

THE SPATIO-TEMPORAL INTERACTION AND DRIVING MECHANISM OF ECOSYSTEM SERVICE VALUE IN A COASTAL TOURIST CITY

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Abstract. With the rapid development of tourism and urbanization, the degradation of ecosystem functions and the decline in the ecosystem services value (ESV) pose a serious threat to the human well-being in tourist destinations as well as the sustainable development of the economy and society. However, the insufficient exploration of driving mechanisms of ESV in coastal tourism destinations has hindered effective territorial spatial governance. In this study, a typical coastal tourist city of China - Rizhao City was taken as an example, an improved ESV evaluation model was adopted to dynamically assess the ecosystem service value considering the ecosystem service flow (ESVF) at grid-scale from 1995 to 2020, and to analyze its spatio-temporal interaction characteristics. Then, the optimal parameters geodetector model was used to analyze the driving factors and its mechanism of ESVF. The results show that: (1) The spatial changes in ESVF were most intense in the built-up area fringe, the coastal area with intensive tourism activity, transition zones of central mountains and plains, and the southwestern agricultural area. (2) In terms of temporal and spatial transitions, the overall spatial correlation structure of ESVF has the characteristics of path dependence and lock-in, but shows a gradually weakening trend over time. The local spatial correlation structure has a significant spatial differentiation feature, and the areas where spatio-temporal transitions occur are principally spread over the fringes of county built-up areas, water landscape belts, mountainous and plain transition zones, and coastal landscape belts. (3) Topography, climate, land urbanization, population urbanization, economic urbanization, agricultural activities, and environmental pollution have a significant impact on ESVF. Over time, influencing factors such as land urbanization, agricultural activities and tourism activities have significantly increased. In terms of interaction effect, there is a strong interaction between population, economic and land urbanization, and a strong interaction effect between urbanization and agricultural activities, tourism activities and environmental pollution.

Keywords: *ecosystem service flows, spatial neighborhood effect, transition zone of mountainous and plain, tourism activities, Rizhao City*

Introduction

Ecosystem services refer to the products and services provided by the structure, functions and processes of ecosystems for human production and life (Wang et al., 2024; Li et al., 2024). Ecosystems provide a wide range of social, economic, cultural and environmental ecosystem services for humans, but at the same time increasing pressure from climate change and human activities, and changes in natural and human drivers may also have a profound negative impact on ecosystem services (Yu et al., 2026; Wang et al., 2026). With the rapid development of tourism and urbanization, tourist destinations are facing increasingly prominent ecological and environmental problems (Dragovich et al., 2017; Liu et al., 2021). For instance, there are significant changes in land cover and

ecological landscapes, a decline in ecological environment quality, and an increase in the pressure on the carrying capacity of resources and the environment (Li et al., 2020; Jiang et al., 2024; Bole et al., 2025; Wang et al., 2025). Therefore, in order to better manage natural capital and prevent further decline in its value, it is necessary to have a clear understanding of the impact of natural and human activities factors on the ESV of the tourist destination, and to explore the driving mechanisms of the evolution of ESV, which is of great significance for the improvement of ESV in tourist destinations and the sustainable development of the social economy.

At the end of the 20th century, Costanza et al. (1997) were the first to study methods for assessing the value of global ecosystem services. Since then, scholars have conducted extensive theoretical, methodological and practical research on ecosystem services. In terms of valuation methods for ecosystem services, the main methods include the economic method (the method for evaluating the equivalent factor of value per unit area and the method for evaluating the price of service function per unit) (Costanza et al., 2017), the InVEST (Integrated Valuation of Ecosystem Services and Trade-off) method (Ouyang et al., 2016), and the valuation method (Liu et al., 2020). From the perspective of ecosystem service flow theory and environmental externality theory, regional ecosystem services can be transferred to spatially adjacent areas, that is, there are interconnections and mutual influences among different ecosystem types in terms of time and space. Therefore, the assessment of ecosystem service value should take into account the differences in function and value quantity among different ecosystems. The spatial proximity effect among various ecosystem types should also be taken into account (Bagstad et al., 2013). However, existing studies have given less consideration to the spatial proximity effect of ecosystem services when assessing the value of ecosystem services.

At the end of the 20th century, the spatial effect and the interaction between space and time have gradually attracted extensive attention and exploration from geographers and landscape ecologists (Ji et al., 2016). Among them, the exploratory spatio-temporal data analysis (ESTDA) model proposed by Ye and Rey (1995) has achieved the quantification and visualization of the spatial-temporal interaction process (Ji et al., 2016; Zhang et al., 2011; Jin et al., 2020). This method has been widely recognized and applied by scholars. With the increasing interregional connections of ecosystem and externality effects, it will be possible to develop dynamic patterns of aggregation and similarity in ecosystem services among neighbors. But, at present, research on the spatio-temporal interaction characteristics of ESV based on the perspective of spatiotemporal interaction is still relatively scarce, and many studies have separated the spatial patterns from the temporal processes.

In terms of the driving factors and its mechanisms of ESV, research on driving factors and its mechanisms of ESV has received increasing attention and emphasis from scholars in recent years. Scholars have conducted empirical studies on driving factors of ESV in River Basin (Liu et al., 2020), mountainous area (Wang et al., 2024), metropolitan areas (Bagstad et al., 2013), urban agglomerations (Tan et al., 2026), and typical cities (Jiang et al., 2025). In terms of research methods, correlation analysis, regression model, GWR model, GeoDetector model, STIRPA model were mostly employed (Bagstad et al., 2013; Liu et al., 2020; Jiang et al., 2025; Tan et al., 2026). In terms of influencing factor indicators, factors such as climate, urbanization, land use and cover change, human disturbance index, population and socio-economic factors, technological factors, resource consumption, and ecological restoration policies were mainly selected (Bagstad et al., 2013; Huang et al., 2019; Liu et al., 2020; Jiang et al., 2025; Tan et al., 2026). However, there are four main deficiencies in the existing research: First, there is a lack of research

on the driving factors and its mechanisms of ESV in tourist cities. Second, most of the existing studies have studied the influencing factors of ecosystem services at the county or city scale, but very few have studied the influencing factors of ecosystem services in typical tourist cities at the grid scale. Third, the selection of natural and socio-economic factors is not comprehensive, and there is a lack of analysis of the interaction between natural and socio-economic factors. Fourth, the drivers of ecosystem services in tourist destinations and their driving mechanisms remain largely unclear, and there is a lack of research on the driving mechanisms of ecosystem service evolution.

Rizhao City in China, as a tourist city deeply influenced by the rapid development of tourism and urbanization, exploring the driving factors and driving mechanisms of its ESV is of great significance for regional environmental management and sustainable development. Based on this, based on the grid scale, this study uses the improved ESV assessment model of to scientifically evaluate the ESV of Rizhao and analyze its spatio-temporal interaction characteristics and driving mechanisms, with the aim of providing theoretical support and decision-making reference for sustainable development of socio-economic of the tourist destination.

Study area and data sources

Study area

Rizhao City is a famous coastal tourist city in China (Fig. 1). Nevertheless, After the turn of the 21st century, tourism development activities, land urbanization expansion and port industrial activities have led to the degradation of ecosystem service functions and the decline in ecological service values, seriously hindering the sustainable development of the region. Therefore, Rizhao City is a typical case region for studying the spatio-temporal evolution and its driving mechanisms of the ESVF in coastal tourist city.

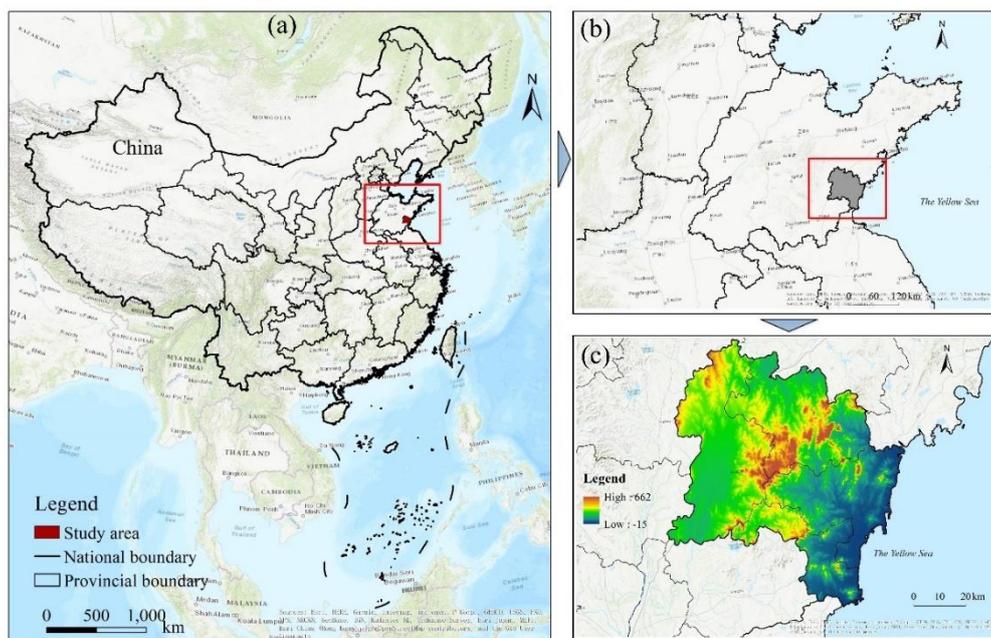


Figure 1. Overview map of the study area (a) and (b), and elevation map of the study area (c)

Data sources

The data used in this study mainly consist of four aspects, including administrative division data, raster data, meteorological data and POI (Point of interest) data. The attributes and detailed source of the data is shown in *Table 1*.

Table 1. Data sources in the study

Data names	Data type	Resolution	Units	Source
The boundary of study area	Vector	-	-	http://www.resdc.cn
Land use data	Raster	30 m	-	http://www.resdc.cn
Normalized difference vegetation index (NDVI)	Raster	1 km	-	http://www.resdc.cn
Net primary productivity of vegetation (NPP)	Raster	1 km	$gC \cdot m^{-2} \cdot a^{-1}$	http://www.resdc.cn
Annual precipitation	Raster	1 km	mm	http://www.geodata.cn
Annual average temperature	Raster	1 km	°C	http://www.geodata.cn
Potential evaporation	Raster	1 km	mm	http://www.geodata.cn
Elevation	Raster	90 m	m	http://www.geodata.cn
POI data of Tourist attraction	Vector	-	-	http://data.cma.cn
GDP spatial raster data	Raster	1 km	Yuan/km ²	http://www.resdc.cn
Population spatial raster data	Raster	1 km	Person/km ²	http://www.resdc.cn
Soil erosion intensity data	Raster	30 m	t/(km ² ·a)	http://westdc.westgis.ac.cn
Annual PM2.5 raster data	Raster	1 km	μg/m ³	https://sites.wustl.edu/acag/datasets

Methods

According to the technical roadmap (*Fig. 2*), our research ideas are mainly divided into three stages: (1) Based on multi-source basic data such as administrative boundary data, remote sensing raster data, meteorological data, POI data, and spatial inversion data, a multi-source database was constructed. (2) Incorporate ecosystem service flows into the assessment framework and construct an improved ecosystem service value assessment (IESV) model. Then, the IESV model is adopted to conduct a spatio-temporal dynamic assessment of the ecosystem service value of typical coastal tourism cities in 1995-2020, and the ESTDA model was introduced to analyze its spatio-temporal interaction characteristics of ESVF. (3) Finally, the optimal parameter geographic detector model was adopted to analyze the driving factors and their interaction effect of the ESVF in 1995-2020, and the driving mechanism of the ESV of typical coastal tourism cities was discussed in detail.

Improved ecosystem service value evaluation (IESV) model based on ecosystem service flow

Ecosystem services (ES) refer to the services provided directly or indirectly by an ecosystem in its interaction with humans, such as food supply, climate regulation. The transformation of ecosystem services into specific values through quantitative means is called ecological service value (*Fig. 3*). From the perspective of ecosystem service flows, regional ecosystem services can be delivered to spatially adjacent areas (Bagstad et al., 2013; Peng et al., 2017). Therefore, this study takes into account spatial proximity interaction effects when calculating ecosystem services and further modifies the assessment results of ecosystem services. The calculation steps are:

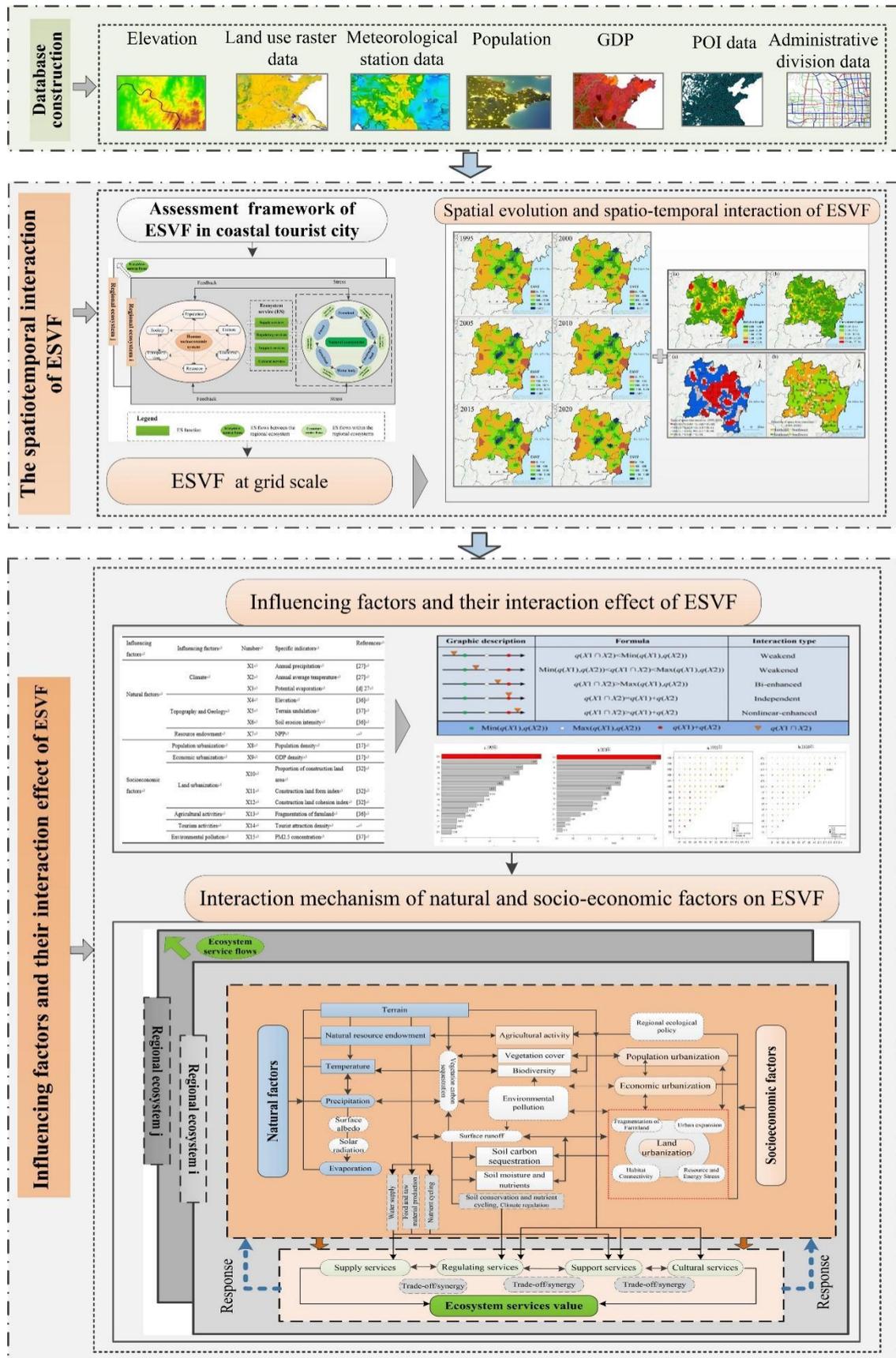


Figure 2. Research framework and content

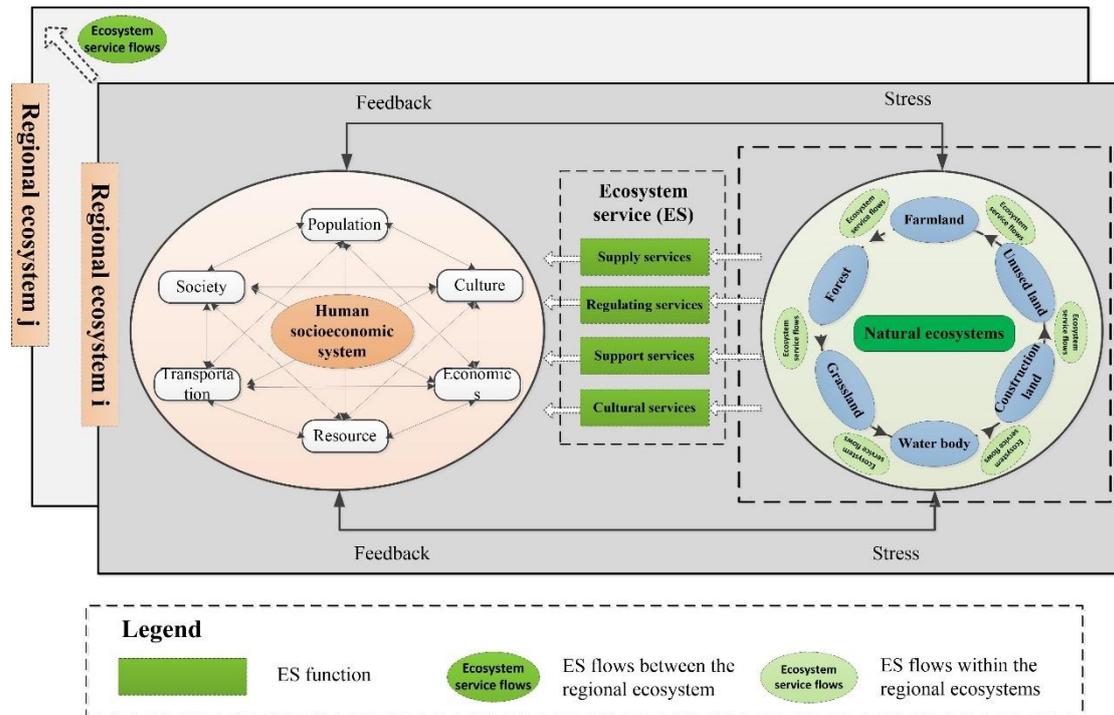


Figure 3. The theoretical framework of the IESV model

(1) Determine the basic equivalent table. Referring to the existing research results (Xie et al., 2008; Xie et al., 2015; Liu et al., 2018), the basic equivalent table of ecosystem service function value per unit area in Rizhao City was determined (Table 2). (2) Determine the value of basic equivalent factor. Referring to relevant studies (Xie et al., 2008, 2015; Liu et al., 2018), determine the value of one standard unit equivalent factor. (3) Dynamic equivalent table. Referring to the spatio-temporal correction method proposed by Xie et al. (2015), a dynamic equivalent table of spatio-temporal dynamic change was constructed. The formula is:

$$F_{nij} = \begin{cases} N_{ij} \times F_{n1} \\ R_{ij} \times F_{n2} \\ A_{ij} \times F_{n3} \end{cases} \quad (\text{Eq.1})$$

In the formula, F_{nij} is equivalent factor in the i -th region, j -th year, and n -th category of service function; $n1$ represents service functions such as FP, RMP, GR, CR, WD, BD, and EC, $n2$ represents WS, and $n3$ represents SC (Table 2); N_{ij} represents the spatiotemporal dynamic correction factor of NPP, R_{ij} represents the correction factor of precipitation, A_{ij} represent the correction factor of soil retention (Stefanidis et al., 2024).

(4) Assessment of ecosystem services value taking into account ecosystem service flow (ESVF). Referring to relevant studies (Pan et al., 2020; Shen et al., 2023a), this study introduces the spatial proximity effect coefficient to reflect the role of ESVF. The formula is:

$$ESVF_{ij} = ESV_{ij} \times CSNE_{ij}$$

$$= \sum_{a=1}^6 (D_{ij} \times F_{ij}^a \times LA_{ij}^a) \times \left[\frac{\sum_{k=1}^m \left(1 + \frac{\sum_{c=1}^8 S_k^c}{100} \right)}{m} \right] \quad (\text{Eq.2})$$

$$= \sum_{a=1}^6 (D_{ij} \times F_{ij}^a \times LA_{ij}^a) \times \left[\frac{\sum_{k=1}^m \left(1 + \frac{(S_k^1 + S_k^2 + S_k^3 + S_k^4 + S_k^5 + S_k^6 + S_k^7 + S_k^8)}{100} \right)}{m} \right]$$

In the formula, $ESVF_{ij}$ is the ecosystem service value considering the ESVF. D_{ij} is the standard equivalent factor (yuan/hm²); F_{ij}^a is the sum of the equivalent quantities contained in all land use types; LA_{ij}^a is the area of each land use type; $CSNE_{ij}$ is the total effect coefficient of spatial proximity. S_k^c is the spatial proximity effect coefficients (Table 3) (Pan et al., 2020; Shen et al., 2023a).

Table 2. Value coefficient of ecosystem services per unit area in Rizhao City

Service function		Ecosystem service value (yuan · hm ⁻² · a ⁻¹)					
		Cultivated land	Forest land	Grassland	Water area	Construction land	Unused land
Supply services	Food production (FP)	1895.37	625.47	815.01	1004.55	0	37.91
	Raw material production (RMP)	739.19	5648.2	682.33	663.38	0	75.81
Adjustment services	Gas regulation (GR)	1364.67	8188	2843.05	966.64	0	113.72
	Climate regulation (CR)	1838.51	7714.15	2956.78	3904.46	0	246.4
	Water supply (WS)	1459.43	7752.06	2880.96	35576.08	0	132.68
	Waste treatment (WD)	2634.56	3260.04	2501.89	28146.23	0	492.8
Support services	Soil conservation (SC)	2786.19	7619.38	4245.63	777.1	0	322.21
	Biodiversity (BD)	1933.28	8548.12	3544.34	6501.12	0	758.15
Cultural services	Entertainment culture (EC)	322.21	3942.37	1648.97	8415.44	0	454.89
Total		14973.42	53297.78	22118.96	85955	0	2634.56

Table 3. Spatial proximity effect coefficient of ecosystem services for each land use type

The land use type of the grid cell adjacent to the central pixel	The land use type of the central pixel					
	Woodland	Grassland	Water bodies	Farmland	Unused land	Construction land
Forestland	+5	+5	+5	+4	+4	+4
Grassland	+4	+5	+4	+2	+3	+3
Water bodies	+5	+4	+5	+2	+4	+4
Cultivated land	-1	-1	-4	+2	-1	+1
Unused land	-1	-2	+5	-3	+1	-1
Construction land	-2	-3	-5	+2	-2	+1

Exploratory spatio-temporal data analysis (ESTDA) model

ESTDA model can clarify the spatio-temporal interaction characteristics of spatial units (Jin et al., 2020; Xiang et al., 2025). This study attempts to introduce the ESTDA method to reveal the spatio-temporal interaction characteristic of ESV.

(1) LISA time path. It is an expression of the temporal continuity of the positional shift of spatial units (Ye et al., 2013; Yang et al., 2025). Relative length and curvature can reveal the extent and direction of spatiotemporal interaction between spatial units. The formula is:

$$\Gamma_i = \frac{\sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})}{[\sum_{i=1}^n \sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})]/n} \quad (\text{Eq.3})$$

$$\varepsilon_i = \frac{\sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})}{d(L_{i,1}, L_{i,T})} \quad (\text{Eq.4})$$

$$L_{i,t} = \frac{z_{i,t} \times \sum_j (w_{i,j} \cdot z_{j,t})}{\sum_i z_{i,t}^2} \quad (\text{Eq.5})$$

In the formula, Γ_i is the relative length of the movement of the spatial unit; ε_i is the curvature of the movement. $d(L_{i,t}, L_{i,t+1})$ indicates the move distance; $L_{i,t}$ is the coordinate; $d(L_{i,1}, L_{i,T})$ is the straight-line distance.

(2) LISA spacetime transition. This study further employs the LISA spatio-temporal transition method to analyze the dynamic transition process of local spatial relations (Ye et al., 2013; Yang et al., 2025). The formula is:

$$STTP = \frac{N(\text{Type II}) + N(\text{Type III})}{m} \quad (\text{Eq.6})$$

$$STCP = \frac{N(\text{Type I}) + N(\text{Type IV(1)})}{m} \quad (\text{Eq.7})$$

In the formula, $STTP$ is the spatio-temporal transition probability; $STCP$ is the spatiotemporal condensation probability; m represents the total number of transitions. The introduction of transformation types is shown in *Table 4*.

Table 4. The representational meaning of the types of time-space transformation

Types of spatio-temporal transitions	Representation
Type I	Neither the spatial form of the spatial element itself nor its neighborhood changes
Type II	Only the spatial element itself undergoes a transition while its neighborhood does not change
Type III	Only the neighborhood of the spatial element undergoes a transition
Type IV (1)	Both the spatial element and its neighborhood undergo a transition, and the transition direction of the spatial element is the same as that of its neighborhood
Type IV (2)	Both the spatial element and its neighborhood undergo a transition, and the transition direction of the spatial element is opposite to that of its neighborhood

Selection of influencing factors for ecosystem services

Natural factors are important bases that determine the formation of key ecosystem services in a region, such as climate, topography and geology, soil properties, resource endowments (Xie et al., 2015; Zhang et al., 2018; Liu et al., 2020; Shen et al., 2023b). Socio-economic factors are generally regarded as the external forces and main factors that influence the ESVF. They can influence the structural and functional integrity of

ecosystems and the supply of ecological services by changing the surface cover, discharging pollutants, interfering with the growth and reproduction of animals and plants, and altering the material and energy circulation process of the biological chain. According to relevant research results (Huang et al., 2019; Liu et al., 2020; Li et al., 2021; Ji et al., 2022; Shen et al., 2023a), socio-economic factors can be mainly classified into urbanization, tourism activities, agricultural activities, environmental pollution (air, water, land pollution). Taking into account the availability of the data on influencing factors, as well as the actual conditions of the study area, this paper constructs an index system of influencing factors from nine aspects: climate conditions, topography, geology, resource endowment, urbanization, tourism activities, agricultural activities, and environmental pollution (Table 5). Considering the availability of influencing factor data, 2000 and 2020 were selected as the node years for influencing factor analysis in this study. 2 km × 2 km grid units were used as the basic spatial analysis units.

Table 5. Index system of influencing factors of ESVF

Factors	Influencing factors	Number	Specific indicators	References
Natural factors	Climate	X1	Annual precipitation	Pan et al., 2020; Shen et al., 2023a
		X2	Annual average temperature	Pan et al., 2020; Shen et al., 2023a
		X3	Potential evaporation	Shen et al., 2023a
	Topography and geology	X4	Elevation	Liu et al., 2020; Shen et al., 2023b
		X5	Terrain undulation	Zhang et al., 2018
		X6	Soil erosion intensity	Shen et al., 2023
	Natural resource endowment	X7	NPP	Li et al., 2024
Socioeconomic factors	Population urbanization	X8	Population density	Liu et al., 2020; Pan et al., 2020; Shen et al., 2023b
	Economic urbanization	X9	GDP density	Pan et al., 2020; Shen et al., 2023b
	Land urbanization	X10	Proportion of construction land area	Li et al., 2021
		X11	Construction land form index	Li et al., 2021
		X12	Construction land cohesion index	Li et al., 2021
	Agricultural activities	X13	Fragmentation of farmland	Shen et al., 2023a
	Tourism activities	X14	Tourist attraction density	-
Environmental pollution	X15	PM2.5 concentration	Mirsanjari et al., 2020; Shen et al., 2023a	

Optimal parameters Geodetector model

Compared with the traditional Geodetector (GD) model, the OPGD model can optimize the results by identifying the best spatial data discretization method and the optimal number of discontinuities (Song et al., 2020; Shen et al., 2024, 2025).

(1) Analysis of main influencing factors. The factor detector was used to analyze the main influencing factors of ESVF, and the model formula is as follows:

$$q = 1 - \left[\frac{\sum_{h=1}^L \sum_{i=1}^{N_h} (Y_{hi} - \bar{Y}_h)^2}{\sum_{i=1}^N (Y_i - \bar{Y})^2} \right] = 1 - \frac{\sum_{h=1}^L N_h \sigma_h^2}{N \sigma^2} = 1 - \frac{SSW}{SST} \quad (\text{Eq.8})$$

$$SSW = \sum_{h=1}^L \sum_{i=1}^{N_h} (Y_{hi} - \bar{Y}_h)^2 = \sum_{h=1}^L N_h \sigma_h^2 \quad (\text{Eq.9})$$

$$SST = \sum_{i=1}^N (Y_i - \bar{Y})^2 = (10) N \sigma^2 \quad (\text{Eq.10})$$

In the formula, the q value indicates that degree of explanation for spatial differentiation of ESVF; h is the number of layers, N is the number of samples, N_h is the number of samples of layer h .

(2) Analysis of interaction effect among influencing factors. The interaction detectors was used to analyze the interaction effect between influencing factors of ESVF. The criteria for each interaction types are shown in *Figure 4*.

Graphic description	Formula	Interaction type
	$q(X1 \cap X2) < \text{Min}(q(X1), q(X2))$	Weakened
	$\text{Min}(q(X1), q(X2)) < q(X1 \cap X2) < \text{Max}(q(X1), q(X2))$	Weakened
	$q(X1 \cap X2) > \text{Max}(q(X1), q(X2))$	Bi-enhanced
	$q(X1 \cap X2) = q(X1) + q(X2)$	Independent
	$q(X1 \cap X2) > q(X1) + q(X2)$	Nonlinear-enhanced

Figure 4. Types of interaction between independent variables

Results and analysis

Spatial evolution of ESVF at grid scale in Rizhao City

As shown in *Figure 5*, on the grid scale, the high-level and relatively high-level areas of ESVF in Rizhao City from 1995 to 2020 were mainly distributed in the mountainous and basin areas in the central and northeastern parts of the study area, as well as the coastal ecological landscape belt in the southeast. The medium-level areas are mainly distributed in the mountainous and plain transition zone and the mountainous and basin transition zone in the central and northeastern regions. The lower-level areas of ESVF are mainly concentrated in the agricultural activity areas of Ju County and Wulian County in the western part of the study area, as well as the built-up area margins of Lanshan District and Donggang District, and the coastal tourism activity areas. The low-level areas of ESVF are mainly distributed in the built-up areas of Rizhao City's jurisdiction, the built-up areas of Ju County and Wulian County in the west, and the port development areas along the southeast coast. In terms of spatial evolution characteristics, the ecosystem service value changes most intensely in the built-up area margins of counties and districts, the coastal tourism activity concentration area, the mountainous - plain transition zone in the central area, and the agricultural area in the southwest. The rapid expansion of construction land caused by human activities such as urbanization, industrial development and tourism development, the occupation of grassland, forest land, water areas and unused land by agricultural activities, and the destruction of coastal ecological landscape belts caused by port economy and tourism industry development have led to a further intensification of the contradiction between human and land in the region.

Spatio-temporal interaction characteristics of ESVF in Rizhao City

Temporal path of the local space of ESVF

The temporal evolution path of the local space of of ESVF within the study period can be analyzed based on the relative length and curvature indicators of the LISA time path. From the perspective of relative length (*Fig. 6a*), the proportion of grid cells with a relative length of LISA time path of ESVF greater than 1 during the study period is 30.5%, indicating that the local pattern of ESVF has significant temporal evolution characteristics. In terms of spatial pattern, the relative length shows a cored-periphery structure with the built-up areas of Lanshan and Donggang, Wulian and Ju counties, the central landscape belt, the middle reaches of the Shu River in Ju County, and the area around the Qiangkuang Reservoir in Wulian County as the high-value centers. Among them, the built-up areas of counties and districts are mainly affected by land urbanization, port economy and tourism industry development. The local spatial structure of ESVF in the middle reaches of the Shu River in Ju County and the area around the Qiangkuang Reservoir in Wulian County is mainly influenced by agricultural activities and the development of the tourism industry. Therefore, the local spatial structure of ESVF in such areas shows strong dynamics; The southern and eastern mountainous areas of Wulian County, the western and eastern mountainous areas of Donggang District, and the western landscape belt of Lanshan District have good natural resource endowments and relatively undulating terrain, with less human activity influence and higher ESVF, forming a stable local spatial structure of ecosystem services.

In terms of curvature (*Fig. 6b*), the curvature of the LISA time path during the study period is all greater than 1, indicating that the value of ESVF in Rizhao City shows a relatively dynamic local spatial dependence on the time scale. In terms of spatial pattern, the units with greater curvature are mainly distributed in the central and southern agricultural areas of Ju County, the northeastern landscape belt of Wulian County, the central basin landscape belt of Donggang District, the southeastern coastal landscape belt, and the built-up areas of Lanshan and Donggang districts. Among them, the curvature distribution pattern of the central basin landscape belt and the coastal built-up area is the same as the relative length distribution pattern. The main reason for the coastal built-up area of Donggang District is that the area is restricted by the terrain development and the stage of urbanization development. Urbanization, port economy and tourism industry mainly develop in a filling and marginal expansion pattern in space. At the same time, the local spatial structure shows strong dynamics and dependencies. The distribution patterns of curvature and relative length in the built-up areas of Lanshan District and Wulian County, the northeastern landscape belt, the built-up area of Ju County and the agricultural area in the central and southern parts are different. Among them, the built-up areas of Wulian County and Ju County are in the early and middle stages of urbanization, with a low urbanization rate and not restricted by terrain. Urbanization mainly develops in the form of peripheral expansion and marginal expansion. As a result, the local spatial structure shows strong dynamics, but the local spatial dependence is not strong; The northeastern landscape belt and the agricultural area in the central and southern parts of Ju County are affected by topography, water systems, reservoirs and other topography and hydrological factors, and the spatial changes of ecosystem services under the influence of agricultural and tourism activities are scattered. Therefore, the local spatial structure only shows strong dynamics, but the local spatial dependence is not strong.

Spatio-temporal transition of ESVF

The LISA spatio-temporal transition analysis can reveal global and local spatial dependencies by constructing a spatio-temporal transition matrix table through the local Markov transition model, and can detail the transition characteristics of the local spatial association types of ESVF.

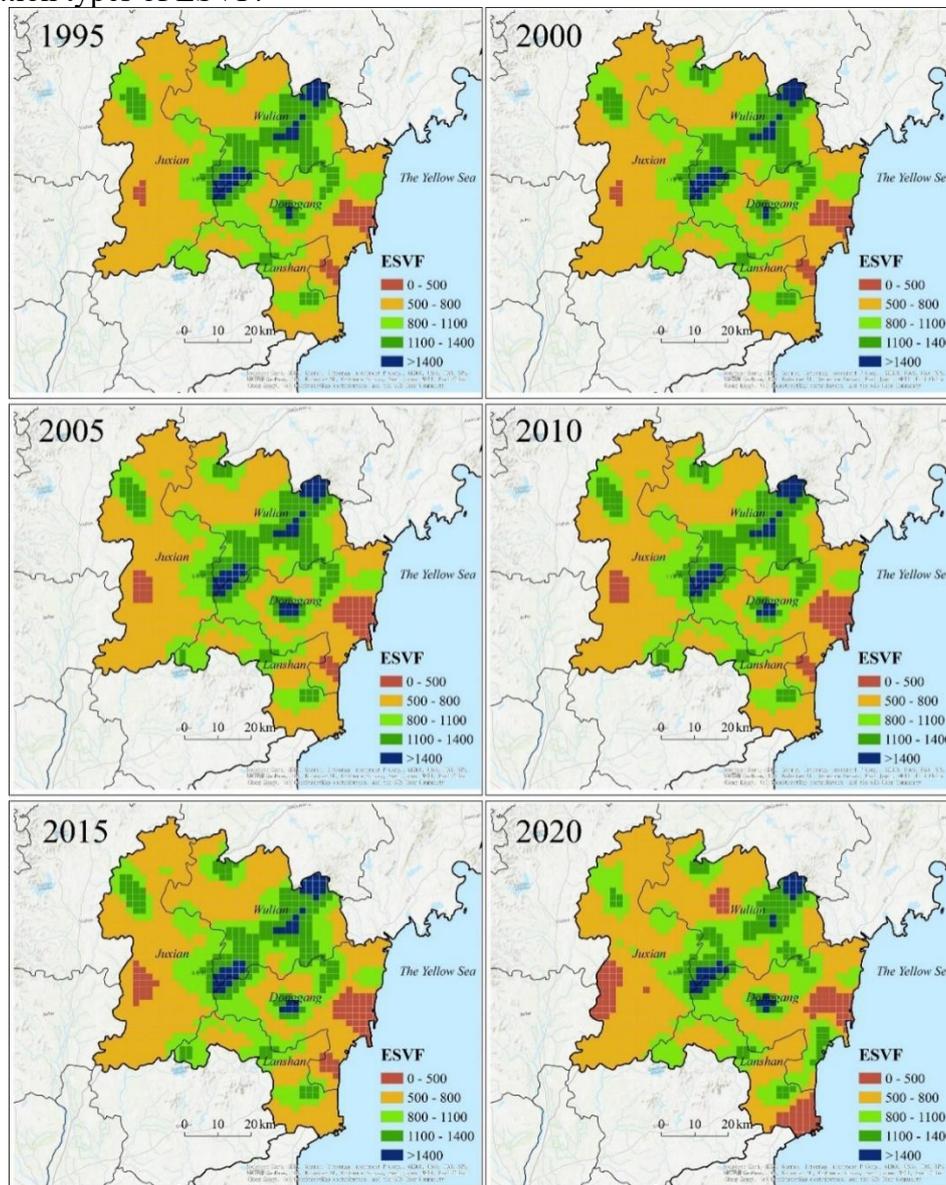


Figure 5. Spatial change of ecosystem service value of Rizhao City from 1995 to 2020

From the perspective of the overall spatial migration characteristics (*Table 6*): (1) The region as a whole has path dependence and lock-in characteristics, but there is a tendency to gradually weaken over time. The proportions of type I transition type (no type transition between periods) in the six time periods of 1995-2000, 2000-2005, 2005-2010, 2010-2015, and 2015-2020 reached 97.8%, 86.0%, 97.4%, 98.9%, and 86.9% respectively. This indicates that the spatial distribution of ecosystem service value in Rizhao has strong path dependence and lock-in characteristics, it shows a gradually weakening trend over time.

(2) The phenomenon of low value agglomeration is more prominent. From the perspective of time traversal, 50% of the units in each of the six periods 1995-2000, 2000-2005, 2005-2010, 2010-2015, and 2015-2020 were in the LL-type spatial agglomeration shape, indicating that the phenomenon of low-value clustering was particularly prominent. (3) The global spatial correlation structure shows volatility. From 1995 to 2020, the probability of temporal and spatial changes (*STTP*) showed a fluctuating trend of first rising (1995-2005), then falling (2005-2015), and then rising again (2015-2020), indicating that the global spatial correlation structure shows fluctuating characteristics in a complex development context.

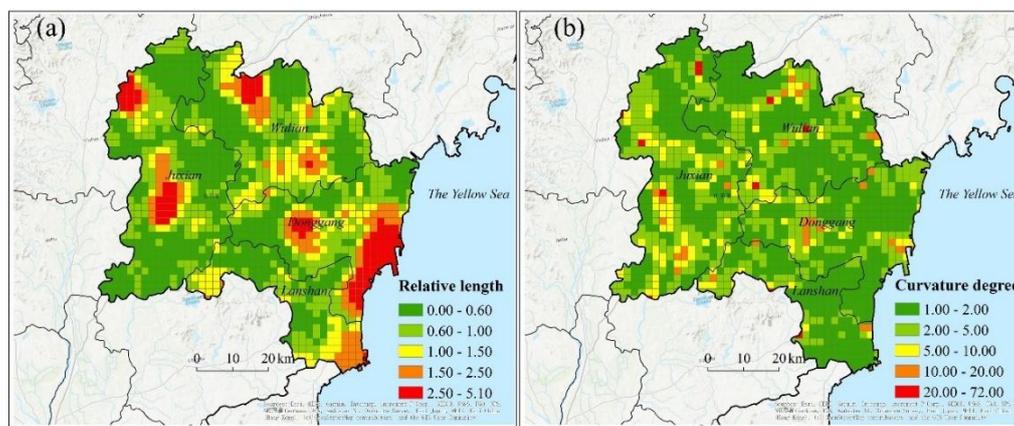


Figure 6. Relative length and curvature of the LISA time path from 1995 to 2020

Table 6. Local Moran's *I* transition matrix and spatio-temporal transitions of *ESVF*

	t/t + 1	HH	LH	LL	HL	Types	Numbers	Proportions	STTP	STCP
1995-2000	HH	518	0	2	4	I	1383	0.978	0.019	0.981
	LH	8	35	0	0	II	13	0.009		
	LL	2	10	814	2	III	14	0.010		
	HL	0	0	3	16	IV	4	0.003		
2000-2005	t/t + 1	HH	LH	LL	HL	Types	Numbers	Proportions	STTP	STCP
	HH	445	8	27	3	I	1216	0.860	0.091	0.908
	LH	41	10	9	2	II	88	0.062		
	LL	41	27	757	13	III	40	0.028		
2005-2010	HL	1	0	26	4	IV	70	0.050		
	t/t + 1	HH	LH	LL	HL	Types	Numbers	Proportions	STTP	STCP
	HH	521	3	2	2	I	1377	0.974	0.025	0.975
	LH	2	39	4	0	II	21	0.015		
2010-2015	LL	0	6	807	6	III	14	0.010		
	HL	2	0	10	10	IV	2	0.001		
	t/t + 1	HH	LH	LL	HL	Types	Numbers	Proportions	STTP	STCP
	HH	523	3	0	1	I	1398	0.989	0.010	0.989
2015-2020	LH	1	41	2	1	II	7	0.005		
	LL	0	2	813	1	III	7	0.005		
	HL	2	1	2	21	IV	2	0.001		
	t/t + 1	HH	LH	LL	HL	Types	Numbers	Proportions	STTP	STCP
HH	475	14	27	9	I	1229	0.869	0.078	0.922	

LH	16	10	25	0	II	57	0.040
LL	48	11	740	16	III	53	0.037
HL	8	0	11	4	IV	75	0.053

HH represents a unit with a high value itself and high values around it; LH represents a unit with a low value itself and high values around it; LL represents a unit with a low value itself and low values around it; HL represents a unit with a high value itself and low values around it. SF is time-space transition probability, SC is space-time agglomeration probability

From the perspective of local spatial migration characteristics (Fig. 7): (1) The spatio-temporal transition types of ESVF in the study area from 1995 to 2020 have significant spatial differentiation characteristics. The areas where spatio-temporal transitions occurred were mainly distributed in the built-up areas of counties and districts, water landscape belts, mountainous and plain transition zones, and coastal landscape belts. Among them, the built-up area mainly transitioned to the LL type and LH type. The water landscape belt mainly shifted to the HH type, the mountainous plain transition zone mainly shifted to the LH and LL types, and the southeastern coastal landscape belt mainly shifted to the HH type. Among them, the transition of the southeastern and northeastern coastal landscape belts to the HH type is mainly attributed to the construction of forest parks, wetland parks and ecological botanical gardens. (2) The marginal areas of county and district built-up areas, water landscape belts and coastal landscape belts are dominated by spatial spillover effects, while the transitional zone between mountainous and plain areas is dominated by spatial polarization effects. Among them, from the perspective of the growth pole theory, the marginal areas of the built-up areas of counties and districts are influenced by the radiation of the urban core economic circle, thus showing spatial spillover effects. From the perspective of the theory of environmental externality and the theory of ecosystem service flow, the coastal landscape belt is affected by the positive externality of the environment and thus shows a spatial spillover effect; The mountainous and plain transition zone is affected by the negative environmental externalities of urbanization, agricultural activities and tourism activities, resulting in a dominant spatial polarization effect.

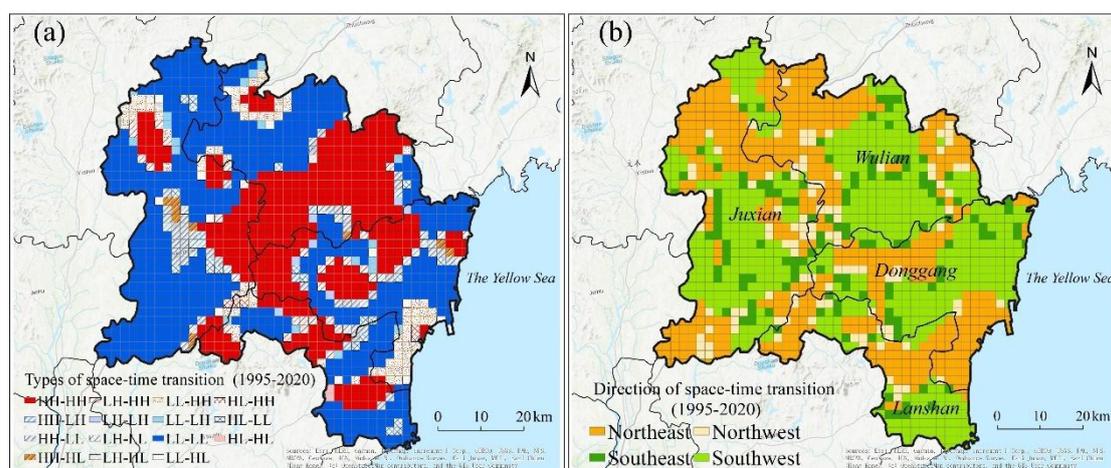


Figure 7. Spatio-temporal transition types and direction of ESVF from 1995 to 2020

Driving mechanism of ESVF in Rizhao City

Driving factors of ESVF

Factor detector analysis results show (Fig. 8), In 2000, land urbanization factors (X10 and X12), topographic and geological factors (X4, X5 and X6), population urbanization factors (X8), economic urbanization factors (X9), climate factors (X2 and X3), agricultural activity factors (X13) and environmental pollution factors (X15) had greater explanatory power for the spatial differentiation of ESVF. Land urbanization factors in 2020 (X10 X11 and X12), topographic and geological factors (X4, X5 and X6), economic urbanization factors (X9), population urbanization factors (X8), agricultural activity factors (X13), climatic factors (X2 and X3), environmental pollution factors (X15) and tourism activities (X14) have greater explanatory power for the spatial differentiation of ESVF. Among them, the explanatory power of land urbanization factor (X11), agricultural activity factor (X13), and tourism activity (X14) has significantly increased compared to 2000.

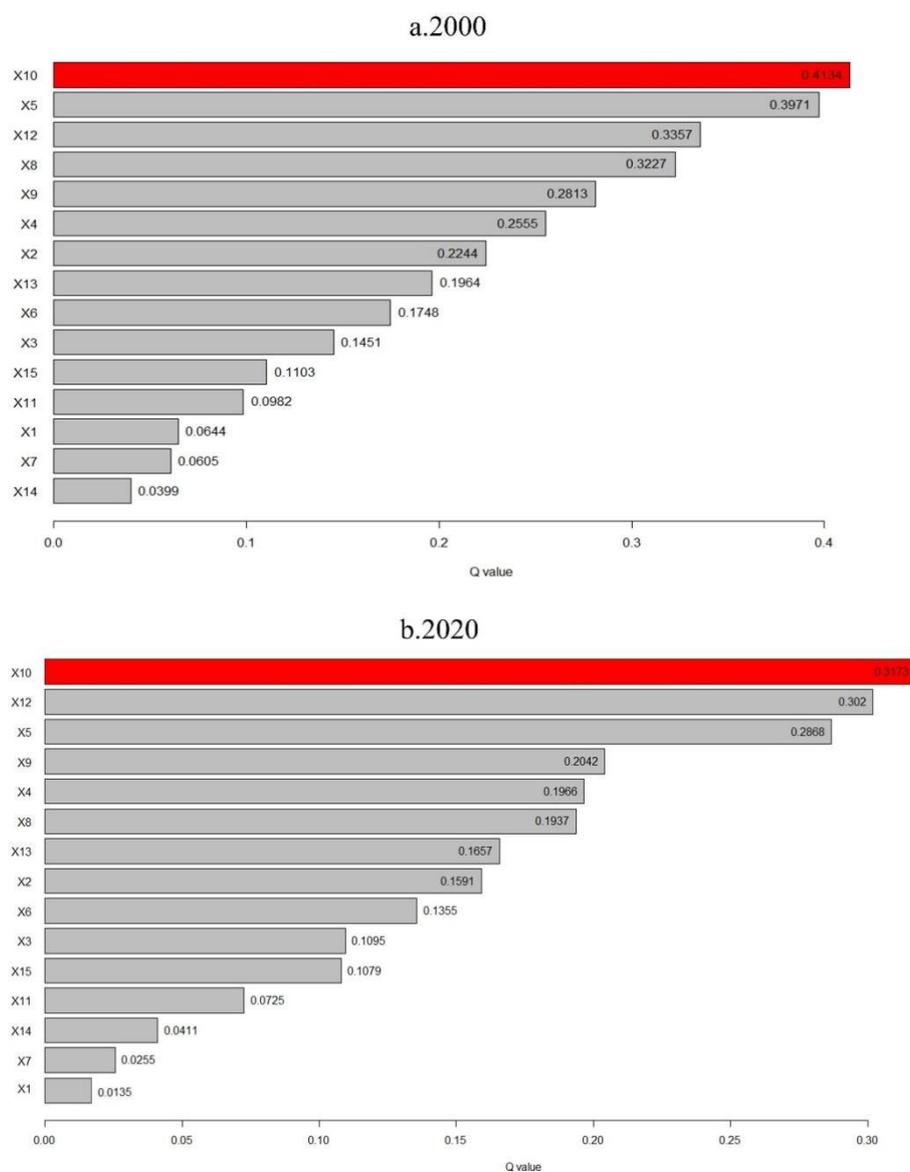


Figure 8. Factor detector analysis results for 2000 and 2020

Interaction effect among driving factors of ESVF

In this study, interaction detectors were used to quantitatively identify the interaction effects of different influencing factors on the ESVF. The results of the interaction detector analysis are shown in *Figure 9*. The superimposition of two factors significantly enhanced the influence on ESVF, indicating that there is a close connection among the detection factors and a significant interaction effect on ESVF.

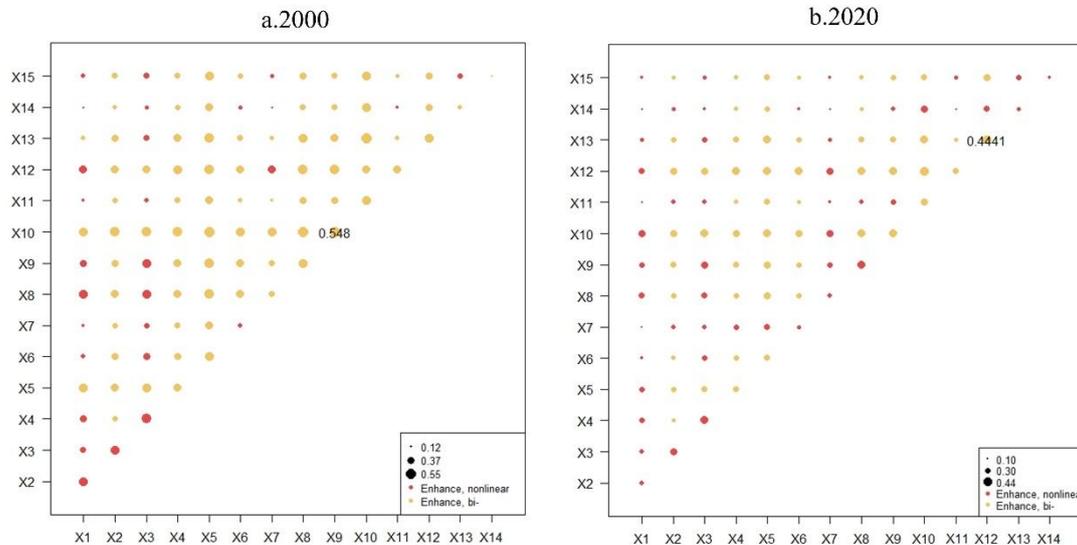


Figure 9. Interaction effect between factors in 2000 and 2020. The numbers 0.548 and 0.4441 in the figure represent the maximum values of the interaction effect in 2000 and 2020 respectively

From the perspective of the interaction among natural factors (*Fig. 10*), the interaction among climatic factors such as annual precipitation, annual average temperature and potential evaporation has a greater interaction effect on the ESVF. The type of interaction between topographic and geological factors and resource endowment factors has evolved from two-factor enhancement to nonlinear enhancement over time, indicating that the interaction force between the two on ecosystem service value has gradually increased. In addition, the interaction type of potential evaporation with topographic and geological factors and resource endowment factors has always been of the nonlinear enhancement type, indicating that their interaction has a greater influence on ecosystem service value. The reason for this is that climate factors mainly affect regional water cycles such as evaporation, water vapor transport, precipitation and runoff, while water cycle processes interact with complex cycles such as topographic and geological environment, atmospheric cycle, physicochemical cycle and biological chain to influence the natural geographical environment and regional ecological service functions.

From the perspective of the interaction between socio-economic factors (*Fig.10*), the interaction force among the three urbanization factors of population urbanization, economic urbanization and land urbanization is the greatest and has increased over time. The interaction between population urbanization, economic urbanization, and land urbanization and agricultural activities, tourism activities, and environmental pollution has significantly increased, indicating that the superimposed effects of urbanization and agricultural activities, tourism activities, and environmental pollution have had a strong

interaction effect on the ESVF. The reason for this is that the development of coastal tourism and related service industries and the development of port economy promote the economic urbanization of Rizhao. Economic urbanization will further promote the urbanization of population and land, and the urbanization of population and land will further promote economic urbanization. But it will also cause drastic changes in land use/cover in the surrounding areas of towns and coastal port areas (expansion of urban construction land, reduction of ecological land, decrease in cultivated land area, decline in cultivated land connectivity and production potential) and environmental pollution (Fig. 8). The sharp decline in total arable land forces people to reclaim wasteland and forest and grassland to fill the gap in arable land, and in the process has a negative impact on regional ecosystem service functions by changing surface cover, reducing soil retention function, disrupting ecological landscape connectivity, and polluting soil and water sources. Secondly, the impact of coastal tourism development on ecosystem service functions is two-sided. On the one hand, tourism development activities cause drastic changes in the coastal ecological landscape, resulting in the fragmentation of the ecological landscape and the decline in connectivity, as well as the corresponding decline in ecosystem service functions; On the other hand, the extensive construction of tourism ecological landscape belts such as wetland parks, botanical gardens, forest parks and scenic spots has significantly improved the regional climate, soil and water conservation functions and landscape connectivity, promoting the enhancement of ecosystem service value. In addition, the rapid development of coastal tourism and related services, as well as the port economy, will lead to increased consumption of energy and resources, along with increased pollution of water, soil and air.

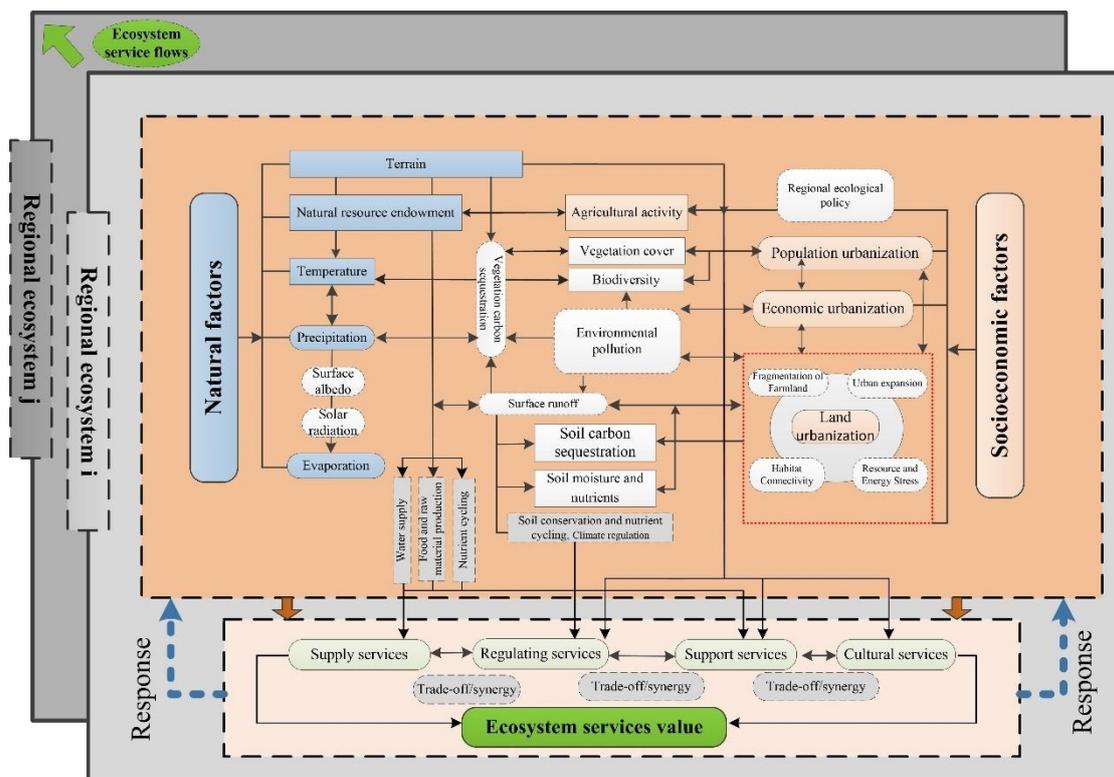


Figure 10. Interaction mechanism of natural and socio-economic factors on ESV

In terms of the interaction between natural factors and socio-economic factors, first of all, the interaction between climate and urbanization, agricultural activities, and tourism activities has significantly increased. Secondly, the interaction force between terrain and urbanization, agricultural activities and tourism activities has increased significantly. In addition, the interaction between resource endowment factors and land urbanization and tourism activities has increased significantly. From the perspective of the interaction mechanism between natural and human factors on ESVF (*Fig. 10*), the coastal area of Rizhao has a relatively humid climate and a well-developed tourism and related service industry and port industry. The suitable living and employment environment promotes the continuous migration and concentration of the population to the coastal towns. Therefore, the interaction between climate factors and urbanization and tourism activities is significant. Topography is one of the fundamental factors influencing human socio-economic activities. In areas with lower terrain and less terrain undulation, the intensity of human activities such as urbanization, agricultural activities, and tourism activities is higher. Therefore, the interaction between topography and urbanization, agricultural activities, and tourism activities has a greater interaction effect on ESVF. The tourism and land resources of coastal tourist cities are mainly concentrated in the coastal landscape belt with good resource endowment and the central mountainous and plain transition zone. However, tourism activities and urban development activities also occur more frequently in this area. Therefore, the interaction between resource endowment factors and urbanization and tourism activity factors in this area has a greater impact on the interaction of ESVF.

Discussion

Suggestions for environmental management in tourist destinations

Geospatial information knowledge mining can not only reveal the temporal and spatial distribution and agglomeration characteristics of ESV, but also discover the spatial risk factors that have a significant impact on ESV and identify ecological risk hotspots. Based on the unique geographical location and industrial layout characteristics of Rizhao City, the built-up areas of its districts and counties, the central basin, the coastal landscape belt and other regions have become the core areas with significantly reduced ESV due to the vigorous development of tourism. To effectively respond to this change and achieve sustainable regional ecological and economic development, it is necessary to precisely implement ecological management measures based on the characteristics of different regions. Suggestions for zonal management for tourist destinations are as follows:

(1) Built-up areas of districts and counties: Optimize planning to enhance land use efficiency. The built-up areas of districts and counties, as the core regions of urban development, face prominent issues of land cover changes brought about by urban expansion and land use structure adjustment. In this regard, a refined urban land use plan should be formulated to reasonably control the speed of urban expansion from a macro perspective and ensure that the scale of urban development matches the carrying capacity of resources and the environment. At the same time, by optimizing the land use structure, improving land use efficiency, and reducing land cover damage caused by disorderly development. In the regulation of the speed and scale of urban expansion, it is necessary to comprehensively consider multiple factors such as the economic scale of the town, the demand for industrial development, and its future development potential. By applying scientific methods and models, make reasonable plans for urban expansion to avoid the

waste of land resources and ecological damage caused by blind expansion. By enhancing the intensive utilization and concentration of urban land, efficient allocation of land resources can be achieved, and the overall operational efficiency and ecological service functions of the city can be improved.

(2) Central mountain basins and coastal landscape belts: Strictly adhere to the red line and strengthen ecological protection. The central mountain basins and coastal landscape belts, with their unique natural landscapes and ecological resources, have become an important support for the development of tourism. However, activities such as tourism development have also brought certain pressure to the local ecological environment. Therefore, it is necessary to demarcate ecological protection red lines for important ecological landscapes such as forests, grasslands and wetlands, clarify the core areas and boundaries of ecological protection, and provide rigid constraints for ecological protection. During the project approval process, strict control is exercised over tourism development projects, real estate development projects, and infrastructure construction projects. Establish a scientific and reasonable project evaluation system to conduct a comprehensive assessment of projects from multiple dimensions such as ecological impact and environmental carrying capacity, ensuring that project construction complies with ecological protection requirements. Projects that do not conform to the ecological conservation red line will be resolutely rejected to reduce the damage caused by human activities to the ecological environment from the source. At the same time, attention should be paid to protecting important ecological sources and corridors. Ecological source areas are important supports for ecosystems, while ecological corridors are crucial channels for species migration and ecological processes. By strengthening the protection of ecological source areas and corridors, maintaining the integrity and stability of the ecosystem, and ensuring the normal functioning of ecological services.

(3) Western plain agricultural region: Green development and optimization of the agricultural ecological pattern. The agricultural area in the western plain is an important agricultural production base in Rizhao City. However, the frequent agricultural activities have also brought about a series of ecological problems. To ensure the sustainable development of agriculture and the security of the ecological environment, a series of ecological management measures should be taken on the basis of adhering to the red line of cultivated land. The expansion of farmland in the surrounding areas of important wetlands, rivers, lakes, etc. is strictly prohibited. These areas are important components of the ecosystem and have significant ecological functions such as water conservation and climate regulation. Prohibiting the expansion of farmland is conducive to protecting the ecological integrity of these areas and maintaining regional ecological balance. Prohibiting the burning of crop straw is an important measure for preventing and controlling air pollution. The burning of crop straw generates a large amount of smoke, dust and harmful gases, which have a serious impact on air quality. By promoting technologies such as returning straw to the field and comprehensive utilization of straw, the resource utilization of straw can be achieved, and the environmental pollution caused by straw burning can be reduced. In addition, improve the planting structure of agricultural land, reduce the fragmentation of agricultural land, and enhance the heterogeneity of agricultural landscapes. Rationally plan the layout of crop planting, promote large-scale and intensive planting models, and reduce the degree of fragmentation of farmland patches. At the same time, increase the diversity of agricultural landscapes, build a diversified agricultural ecosystem, and enhance the stability and anti-interference ability of agricultural ecosystems.

(4) Sloping land in the northeastern mountainous region: Return farmland to forest and promote ecological farming models. The hilly terrain in the northeastern mountainous area is complex, and the risk of soil erosion is relatively high. To prevent soil erosion and ecological landscape damage, government administrative departments should actively guide farmers to return farmland to forest. Through policy incentives and publicity guidance, farmers are encouraged to return farmland with steep slopes and severe soil erosion to forest, restore vegetation coverage, and enhance soil retention capacity. Vigorously promote conservation tillage methods such as no-tillage and mulching. No-till farming can reduce the frequency of soil tillage and lower the risk of soil erosion. Mulching planting can maintain soil moisture and temperature and improve soil structure by covering crop straw, plastic film and other materials. At the same time, promote intercropping methods such as grain-forest-fruit intercropping and soil-conserving rotation and intercropping. Intercropping of grain, forest and fruit can make full use of spatial resources and improve land use efficiency. Soil conservation rotation and intercropping can improve soil fertility and reduce the occurrence of pests and diseases through the combination of different crops, achieving a win-win situation of ecological and economic benefits.

Deficiencies and prospects

In terms of influencing factors, we have systematically classified natural and socio-economic factors and attempted to comprehensively analyze the impact and mechanisms of natural and socio-economic factors on ESVF using the OPGD model. However, there are two deficiencies in our study: Firstly, due to the difficulty in quantifying socio-economic factors at the grid scale and the complexity of the mechanism by which human activities affect the ESVF, the socio-economic factors selected in this study may not be comprehensive enough. Therefore, in future studies, we should use new technological means to quantify more socio-economic factors, such as water and soil pollution caused by industrial activities, and ecological and environmental protection policies and measures. Second, there are extremely complex interactions among the influencing factors of ESVF, so it is difficult to clarify the interaction mechanism of multiple factors on ESVF, which is an aspect that needs to be further improved in future research.

Conclusions

Based on multi-source data, the improved ESV assessment model was used to conduct spatio-temporal dynamic assessment of ESVF in Rizhao City, and analyze its spatio-temporal interaction characteristics. Then, the OPGD model based on was used to analyze the driving factors and their interactions effect of ESVF, and to explore the driving mechanism of ESVF. The main conclusions are as follows:

(1) The high and relatively high-level areas of ESVF in Rizhao City from 1995 to 2020 were mainly distributed in the mountainous and basin areas in the central and northeastern parts of the study area, as well as the coastal ecological landscape belt in the southeast. The medium-level areas were mainly distributed in the mountainous and plain transition zone and the mountainous and basin transition zone in the central and northeastern regions. In terms of spatial evolution, the most dramatic changes in the ESVF were observed in the built-up area margins, coastal tourism areas, the central mountainous and plain transition zone, and the southwestern agricultural area.

(2) In terms of temporal pathways, the local pattern of ESVF shows significant temporal evolution characteristics. The county built-up area, the central mountain-plain transition zone, the northeastern mountainous landscape zone and the eastern coastal area show more dynamic local spatial structure and stronger spatial dependence.

(3) In terms of spatio-temporal transition, the overall spatial correlation structure of ESVF has the characteristics of path dependence and lock-in, but shows a gradually weakening trend over time. The local spatial correlation structure has significant spatial differentiation characteristics, and the areas where spatio-temporal transitions occur are mainly distributed in the marginal areas of county and district built-up areas, water landscape belts, mountainous and plain transition zones, and coastal landscape belts. Among them, the marginal areas of county built-up areas, water landscape belts and coastal landscape belts are dominated by spatial spillover effects, while the transitional zone between mountainous and plain in the middle is dominated by spatial polarization effects.

(4) Topography, climate, land urbanization, population urbanization, economic urbanization, agricultural activities and environmental pollution factors have a significant impact on the ESVF. The influence of factors such as land urbanization, agricultural activities and tourism activities has significantly increased on the time scale. In terms of interaction, there is a strong interaction among population urbanization, economic urbanization and land urbanization, and urbanization has a strong interaction with agricultural activities, tourism activities and environmental pollution factors.

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