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Coastal land use change and evaluation of ecosystem services value enhancement under the background of Yangtze River protection: Taking Jiangyin coastal areas as an example

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Evaluating the ecosystem service value is an important step to promote the sustainable development and the construction of ecological civilization of the Yangtze River Economic Belt, the related research is already very rich. However, they neglect the evaluation of coastal areas and lack the deeper thinking of ecological value. To improve these deficiencies, this study takes the coastal area of Jiangyin as the study area, constructs the evaluation method system of ecosystem service value based on the land use data in 2016 and 2020, explores the temporal and spatial variation characteristics of land use and ecosystem service value in the study area, and analyzes reasons for these changes. The results show that: (1) Cultivated land is the main land type in the coastal area, with an area change rate of -15.89%, forest land increases rapidly, with a growth rate of 281.62%, followed by water area with a growth rate of 55.98%, garden land decreases the most, with a decrease rate of 86.36%, followed by construction land of 62.19%. Land use mainly presents the characteristics of changes from construction land to other land, construction land and green space, and cultivated land to cultivated land, water area and forest land. (2) The net increase of ecosystem service value in the coastal area is 483 million, with a growth rate of 137.27%. Among them, the value of forest land accounts for the largest proportion, with a net increase of 264 million yuan and a growth rate of 109.54%. In terms of single function, flood regulation and storage accounts for the main ecosystem service value, reaching more than 65%, with a net increase of 394 million yuan. (3) In terms of spatial distribution, the ecosystem service value of water conservation, flood regulation and storage has a spatial distribution characteristic of being high in the east and low in the west, while the distribution of ecosystem service value of wind prevention and sand fixation is both high and low in the west. In addition, this study further explores the response mechanism of ecological value to the protection measures along the river and the transformation path of ecosystem service value, which provides a new path for the study of government-led evaluation of ecological protection effects in important coastal areas and ecologically sustainable development with regional multi-subject participation.

KEYWORDS

ecosystem services, evaluation of ecosystem services value, land use change, yangtze river protection, Jiangyin

1 Introduction

The Yangtze River is the key area of China's economic and social development, and it also has a high position in safeguarding national ecological security. Since modern times, due to the influence of unreasonable production and lifestyle, the Yangtze River Economic Belt has become one of the areas with the most prominent water environment problems in China. The area of farmland, forests, grasslands, wetlands and other ecosystems has decreased, the ecosystem pattern has changed drastically, the soil erosion in the upstream and downstream areas has been serious, the contradiction between people and land has intensified along the Yangtze River, lakes have shrunk, the ecosystem functions of forests and wetlands have gradually deteriorated. In this context, evaluating the function of coastal ecosystems and studying the effect of ecological protection has become an important step in promoting the sustainable development of the Yangtze River Economic Belt and the construction of ecological civilization. Specifically, quantifying and evaluating ecosystem functions can deepen the research on ecosystem function evaluation and scientifically evaluate the development status of different ecosystems in theory, and improve the economic benefits of natural resources and promote sustainable economic and social development in practice.

Ecosystem service value (ESV) is the direct embodiment of ecosystem functions. Ecosystem services (ES) are products and services that are directly or indirectly obtained through the structure, functions and processes of ecosystems to support life (Xie et al., 2015). In the past few decades, scholars have gradually realized that the value of ecosystem services has a great impact on the sustainable development of social economy (Kohler, 1984; Rudolf, 1997; Bockstael et al., 2000; Boyd and Banzhaf, 2007; Fisher et al., 2009). They have carried out evaluation studies on the ecosystem service value with various contents, varied perspectives, multi-dimensional scales, and multiple methods (Costanza et al., 1998; Sun, 2011; Yu and Bi, 2011; Xie, 2017). In terms of research content, on one hand, it includes the evaluation of all ecosystem services (ecosystem material products, ecosystem regulation service and culture), on the other hand, scholars focus on ecosystem regulation service, which is the main type of ecosystem services. They research water conservation (Cheng and Shi, 2004; Sheng et al., 2010), soil conservation (Pimentel et al., 1995; Xiao et al., 2000), carbon sequestration and oxygen release (Liu and Lu, 2008; Zhou et al., 2013), air purification (Wu et al., 2009), water purification (He and Kang, 2008), flood regulation and storage (Liu, 2007), wind prevention and sand fixation (Jiang et al., 2016) and other regulation services. In terms of research perspective, various ecosystems (United Nations, 2014), such as forests (O'Brien, 1998), plateaus (Xie et al., 2003), wetlands (Duan et al., 2005; Jiang et al., 2015; Zhou et al., 2021; The Encyclopedia of Earth, 2022), and the theory of ecosystem protection are focused and discussed. In terms of research scale, it involves globe (Costanza et al., 1998), nation (Ma et al., 2017), province (Bai et al., 2017; Song and Ouyang, 2020), city (Wang et al., 2017; Dong et al., 2019) county (Pema et al., 2020) and other spatial scopes (Qiu et al., 2017; Shifaw et al., 2019). Scholars evaluate the value of ecosystem services at different scales to explore their spatial distribution and driving factors, and provide new perspectives for ecological protection in different situations. The research methods are divided into two types: value evaluation and material quality evaluation (Fu and Zhang, 2014), in terms of value evaluation, Costanza et al. (Costanza et al., 1998) published research on global ecosystem services and their value in 1997, which attracted a lot of attention. Xie (Xie et al., 2003) referred to some results of global ecosystem service value evaluation by Constanza et al. and integrated questionnaire surveys to establish a service value table per unit area, which has been widely used. However, considering different research angles, scales, and the complexity of estimation, the value evaluation method has been questioned a lot, and different theoretical frameworks and evaluation methods have been formed (Ouyang et al., 1999; Sukhdev et al., 2010). In terms of material quality evaluation, it is generally assessed by combining observed data and ecological models (Fu and Zhang, 2014), and it also has different evaluation methods on large and small scales (Feng et al., 2010). Comparing the two research methods, the former calculation is more convenient and fast, suitable for comparative research under different changing conditions, while the latter calculation is more complicated but more rigorous, suitable for long-term and continuous analysis. In general, the research on ecosystem service value has already been very rich, but the lack of reliable data and the inconsistency of evaluation methods have made these researches still insufficient.

With the deepening of research, many scholars have noticed the topic of land use, which has always been a hot topic in various fields, especially in recent years, the urbanization process has given birth to the discussion of land use efficiency (Jin et al., 2018) and the relationship between land use and ecosystem services (Daily, 1997). They believe that ESV and Land Use Change (LUC) influence each other, and land is the carrier of ESV, changes in land use patterns will affect ecological processes such as the water cycle by changing the structure and function of ecosystems, leading to changes in ecosystem services. Evaluation of ecosystem services also affects land development and land use planning (Li et al., 2010; Lawler et al., 2014; Ouyang et al., 2016). Therefore, the quantitative evaluation of ecosystem services under the background of land use change has become a research hotspot. At present, there are many studies on the response of ESV to LUC (Dale, 1997; Fu et al., 2000; Su et al., 2010; Wainger et al., 2010; Sonter et al., 2017; Tolessa et al., 2017; Li et al., 2018). Based on the value equivalent method proposed by Xie, most scholars have evaluated ESV from different perspectives and scales in combination with LUC (Zhao et al., 2004; Liu et al., 2018; Lei et al., 2019; Wang and Ma, 2020), on this basis, explore the impact of LUC on ESV and the spatial dependence of service values on land use patterns. Although these studies adopt a variety of methods and draw conclusions with their own characteristics, most of them ignore the role of human activities and lack the discussion on the response mechanism of ESV to the cause of LUC.

Therefore, on the basis of the existing research on ESV evaluation and value evaluation combined with LUC, it is not

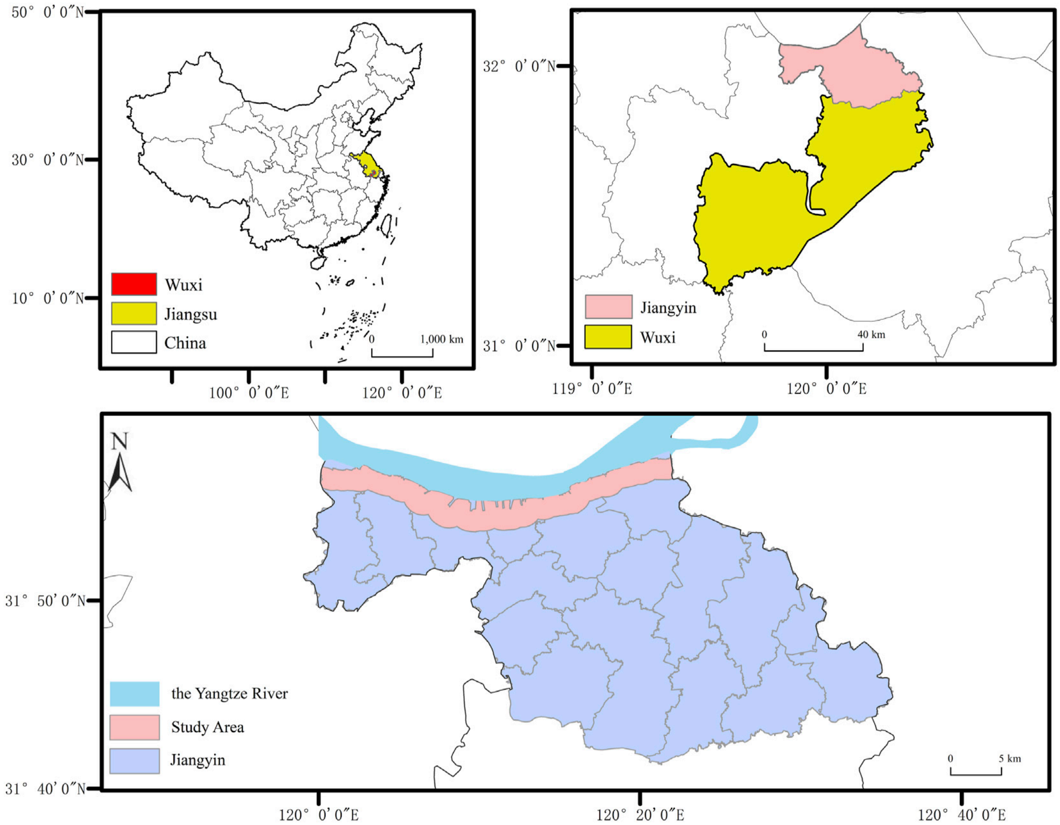

FIGURE 1
Location of Jiangyin and the study area.

difficult to see that it is still not easy to select a suitable study area, suitable research content and suitable research methods to carry out the evaluation of ESV. Specifically, when selecting study areas, many scholars blindly select large spatial areas and ignore small regional units in order to evaluate more general evaluation conclusions for direct use in subsequent research. In terms of research content, most studies directly evaluate all indicators of the ecosystem services in the study area, and make a general summary in order to win by quantity, while omitting the consideration of combining land, economy, society and other factors. In terms of research methods, the most serious problem is the use of general accounting methods and calculation parameters, ignoring regional differences, and the results obtained are basically not typical.

Based on this, in terms of the study area, this study selects the coastal area in Jiangyin, a special regional unit with prominent human-land conflicts (Zhou et al., 2011; Wang et al., 2020a). On one hand, there are few studies on the evaluation and protection of relevant ESV along large rivers; on the other hand, the small study area facilitates the analysis of specific driving factors of LUC (Zhang et al., 2013). In terms of research content, since regulation service is the most important type of ecosystem services, and the value cannot be measured uniformly (Lai et al., 2013), choosing the regulation service to build the accounting system can produce regional differences. In terms of research methods, some accounting methods are optimized, and some accounting parameters are innovated in this research to carry out accounting, so as to better understand the spatial differences of service value. On the whole, this study analyzes the land use changes in the coastal area under the land use data in 2016 and 2020, scientifically evaluates the functional and structural changes of ecosystem regulation service value, explores the reasons for the changes, and further explores the response mechanism of ecological value to government protection policies and the transformation path of ecological value, providing new ideas for the study of the government-led evaluation of ecological protection effects in important coastal areas and ecologically sustainable development with regional multi-subject participation.

2 Materials and methods

2.1 Study area

Jiangyin is located in the southeast of Jiangsu Province, it is 31 degrees 55 min north latitude and 120 degrees 17 min east longitude. Jiangyin, which is adjacent to the Yangtze River in the north, is a very important riverside city in the lower reaches of the Yangtze River (Figure 1). In recent years, due to over-exploitation of the economy, it has brought a heavy ecological burden to the Jiangyin section of the Yangtze River, and the contradiction between human and land is very prominent. In order to ease the pressure of ecological environment, over the years, Jiangyin has attached great importance to and vigorously promoted environmental protection and ecological construction, adhered to the development policy of giving priority to environmental protection, improved the coordination of economic, social and environmental resources, made certain achievements, among them, ESV reached 61.9 billion in 2022, and became the first batch of national ecological cities.

Considering the typicality of the coastal area in Jiangyin in the following aspects, this study selects the area 2 km along the Yangtze River in Jiangyin as the study area, and the details are as follows: (1) In recent years, there have been some problems in the area 2 km along the Yangtze River in Jiangyin, such as high-intensity development along the Yangtze River, a high proportion of shoreline construction, serious water quality problems and deterioration of ecological environment. So it is the hardest hit area of ecological problems, and it is also the key area to explore ecological protection. (2) There are many types of ecosystems within 2 km along the Yangtze River in Jiangyin, and the shoreline of the Yangtze River is an important part of the ecosystem along the Yangtze River. It is a strategic resource and an important carrier to promote the high-quality development of the Yangtze River Economic Belt by relying on the golden waterway, and it is also the key object of ecological restoration and protection. The protection of the Yangtze River area can not only take into account the ecological protection of the Yangtze River, but also relate to the economic and social development of coastal urban areas, and provide the optimization ideas of ecology and development for the main urban areas, which is a measure to achieve the integration of ecological benefits and economic and social benefits. (3) Enterprises and production activities gather within 2 km along the Yangtze River in Jiangyin, and the contradiction between people and land is prominent. Analyzing the 2 km along the Yangtze River can provide more detailed suggestions for the follow-up industrial transformation and upgrading and ecological protection measures.

2.2 Data sources

The land use data used in this study comes from Jiangyin Bureau of Natural Resources and Planning, in 2016, the National Ecological Civilization Experimental Zone began to be implemented. In 2020, the third national land survey in Jiangsu Province was completed, the land use types in the province changed, in the same year, the realization and protection of the ecosystem value of the Yangtze River Basin received full attention from the government. Based on this, this study selects two periods of land use data in 2016 and 2020, which can more intuitively show the land use change and the improvement of ecosystem service value in the coastal area of Jiangyin. Statistical data such as rainfall is from the Statistical Yearbook of Jiangyin, and data such as evapotranspiration, surface runoff, and purification of air pollutants refer to relevant materials and literature, the NDVI data comes from Geospatial Data Cloud (https://www.gscloud.cn/), and the NPP data comes from MOD17A3HGF.v006 version of NASA. The specific data sources will be stated in Section 2.3.2 of this paper.

2.3 Methods

2.3.1 Regulation service function index selection

The selection of ecosystem regulation services is an important part of ESV evaluation. However, many related studies lack specific reasons for the selection, which reduces the rationality and accuracy of the research. Based on this, this study will clarify the reasons for the selection while constructing the ecosystem regulation service accounting system, in order to improve the reliability of the research and provide a theoretical basis for follow-up research. The accounting system of this study contains seven indicators including water conservation, flood regulation and storage, air purification, water purification, wind prevention and sand fixation, carbon sequestration, and oxygen release. The specific reasons are as follows:

Water ecosystem is the environment on which human beings depend for survival. Water resources include four elements: water quantity, water quality, water energy, and aquatic organisms. Based on this, water ecosystem services can be divided into four categories: water supply, water energy, aquatic organisms, and environmental benefits (Cai et al., 2003), among them, aquatic organisms highlight the importance of carbon sequestration and oxygen release, and environmental benefits highlight the importance of water conservation, flood regulation and storage, and water purification. Where water resources are abundant, these functions are very obvious. Jiangyin is close to the Yangtze River, where the pressure of flood control of lakes is high, the problems of water environment are serious, and the contradiction of water resources is intensified. In this way, research on water conservation, flood regulation and storage, water purification, carbon sequestration and oxygen release can be carried out. In addition, the importance of evaluating these functions is also reflected in other ecosystems. For example, wetland ecosystems can reduce flood peaks, delay flood processes, and reduce economic damage caused by floods, it also has important ecological value (Hans et al., 2001; Yao and Yang, 2009) to apply natural wetlands to water purification and carbon sequestration and oxygen release. The forest ecosystem can make the soil more permeable to rainwater, making the water conservation ability outstanding, and the forest photosynthesis is strong, making the carbon sequestration and oxygen release function obvious. The coastal area in Jiangyin is rich in types of wetlands and forests, so evaluating the above functions plays an important role in exploring ESV in Jiangyin (Cao et al., 2013).

In Jiangyin, there are rich and diverse ecological lands. Among them, vegetation, as an important natural resource, has an obvious function of wind prevention and sand fixation (Han et al., 2011). Although this function is generally applicable to wind erosion areas, some studies have shown that vegetation coverage and the amount of soil wind erosion are negatively correlated (Huang et al., 2001). Therefore, under the background of land use changes in Jiangyin, it is necessary to study the function of wind prevention and sand fixation. In addition, air purification is also a regulation service that cannot be ignored, especially in the context of the rapid development of urbanization in recent years, the urban air pollution problem in

TABLE 1 Ecosystem regulation service function.

Service type	Evaluation method	Calculation function	Parameter introduction	Parameter source
Water Conservation	Model method for water conservation capacity	$TQ = \sum_{i=1}^{j}(P_i - R_i - ET_i) \times A_i \times 10^{-3}$	TQ is the water conservation capacity (m^3);	64
			P_i is the rainfall (mm);	
			R_i is the surface runoff (mm);	
			ET_i is evapotranspiration (mm);	
			A_i is the area of the ecosystem of type i (km^2); i is the type i ecosystem in the study area;	
			j is the total number of ecosystem types in the study area.	
Flood Regulation and Storage	The sum of water storage capacity of vegetation and stagnant water in flood period	$C_{fm} = C_{vfm} + C_{rfm} + C_{lfm} + C_{mfm}$ $C_{vfm} = \sum_{i=1}^{n}(P_i - R_{fi}) \times A_i \times 1000$ $C_{rfm} = 0.29 \times C_t$ $C_{lfm} = e^{4.924} \times A^{1.128} \times 3.19$ $C_{mfm} = C_{sws} + C_{sr}$ $C_{sws} = S \times h \times \rho \times (F - E) \times 10^{-2}/\rho_w$ $C_{sr} = S \times H \times 10^{-2}$	C_{fm} is the flood storage capacity (m^3/a);	64
			C_{vfm} is the vegetation flood storage capacity (m^3/a);	
			C_{rfm} is the reservoir flood storage capacity (m^3/a);	
			C_{lfm} is the lake flood storage capacity (m^3/a);	
			C_{mfm} is the swamp flood storage capacity (m^3/a);	
			P_i is the rainstorm rainfall (mm);	
			R_{fi} is rainstorm runoff of the vegetation ecosystem of type i (mm);	
			A_i is the area of the vegetation ecosystem of type i (km^2); i is the vegetation ecosystem of type i in the accounting area, i = 1,2, . . . , n;	
			C_t is the total storage capacity of the reservoir (m^3);	
			C_{sws} is the swamp soil water storage capacity (m^3/a);	
			C_{sr} is the swamp surface water retention (m^3/a);	
			S is the total area of swamp (km^2); h is the water storage depth of marsh wetland soil (m);	
			ρ is the bulk density of swamp wetland soil (g/cm^3);	
			F is the saturated water content of marsh wetland soil (dimensionless);	
			E is the natural moisture content of swamp wetland before flooding (dimensionless);	
			ρ_w is the density of water (g/cm^3);	
			H is the surface stagnant water height of swamp wetland (m).	
Air Purification	Self-purification ability of ecosystem	$Q_{ap} = \sum_{i=1}^{n}\sum_{j=1}^{m} Q_{ij} \times A_j$	Q_{ap} is the air purification capacity of the ecosystem (kg/a);	
			Q_{ij} is the purification amount of type j ecosystem to type i air pollutants per unit	

(Continued on following page)

TABLE 1 (*Continued*) Ecosystem regulation service function.

Service type	Evaluation method	Calculation function	Parameter introduction	Parameter source
			area ($kg/km^2 \cdot a$); i is the air pollutant category, i = 1,2, . . . , n;	
			j is the ecosystem type, j = 1,2, . . ., m;	
			A_j is the area of type j ecosystem (km^2).	
Water Purification	Purification function of ecosystem water environment	$Q_{wp} = \sum_{i=1}^{n}\sum_{j=1}^{m} P_{ij} \times A_j$	Q_{wp} is the purification amount of water pollutants (kg/a);	
			P_{ij} is the purification amount of type i pollutants by type j ecosystem per unit area ($kg/km^2 \cdot a$); i is the water pollutant category, i = 1,2, . . . , n; A_j is the area of the type j ecosystem (km^2);	
			j is the ecosystem type, j = 1,2, . . . , m.	
Wind Prevention and Sand Fixation	Wind erosion reduction of ecosystem	$Q_{sf} = 0.1699 \times (WF \times EF \times SCF \times K')^{1.3711} \times (1 - C^{1.3711})$ $WF = Wf \times \frac{\rho}{g} \times SW \times SD$ $K' = \frac{(AC^*AB)}{(AC^*AC)} = 1/\cos a$ SCF is the soil crust factor; C is the vegetation cover factor; $C = (NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min})$	Q_{sf} is the amount of wind prevention and sand fixation (t/a);	GEP (2023)
			WF is the climatic erosion factor (kg/m);	
			K' is the surface roughness factor;	
			EF is the soil erosion factor;	
			Wf is the multi-month average wind factor;	
			ρ is the air density; g is the acceleration of gravity;	
			SW is the monthly annual average soil moisture factor, (dimensionless);	
			SD is snow cover factor.	
Carbon Sequestration	NEP method	$Q_{CO_2} = M_{CO_2}/M_C \times NEP$ $NEP = \alpha \times NPP \times M_{C_6}/M_{C_6H_{10}O_5}$	Q_{CO_2} is the carbon sequestration of ecosystem (tCO_2/a);	GEP (2023)
			M_{CO_2}/M_C =44/12 is the coefficient of conversion of C into CO_2;	
			NEP is net ecosystem productivity (TC/a);	
			α is conversion factor	
			NPP is net primary productivity (t dry matter/a);	
			$M_{C_6}/M_{C_6H_{10}O_5}$ =72/162 is the coefficient of conversion of dry matter into C.	
Oxygen Release	NEP method	$Q_{CO_2} = M_{CO_2}/M_C \times NEP$ $Q_{op} = M_{O_2}/M_{CO_2} \times Q_{tCO_2}$	Q_{CO_2} is the carbon sequestration of ecosystem (tCO_2/a);	GEP (2023)
			M_{CO_2}/M_C =44/12 is the coefficient of conversion of C into CO_2;	
			NEP is net ecosystem productivity (TC/a);	
			Q_{op} is Oxygen release for ecosystem (t);	
			M_{O_2}/M_{CO_2} =32/44 is the coefficient of CO_2 conversion to O_2;	
			Q_{tCO_2} is Carbon sequestration for ecosystem (tCO_2/a).	

Jiangyin is still difficult (Wu et al., 2009), and the evaluation methods for the value of air purification are also very diverse. Therefore, research based on this can enrich the research content and research methods. It is worth noting that although the importance of the above-mentioned regulation services is reflected in different ecosystems, they can still be valued in other ecological lands, so the selection of these seven indicators will not affect the scientificity of subsequent research.

2.3.2 Accounting methods

The evaluation types of ecosystem regulation service functions in Jiangyin include water conservation, flood regulation and storage, air purification, water purification, wind prevention and sand fixation, carbon sequestration and oxygen release. The evaluation method, calculation formula and calculation parameters of each service type are shown in Table 1.

In Table 1, the evaluation methods of each function are different, and the sources of parameters are also diverse. Among them, (1) water conservation: we use the model method for water conservation capacity to evaluate the function quantity, and the rainfall data in the calculation function comes from "Jiangyin Statistical Yearbook 2021" (Jiangyin Statistics Bureau, 2021), the evapotranspiration data is calculated according to the Haude method, and the surface runoff data of different land types come from "Guidelines for Ecosystem Product Value Accounting (Trial)" provided by Jiangyin. (2) Flood regulation and storage: This function is characterized by the sum of water storage capacity of vegetation and stagnant water (reservoirs, lakes, swamps) in flood period. The data of rainstorm rainfall comes from "Jiangyin Statistical Yearbook 2021" (Jiangyin Statistics Bureau, 2021), and the data of rainstorm runoff of different land types come from "Guidelines for Ecosystem Product Value Accounting (Trial) ", the total storage capacity of the reservoir refers to "Jiangyin Statistical Yearbook 2021" (Jiangyin Statistics Bureau, 2021), and the bulk density and other parameters of the swamp flood storage capacity are from "Guidelines for Ecosystem Product Value Accounting (Trial)". (3) Air purification: We use the self-purification ability of ecosystem to estimate the function quantity. The types of air pollutants are SO_2, NO_X and dust. The data of the purification amount of air pollutants in different land types come from "Guidelines for Ecosystem Product Value Accounting (Trial) ". (4) Water purification: We use the purification function of ecosystem water environment as the evaluation index, the pollutant types are COD, ammonia nitrogen and total phosphorus, and the data comes from "Guidelines for Ecosystem Product Value Accounting (Trial) ". (5) Wind prevention and sand fixation: We take the wind erosion reduction of ecosystem as the evaluation index. The calculation process of parameters such as soil erosion factor and climate erosion factor refer to Appendix C.2 of "The Technical Guide on Gross Ecosystem Product (GEP)" (GEP, 2023), and NDVI data comes from Geospatial Data Cloud (https://www.gscloud.cn/). (6) Carbon sequestration and oxygen release: We all use the NEP method to estimate their function quantity, and the conversion factor comes from Appendix C.3 of "The Technical Guide on Gross Ecosystem Product (GEP)" (GEP, 2023).

The evaluation types of ecosystem regulation service value in Jiangyin include water conservation, flood regulation and storage, air purification, water purification, wind prevention and sand fixation, carbon sequestration and oxygen release. The evaluation methods, calculation formulas and calculation parameters of each service type are shown in Table 2.

In Table 2, we use the shadow project method to evaluate the value of water conservation, and use the replacement cost method to evaluate the value of other regulation services. The cost sources of each method are different. Among them, (1) Water conservation, flood regulation and storage: cost data refer to "Specifications for Assessment of Forest Ecosystem Services" (Forest Ecosystem Services, 2008). (2) Air purification: The treatment cost comes from (Shi, 2016). In addition, we calculate the value of negative ions, which is composed of indicators such as negative ion concentration (Yao et al., 2019), negative ion lifetime (Wang and Yu, 2013), negative ion production cost (Forest Ecosystem Services, 2008) and vegetation height, so as to jointly evaluate the air purification value. (3) Water purification: The treatment cost refers to the market price. (4) Wind prevention and sand fixation: the cost refers to "Specifications for Assessment of Forest Ecosystem Services" (Forest Ecosystem Services, 2008). (5) Carbon fixation: The carbon dioxide price refers to the Swedish carbon tax rate. (6) Oxygen release: The price of medical oxygen production refers to the average price of oxygen on the website of the Ministry of Health of the People's Republic of China.

3 Results analysis

3.1 Analysis of land use change

According to the data of land use in 2016 and 2020, it can be seen in Figure 2 that the land use types in the study area were mainly cultivated land, generally distributed in the west of the area; followed by the water area, which was more scattered, combined with Table 3, the sum of the area of the two areas exceeded half of the total area. In terms of area change, the area of forest land, grassland and green space increased significantly. Combined with Table 3, it can be quantitatively analyzed that the land types and land type areas in the study area underwent great changes, and the total area of each land type increased by 8.55 km^2. Among them, the forest land area increased the most, with a net increase of 3.83 km^2, and the garden land area decreased the most, with a net decrease of 2.85 km^2. In addition, the water area increased by 2.63 km^2, the cultivated land area decreased by 1.64 km^2, and the wetland area decreased by 0.03 km^2. Due to the high concentration of coastal enterprises and the long coastline, the area of grassland and green space was 0 in 2016 and increased by 3.06 km^2 and 2.54 km^2 in 2020. In terms of area change rate, the area of forest land had the largest change rate, with an increase rate of 281.62%, the change rates of garden land and water area were also relatively large, which were -86.36% and 55.98%, by contrast, the change rates of cultivated land and wetland were small (Table 3).

According to Table 4, the characteristics of land use transfer are as follows: (1) The transfer-in and transfer-out areas of other land and construction land were the largest, accounting for 24.39km^2 and 64.51 km^2 respectively, among which the main transfer-in sources of other land were construction land,

TABLE 2 Ecosystem regulation service value.

Service type	Evaluation method	Calculation function	Parameter introduction	Parameter source
Water Conservation	Shadow project	$V_{wr} = Q_{wr} \times C_{we}$	V_{wr} is the value of water conservation (yuan/a);	69
			Q_{wr} is the total water conservation in the accounting area (m^3/a);	
			C_{we} is the project cost and maintenance cost per unit capacity of the reservoir (yuan/m^3).	
Flood Regulation and Storage	Replacement cost method	$V_{fm} = C_{fm} \times C_{we}$	V_{fm} is the value of ecosystem flood regulation and storage (yuan/a);	69
			C_{fm} is the flood storage capacity of ecosystem (m^3/a);	
			C_{we} is the project cost and maintenance cost per unit capacity of the reservoir (yuan/m^3).	
Air Purification	Replacement cost method	$V_{ap} = \sum_{i=1}^{n} Q_i \times c_i$ $U_A = 5.256 \times 10^{15} \times A \times H \times K_A \times Q_A/L$	V_{ap} is the value of air purification for ecosystem (yuan/a);	69
			Q_i is the purification amount of the type i air pollutants (t/a); i is the air pollutant category, i = 1,2, . . . , n;	
			c_i is the treatment cost of type i air pollutants (yuan/t);	
			U_A is the negative ion value (yuan/a);	
			A is the area of ecosystem (hm^2);	
			H is the vegetation height (m/a);	
			K_A is the negative ion production cost (yuan/piece);	
			Q_A is the negative ion concentration (units/cubic centimeter);	
			L is negative ion lifetime (min)	
Water Purification	Replacement cost method	$V_{wp} = \sum_{i=1}^{n} Q_{wpi} \times c_i$	V_{wp} is the value of water purification for ecosystem (yuan/a);	
			Q_{wpi} is the purified amount of the type i water pollutant (ton/a); c_i is the unit treatment cost of type i water pollutants (yuan/t);	
			i is the type i water pollutant category in the study area, i = 1,2, . . . , n.	
Wind Prevention and Sand Fixation	Replacement cost method	$V_{sf} = \frac{Q_{sf}}{\rho \cdot h} \times c$	V_{sf} is the value of wind prevention and sand fixation (yuan/t);	69
			Q_{sf} is the amount of wind prevention and sand fixation (t/a);	
			ρ is the soil bulk density (t/m^3); h is the thickness of sand covered by soil desertification (m);	
			c is the unit cost of desertification control project or the unit cost of vegetation restoration (yuan/m^2).	
Carbon Sequestration	Replacement cost method	$V_{Cf} = Q_{CO_2} \times C_c$	V_{Cf} is the value of carbon sequestration for ecosystem (yuan/a);	
			Q_{CO_2} is total carbon sequestration for ecosystem (tCO_2/a);	
			C_c is the price of carbon dioxide (yuan/t).	
Oxygen Release	Replacement cost method	$V_{op} = Q_{op} \times C_o$	V_{op} is the value of oxygen release for ecosystem (yuan/a);	
			Q_{op} is the oxygen release of ecosystem (tO_2/a);	
			C_o is the price of medical oxygen production (yuan/t).	

cultivated land and garden land, and the main transfer-out sources of construction land were other land, construction land and green space. (2) The difference between the transfer-in area and the transfer-out area of construction land was the largest, and the main transfer-in sources were construction land, garden land and cultivated land. (3) The

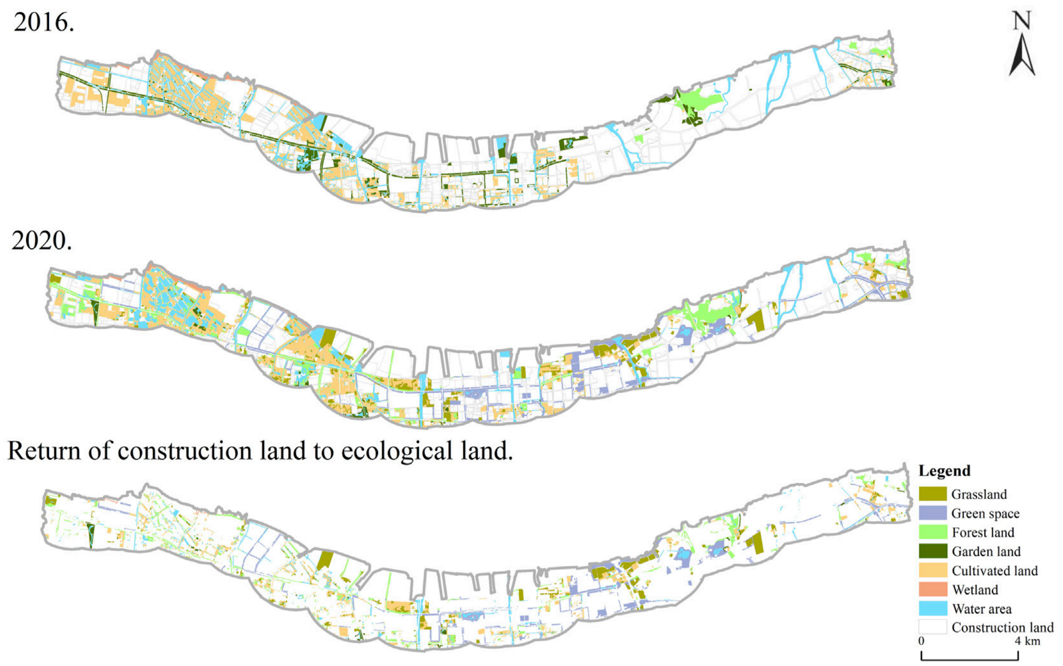

FIGURE 2
Land use situation and changes of return of construction land to ecological land in the study area of Jiangyin in 2016 and 2020.

TABLE 3 Changes of land use area of the study area in Jiangyin.

Land	2016		2020		Area change
Use type	Area/km^2	Proportion/%	Area/km^2	Proportion/%	Area change rate/%
Forest land	1.36	1.60	5.19	9.73	281.62
Grassland	0	0	3.06	5.74	0
Cultivated land	10.32	12.15	8.68	16.28	-15.89
Wetland	0.74	0.87	0.71	1.33	-4.05
Water area	4.68	5.51	7.30	13.69	55.98
Garden land	3.30	3.89	0.45	0.84	-86.36
Green space	0	0	3.54	6.64	0
Construction land	64.51	75.97	24.39	45.74	-62.19

transfer-in area and transfer-out area of forest land were 5.19 km^2 and 1.36 km^2, respectively, the main transfer-in sources of forest land were cultivated land, garden land and construction land, and the transfer-in area and transfer-out area of cultivated land were 8.57 km^2 and 10.32 km^2, respectively, the main transfer-out sources of cultivated land were cultivated land, water area and forest land (Table 4).

Combined with the obvious changes in some land types in Table 3 and Table 4, such as the large increase in the area of forest land due to the transfer of cultivated land, garden land, and construction land, the moderate transfer of cultivated land and the large transfer of construction land. To find out the reason, we can explore the contribution made by Jiangyin in balancing ecological and economic benefits from the perspective of the government. First, the increase of forest land not only benefited from the forest protection measures in response to the protection of the Yangtze River, but also benefited from ecological engineering construction. These measures have largely protected forest resources and indirectly affected ecological and social economic benefits. Second, cultivated land is the foundation of grain production, it is also an important part of “converting farmland to forests”. Therefore, moderately adjusting cultivated land can take ecological benefits into consideration without affecting grain production. Third,

TABLE 4 Transfer matrix of land use types of the study area in Jiangyin from 2016 to 2020/km^2.

2016	2020								
	Grassland	Cultivated land	Forest land	Green space	Wetland	Water area	Garden land	Other land	Construction land
Grassland	0	0	0	0	0	0	0	0	0
Cultivated land	0.0679	5.2398	1.4689	0.3558	0.0058	2.2318	0.1504	0.5311	0.2676
Forest land	0.0197	0.0001	1.1242	0.0002	0	0.0011	0	0.0031	0.2071
Green space	0	0	0	0	0	0	0	0	0
Wetland	0	0	0.0306	0	0.5986	0.0875	0	0.0000	0.0245
Water area	0.1149	0.2487	0.1660	0.0867	0.0567	3.5209	0.0106	0.2490	0.2240
Garden land	0.1337	0.2898	1.2341	0.7890	0	0.2050	0.0616	0.3114	0.2715
Other land	0.0374	0.0821	0.0423	0.0313	0	0.0312	0.0114	0.2581	0.0983
Construction land	2.5247	2.7103	1.1264	4.2756	0.0469	0.9445	0.2139	29.3635	23.3015

reducing the area of construction land can optimize the land supply structure, reduce the consumption of land resources, and realize the sustainable use of land resources. On the other hand, it can optimize the industrial structure and promote industrial upgrading, turning to green path development.

3.2 Regulation service value change analysis

3.2.1 Value change of single function of ecosystem regulation service

According to the accounting methods of ecosystem regulation services provided in Table 1 and Table 2, combined with the land use area data of Jiangyin in Table 3, we can obtain the changes of function quantities and values of seven types of ecosystem regulation services in 2016 and 2020 (Table 5) and their spatial distribution characteristics (Figure 3).

In Figure 3, the spatial distribution characteristics of the value of flood regulation and storage change significantly, which is consistent with the substantial increase of its value in Table 5, and the changes of spatial characteristics of other regulation services are not significant, which is also consistent with the results in Table 5. Combined with Table 5, it can be quantitatively analyzed that in 2016 and 2020, the value of flood regulation and storage accounted for the highest proportion of the total value, and it increased the most, which was the main contributor, while the value of oxygen release accounted for the lowest proportion, it also had the smallest change. In terms of changes, the value of regulation services in the study area increased significantly, with a change of 483 million. Among them, water conservation, flood regulation and storage, water purification, wind prevention and sand fixation, and carbon sequestration all increased, with flood regulation and storage having the largest change of 394 million, followed by water conservation of 40 million.

To investigate the reason, it can be seen from Table 3 that the change in the value of regulation services comes from the change of the function quantity. On one hand, the change of the function quantity is caused by the change of the area of different land types, which is intuitively reflected in Table 1, such as water conservation, flood regulation and storage, water purification and other regulation services, the area of some land types decreased, but benefiting from the large increase in the area of forest land and water area, the function quantity increased. On the other hand, the change of function quantity is affected by multiple factors, such as air purification, wind prevention and sand fixation, carbon fixation, and oxygen release, some parameters in their accounting methods are affected by multiple factors. Among them, the vegetation coverage factor is influenced by NDVI data, which is related to vegetation coverage and other natural factors, NEP is affected by NPP, which is related to LUC, temperature and precipitation (Guo et al., 2008). Therefore, judging from the results, the change of value is not strongly correlated with the change in land type area, but it is also affected to a certain extent.

3.2.2 Structural changes of ecosystem regulation service value

According to the data of the function quantities and values of seven types of ecosystem regulation services in the study area obtained in Table 5, combined with the land use data in Table 3, the value of each land use type in 2016 and 2020 can be obtained (Table 6).

The change of land use types in the study area affects the function of ecosystem, so the values of ecosystem regulation services also change. It can be seen from Table 6 that in 2016 and 2020, the value of forest land accounts for the largest proportion of the total value, and is the largest contributor to the value of ecosystem assets, the value of grassland was 0 in 2016 and second only to forest land in 2020. In terms of changes, the composition of the ecological value of the study area underwent major changes, and the total value increased by 480 million. Among them, the total value of forest land, grassland, wetland, water area and green space all increased, forest land had the largest increase, with an increase of 264 million, and the growth rate reached 109.54%, followed by grassland, with an increase of 176 million, and cultivated land had the smallest increase of only 0.6 million,

TABLE 5 Changes of function quantity and value of regulation services in 2016&2020.

Ecosystem regulation service	2016		2020		Changes
	Function quantity	Value (billion)	Function quantity	Value (billion)	Variation (billion)
Water conservation	1480198.07	0.09	8055865.99	0.49	0.4
Flood regulation and storage	30989979.14	2.33	83272479.10	6.27	3.94
Air purification	11906182.49	0.17	11913105.20	0.11	-0.06
Water purification	3206566.93	0.22	6855225.43	0.47	0.25
Wind prevention and sand fixation	146321.14	0.61	394564.15	0.90	0.29
Carbon sequestration	8013.24	0.096	8645.25	0.104	0.008
Oxygen release	5827.97	0.0583	5763.50	0.0576	-0.0007
Total		3.58		8.41	4.83

garden land was the only land type with a decrease in value, with a net decrease of 8 million yuan and a decrease rate of -83.3%.

Combined with Table 3 and Table 5, we can see that the reason for the value change of different land types is not single. Among them, the phenomenon of value change of forest land, grassland, water area, garden land and green space is consistent with Table 3, while the reduction of cultivated land and wetland brought about the increase of their value, this phenomenon is due to the comprehensive influence of many factors. Firstly, changes of regulation services such as water conservation of cultivated land and wetland are strongly correlated with changes of the area of land types, the reduction of the two land types led to the decrease of the regulation service value. Secondly, changes of function quantities of wind prevention and sand fixation, carbon sequestration, and oxygen release are less correlated with LUC. For wind prevention and sand fixation, the vegetation coverage factor in the accounting method is represented by NDVI, and NDVI is related to vegetation coverage and other natural factors, in Table 4, the transfer of cultivated land changed the vegetation coverage, which led to the change of the function quantity. For carbon sequestration and oxygen release, NEP is affected by NPP, and NPP is affected by multiple factors, making the correlation between the value of cultivated land and wetland and land type areas weak, from the results, the value of cultivated land and wetland increased slightly.

4 Discussion

4.1 Response mechanism of ecological value to the protection measures along the river in Jiangyin

Generally speaking, protection measures based on ecological problems such as the deterioration of ecological environment and the prominent contradiction between human and land will objectively change the area and type of land use, and the change of land use will be directly reflected in the change of ecosystem service value. Many previous studies have explored this (Wang et al., 2021; Li and Li, 2022; Liu et al., 2022), but most scholars focus on the interaction between LUC and ESV, while ignoring the actual causes of land use change, which makes the logic chain of the whole research incomplete. Based on this, this study will briefly discuss the response of ecological value to the reasons behind LUC in order to complete the logic chain and provide suggestions for subsequent ecological protection.

Combining Table 3 and Table 5, in Section 3.2.1, we analyzed the root cause of the change of the value. Among them, the value of water conservation, flood regulation and storage, and water purification are affected by changes of land types. The value changes of wind prevention and sand fixation, carbon sequestration, and oxygen release are affected by many factors, and LUC is also one of the influencing factors. So we can explore the protection measures launched by Jiangyin that lead to LUC according to some changes. For example, the increase of the value of water conservation, flood regulation and storage, and water purification is due to the increase of the area of forest land and water areas, this is reflected in the measures taken by Jiangyin for forest land and water areas. In terms of forest land, under the background of the sharp contradiction between forest land protection and economic development and the relatively weak forestry foundation, Jiangyin has carried out ecological restoration measures, which has promoted a substantial increase in the area of forest land in the coastal area. In terms of water areas, under the background of serious water source and river pollution and soil erosion in recent years, Jiangyin has improved the supply capacity of water source protected areas, promoted the normal operation of protected areas through source control and interception, and reduced soil erosion, then adopted measures such as river dredging and shore appearance treatment, which reduced pollution and improved the ecological problems of water areas.

In addition to the increase of the area of forest land and water areas, changes of other land types such as grassland and green space are also important influencing factors, this is reflected in the governance of mines and shorelines in the coastal area by Jiangyin. Under the background of long-term development of the mountain body and serious damage to agricultural land and construction land, Jiangyin closed the quarry mines and carried out several mining area treatment projects, effectively controlling the mine geological environment, curbing the trend of continuous

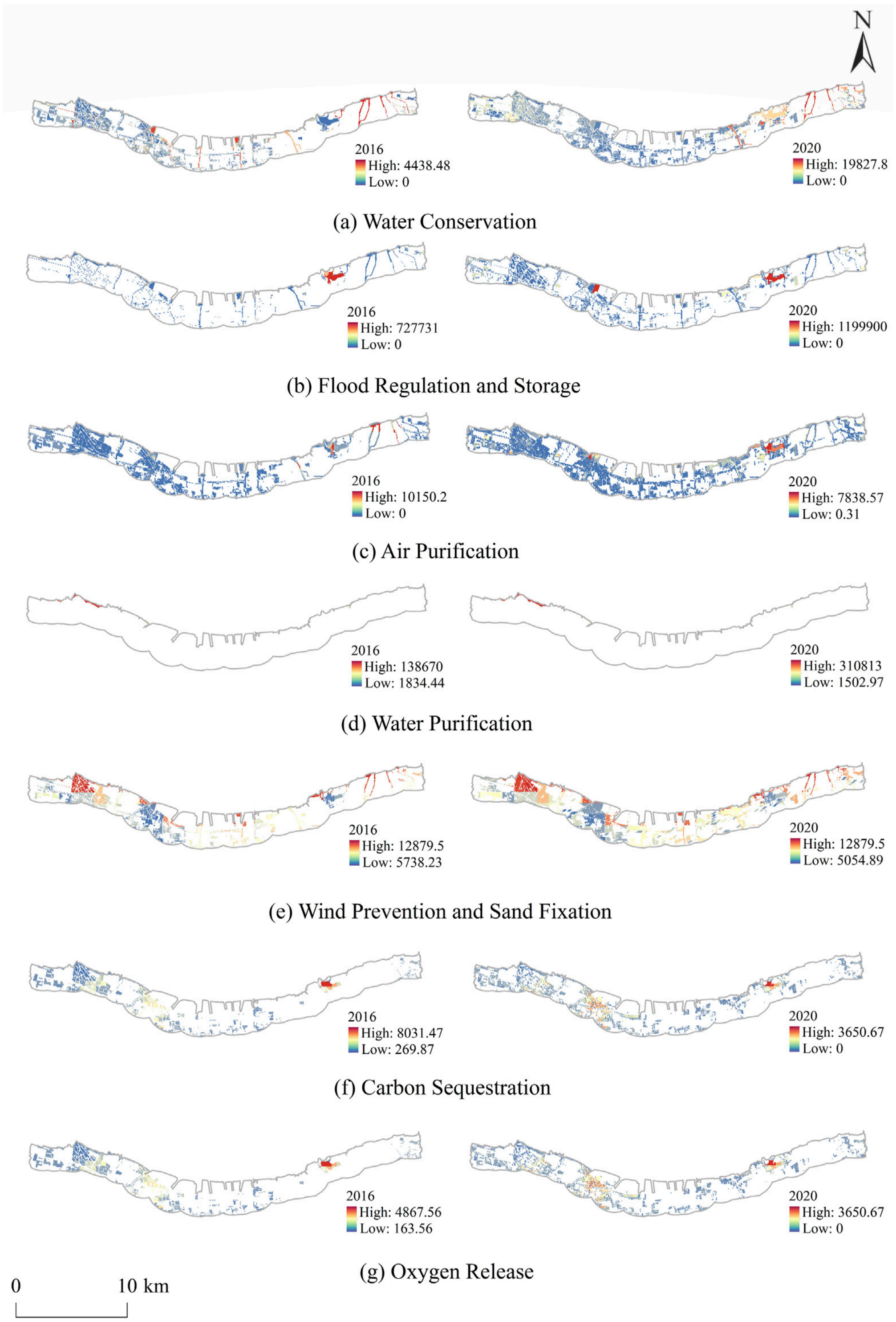

FIGURE 3
The spatial distribution of the value of regulation services in the study area in 2016 and 2020 **(A–G)**.

land damage, and increasing the area of ecological land. In terms of coordinating the development of the shoreline, Jiangyin has successively completed the closure and relocation of chemical enterprises along the river, optimized the ecological environment along the coast, reduced the development intensity of the shoreline, increased the green area of the riverside, which offers the potential to increase the ESV.

Combined with Table 3, we also find that the protection measures by Jiangyin still lacking, which is reflected in the reduction of wetlands, the reason is the lack of awareness of

TABLE 6 Changes of land use value of the study area in Jiangyin.

Period	Forest land (billion)	Grassland (billion)	Cultivated land (billion)	Wetland (billion)	Water area (billion)	Garden land (billion)	Green space (billion)	Total
2016	2.41	0.00	0.457	0.26	0.30	0.096	0.00	3.523
2020	5.05	1.76	0.463	0.51	0.54	0.016	0.02	8.359
Value change	2.64	1.76	0.006	0.25	0.24	-0.08	0.02	4.836
Change rate of value/%	109.54		1.31	96.15	80	-83.3		137.27

wetland protection and inadequate protection measures. Therefore, considering that human-induced economic and social factors play a leading role in the change of land use quantity (Verburg et al., 2004) (this process can be visualized by PSR framework (Figure 4)), combined with the change of land use along the river, we can put forward the method of setting the ecological protection red line, which is an important measure to construct the regional ecological security pattern and promote the regional economic and social development. Firstly, compulsory and strict protection can be carried out for areas with important ecological functions and fragile water ecological environments along the river (Kong et al., 2019), and demonstration projects can be developed in this area. Secondly, an integrated management and control system should be established for areas with reduced service value, daily supervision should be strengthened, and ecological compensation mechanism should be improved, on this basis, ecological re-greening should be implemented, and ecological protection projects such as returning farmland to forests should be vigorously promoted. Thirdly, the development activities of areas with increased service value should be further restricted and developed moderately. Finally, it is also an indispensable step to consider making tenure security one of the major planned outcomes of land-use planning process (Uchendu et al., 2017). In a word, scientific classification of land is conducive to regulating land resources macroscopically, reducing land use costs and promoting urban development.

In general, when studying the interaction between ecological value and LUC, it is necessary to explore the relationship between ecological value and the actual causes of LUC. This part briefly summarizes the response mechanism of ecological value to the protection measures along the river in Jiangyin, and put forward relevant ecological protection suggestions, but there are still many deficiencies in the research. On one hand, the discussion on the response mechanism is not comprehensive enough, and the discussion on the protection measures of other land types is ignored. On the other hand, due to the limitations of data acquisition and other reasons, this study only considered the government-led social and economic actions behind LUC, ignoring individual factors and natural factors. The direction of future research is to increase the discussion of other ecological land protection measures and the response mechanism of ecological value to non-government factors.

4.2 The transformation path of ecosystem service value

Before the effective transformation of ecological value, we must understand that the monetization evaluation of ecosystem service value is aimed at showing the potential value of ecosystem service scientifically, which is not the same as market manifestation (Shi and Chen, 2022). The correlation between the two is that market manifestation can transform the potential value of ecosystem services into actual economic value through different means, and there are two ways, namely, market mechanism and government regulation. Market mechanism means and government regulation means are respectively through ecological industrialization and ecological compensation and other mechanisms to make potential value appear, so that it can be transformed into realistic economic value (Shi, 2021).

The value of ecosystem services cannot be directly transformed into economic value. In addition, due to the disunity of the current value accounting system, the indicators and methods adopted by different researchers are also different, which leads to the difficulty in comparing the values of different types of ecosystems in different degrees, and the unconvincing results. In addition, the market of ecological products lacks institutional guarantee. Therefore, in order to effectively transform the ecological value, extensive data collection and collaboration and sharing among government departments, social organizations, companies and enterprises are required by different means. Specifically, ecological products are carriers and attachments of ecosystem service value, and ecological value depends on ecological products. Therefore, we can also discuss the transformation of ecosystem service value from the perspective of ecological product transformation. Many studies have explored from this perspective, some scholars propose that the government should be the guide and the market should be the main body to establish an operation transformation mechanism for ecological products from resources to assets and then to capital (Nie and Jin, 2019), some believe that both the government and the market can be the main body (Liu and Mou, 2020), and the two main bodies have different realization paths. However, these typical studies have some shortcomings. On one hand, they are based on the premise that the concept of ecological products is not yet clear, on the other hand, most of them are normative analyzes with subjective judgments, which cannot be combined with specific cases. In addition, there are also studies based on the classification of ecological products (Wang et al., 2020b; Gao et al., 2020). These scholars have different

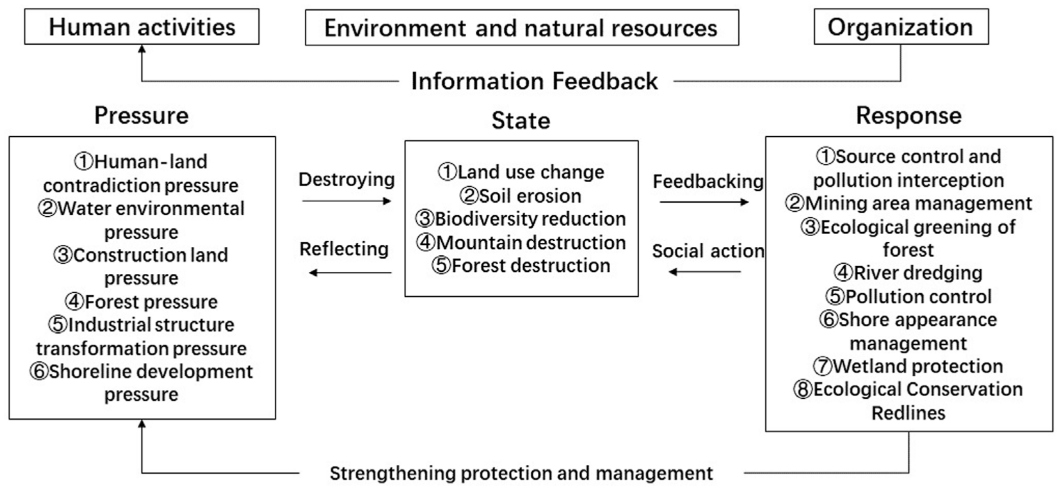

FIGURE 4
"Pressure-State-Response" framework of ecological value.

classifications of ecological products and put forward multiple models, but this type of research lacks empirical analysis, making the conclusions not typical. Based on this, according to the attribute differences of ecological products, we divide them into three categories, namely, pure public products, private products and quasi-public products. Combined with the existing research, the transformation paths of three different types of products are proposed:

Firstly, in terms of the value transformation of ecological products that are purely public products, the government, as the main body, can lead private individuals or enterprises to improve the ecological compensation mechanism and optimize market trading rules. The "Opinions on Adjusting and Perfecting the Ecological Compensation Policies" issued by Jiangyin in 2022 raised the compensation standard, curbed the "non-agriculturalization", and realized the greening of the society and the profits of farmers and fishermen, thus realizing the transformation of the value of ecological products. This measure reflected the leading role of the Jiangyin Municipal Government. In addition, Jiangyin can take the form of transfer payment and redemption to make ecological compensation and financial subsidies for ecological functional areas such as natural wetlands and ecological public welfare forests, as well as farmers and fishermen, so as to improve the ecological compensation mechanism. Jiangyin can also build and improve a series of trading mechanisms for ecological resources and ecological products, such as carbon sink trading and emission trading, to promote and optimize the construction of relevant market trading rules and systems (Figure 5).

Secondly, in terms of the value transformation of ecological products with private product attributes, private individuals or enterprises, as suppliers, can innovate and process ecological products and expand the ecological value chain with the assistance of the government, so as to transform ecological value into industrial value. Jiangyin is rich in its own characteristic ecological products, and the market plays a decisive role in the allocation of ecological resources. Therefore, Jiangyin can rely on its own regional brand products, such as Huaxi rice, Gushanshui peach, Huangtu grape, Yuecheng Cuiguan pear and other characteristic aquatic products along the river. On the basis of rural revitalization and cross-regional cooperation, through innovative processing of resource endowments and expansion of the product value chain, it can expand its own ecological advantages and promote the transformation of ecological advantages into industrial advantages, develop and utilize ecological products according to local conditions, and convert ecological value into industrial value (Figure 5).

Thirdly, the value transformation of ecological products of quasi-public products should be considered from two aspects. On one hand, the government can guide the establishment of environmental protection funds and ecological banks to promote individuals or enterprises; For another hand, under the authorization of the government, individuals or enterprises can enhance the ecological value of ecological products through various ways and convert them into ecological product income. Therefore, the Jiangyin Municipal Government should set up environmental protection fund and "Two Mountains" banks, actively guide individuals and various financial enterprises to increase their support for regional green development, and give priority to key projects for realizing ecological product value. What's more, the Jiangyin Municipal Government can entrust the ecological resources to the market entities in the form of authorization, and promote the cooperation between individuals and financial institutions and counties to set up relevant special funds, promote the centralized flow of resources, enhance the ecological value, and enrich the ways to realize the value of ecological products, so as to effectively transform the ecological value into ecological products operational income (Figure 5).

To sum up, taking the classification of ecological products as a perspective to study the transformation of ecological value can clearly reflect the collaboration among multiple subjects such as the government and enterprises under different circumstances.

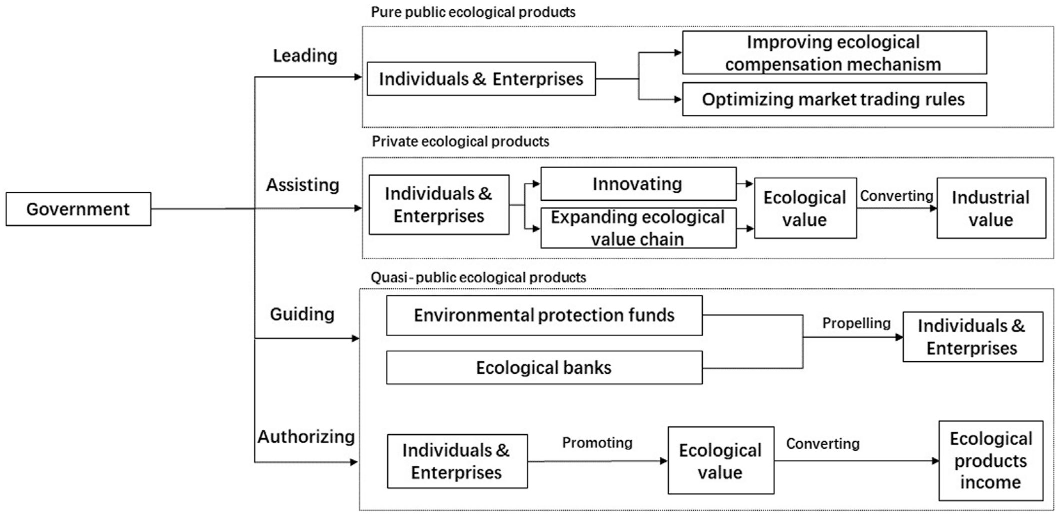

FIGURE 5
Framework of ecosystem service value transformation.

Combined with the quantitative analysis of the coastal ecosystem services in this study, it can provide a theoretical basis for the practice and innovation path of the subsequent value transformation of ecological products. However, there are still many shortcomings in this study. First, the combination of theoretical research and practical application is insufficient. Second, there are some bottlenecks in the value transformation of ecological products, for example, the accounting system for the value of ecological products is not perfect, and the market transaction mechanism for the value transformation of ecological products is not yet mature. In future research, we will comprehensively use theoretical analysis and empirical analysis, focus on the realization of the value of emerging ecological products, and deeply explore the more accurate and detailed transformation paths of different types of ecological products in different regions.

5 Conclusion

This study takes the coastal area of Jiangyin as the study area, analyzes the changes of land use data in 2016 and 2020, and the changes of ecosystem regulation service value under LUC, and draws some different conclusions from previous studies. The results showed that:

(1) In 2016 and 2020, the overall land use changes in the study area were relatively large, and the cultivated land and water area accounted for more than half of the total area. The total area of each land type increased by 8.55 km^2, with the largest increase in forest land and the largest decrease in garden land. The grassland and green space grew from scratch, with a net increase of 3.06 km^2 and 3.54 km^2 respectively; the transfer-in area of other land was the largest, and the main transfer-in sources were construction land, cultivated land and garden land, the transfer-out area of construction land was the largest, and the main transfer-out sources were other land, construction land and green space.

(2) In terms of the structural changes of ecosystem regulation service value, the total value of regulation service in the study area increased by 480 million yuan, of which forest land increased the most, by 264 million yuan, with a growth rate of 109.54%, while cultivated land increased the least, only by 0.6 million yuan. Garden land was the only land type with a decrease in value, with a net decrease of 8 million yuan and a decrease rate of -83.3%. In 2016 and 2020, the value of forest land accounted for the largest proportion of the total value, the value of grassland was 0 in 2016, and its proportion was second only to forest land in 2020, the value of other land types changed little.

(3) In terms of the value change of single function of ecosystem regulation service, the value of flood regulation and storage accounted for the highest proportion and the largest change in 2016 and 2020, the increase of the value of water conservation was second only to flood regulation and storage, both of which were mainly due to the substantial increase of forest land, the value of air purification and oxygen release decreased, and the value of other functions increased.

However, there are still many deficiencies and the content that needs to be improved in this study, the details are as follows:

(1) The selection of some parameters refers to earlier literature, which reduces the accuracy of the results. Improving the timeliness of data is one of the key points in future research. (2) The accounting methods of value are not rich enough, and the pertinence is weak. One of the key points of future research is to optimize the accounting methods. (3) The discussion on the response mechanism of protection measures is not comprehensive enough, ignoring the discussion on the protection measures of other land types, only the

government-led factors behind the land use change are considered. In future research, we will increase the discussion of other ecological land protection measures and the response mechanism of ecological value to non-government factors. (4) There are some defects in the transformation path of ecological value. In future research, we will comprehensively use theoretical analysis and empirical analysis, focus on the realization of the value of emerging ecological products, and deepen the exploration of more accurate and detailed transformation paths for different types of ecological products in different regions.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author. Requests to access these datasets should be directed to jincheng@njnu.edu.cn.

Author contributions

Conceptualization methodology formal analysis investigation writing—original draft preparation data curation visualization, SZ; software resources, SZ, XP, LW, and HS; validation supervision project administration, SZ and CJ; writing—review and editing, SZ, CJ, and HS; funding acquisition, CJ. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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