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Land ecological protection polices improve ecosystem services: A case study of Lishui, China

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Ecological priority and green development have become the main theme of the times in China. The policy performance evaluation of ecological protection needs to quantitatively identify the changes of ecosystem quality and services firstly. This paper constructed the analytical framework driven by ecological protection policy of “Goal-oriented—Policy driven—Ecological quality—Service improvement”, and used multi-source data to establish the evaluation approach of “ecosystem quality-ecosystem services-ecosystem services value”. This study took Lishui as a case study to confirm the framework proposed. The results show that the ecosystem quality of Lishui has been steadily improved in recent 10 years. The overall quality of ecosystem services such as vegetation oxygen release, carbon sequestration, pollution removal, cooling service, humidification regulation and water conservation service has been improved by a range of 2%–6%. The value of ecological products has increased from 143.28 billion CNY in 2009 to 150.23 billion CNY in 2019. Lishui has implemented the development concept of “ecological civilization”, and the policies of ecological restoration or land remediation have changed land use and ecosystem quality, which was the main driving force for the improvement of ecological quality and the main promotion of ecological products value. The methods and results can provide insight into the impact of land policies on ecosystem services and decisions that support for further optimizing land ecological protection policies.

KEYWORDS

ecological civilization, ecological quality, ecological economic, ecosystem service, land use, spatial analysis

Introduction

With the development of industrialization and urbanization, more than 77% of land has been modified by the direct effects of human activities (Watson et al., 2018; Vargas et al., 2019; Liu et al., 2021). A large amount of natural vegetation has been destroyed, which resulted in irreversible changes in the ecosystem. At present, ecological problems

have become a “bottleneck” to further economic development, and China’s economy has transformed from the stage of high-speed growth to the stage of high-quality development (Wang, 2021). The construction of ecological civilization is a major plan related to the well-being of people and the future of nature. Ecological civilization is a form of human civilization based on the premise of respecting and maintaining nature, with the connotation of establishing sustainable modes and the goal of the continued development of mankind in the future (Marinelli, 2018; Hansen et al., 2018). Adhering to the concept of “ecological civilization”, unswervingly taking the road of ecological priority and green development have become major strategic choices of national development (Jiang et al., 2019). Ecosystems contribute to economic development through the supply of ecosystem services. Information and data on ecosystem services are required to support policy making. Currently, the monitoring of ecosystem change and the accounting of ecosystem service value have become important test criteria for the effectiveness of ecological civilization construction (Jia et al., 2021; Hu and Zhang, 2021). Therefore, it is of great practical significance to establish an evaluation method for changes in ecosystem quality and to account for the value of ecosystem services.

Ecosystem services refer to all the benefits that human beings get from the ecosystem. In recent years, the accounting of ecosystem services and value has become a hot topic of research (Mancini et al., 2018; Liao et al., 2021; Wu et al., 2021). The accounting of ecosystem services value attaches a “price tag” to the clear waters and green mountains, which presents the benefits and values brought from the ecosystem to human beings visually, and provides a measurement standard for the target responsibility system of ecological environmental protection and off-office auditing of natural resource assets (Song and Ouyang, 2020). Different ecosystem types provide different services and values for human beings. In recent years, based on different study areas, time scales and ways of service classification, scholars from different countries have assessed the ecosystem services for different ecosystem types, such as forest, land, grassland and wetland (Rahimi et al., 2020; Tamburini et al., 2020). Many studies have calculated the value of ecosystem services. The results not only enrich the system of ecological value accounting methods, but also provide a theoretical basis for the evaluation of ecological protection achievements and the exploration of ecological compensation methods (Ouyang et al., 2020). The accounting of the quality and value of ecosystem services is the basis of ecological environment assessment (Li et al., 2018; Chen et al., 2022). Besides, through the accounting of the quality and value of ecosystem services, the spatial and temporal pattern change of ecosystem services and functions can be expressed (Wu et al., 2015; Xiang et al., 2022). However, the current research focuses on the quality and value accounting of ecosystem services, and there is still insufficient research on the practice of ecosystem

service value changes and policy performance evaluation of ecological construction.

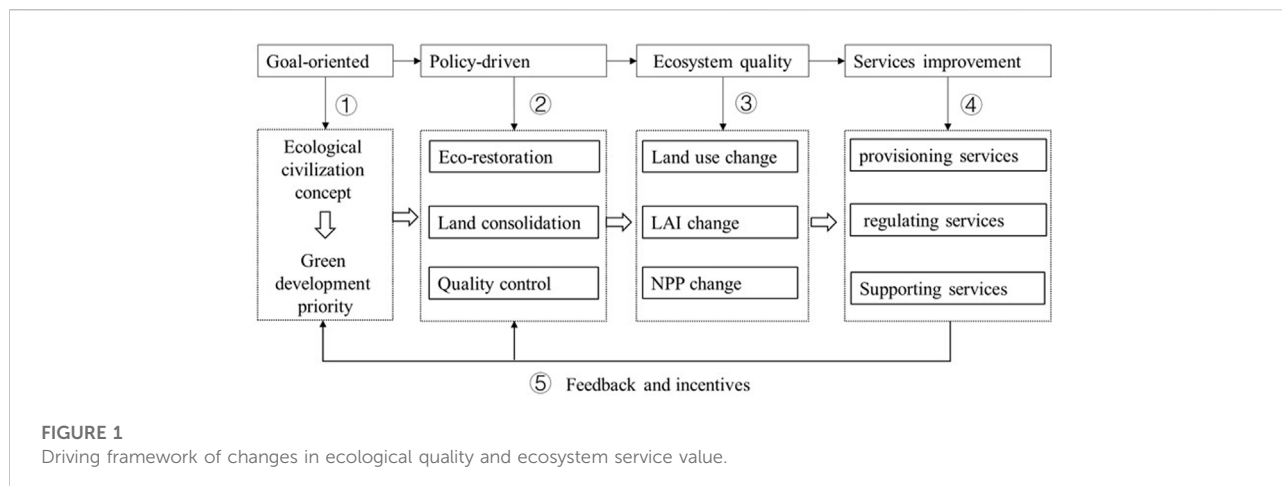
We tried to establish an ecosystem evaluation system of “ecosystem quality-ecosystem services-services value”, and explored the technical methods of monitoring the temporal and spatial changes of ecosystem quality, services and value. Lishui is one of the ecological demonstration zones in China, and it is the practice and innovation base of ecological civilization construction. This study aimed to 1) assess the temporal and spatial changes of Lishui ecosystem quality and service value in the past 10 years; 2) consider the causes and mechanisms of policy-driven ecosystem changes; 3) provide insight to the impact of land policies on ecosystem services and support for ecological construction performance evaluation.

Study area and methodology

Analytical framework

China’s eco-environmental protection is mainly a top-down government behavior. Over the past 2 decades, China’s environmental policy has two important nodes (Xu et al., 2020). First, in 2008, the State Environmental Protection Administration was upgraded to the Ministry of environmental protection (at the ministerial level) and became a constituent Department of the State Council; Second, the Chinese government proposes to establish a systematic and complete system of ecological civilization. With the goal of ecological and environmental protection, the supervision system of ecological and environmental administrative law enforcement has gradually taken shape from the central to local level, including total amount control, quantitative assessment and strict accountability (Lü et al., 2012; Li et al., 2022). Guided by the goal of ecological civilization construction of the central government, local governments refine and implement macro policies, putting forward specific implementation paths (Viglizzo et al., 2012; Albert et al., 2016; Cord et al., 2017). In order to further explore the causes and mechanisms of ecosystem quality improvement and find out ecosystem service enhancement in Lishui, we proposed an analytical framework of “Goal-oriented—policy driven—Ecological quality—Service improvement” (Figure 1).

We divide the impact of policies on ecosystem services into five stages: goal orientation, policy drive, Ecological change, ecosystem service change and feedback (Figure 1). ① Goal orientation means that local policies implement the national strategic goal of ecological civilization construction, and they are reflected in the government’s Five-Year Plan and Special Ecological plan. Lishui put forward the government objectives of ecological protection at different stages. In 2008, Lishui released the outline of ecological civilization construction for the first time in China. Lishui proposed to build an ecological



civilization demonstration area in the 12th Five Year Plan in 2011. Lishui implemented national ecological protection and ecological economy demonstration area in the 13th Five Year Plan in 2016. In 2019, Lishui proposed the pilot of value realization mechanism of ecological products. ② Formulate operable policies based on ecological goal. Under the government's goal, Lishui has issued a series of policies to implement the ecological objectives. During the 12th Five Year Plan period, it has proposed water and soil loss prevention, mine restoration to strength the protection and construction of ecological public welfare forests and nature reserves. Lishui established an automatic monitoring system for water quality and atmosphere, and improved the ability of environmental monitoring. During the 13th Five Year Plan period, Lishui carried out the demarcation of ecological red line, established ecological red line control rules, and improved the forest ecological benefit compensation system. Land remediation and ecological restoration projects were vigorously implemented, which guided farmers to move from ecologically sensitive areas to cities, freed up ecological space and reduced human interference in protected areas. ③ Policy driven changes in ecological spatial patterns and quality. Driven by eco-environmental protection policies, land use has changed, forest area has increased, environmental quality has improved, and the supply capacity of ecosystem services has improved. ④ Policies promoted the change of ecosystem services, such as provisioning services, regulating services, supporting services and cultural services. The beautiful eco-logical environment provides a material basis for economic development such as eco-tourism and ecological agriculture; ⑤ Policy performance would generate feedback and incentives. Through the realization of the value of ecological products, the win-win situation of ecological protection and economic development has been realized, which not only further inspired the government to formulate ecological protection measures, but also stimulated residents to actively participate in ecological protection.

Therefore, this study mainly demonstrates the framework of “Goal-oriented—policy driven—Ecological quality—Service improvement”. Taking the ecological protection practice of Lishui as an example, this paper used remote sensing and other objective data to evaluate the changes of ecological environment quality and ecosystem services that focusing stages ③ and ④ in Lishui. This research will provide technical support for policy performance evaluation.

Study area

Lishui is located in the southwest of Zhejiang Province, China, with an area of 17,300 square kilometers and a resident population of 2.507 million (Figure 2). Besides, its urbanization rate is 61.82%. Lishui has a subtropical monsoon climate, with an annual average temperature of 11.5–18.3°C. The surface of Lishui belongs to the hills in the south of the Yangtze River, and the forest coverage reaches 81.7% (Wu et al., 2021; Diao et al., 2022). It is the most ecologically preserved area in East China. Its superior ecological environment is not only an important green ecological barrier in East China, but also one of the centers of biodiversity, which plays a decisive role in the ecosystem stability of Zhejiang Province and even the whole East China.

Lishui is an important birthplace and practice place of the concept that “Clear waters and green mountains are as good as mountains of gold and silver” in China. As one of the first batch of national ecological civilization pilot demonstration areas in China, Lishui has adhered to the ecological priority green development strategy chronically. Lishui issued a series of policies to protect the ecosystem and improve the environmental quality in the past decade. The ecological environment quality and people's living standards of Lishui have been improving steadily. Among them, indicators such as ecological environment quality, development process index,

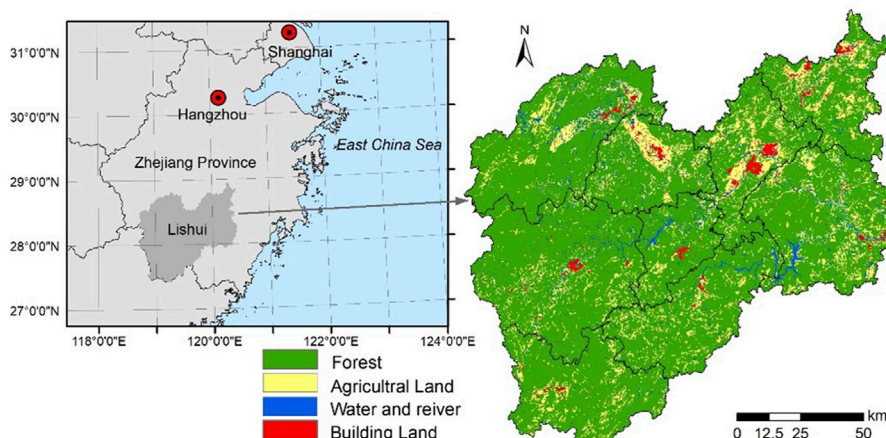


FIGURE 2
Study area and land use.

and farmers' income growth have been in the forefront of Zhejiang Province for many years.

Methodology

We used multi-source remote sensing to interpret data products and analyzed the changing characteristics of land use, ecological quality and ecosystem services in Lishui from 2009 to 2019 by means of ecological analysis and ecosystem service value accounting. TM images interpretation data and statistical data from natural resources administration were used to study how policy driven land use change. Ecosystem quality was characterized by net primary productivity (NPP) and leaf area index (LAI). The data were mainly from MODIS and the spatial resolution of NPP and LAI is 500 m.

For a specific region, the ecosystem provides a variety of different services. It requires to grasp one or more core services representative and typical in the area while assessing regional ecosystem regulation services (Zhao., 2015). By considering the actual situation around Lishui city and scientific operability, we choose six regulating services to assess regulating services of Lishui city, including carbon sequestration, oxygen release, PM_{2.5} removal, temperature regulation, humidification adjustment, water conservation. These regulating services mentioned above are particularly important in Lishui City. The basic parameters including the dry deposition flux of PM_{2.5}, daily transpiration, daily variation of regional water pressure, measured precipitation, measured stand evapotranspiration. All meteorological data was obtained from China Meteorological Data (<http://data.cma.cn/>) and the spatial resolution of all the meteorological data is 500 m by Kriging interpolation. The specific evaluation methods of ecosystem services are shown in Table 1.

The quantification of ecological product value was mainly based on the Gross Ecosystem Production (GEP) accounting method (Zhejiang Provincial Market Supervision Administration, 2020). It was calculated by multiplying the unit price of the substitute. The price coefficient per unit quantity is shown in Table 2.

Results

Changes of ecosystem quality in Lishui

Net primary productivity (NPP) and leaf area index (LAI) were used to characterize ecosystem quality. Based on the remote sensing image data from 2009 to 2019, the change trend of NPP and LAI was analyzed using the pixel-by-pixel slope method with a resolution of 500 m (Figure 3). The results showed that both NPP and LAI in Lishui showed an upward trend in recent 10 years, as shown in Figure 2. 93% of the Land, NPP showed an increasing trend, of which 24% had a significant increase, and 69% had an insignificant increase. 74% of the land LAI showed an increasing trend, of which 18% had a significant increase, and 56% had an insignificant increase. The city's NPP increased at an average rate of 4 g C m⁻² per year, and the LAI increased at an average rate of 0.8% per year, indicating that the quality of Lishui's ecosystem was overall improved.

The trend of significant decline in NPP and LAI had similar characteristics in space. 7% of the urban land, NPP showed a downward trend, but only 0.9% of the land reached a significant level. LAI declined in the 26% of the land, and 3.5% reached a significant level of decline. Significant decline of NPP and LAI were mainly distributed in the areas of rapid urbanization. The

TABLE 1 Evaluation method of ecosystem services.

Service type	Modeling	Parameter meaning
Carbon sequestration	$ES_c = 1.63 \times (NPP - R)$	NPP is plant net primary productivity, and R is soil respiration rate
Oxygen release	$ES_o = 1.2 \times (NPP - R)$	NPP is plant net primary productivity, and R is soil respiration rate
PM _{2.5} removal	$PM_{Removal} = F \times A \times (1 - R)$	F is the dry deposition flux of PM _{2.5} (g/(m ² ·h)), a is the blade surface area, and R is the resuspension rate of PM _{2.5}
Temperature regulation	$Q_{tr} = Q_{ew} \times v_{ch} \div (H_{ml} \times A' \times 10^4) \div p_c$	Q _{ew} is the daily transpiration (kg) in the forest growing season, v _{ch} is the heat of vaporization of water at 20 °C (kJ/kg), H _{ml} is the height of the atmospheric mixing layer (m), and P _c is the volumetric heat capacity of air (M3·°C)
Humidity regulation	$Q_{hi} = \Delta e \div e_s \times 100$	Δe is the daily variation of regional water pressure (HPA), and ES is the regional saturated water vapor pressure (hpa)
Water conservation	$Q_{cw} = 10(P - E - C)$	P is the measured precipitation outside the forest mm ·a ⁻¹ ; E is the measured stand evapotranspiration, unit mm ·a ⁻¹ , and C is the measured stand surface rapid runoff mm ·a ⁻¹

TABLE 2 Value efficient of ecosystem services.

Ecosystem service	Carbon sequestration	Oxygen release	PM _{2.5} removal	Temperature regulation	Humidity regulation	Water conservation
Substitute	The price of carbon trading	Industrial oxygen production cost	Disposal cost of PM _{2.5}	Power consumption of air conditioning	Power consumption of humidifier	The price of water
Unit price	50 CNY per ton	1200 CNY per ton	150 CNY per ton	0.57 CNY per kwh	0.57 CNY per kwh	2.7 CNY per ton

TABLE 3 Changes of ecosystem material quality and ecosystem service value in Lishui City.

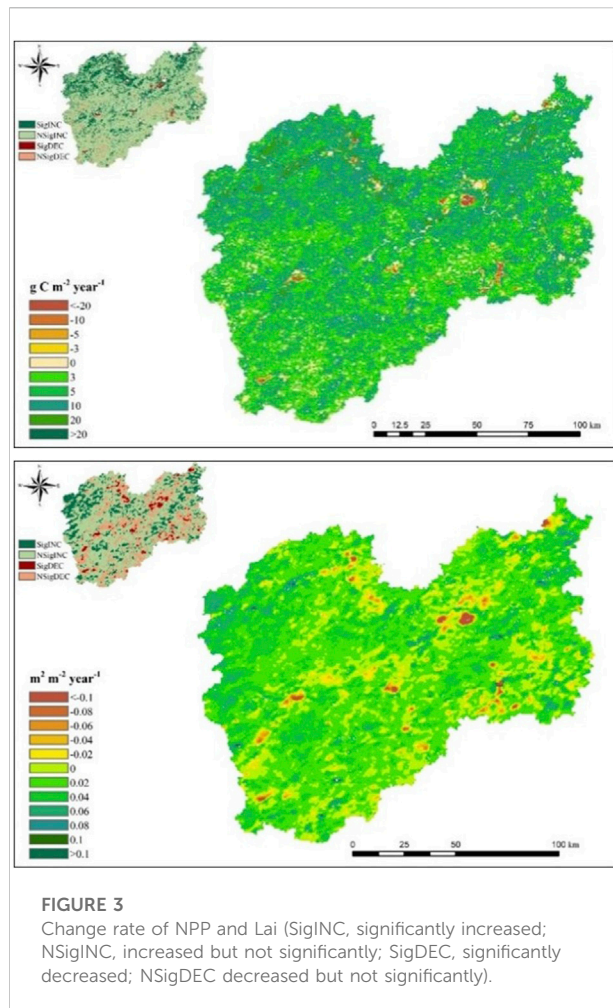
Type of service	Services change			(M¥)Value change		
	2009	2019	Variation	2009	2019	Change in value
Carbon sequestration (MT)	5.72	5.987	0.26	233.7	244.1	10.4
Oxygen release (MT)	3.03	3.17	0.14	3,639.9	3,802.4	162.5
PM _{2.5} removal (kT)	207.6	211.8	4.15	3.3	3.4	0.1
Temperature regulation (BKWh)	173	183	103.8	98,610.0	104,526.6	5,916.6
Humidity regulation (BKWh)	3.38	3.53	1.49	836.6	874.0	37.4
Water conservation (Mm ³)	148.0	151.0	3.04	39,959.3	40,780.3	821

conversion of ecological land and cultivated land into urban land was the main reason for the decline of ecosystem quality.

Temporal and spatial changes of ecosystem service

The average values of carbon sequestration and oxygen release in 2009 were 90.1 g C m⁻² a⁻¹ and 175.3 g m⁻² a⁻¹. Carbon sequestration and oxygen release were related to vegetation productivity so they had a similar spatial pattern. High value

areas of them were in areas with high forest cover, such as Qingyuan, Longquan and Suichang, while low value areas were in urban and farmland-intensive areas, respectively. The average values of pollution removal, temperature regulation and humidity regulation were 1.6g m⁻², 6.6°C and 14.7%. These three types of services are related to the leaf area index, therefore they have similar spatial patterns. Areas with stable vegetation system and complete canopy structure were high-value areas, while towns and farmland were low-value areas. The variation range of water conservation was 176–958 mm, and the average value was 855 mm. Water conservation is a comprehensive function of precipitation,



vegetation and terrain. The southern part of Lishui was higher than the northern part, as shown in Figure 4.

The spatial distribution pattern of ecosystem services in 2019 is shown in Figure 5. We took 2009 as the benchmark, and the range of ecosystem service improvement was between 2 and 6%. Spatial pattern of ecosystem service changes in Lishui from 2009 to 2019 were shown in Figure 6. In the past 10 years, ecosystem services in Lishui have shown an upward trend, but there was an obvious downward trend in urbanized areas rapidly. The temperature regulation service had the largest increase, reaching 6%, from 6.6 to 7.0°C. The increase in pollution removal services was relatively small by 2%. The areas with higher improvement of ecosystem services were the areas where the quality of ecological environment had improved better in the past decade, such as the northwest of Lishui. The increase in the areas with stable eco-environmental quality was relatively small, such as the nature reserves where the forests are mature. Urbanization had a great impact on local ecosystem services, and the material quality of some ecosystem services could be reduced by 80%.

Temporal changes of ecosystem service value

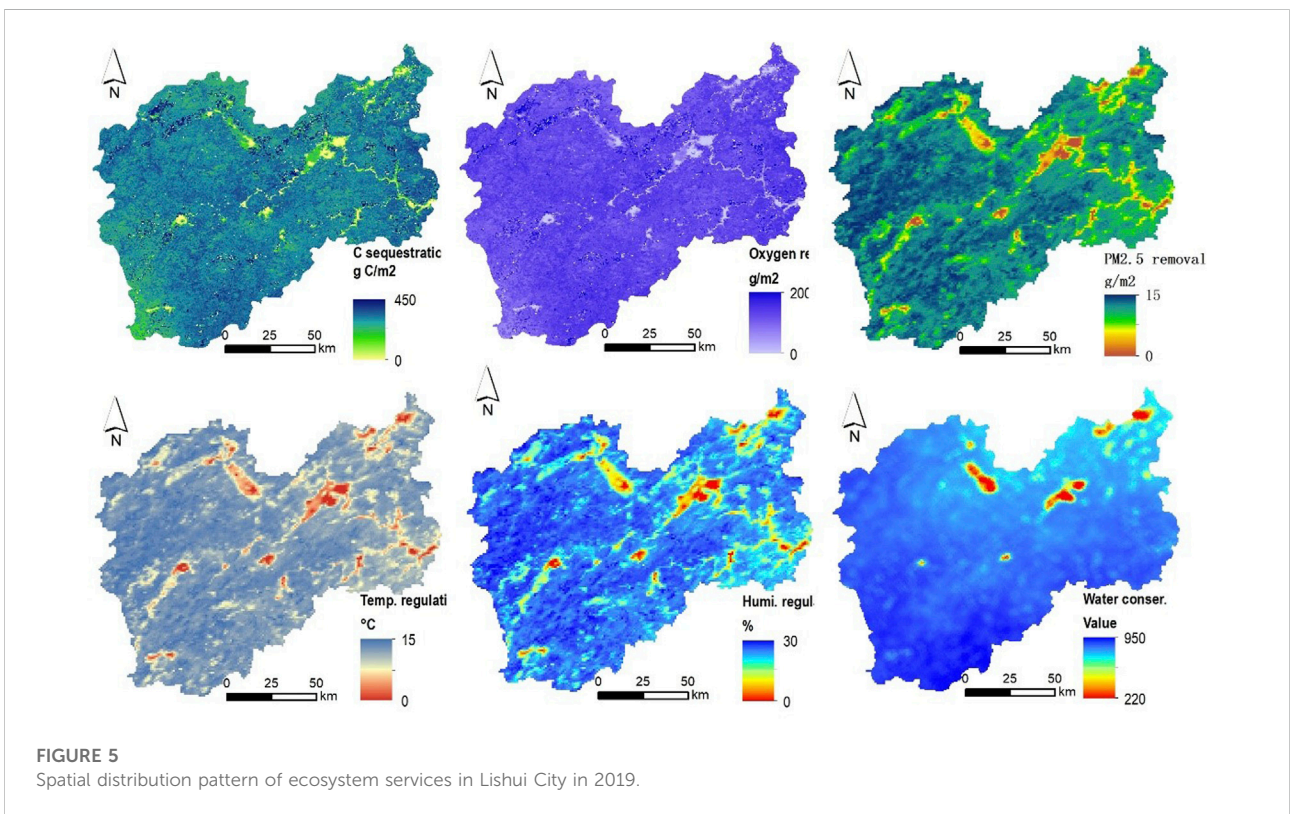
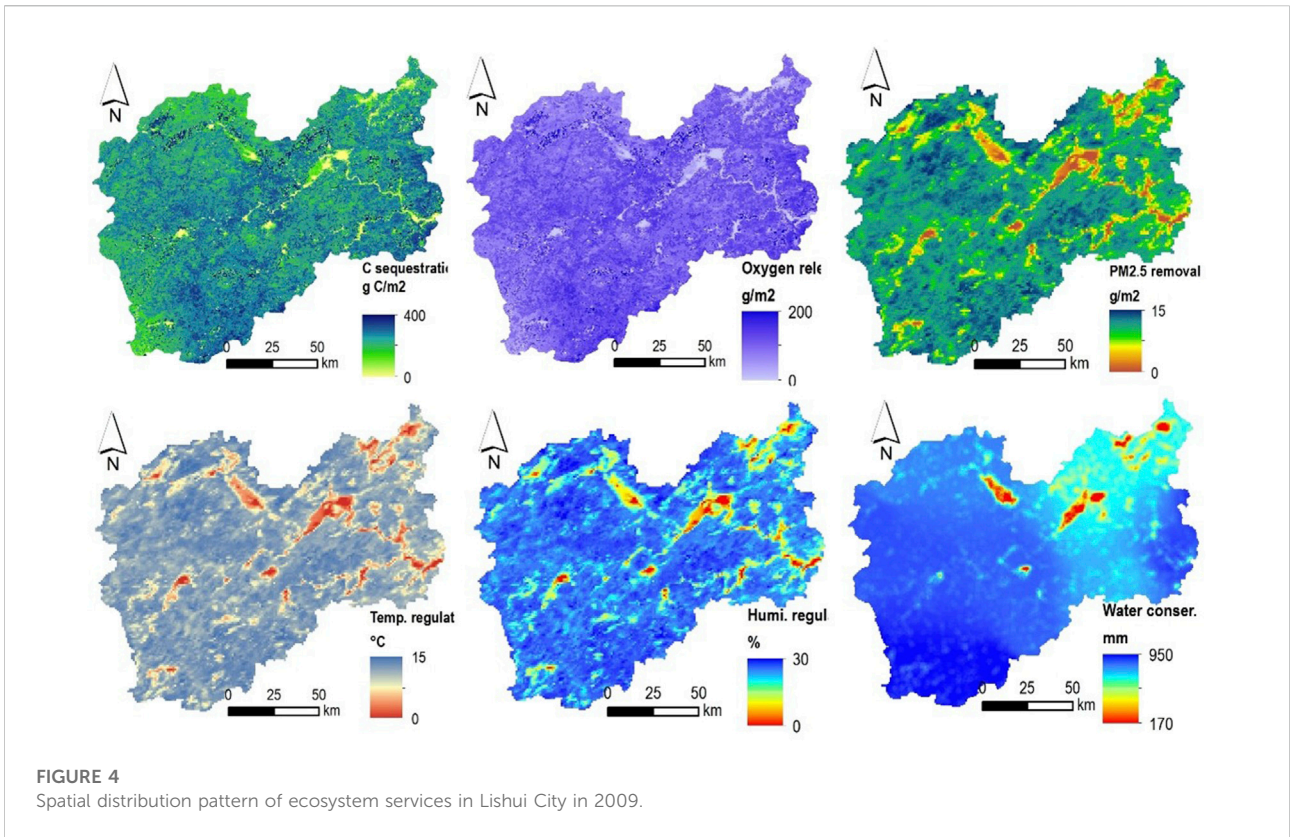
The method of ecosystem service quality characterized the physical meaning of ecosystem service well, but it lacks comparability and intuitiveness, so we used Gross Ecosystem Production (GEP) accounting method to calculate the value of ecosystem services on the basis of material quality accounting (Table 3). In 2019, the total value of six ecosystem services surpassed 150 billion, and there were great differences among them. Temperature regulation reached 104.5 billion CNY, accounting for 70%, water conservation 40.78 billion CNY, accounting for 27%, and the other four types accounted for only 3%.

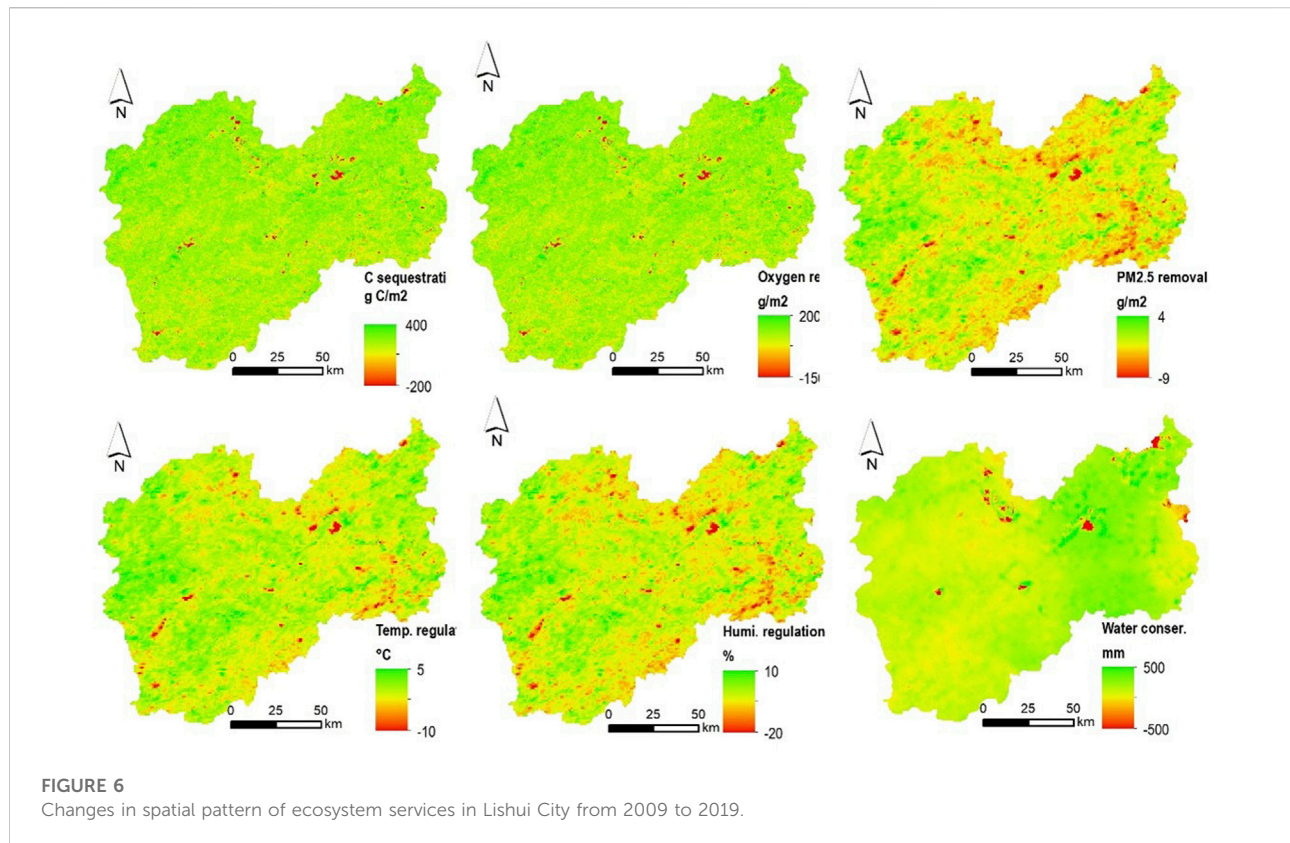
In the past decade, the total value of the six ecosystem services increased from 143.28 billion CNY in 2009 to 150.23 billion CNY in 2019, with a net increase of 6.95 billion CNY. The temperature regulation service rose from 173 billion kWh in 2009 to 183.4 billion kWh in 2019, with a value increase of 5.92 billion CNY. The areas with a large increase are in the west and southwest of Lishui, where the level of economic development is low. Water conservation grew from 14.8 billion cubic meters in 2009 to 15.1 billion cubic meters in 2019, with a value increase of 1.64 billion CNY. The largest increase was in the central area of Lishui. Carbon sequestration service rose from 1.56 Mt in 2009 to 1.63 Mt in 2019, and its value increased from 230 million CNY to 240 million CNY, with the largest increase in the north of Lishui. The spatial pattern of ecosystem services decline had similar distribution characteristics, and the ecosystem service value decreased significantly in the rapid urbanization area (Figure 7).

Discussion

The evolution of land ecological protection polices in Lishui

Lishui's ecological land area is significant, and Lishui's ecological policy is broader and deeper than other prefecture-level cities in Zhejiang province. The evolution of land ecological protection polices in Lishui could be divided into three stages: strategic policy, implementation projects and process supervision. They affected the ecosystem at different stages. Firstly, Lishui Government put forward the overall strategic concept of ecological civilization construction since 2008 in order to implement the concept of "ecological civilization". Adhering to the ecological priority green development strategy firmly, Lishui gradually established the management system and policy system reflecting ecological construction. Secondly, under the guidance of the concept of "ecological civilization", Lishui had formulated a series of plans and project to enhance the value of ecosystem services, including ecological restoration, land renovation and





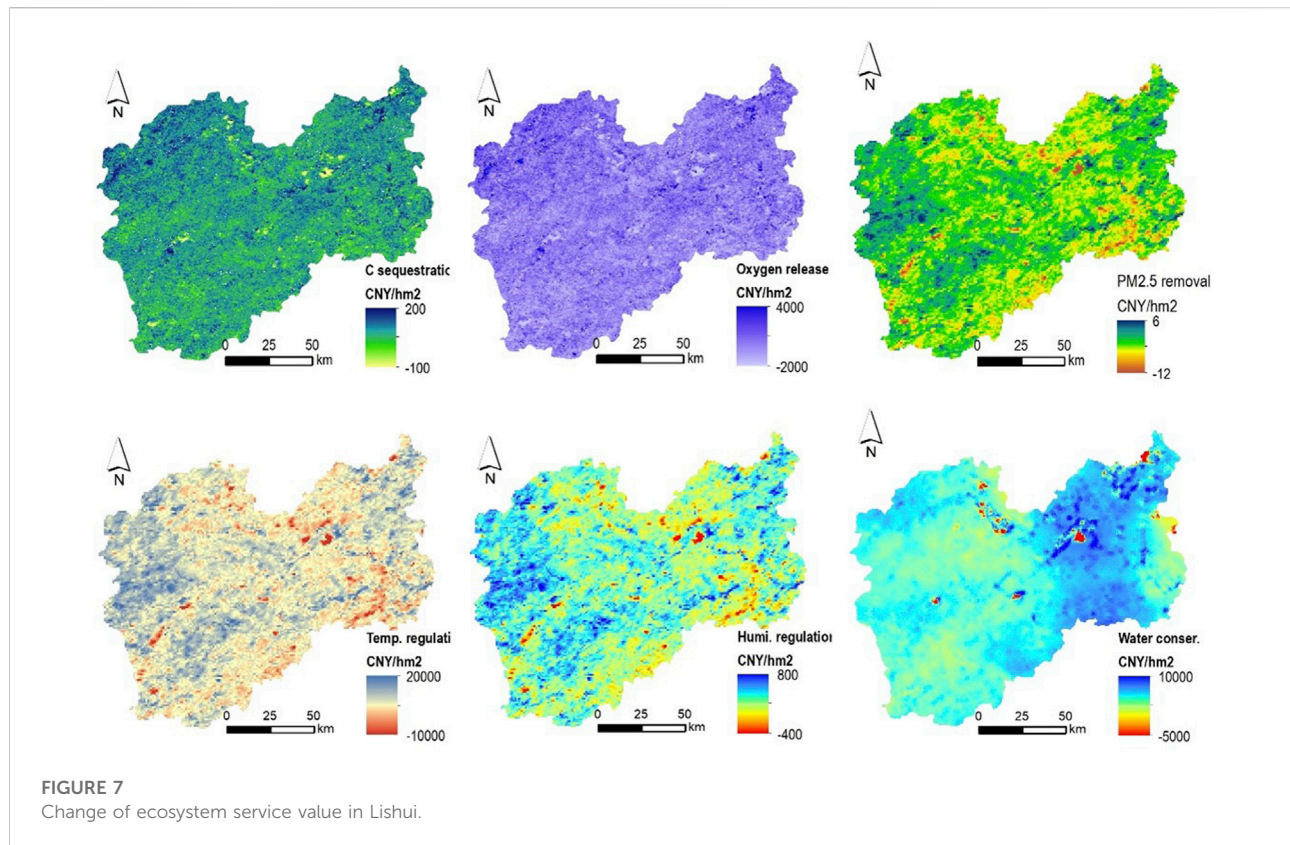
environmental quality improvement (Wu et al., 2021). At the same time, Lishui promoted ecological restoration through actions such as nature reserve construction, soil and water conservation, water ecosystem restoration, mine ecological management, etc. Lishui implemented citywide renovation to optimize the ecological factor structure of mountains, waters, forests, fields and lakes in this city (Diao et al., 2022). Thirdly, Lishui ensured the coordination of monitoring and management of dynamic changes of water, soil and atmospheric environmental quality, which promoted the improvement of ecosystem quality and ecosystem service. It was precisely because of the whole process of ecological protection policy from strategy to implementation to supervision that the ecological quality of Lishui had been continuously improved in the past decade.

Policies driving ecosystem quality and service change

Policies and actions such as ecological restoration, integrated land management promoted land use change directly, which was the key process of ecosystem services and value change (Liu et al., 2010; Zhao et al., 2017). In 2019, the total area of forest land in Lishui was 1,385,761.51 ha, an increase of 20,667.36 ha compared

with 2009. In the past decade, the impact of short-term climate change on ecosystems was less than the impact of land policies. The main reason for land use change in Lishui was driven by land ecological protection policies and actions. Through afforestation and ecological restoration, a large number of bare lands was planted with trees, and the number of shrubs increased by 40,378.85 ha. The protection of forests and the reduction of human disturbance made the vegetation grow better. The improvement of woodland and other ecological land in the whole area has promoted the growth of NPP at the rate of 4 g C m^{-2} per year, and LAI at the rate of 0.8% per year. Therefore, ecosystem services such as carbon sequestration and water conservation have been significantly improved. Therefore, we consider that policy driven land use change was the most important reason for improving ecosystem quality and ecosystem services.

While the quality and value of the overall ecosystem services in Lishui have improved, the changes in the value of partial ecosystem services have decreased, particularly in areas with rapid urbanization and high levels of economic development. In the past 10 years, urban and rural construction land in the city has increased by 2,300 ha. The conversion of agricultural land and ecological land into construction land has led to a decline in ecosystem productivity and service supply capacity, resulting in an obvious decline in the value of ecosystem services in these areas. (Gao et al., 2020; Chen et al., 2021).



Implications and limitations

The policy analysis framework proposed in this paper could be used to evaluate the impact of policies on ecosystems. This study represented spatial-explicitly changes of ecological quality and ecosystem services, which could provide a basis for the targeted land ecological protection policy. We could find the areas where the ecological quality was improved quickly and identify the effectiveness of land ecological protection policies in these areas through the spatial-explicitly ecological quality and system service evaluation. At the same time, we could also identify those areas with degraded ecological quality and services, find out the causes of degradation, and then we could propose targeted improvement strategies. For example, we found that ecosystem services in areas with rapid urbanization and conversion of forest land to arable land declined rapidly. The policies of compact development and intensive agricultural utilization might effectively avoid the decline of ecological quality and ecosystem services.

The uncertainty of this study mainly came from the accuracy of data and the diversity of ecosystem services. We used remote sensing data with an accuracy of 500 m, and the interpretation results were insufficient to characterize the spatial changes of the ecosystem. At present, there are various methods to evaluate the

function and value of ecosystem services, and different evaluation methods may lead to differences in evaluation results. The evaluation model of ecosystem services needs to be further improved and unified. Qualitative analysis of the impact of policy on ecosystem is the main limitation of this study. We plan to quantify the contribution of policy in the further study. In addition, climate change is also an important factor on ecosystem quality and service changes. Separating the contributions of human factors and climate changes to ecosystem services is an important direction for further research.

Conclusion

We proposed an evaluation framework of “Goal-oriented-Policy driven-Ecological quality-Service improvement” for ecosystem quality and service change. The empirical study showed that the NPP and LAI of Lishui represented an increasing trend in the past 10 years. The supply capacity of ecosystem services in Lishui had been enhanced.

The analysis framework can be used to evaluate the impact of policies on ecosystems. Under the goal of green development, policy actions promoted the optimization of land use structure and reduced human disturbance, which was the main driving

force for the improvement of ecological environment quality and the value of ecological products in Lishui. Qualitative analysis of the impact of policy on ecosystem is the main limitation of this study. Qualifying and separating the contribution of human factors and climate changes to ecosystem services is an important direction for further research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Writing—original draft preparation, YT and DC; writing—review and editing, LQ, XH, and JW; investigation, JT and XY; conceptualization, DC. 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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