ASSESSMENT OF THE IMPACT OF TERRITORY-WIDE COMPREHENSIVE LAND REMEDIATION ON THE VALUE OF ECOSYSTEM SERVICES: A CASE STUDY OF NINGBO, CHINA

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Abstract: Territory-wide Comprehensive Land Remediation is a new path to promote ecological security and an innovative project to promote high-quality development and common prosperity in China. The study on the impacts of remediation and ecosystems is an exploration to test the effectiveness of the demonstration project. Taking Ningbo in Zhejiang Province as the research area, we constructed an equivalent factor modification model, proposed an ecosystem service value (ESV) accounting method based on the modified equivalent factor table, and measured the ESV of Ningbo and the remediation area. The conclusions are as follows: (1) the ESV shows an increasing trend before and after remediation: the total value of ESV before remediation is 93.923 billion yuan, and the total value of ESV after remediation is 97.119 billion yuan; (2) the ESV of Ningbo shows geographic differentiation, with the low-value areas concentrated in the northeast and the high-value areas concentrated in Fenghua, Ninghai and Xiangshan. (3) the ESV shows significant differences among remediation areas, with notable growth in Zhouxiang Area and Hengjie Area, while a decreasing trend in seven areas, including the Huanghu Area. The research is highly valuable for quantifying the ecological effectiveness of comprehensive remediation of territorial space and optimizing the arrangement of remediation projects.
Keywords: *territory-wide comprehensive land remediation, ecosystem service value, equivalent factor modification model, assessment, Ningbo City*

Introduction

Ecological civilization represents China's key strategic orientations, with implications for the well-being of the population and the future of the nation (Xun, 2023). Land space plays an important role in the development of ecological civilization. The rapid advancement of industrialization, urbanization, and agricultural modernization has led to the emergence of multifaceted challenges within the same land space, including the inefficient utilization of land, the deterioration of ecological quality, etc. To address multidimensional issues, China has adopted the Pilot Program for Comprehensive Territory-wide Comprehensive Land Remediation, which emphasizes the use of ecosystem theory and methodology for the integrated management of all elements within the scope of territorial space and optimizes the function and quality of human socio-

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economic-natural ecosystems through the systematic allocation of resource elements. It is the conceptual innovation and iterative upgrading of the land remediation model. The program initially optimized the functional layout of the city in the past two years. The quantitative ecological evaluation is at an early stage, and only explored in the design of ecological quality evaluation model (Li et al., 2023), and performance evaluation index system (Zhang et al., 2022). Few studies have been conducted on the overall impacts of Territory-wide Comprehensive Land Remediation on regional ecosystems. Ecosystem service values are widely used as objective reflectors of ecosystems. Currently, the estimation methods of ecosystem service value can be broadly divided into three categories: functional value method (Ouyang et al., 1999), energy value accounting method (Liu et al., 2019), and equivalent factor method (Costanza et al., 1997; Xie et al., 2015). The equivalent factor method is used in multi-scale scenario studies, including studies at the county and city levels (Xu et al., 2018; Lin et al., 2019; Yang et al., 2020), provincial levels (Jiang et al., 2021), national levels (Song et al., 2017; Estoque et al., 2018), and global levels (Sannigrahi et al., 2018), due to its low data demand and strong operability. It is also used in studies at the scale of typical geomorphologic units (Eziz et al., 2016; Yue et al., 2024), economic units (He et al., 2021), and main functional areas (Guan et al., 2022). We propose an ecosystem service value (ESV) accounting method based on the modified equivalent factor table and apply it to measure the ecosystem service value before and after remediation in Ningbo and its remediation area, to quantify the ecological effectiveness of Territory-wide Comprehensive Land Remediation effectively. This study aims to establish a pilot assessment system to explore the application of the methodology and to fill the gap in the monitoring and evaluation of ecosystem function in the long-term continuous comprehensive remediation of territorial space.

Materials and methods

Research framework

Territory-wide comprehensive land remediation is a systematic project. It includes agricultural land remediation, village remediation, ecological protection and restoration, industrial land remediation, redevelopment of urban low-utility land, and remediation of local characteristics. The objective of this study is to quantitatively assess the impact of territory-wide comprehensive land remediation on the value of ecosystem services. Therefore, it is necessary to analyze the impacts of comprehensive territorial spatial management on the value of ecosystem services of various land types (*Figure 1*).

(1) Agricultural land remediation. Cultivated land is remediated mainly by reclaiming arable land, constructing high-standard farmland, and carrying out restoration of arable land functions. It improves the quantity, contiguity and quality of regional arable land and enhance ecological functions and ecosystem service values. (2) Village improvement. By upgrading the concentration of village construction land and remediating inefficient rural settlements, inefficient and abandoned rural settlements will be reclaimed as arable land. The new arable land has production functions, provides ecological functions and enhances the value of regional ecosystem services. (3) Ecological protection and restoration. ①Mines: through the rehabilitation of mines, restored to woodlands and grasslands, realizing the enhancement of regional ecosystem service value; ②Woodlands and grasslands: mainly through ecological restoration and protection to improve the quality and enhance the value of ecosystem services; ③Wetlands: mainly through the

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implementation of spartina alterniflora treatment to restore the function, which is conducive to the enhancement of the value of ecosystem services. (4) Industrial land remediation: Improvement of land use through vacating and clustering, transformation and upgrading. Before and after remediation, it is construction land. The ecosystem service value of construction land was set to zero in the study, so its impact was not considered. (5) Redevelopment of urban low-utility land. ①Unutilized land: regraded to arable land or restored to forest and grassland to enhance the value of regional ecosystem services; ②Urban low utility land: regraded by revitalizing and utilizing urban low utility land. Urban low utility land is also used as construction land before and after reuse, so its impact is not considered. (6) Local character remediation: Which mainly refers to the beautification of the water area. Through the beautiful river and lake construction project, the water area environment is upgraded to serve the optimization of the human habitat.

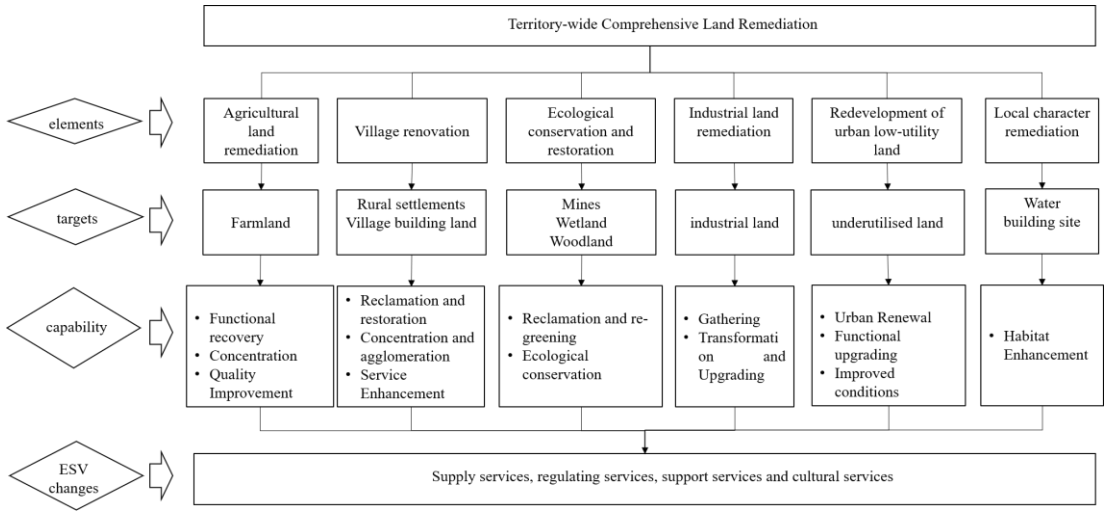

Figure 1. *Mechanisms of Territory-wide Comprehensive Land Remediation on the value of ecosystem services*

Through territory-wide comprehensive land remediation, the area of land categories such as forest land, grassland and cropland can be increased, and the quality of each category can be comprehensively improved, so that the value of regional ecosystem services can be increased. By calculating the regional ecosystem service value before and after remediation and restoration, the impact of comprehensive land space remediation on the regional ecosystem service value is assessed. The ecosystem service value accounting process was designed as shown in *Figure 2*. The research process includes five parts:

- Production of vectorized data on terrestrial ecosystems based on the correspondence between the territorial survey and the indicator content of the ecosystem classification.
- Combined with relevant research results, determine the ecosystem service function of Ningbo City and construct the ecosystem service value model. The data are pre-processed to consider the demand for quantitative and spatialized evaluation of remediation ecological value.
- Determine the ecosystem service value equivalent factor. Quantitative remote sensing methods were used to identify critical parameters and optimize the evaluation of selected models.

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- Obtain ecosystem service values at the scale of Ningbo City and each remediation area, and analyze the spatial and temporal heterogeneity.
- Analyze the evaluation results, explore the shortcomings, and make targeted suggestions for improvement. Provide support for optimizing the ecological effects of comprehensive land space management.

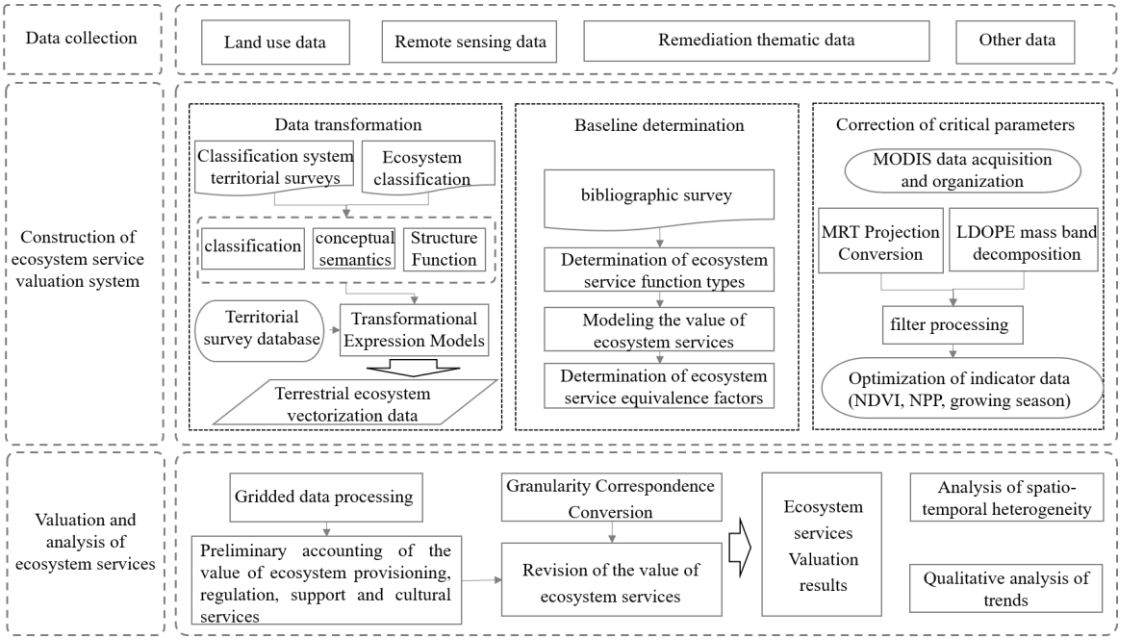

Figure 2. *Research Process*

Value-volume assessment method

Ecosystem structure and service classification

According to *SEEA- Experimental Ecosystem Accounting* of United Nations' , the surface cover of each spatial unit is transformed into different terrestrial ecosystems according to their internal structure and function. The ecosystem classification system adopts the terrestrial ecosystem classification standard in China Ecosystem. The land use vector data were grouped according to the conceptual semantics of its three-level indicators to form a table corresponding to the content indicators of ecosystem classification and land survey classification system. Based on the table, the land use data for 2020 and 2022 were rearranged to obtain the ecosystem classification data for Ningbo City, and the organized data are shown in *Table 1*.

Based on the Millennium Ecosystem Assessment (MA) and the classification and internal structure of terrestrial ecosystems in Ningbo, the ecosystem services are designed to categorize ecosystem services into four major categories: provisioning services, regulating services, supporting services and cultural services. They are further subdivided into 11 service functions: food production, raw material production, water supply, gas regulation, climate regulation, environmental purification, hydrological regulation, soil conservation, maintenance of nutrient cycles, biodiversity and aesthetic landscape.

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Table 1. *Correspondence table between land survey classification and ecosystem classification conversion*

Ecosystem classification	Land survey classification
Dryland	Dryland
Paddy field	Paddy field
Facility agriculture	Facility agricultural land
Mixed coniferous forests	Tree woodlands, parks and green spaces
Broad-leaved forests	Orchards
Shrublands	Other parklands, adjustable parklands, shrublands, other woodlands
Grassland	Natural pasture land, artificial pasture land, other grassland
Bare land	Vacant land, saline land, bare land, bare gravel land
Water area	River, lake, reservoir, pond
Wetland	Reed land, mudflat

Baseline value of ecosystem services

Based on equivalent value of ecosystem services per unit area of China's terrestrial ecosystems (Xie et al., 2015), the ecosystem types were identified and temporally corrected in combination with the actual situation in Ningbo. The greenhouse ecosystem was considered as a separate ecosystem sub-system of the farmland ecosystem, and the grassland and glacier snow ecosystem types were excluded. With the spatial and temporal correction of the grain production data published by the China Bureau of Statistics, the average economic value of the annual natural grain production of China's farmland from 2020 to 2022 was 18,630 yuan/hm^2, and the economic value of one ecological service value equivalent factor was 2,661.43 yuan/hm^2. The resulting standardized equivalence table of ecosystem service functions is calculated as follows (*Figure 3*).

Categorization		Supply services			Regulatory services				Support Services			cultural service
Cat I	Cat III	food product	material production	water supply	gas	climate	Purify	hydrological regulation	soil conservation	nutrient cycling	biodiversity	aesthetic landscape
Farm	arid	0.85	0.40	0.02	0.67	0.36	0.10	0.27	1.03	0.12	0.13	0.06
	paddy	1.36	0.09	-2.63	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09
	Green house	1.40	0.66	0.00	0.57	0.27	0.00	0.00	2.01	0.13	0.09	0.03
Forest	needle-leaved	0.22	0.52	0.27	1.70	5.07	1.49	3.34	2.06	0.16	1.88	0.82
	needle-cropping	031	0.71	0.37	2.35	7.03	1.99	3.51	2.86	0.22	2.60	1.14
	broad-leaved	0.29	0.66	0.34	2.17	6.50	1.93	4.74	2.65	0.20	2.41	1.06
	dioecious	0.19	0.43	0.22	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69
Grass lands	meadow	0.22	0.33	0.18	1.14	3.02	1.00	2.21	139	0.11	1.27	0.56
Wet lands	wetlands	0.51	0.50	2.59	1.90	3.60	3.60	24.23	2.31	0.18	7.87	4.73
deserts	bare land	0.00	0.00	0.00	0.02	0.00	0.10	0.03	0.02	0.00	0.02	0.01
Water area	Water area	0.80	0.23	8.29	0.77	2.29	5.55	102.24	0.93	0.07	2.55	1.89

Figure 3. *Scale of standardized value equivalents for ecosystem service functions*

Spatially modified model of ecosystem services based on vegetation physiognomy

The ability of ecosystems to provide services depends on the area and condition of coverage. Factors such as climate, soils, and anthropogenic disturbances in different geospatial locations can directly affect the supply of ecological services. Vegetation

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photosynthesis time is closely related to climate regulation, aesthetic landscape and other functions. Indicators of NPP, NDVI, and physiological characteristics of vegetation in the growing season were selected to spatially correct the baseline values of farmland, forest, and grassland (*Table 2*). A standardized equivalence table of ecosystem service functions was calculated from the above.

Table 2. *Indicators of ecosystem service function adjustment*

Type of ecosystem	Function Type	Revised indicator
Farm, forest, grassland	Supply services	NPP
	Regulatory services	NDVI, growing season
	Support Services	NDVI
	cultural service	growing season

Based on the terrestrial ecosystem database provided by the "China Ecosystem Assessment and Ecological Security Database", we extracted the nationwide averages of NDVI, NPP, and length of the growing season of different ecosystems from 2020 to 2022, which were used as the basis for the revision of the model for ecosystem service valuation (*Table 3*).

Table 3. *Mean values of correction parameters for different ecosystem types*

Type	Aridland	Paddy field	Mixed coniferous forests	Broad-leaved forests	Shrublands	Grasslands
NDVI	0.52	0.53	0.55	0.57	0.51	0.33
NPP	427.1	467.5	542.9	533.0	433.3	233.6
growing season	167.8	186.6	147.1	159.5	171.6	117.0

Supply service value correction equations:

$$V_{ig} = V_n \times \frac{NPP_i}{NPP'} \quad \text{(Eq.1)}$$

Reconciliation service value correction equations:

$$V_{it} = V_n \times \frac{GS_i}{GS'} \times \frac{NDVI_i}{NDVI'} \quad \text{(Eq.2)}$$

Support service value correction equations:

$$V_{iz} = V_n \times \frac{NDVI_i}{NDVI'} \quad \text{(Eq.3)}$$

Cultural services value correction methodology:

$$V_{iw} = V_n \times \frac{GS_i}{GS'} \quad \text{(Eq.4)}$$

Remark 1: V_{ig}, V_{it}, V_{iz} and V_{iw} are the corrected region i supply, regulation, support, and cultural ecological service value statistics; NPP_i is specific NPP cover type

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(farmland, forest or grassland) for the area *i*; NPP' is the national average NPP for ecosystems of a given cover type; $NDVI_i$ is specific *NDVI* cover type (farmland, forest or grassland) for the area *i*; $NDVI'$ is the national average NDVI for ecosystems of a given cover type. GS_i is the growing season for a specific cover type (farmland, forest, or grassland) for the area *i*; GS' is the national average growing season for a given cover type of ecosystem.

Account for the value of ecosystem services

To realize the spatialized expression of ecosystem service values, 1km×1km grid was used as a statistical unit for regional ecosystem service values. The value of each ecosystem service for each type of ecosystem within each geographic grid is accounted for on an itemized basis. The cumulative value of the accounting value within each grid is the amount of ecosystem service value provided by all ecosystems within that grid. The accounting method is described below:

$$ESV_i = ESV_{\text{standard equivalent}} \times \sum_{a=1}^{4} ESV_{ai} \quad \text{(Eq.5)}$$

$$ESV_{ai} = \sum_{j=1}^{n} A_{ij} \times V_{aij} \quad \text{(Eq.6)}$$

Remark 2: ESV_i is the total value of each type of ecological service in grid *i* (*i*=1,2,…); $ESV_{\text{standard equivalent}}$ is the standard ecological service value equivalent of ecological service function discounted; ESV_{ai} is the total standardized ecosystem service value equivalent of an ecosystem service function for all coverage types in grid i (a=1,2,3,4); A_{ij} is the area of maps of cover type *j* in grid i (j=1,2,3……,n); V_{aij} is the standardized ecosystem service value equivalent of ecosystem service function a for a patch of cover type *j* in grid *i*.

Remediation of ecological profit and loss

The value of regional ecosystem services before and after remediation was calculated by multiplying the area of each category in the regional grid with the ecosystem service value per unit area of the corresponding category. The difference between the ecosystem service value before and after remediation is the effect of remediation on the ecosystem service value. The formula is as follows:

$$\Delta ESV_i = ESV_{Ai} - ESV_{Pi} \quad \text{(Eq.7)}$$

Remark 3: ΔESV_i is the difference in the value of ecosystem services before and after remediation of area *i*, ESV_{Ai} is the value of remediation ecosystem services in the area *i*, ESV_{Pi} is the value of ecosystem services in the region before remediation.

Overview of the study area

Study area remediation profile

Ningbo is located in the eastern part of Zhejiang, and is the economic center and important port city of the southern wing of the Yangtze River Delta region along the southeastern coast (*Figure 4*). The terrain of Ningbo is high in the southwest and low in the northeast, with mountainous hills in the west and south, and facing the sea in the east

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and north. The Yong River, Yao River, and Fenghua River traverse the whole territory, and the forest coverage rate reaches 48.08% (Wang et al., 2024). Since 2020, Ningbo has actively practiced and planned to implement Territory-wide Comprehensive Land Remediation, implementing five major remediation tasks for agricultural land, villages, industrial land, urban low-utility land, and ecological restoration. By 2022, the city has initiated the implementation of 11 remediation demonstration areas and nearly 1,000 projects. Therefore, the study area is Ningbo city and 11 remediation areas. In order to enhance the feasibility of the ecological service value evaluation method on the scale of Ningbo administrative area, the geographic grid was divided based on the administrative area of Ningbo. A total of 10,234 geographic grids covering the whole area of Ningbo were constructed by taking 1 km×1 km geographic grids as the granularity unit of ecological service value evaluation.

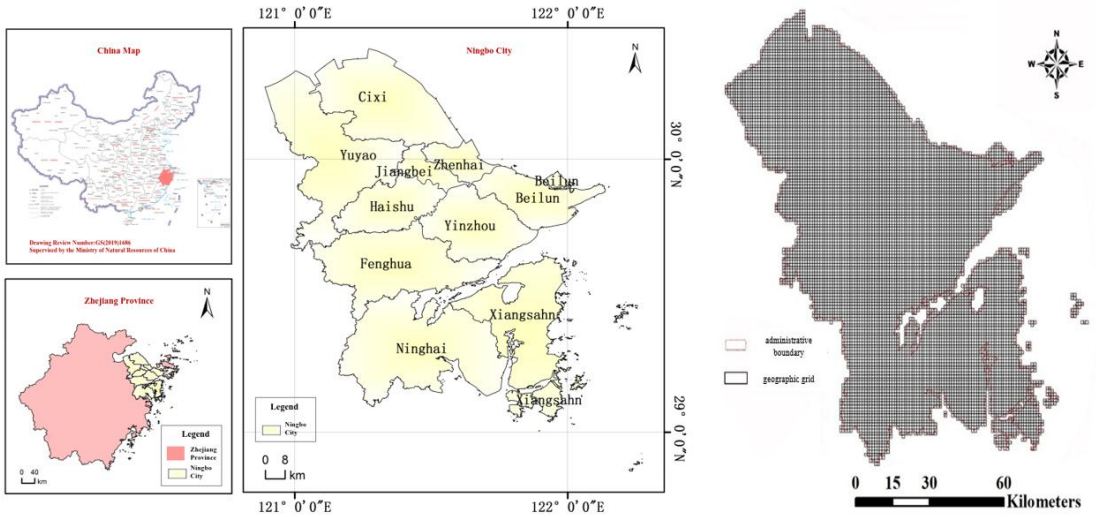

Figure 4. *Geographic location and Geographic Grid of Ningbo*

Data resource

The data encompass land use, remote sensing imagery, and the extent of the area subjected to comprehensive territorial spatial management. The land use data were employed to generate vector data of terrestrial ecosystems. Remote sensing images were utilized to calculate the normalized vegetation index (NDVI), vegetation growing season, and net primary productivity (NPP) of vegetation. The area coverage of the territory spatial comprehensive management area was utilized to quantify the efficacy of the entire territory spatial comprehensive management pilot (*Table 4*).

Table 4. *Data Sources*

Number	Data	Name	Type	Resolution	Data Sources
1	2020.8.16	landsat 8 OLI	raster	30m	https://earthexplorer.usgs.gov/
2	2022.8.14	landsat 8 OLI	raster	30m	https://earthexplorer.usgs.gov/
3	2020/2022	MOD13 Q1	raster	250m	https://modis.gsfc.nasa.gov/
4	2020/2022	MOD17A2	raster	500m	https://modis.gsfc.nasa.gov/
5	2020/2022	Current land-use data	spatial	-	Project Subjects
6	2022	ScopeofImprovement Remediation Area	spatial	-	Project Subjects

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Results

Results of ecosystem service value measurements

The ecosystem service value of Ningbo City before and after remediation was measured by the above method. The results show that the total ecosystem service value of Ningbo City before remediation is 9.39×10^{10} yuan, with a mean value of 1.23×10^{7} yuan/km^2. And the total ecosystem service value of the whole area after remediation in Ningbo City in 2022 is 9.71×10^{10} yuan, with a mean value of 1.28×10^{7} yuan/km^2. It's significantly higher than the 2015 national average (0.41×10^{7} yuan/km^2) and three times the national average value of ecological services (Xu et al., 2018). It indicates that the capacity of Ningbo's ecosystems to provide ecological services is superior to the Chinese average.

Analyze the composition of ecological service value contributed by different ecological service function types. Before remediation, regulating services were the type that provided the greatest ecological service value, amounting to 7.48×10^{10} and 79.67% of the total value. It was followed by support services and provisioning services, providing 1.15×10^{10} and 4.7×10^{9}. Cultural services were the least valuable at only 2.8×10^{9}. After remediation, regulating services remained the type that provided the greatest value of ecological services, at a high of 7.84×10^{10}. It is closely followed by support services and provisioning services, providing 1.11×10^{10} and 4.6×10^{9} respectively. Cultural services still have the lowest total value volume of 3×10^{9}. In summary, the ranking of each service function remained the same before and after remediation, and the amount of contribution changed. After remediation, the contribution of regulating services and cultural services increase. Supporting Services and Provisioning Services decrease slightly in contribution.

Before remediation, the total value of ecological services provided by different ecosystem types in descending order was mixed coniferous, broad-leaved forests, watersheds, shrub forests, broad-leaved forests, water area, paddy fields, grasslands, drylands, facility-based agriculture, and bare land. The value of ecological services provided by mixed coniferous and broad-leaved forests is the highest at 3.61×10^{10} yuan. The value of ecological services provided by bare land is the lowest at 584,092.5 yuan. After remediation, the ranking of the total value of ecological services provided by different ecosystems do not change, but the proportion change. The contribution of mixed conifer forest increased. The share of agricultural land for facilities remained unchanged. The rest of the land categories decreased slightly. The total value of ecological services provided by mixed coniferous and broad forests amounted to 3.95×10^{10} yuan, which increase. Bare ground is still the type that provide the lowest value of ecological services, contributing 552,977.4 yuan, with a decrease in the proportion.

Spatial distribution of ecosystem service values

The total value of ecological services in Ningbo City was characterized by obvious geographical differentiation during the study period (*Figure 5*). Before and after the remediation, the ecological service value was high in the north-central part and low in the southwestern part of Ningbo in terms of geospatial characteristics. The spatial distribution has an obvious correlation with the current land use status. The ecological service value is lower in the central area where cities or towns are distributed, while the ecological service value is higher in the Siming Mountain area where mixed coniferous and broad forests and shrub forests are distributed.

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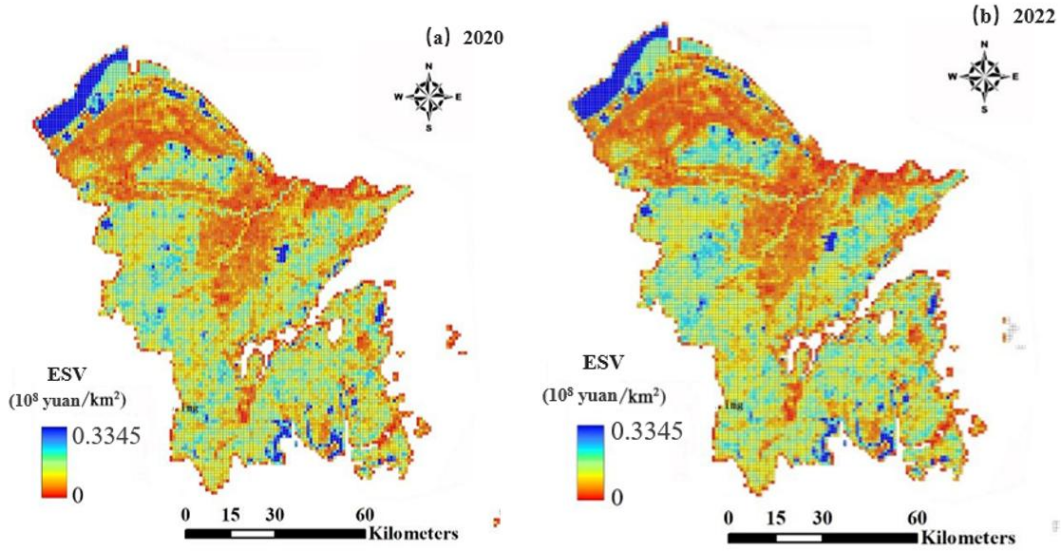

Figure 5. *Spatial change of ESV before and after comprehensive land space improvement in Ningbo City*

The spatial pattern of the value of different types of ecological services shows spatial consistency with the pattern of the value of total ecological services. Supply services are more homogeneous in spatial layout than regulation, support and cultural services. Due to the distribution of many paddy fields in the northern region, low values of provisioning services occurred in the northern part of Yuyao City and Fenghua District. The southern part of Yuyao, the western part of Fenghua district, the southern part of Yinzhou, and the western part of Ninghai county all belong to the distribution area of high values of regulating services. The main reason is that the landscape is mountainous, and the vegetation is mostly dominated by mixed coniferous and broad forests and shrublands. Supporting and cultural services show the same consistency with regulating services in the spatial pattern. Overall, the total value of ecological services and the spatial pattern of the value of each ecological service in Ningbo are spatially controlled by the surface land use pattern, and are closely consistent with the ecosystem pattern. Through influencing the land types, the whole region has been improved so that the production, living and ecological space can be optimized, and the concentration and agglomeration of adjustable land types and the quality improvement of other land types can be achieved. It enhances the value of regional ecosystem services.

Changes in ecosystem service values

Analyze the changes in the value of regional ecosystem services before and after the comprehensive remediation of territorial space in the whole region (*Table 5*). The results show that the total value of ecosystem services in Ningbo before remediation and restoration was 93.923 billion yuan, and the total value of ecosystem services after remediation and restoration increased to 97.119 billion yuan, with an increased ratio of 0.36%. It can be seen that through remediation and restoration, the overall ecosystem service value of the region has been improved to different degrees. The increase in ecosystem service value mainly comes from the remediation of cultivated land and the ecological restoration of forest land. The value of mixed coniferous and broad forests

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increased the most, amounting to 3.388 billion yuan, with an increased ratio of about 0.09%. The total value of ecosystem services of grassland, bare land, water area, and wetland decreased, with a decrease ratio of less than 0.1%.

Table 5. *Regional ecosystem service value before and after remediation in Ningbo City*

Landform	pre-remediation		after remediation		ESV change	
	AREA (km^2)	ESV (10^8/yuan)	AREA (km^2)	ESV (10^8/yuan)	variation (10^8/yuan)	Percentage (%)
aridland	400.40	5.90	421.82	6.68	0.78	0.13
paddy field	1103.84	16.75	1099.90	16.94	0.19	0.01
agricultural land for facilities	13.42	0.18	17.41	0.24	0.05	0.30
mixed coniferous-broad forest	2763.78	360.84	2764.23	394.72	33.88	0.09
broad-leaved forest	504.67	51.16	473.91	52.58	1.43	0.03
shrubbery	1563.70	135.14	1535.39	136.58	1.45	0.01
grass	119.94	10.24	131.12	9.44	-0.79	-0.08
bare ground	10.97	0.01	10.39	0.01	0.00	-0.05
water area	1009.74	337.56	999.52	334.14	-3.42	-0.01
wetland	154.94	21.45	143.37	19.85	-1.60	-0.07
Total	7645.41	939.23	7597.05	971.19	31.96	0.36

Before and after remediation, the damage and gain of ecological service value in Ningbo City exhibit distinct geographical differentiation characteristics (*Figure 6*). The area exhibiting the most significant gain in ecological service is concentrated in the central region of Ningbo City, while the damage to ecological service is concentrated along the coastal areas of Cixi City and the southern region of Fenghua District. Additionally, the intertwined distribution of ecological gain and damage is evident in the areas of Ninghai County and Xiangshan County.

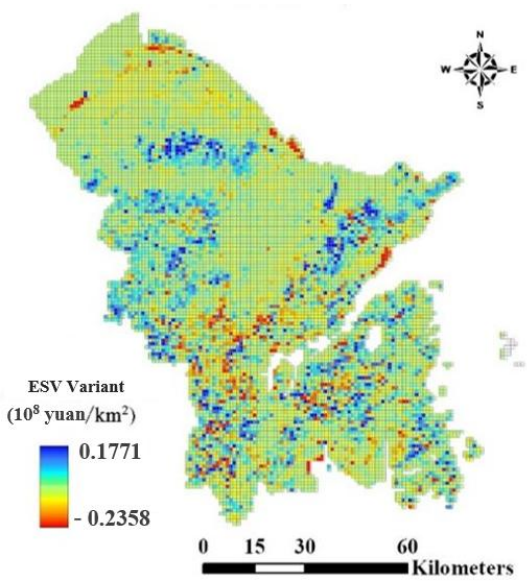

Figure 6. *Spatial changes in the value of regional ecosystem services in Ningbo after remediation*

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Changes in the value of ecosystem services in the remediation area

Analyze the changes in regional ecosystem service value before and after remediation in the 11 areas of the Territorial Land Space Comprehensive Remediation Pilot (*Table 6*). The value share of ecosystem services for each ecosystem type in 2022 changed in the different project areas compared to 2020. Before and after remediation, the total ecosystem service value of the two areas, the southern coastal new area and the central urban section of the eastern coastal belt was the highest, with an ecosystem service value of 400 million yuan.

Table 6. *Changes in ecosystem service value before and after the remediation of 11 areas in Ningbo City*

Region	district	area (km2)	pre- ESV (billions)	After-ESV (billions)	ESV change	
					ESVvariation (billions)	Percentage （%）
Qianwan	Andong district	26.95	2.60	2.55	-0.05	-2.04
Haishu	Hengjie district	23.09	2.23	2.24	0.02	0.72
Zhenhai	Jiaochuan district	11.50	1.07	1.08	0.01	1.01
Yuyao	Huanghu Model district	25.95	2.16	1.13	-1.03	-47.77
Jiangbei	Hongtang-Zhuangqiao district	15.04	1.14	1.12	-0.02	-1.98
Cixi	Zhouxiang Model district	23.51	1.66	1.68	0.02	1.12
Yinzhou	Jiangshan-Yunlong district	34.42	2.25	2.17	-0.07	-3.22
Beilun	Beilun Harbor Marina Remediation Demonstration district	14.82	1.75	1.75	0.00	0.00
Xiangshan	East Coastal Zone Center City district	31.81	4.07	4.00	-0.06	-1.57
Ninghai	Southern Coastal New district	39.75	4.27	4.08	-0.20	-4.60
Fenghua	Ningnan Idyllic City Comprehensive Improvement district	28.02	2.80	1.92	-0.88	-31.37

After remediation, the ranking of Ningnan Field City Comprehensive Remediation Area and Huanghu Demonstration Area decreased, and the ranking of Umdong Area, Hengjie Area, Beilun Harbor Coastal Area Remediation Demonstration Area, and Zhouxiang Demonstration Area increased. In terms of the amount and proportion of change in the value of ecosystem services, the value of ecosystem services in Zhouxiang Demonstration Area and Hengjie Area showed ecological gain. The total ecosystem service value of the seven areas of Huanghu Demonstration Area, Ningnan Field City Comprehensive Improvement Area, Southern Binhai New Area Area, Jiangshan-Yunlong Area, Eastern Coastal Belt Center City Section, Andong Area, and Hongtang-Zhuangqiao Area is shown as ecological damage.

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The most obvious changes are in the Yellow Lake Demonstration Area and the Ningnan Rural City Comprehensive Improvement Area. Analyzed from the perspective of land type, in 2022, the ecological service value provided by mixed coniferous and broad forests in the Huanghu Demonstration Area decreased by 24.59% to 27.03% of the total value compared with 2020, while the share of water area increased by 43.40% to 53.42%.In 2022, the ecological service value provided by broad-leaved forests and shrub forests in the Ningnan Fields Urban Comprehensive Improvement Area decreased by 18.70% and 11.55%, while the ecological service value provided by water area increased by 24.62% to 53.42% compared with 2020 respectively. decreased by 18.70% and 11.55%, while the share of ecological service value provided by water area increased by 24.62% to 74.32%.

To summarize, the Ningnan Rural Urban Comprehensive Improvement Area is the area that should be focused on among the 11 zones. Hengjie Area is the area where the total and average value of ecological services are gained, i.e., the ecological service function is optimized in the area of total and intensity enhancement. The rest of the project areas have unilateral gain or damage in the total or average value of ecological services, and the next remediation work should pay more attention to the ecological service function of these project areas.

Discussion

This study assessed the changes in ecosystem service value caused by the implementation of the pilot project of comprehensive land spatial management in the whole area of Ningbo City and found that the sources of ecosystem service value increase in Ningbo City are forest land and cropland. Generally speaking, different areas have different sources of ecosystem service value increase due to the different types of projects implemented in comprehensive land management, and cropland, woodland, and grassland are usually the factors with the highest contribution to the ecosystem service value change, e.g., Tang et al. (2024) found that the ecosystem service value increase in Hezhou City of the Guangxi Zhuang Autonomous Region originated from cropland, grassland, and woodland; Jiang and Lu (2018) found that that the change in ecosystem service value of a place in Hubei Province originated from forest land, water area and cropland, and Hong and Li (2016) found that the increase in ecosystem service value of a town in Huocheng County, Xinjiang Uygur Autonomous Region originated from cropland, grassland, water area and land for water conservancy facilities, and forest land.

It is worth mentioning that the pilot project of comprehensive land space remediation in Ningbo City is still under implementation, and the total ecosystem service value of seven areas was found to decrease after assessment, but this is not enough to show that the remediation will bring negative ecological effects. As shown in Li's (2023) study, the total value of ecosystem services in Langxia Town and Mao Town of Shanghai City decreased and then increased within six years of the implementation of comprehensive land remediation, which indicates that land remediation activities need to be monitored on a regular basis for long-term objectives and ecological effects, and that the results of the evaluation should be quantified objectively in order to provide scientific decisions for the management of land remediation activities.

Due to the limited information and the complexity of the drivers of ecological service function changes, this paper does not strip the impact of climate fluctuations on ecological value, and the results amplify the effectiveness of comprehensive land remediation of the

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whole land space to a certain extent. It is necessary to distinguish between the contribution of climate change and comprehensive territory-wide spatial improvement to the damage and gain of ecosystem service value in the future, so as to provide scientific support for the future direction of territory-wide spatial improvement in Ningbo City.

Conclusions

Based on the theory of ecological civilization, the theory of sustainable development, and the actual situation of the comprehensive improvement of territorial space in the whole area, this study constructs a quantitative assessment model and method for the value of ecosystem services of the pilot of the comprehensive improvement of territorial space in Ningbo City, starting from the four dimensions of cultural services, regulating services, supporting services and provisioning services, and taking the analysis perspective of the environmental elements and the function of ecosystem services as the main conclusions. The main conclusions are as follows:

(1) This study constructed a modified equivalent factor model for Ningbo City, proposed an ecosystem service value accounting method based on the modified equivalent factor table, and measured the ecosystem service values of different types of ecosystems before and after remediation in Ningbo City and remediation areas. There is a considerable discrepancy in the ecosystem service values of different ecosystem types. The ecosystem service values per unit area provided by water area, forested land, and cultivated land in Ningbo are notably higher, at approximately 1.14×10^7 yuan/km², 3.34×10^7 yuan/km², and 1.50×106 yuan/km², respectively. The ecosystem service value per unit area provided by bare land is lower, with a unit value of approximately 5.32×10^4 yuan/km².

(2) Prior to the comprehensive enhancement of the entire land area in Ningbo City, the aggregate value of ecosystem services was 93.923 billion yuan. Following the implementation of these improvements and subsequent restoration efforts, the total value of ecosystem services is projected to reach 97.119 billion yuan, representing a 3.40% increase. Of which, the cultural services accounted for only 3%, while the regulation services accounted for 80%. The sources of the increase in the value of ecosystem services in Ningbo City are different. The ecosystems of the forested land contribute the highest, followed by dryland and paddy field. In contrast, the contribution of the ecosystem service value of grassland, water area, and wetland decreased.

(3) The total ecosystem service value of Ningbo City exhibits pronounced regional differentiation characteristics, exhibiting a strong correlation with the prevailing land use status. The ecosystem service value of urban areas is comparatively low, whereas the ecosystem service value of mountainous areas with mixed coniferous and broad forests and shrub forests is higher. Overall, the distribution of ecosystem service value in the city exhibits a pattern of high values in the north-central and low values in the southwestern part of the city. The low-value area is concentrated in the northeastern part of the city, while the high-value area is concentrated in the Fenghua District, Ninghai County, and Xiangshan County.

(4) The alterations in ecosystem service value across the remediation areas in Ningbo City are notable, with an uptick observed in the Zhouxiang Demonstration Area in Cixi City and the Hengjie Area in Haishu District. Conversely, the aggregate ecosystem service value of the seven regions, including the Huanghu Demonstration Area in Yuyao City, experienced a decline to a certain degree.

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