All selected indicators were taken as alternative levels. Related indicators were merged with four criteria levels: landscape ecological factors, topography and hydrology factors, land use factors, and human activities factors. The ecotourism risk of Yaoluoping Nature Reserve was goal level. The weights of three levels (goal level, criteria level, and alternative level) were obtained using AHP method (Purucker et al. 2007; Tian et al. 2019).

Construction of evaluation model

The consistency ratio (CR) of the judgment matrix is calculated using maximum eigenvalue, and the maximum eigenvalue was obtained through AHP method. The judgment matrix is considered to have satisfactory consistency when $CR < 0.1$. To calculate the weight of each assessment indicator, the importance of various indicators was ranked based on a questionnaire to 15 industry experts from colleges, universities, and forestry institution first. Second, the weights of factors affecting ecotourism risks were calculated using Yaahp12.1 software. Finally, an ecotourism risk evaluation index system was built for Yaoluoping Nature Reserve (Table 2). The single-ranking CR value of each factor of the criterion level is less than 0.1, and the total ranking CR at the model level = 0.003 is also less than 0.1. Therefore, it implies that the single ranking and total ranking of the evaluation model index level have met the requirement of CR.

Ecological risk index can quantitatively evaluate the comprehensive level of ecological risk in different research units. It can better reflect the change of ecological risk caused by multi-factor change. It has been widely used in ecological risk assessment of landscapes, watersheds, and regions (Zhang et al. 2020; Mann et al. 2021). In this study, the ERI is established on the basis of landscape ecological factors, terrain hydrological factors, land utilization factors, and human activity factors. The ERI was calculated as follows:

Table 2 The ecotourism risk assessment indicator system

Goal level (A)	Criteria level (C_i)		Alternative level (P_i)		General ranking
	Criteria name	Weight	Alternative name	Weight	
Ecotourism risk assessment of Yaoluoping nature reserve	Landscape ecological factors (C_1)	0.426	Functional zoning (P_1)	0.1677	1
			Vegetation coverage (P_2)	0.1196	3
			Landscape fragmentation (P_3)	0.0723	5
			Landscape separation (P_4)	0.0405	10
			Landscape dominance (P_5)	0.0253	14
	Terrain hydrological factors (C_2)	0.358	Basin area (P_6)	0.1388	2
			Slope (P_7)	0.0959	4
			Elevation (P_8)	0.0643	6
			Relief of topography (P_9)	0.0359	11
			Gully density (P_{10})	0.0277	13
	land utilization factor (C_3)	0.127	Road network density (P_{11})	0.0638	7
			Construction land proportion (P_{12})	0.0463	9
			Agricultural land proportion (P_{13})	0.0168	15
	Humanity activity factor (C_4)	0.09	Tourist distribution proportion (P_{14})	0.0578	8
			Registered population density (P_{15})	0.0321	12

$$ERI = \sum_{i=1}^n (C_i \cdot U_i) = \sum_{i=1}^n (P_i \cdot V_i \cdot U_i), \tag{3}$$

where C_i and P_i are the value of the i th evaluation index at the criteria level and the alternative level, respectively; U_i and V_i are the weights of their corresponding indices, respectively. Using the reclassification module of ArcGIS10.2, the grid data of weighted criteria level and goal level are divided into five levels by the natural break point grading method (Wang and Song 2019). Levels from low to high are defined as low-risk area, medium-low-risk area, medium risk area, medium-high-risk area and high-risk area. Finally, the ecological tourism risk evaluation model of Yaoluoping Nature Reserve is established based on AHP and ERI (Gaines et al. 2004; Eccles et al. 2019; Wu et al. 2021; Wang et al. 2021).

Results

Analysis of single factor evaluation results

The results of some evaluation factors are showed in Fig. 3. Figure 4 shows the results of overlaying four criterion levels that affect the ecotourism risk of the nature reserve with the administrative boundaries and functional zoning data.

The high ecotourism risk areas of landscape ecology in the nature reserve are mainly distributed along roads and construction lands. The vegetation coverage in the area is over 90%. The classification result (Fig. 3a) shows that the mean patch area of forest land is large, and the patch number is limited. It indicates that the landscape separation of

forest land is small, and the dominance is the highest. It shows that the regional vegetation protection is relatively complete and has a good ecological function. The largest patch area of other landscape types except for forest land is small. The fragmentation and separation level are high, and the landscape patches are scattered. These results are mainly affected greatly by human interference. Therefore, most of the landscape ecological risk in the nature reserve is relatively low except roads, construction land and arable land. However, the average landscape ecological risk in core zones is lower than that in buffer areas and experimental areas. It was mainly due to the abundant landscape resources within core zone and the prohibition of human activities. However, the Diaoguanjing core zone is one of the peak areas of landscape ecological risk because of the passage of some main roads.

In general, the topographic and hydrological risk of the nature reserve is gradually decreasing from north to south (Fig. 4c). This spatial distribution characteristic is consistent with the gradual increase of watershed area. In addition, the distribution trend of elevation rising from the center of upper experimental zone of the Diaoguanjing to outside can also explain the characteristic. The slopes of rivers and roads above the Diaoguanjing are relatively little variant, and the relief of topography and gully density from the below part of the Diaoguanjing buffer zone to Duozhijian buffer zone is lower. Therefore, the topography and hydrology risks in these regions are relatively less than those in their surrounding regions. The terrain distribution of each functional zone is rich. The entire Chuanshi zone and the Diaoguanjing core zone may face a higher ecotourism risk in the aspect of topographic and

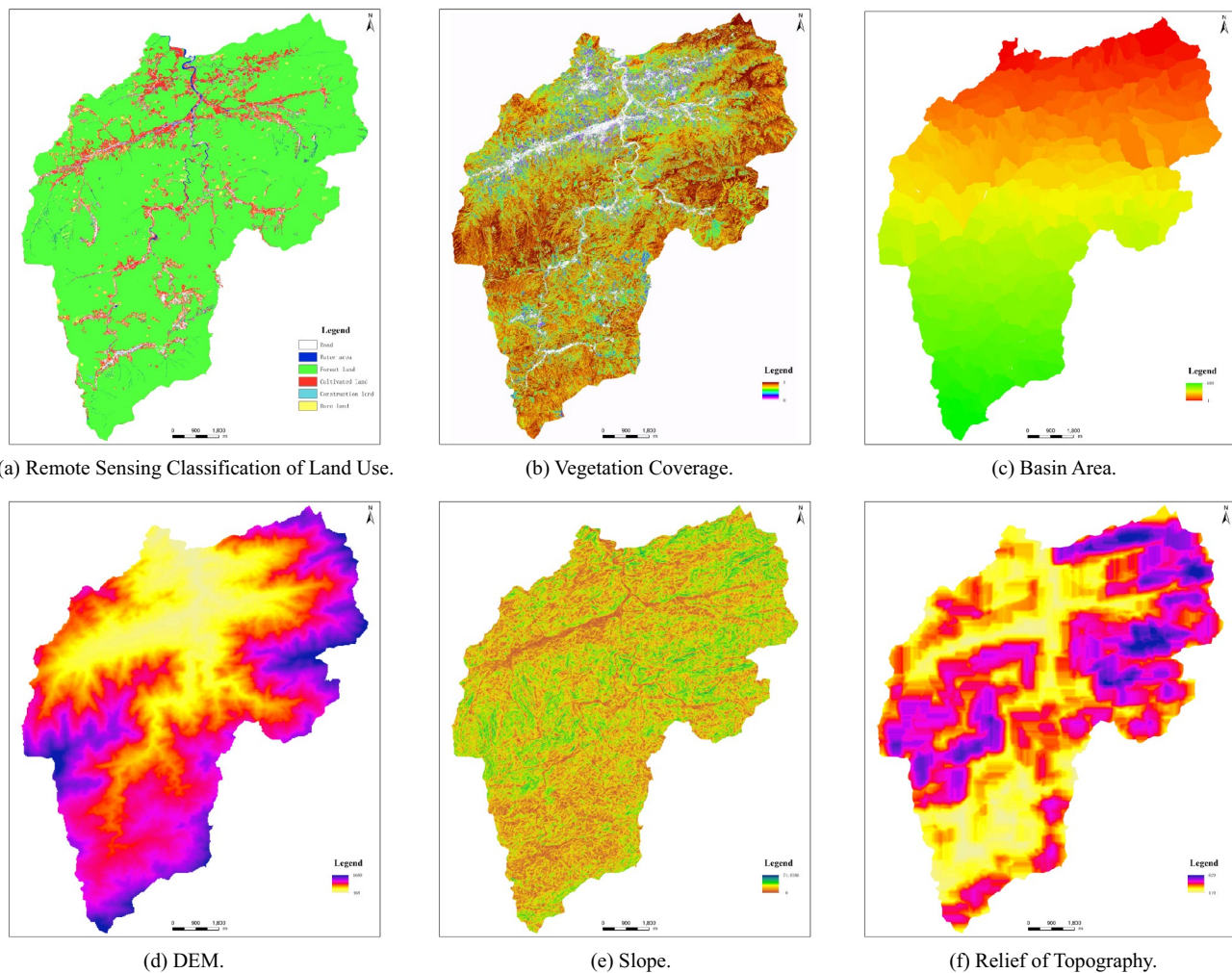


Fig. 3 The results of evaluation factors

hydrological. In contrast, the entire Duozhijian core zone is lower.

The result of land use risk area (Fig. 4d) shows that the four core zones are all at a state of low ecological risk. The risk value range of buffer zone is medium and below. However, there are some land types are at increasing risk. The high-risk areas of the experimental zone are located between Diaoguanjing and Qilingou, as well as Diaoguanjing and Duozhijian. The order of risk values of human activities in the nature reserve is: core zone < buffer zone < experimental zone. The result of human activities risk area (Fig. 4d) shows that the Duozhijian mountainous area is at medium–low risk because of high altitude and policy control. The risk values of Shili Gallery and Yaoluoping base scenic area increase significantly. These two areas reflect rich tourism functions such as enjoying natural scenery, landscape photography, unique animal and plant ornamental.

Results analysis of comprehensive ecotourism risk assessment

The score range of the ecotourism risk is from 1.180 to 2.090 by accumulating the scores of each level. The five grades' scores of the ecotourism risk are: low-risk area (1.180–2.090), medium–low-risk area (2.090–2.719), medium risk area (2.719–3.209), medium–high-risk area (3.209–3.733), and high-risk area (3.733–4.910). The results of ecotourism risk levels in the Yaoluoping Nature Reserve are shown in Fig. 5 and Table 3. The ecotourism risk of Yaoluoping Nature Reserve has obvious spatial differences. The south of the Diaoguanjing core zone is mostly a low-risk area, while the risk level in the north is significantly higher than that in the south. Medium–high and high-risk areas are mainly located around rivers, roads, construction land and the northeast of the Chuanshi core zone (Figs. 3a, 5). In general, nearly 90% of the ecological tourism risks in the

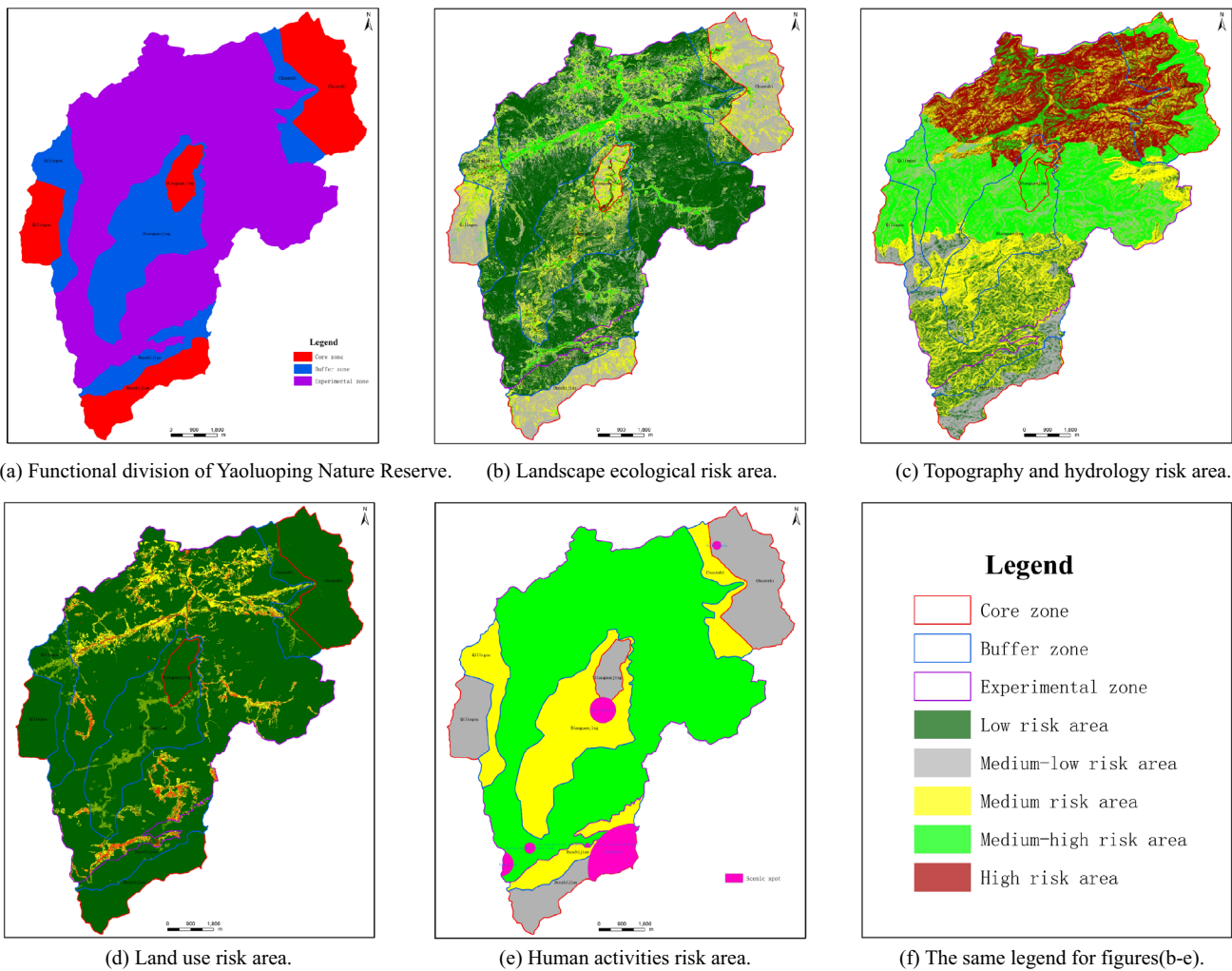


Fig. 4 Spatial distribution of landscape ecology, topographic hydrology, land use and human activities' risk

nature reserve are at the medium or lower level due to good natural conditions and moderate dispersion of land use, and most of them are at good levels. However, the ecological risk value is high in some areas, the ecosystem is fragile, and the stability and natural recovery ability are poor.

The proportion of medium–high and high ecotourism risk areas in the core zone is 6.77% and 1.74%, respectively. In terms of specific areas, although the risk of landscape, land and humanities in the Chuanshi core zone is at a low or medium–low level, the risk of natural terrain factors is high, and geological disasters are very likely to occur because its water area is small and human activities are frequent on low terrain. The Diaoguanjing core zone is located in the center of the nature reserve and has high risks of landscape ecology and topographic hydrology. In addition, it is adjacent to the Shili Gallery scenic area that is vulnerable to human interference, and its resulting high risk of ecotourism needs to be focused on and measured for prevention. The Duozhijian area in the south

is well protected due to its steep terrain, rich biological habitat resources and restricted human activities. It has larger area and relatively complete ecological low-risk districts, which is conducive to water conservation and ecosystem function. In the horizontal comparison of functional zones, except for low-risk areas, the proportion of risk areas at all levels in the core zone is greater than that in the buffer zone, and the proportion of medium and medium–high-risk areas in the buffer zone is greater than that in the experimental zone. It indicates that the ecotourism risks faced by the core zones and buffer zones in the nature reserve are not optimistic, and the functional distribution of the nature reserve might be negatively affected.

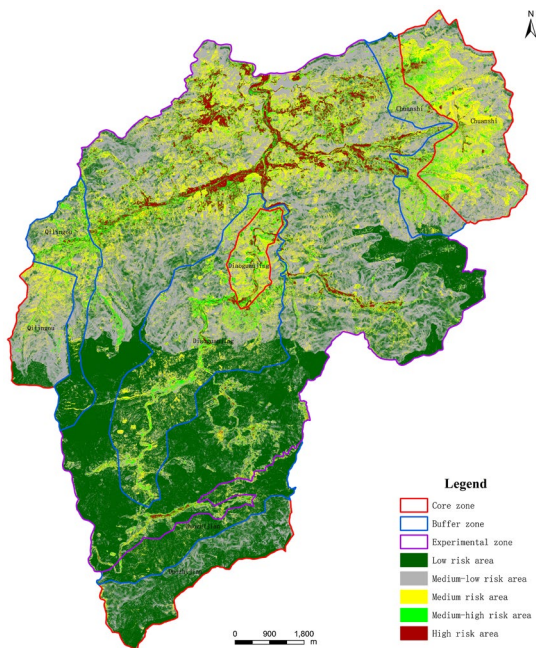


Fig. 5 Distribution of ecotourism risk levels in Yaoluoping Nature Reserve

Discussion

Ecotourism development has gradually become one of the hot spots in the nature reserve planning. Existing researches on ecotourism in nature reserve mainly focus on developing potential evaluation, development status and planning, etc. However, there are few research on ecological risk assessment and protection that are or have been caused by ecotourism development. This study used biological resource factors expressed by functional zoning of the nature reserve, as well as the comprehensive landscape pattern indices as landscape ecological factors, to evaluate the ecotourism risk. It is one of the innovations in this study. Ecotourism risk level for the Yaoluoping National Nature Reserve was divided, corresponding analysis and evaluation were carried out, and plans of adjusting measures to local conditions and rational

development of ecological tourism were proposed. It can provide a theoretical and practical reference for the nature reserve. In 2020, the integration and optimization of national nature protected areas has been gradually carried out, and the functional zoning of nature reserves will be further improved. The original core zones and buffer zones have been transformed into core protection zone, and the original experimental zones have become general control zones. At the same time, the transformation of the core protection zones and the general control zones will be carried out according to the actual situations of those regions. The results of ecotourism risk assessment can also be used as practical reference and guidance for analysis of transformation trend in functional zoning.

Since GF-2 satellite image is four-band multispectral remote sensing image with high spatial resolution, this study directly used the maximum likelihood method with human intervention to select training samples in the process of supervised classification of remote sensing images. Some classifiers (e.g., artificial neural network, support vector machine) have been widely used in classification for high-resolution images. Comparison and validation of various classification methods can explore the difference and superiority of results.

The key to determine the source of ecological risk is the objectivity that how to select qualitative indices and quantitative factors. This study established the ecological tourism risk evaluation index system by developing four criteria levels and 15 alternative levels, and each factor weight of the evaluation model was determined by reference, numerical calculation and expert scoring. However, to make the evaluation process more rational and scientifically sound, further research should consider comprehensively the development of ecotourism project under human disturbance, ecosystem restoration and maintenance mechanism of ecological service for nature reserve.

The significance of ecotourism risk evaluation is to provide the guidance of risk mechanism management so as to feedback and act on the further implementation and development of ecotourism. Thus, the future development of ecotourism risk evaluation shall set up a risk information database that includes risk source and risk receptor combining

Table 3 Proportion of the ecotourism risk zones in the reserve

Ecological tourism risk level	Area Proportion of functional zone			Gross area ratio (%)
	Core area (%)	Buffer area (%)	Experimental area (%)	
Low risk area	23.67	40.71	35.47	34.50
Medium-low risk area	44.90	36.33	38.62	39.25
Medium risk area	22.97	15.12	14.24	16.07
Medium-high risk area	6.77	6.42	5.82	6.13
High risk area	1.74	1.43	5.85	4.05

with the characteristics of socio-economic development and GIS technology, construct better evaluation index systems and models, establish risk assessment criteria of reasonable dimensions, and discuss the development plans and patterns for sustainable ecotourism in nature reserve.

Conclusion

This study divided Yaoluoping Nature Reserve into six land types by supervised classification. The classification accuracy was 90.4%, and the Kappa coefficient was 0.84. 15 factors were selected as indicators of ecotourism risk assessment. These factors were functional zoning, vegetation coverage, landscape fragmentation, landscape separation, landscape dominance, basin area, slope, elevation, relief of topography, gully density, road network density, construction land proportion, agricultural land proportion, tourist distribution proportion, and registered population density. AHP was used to calculate the weight of each criteria level and alternative level. Results showed that the weight of landscape ecological factors was the highest (0.4255). The factors with a large contribution to ecological risk were functional zoning, basin area, vegetation coverage, slope, landscape fragmentation, elevation, and road network density. The cumulative weight reached 0.7224.

Weighted linear model was used to calculate the ERI. Results showed that the ERI in Yaoluoping Nature Reserve ranged from 1.180 to 4.910. The ecological risk of the study area was divided into five levels using the natural break point grading method of ArcGIS10.2. Statistical results suggested that the area proportion in medium–low-risk area and low-risk area were relatively large, which were 39.25%, and 34.50%, respectively. Those in medium risk area and medium–high-risk area were 16.07%, and 6.13%, respectively. High-risk area had the smallest proportion of only 4.05%. The statistical results from the perspective of the functional zoning showed that the area proportion of medium–low-risk area in core zone and experimental zone was the largest, reaching 44.90% and 38.62%, respectively. The largest area proportion of buffer zone was low-risk area with 40.71%. The area proportion of high-risk area was the lowest among the three functional zones, which were 1.74%, 1.43% and 5.85%, respectively. The area proportion of high-risk area was the lowest in experimental zone with 5.82%. These results indicated that approximately 90% of the functional zones of the nature reserve were at middle and lower levels of ecotourism risks. From the perspective of the results of criterion layer, the nature reserve was basically in the low-risk state of land use, followed by landscape ecological risk. The human disturbance factors under the influence of natural factors and tourism development led to significant differences in the spatial distribution of topographic

hydrological risks and human activities risks. The results of Fig. 5 and Table 3 showed that the overall level of ecotourism risk in the nature reserve is low, the spatial differentiation among risk grade areas was clear, and regional overall risk was significantly reduced from north to south. In addition, the high-risk areas in the nature reserve showed a banded distribution and were located mainly around rivers, roads, construction lands.

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Author contributions XT: design and conception; YW: data processing; JY: data processing; HL: interpretation of data; FS: editing and proofreading; QH: data analysis.

Declarations

Conflict of interest The authors have declared that no competing interests exist.

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