



# LUCC-based analysis of ecosystem service value drivers in the South–North Water Transfer Central Line recharge area

Shaolei Guo<sup>1</sup> · Jiafeng Huang<sup>1</sup> · Xianqi Zhang<sup>1,2,3</sup> · Guoyu Zhu<sup>4</sup> · Yihao Wen<sup>1</sup>

Received: 19 December 2022 / Accepted: 18 May 2023 / Published online: 24 May 2023  
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2023

## Abstract

A study on the evolution of ecosystem service values (ESV) in the South–North Water Transfer Central Line Water Replenishment Area was conducted to reveal the mechanism of ESV evolution in the study area, which is of great value to regional ecological environmental protection. Taking Anyang County as the research object, based on LUCC (land use and land cover change) and GIS technology, the spatial and temporal changes in land use change and ESV in Anyang County from 2008 to 2021 were quantitatively assessed using the equivalent factor method, revealing the evolutionary characteristics of ESV in Anyang County. The results show that the total value of ecosystem services in the study area showed an overall upward trend from 2008 to 2021, with a cumulative increase of RMB 834 million, and the increase in water surface area was the main driver of its ESV increase; the spatial pattern of ESV in Anyang County remained basically stable from 2008 to 2021, with a general trend of high in the west and low in the east. The ESV of hydrological regulation in the study area increased from 1.147 billion yuan to 1.613 billion yuan in 2008–2021, which contributed the most to the change of total ESV. Forest land and water area have great influence on the change of ESV in the study area, and are sensitive factors of ESV change. Combined with the results of the 2025 simulation, the value of ecosystem services in Anyang County will rise further in the future.

**Keywords** Value of ecosystem services · LUCC · Ecological recharge · Driver analysis · Anyang County

✉ Xianqi Zhang  
836361512@qq.com

Shaolei Guo  
hhh551523@163.com

Jiafeng Huang  
2944652780@qq.com

Guoyu Zhu  
18839783482@163.com

Yihao Wen  
1368928033@qq.com

- <sup>1</sup> Water Conservancy College, North China University of Water Resources and Electric Power, Zhengzhou 450046, People's Republic of China
- <sup>2</sup> Collaborative Innovation Center of Water Resources Efficient Utilization and Protection Engineering, Zhengzhou 450046, People's Republic of China
- <sup>3</sup> Technology Research Center of Water Conservancy and Marine Traffic Engineering, Henan Province, Zhengzhou 450046, People's Republic of China
- <sup>4</sup> State Key Laboratory of Hydraulics and Mountain River Engineering, College of Water Resource and Hydropower, Sichuan University, Chengdu 610000, Sichuan, People's Republic of China

## Introduction

Ecosystem service value (ESV) refers to the benefits that humans obtain directly or indirectly from ecosystems, and is the material basis and basic condition for human survival and development (Adnan et al. 2022; Sannigrahi et al. 2019; Zhao et al. 2021). People can gain a more intuitive grasp of the natural ecosystem and offer a crucial foundation for the use of natural resources using the appropriate methodologies of environmental science and economics to provide the ESV in the form of currency (Gao et al. 2021). Therefore, the study of ESV assessment is the current research hotspot and focus of ecological economics and environmental economics. Since the 1990s, ESV has been extensively studied by researchers both domestically and overseas. The first time the idea of ecosystem services was mentioned was in the report Study of Critical Environmental Problems from 1970; Costanza et al. (1997) classified and comprehensively assessed the value of global ecosystem services, and the paper published in Nature attracted widespread attention. After that, scholars in China and abroad have conducted numerous studies on ecosystems around the

globe. Steenberg et al. (2017) analyzed the spatial and temporal variability and potential vulnerability of urban forest resources in Toronto, Canada, based on the i-Tree prediction model to study the structural and spatial and temporal variability of urban forests; Weiskopf et al. (2020) studied the impacts of climate change on biodiversity, ecosystem services and natural resource management in the United States to explore the linkages between climate change and important ecosystem service functions; In the same year, Cornejo et al. (2020) conducted decomposition experiments on litterfall in tropical catchment streams to assess the extent of damage caused by agriculture to riverine ecosystems in tropical catchments, providing key evidence of the impact of agriculture on tropical riverine ecosystem functioning; Malone et al. (2022) collected and compiled monitoring data on kelp forest ecosystems in California and Oregon, USA, over the last 10 years to advance research related to kelp forest ecosystems; Lheureux et al. (2023) studied 11 French coastal ecosystems over a period of more than 20 years to study changes in coastal ecosystems and their drivers, and the results were published in 2023. Compared with foreign countries, the research on the value of ecosystem services in China started relatively late, but it has achieved rapid development in recent years. Ouyang et al. (1999) conducted a preliminary study on the economic value of terrestrial ecosystems in China using shadow prices, alternative engineering, and profit-and-loss analysis, initiating the first study of ecosystems in China. Xie et al. (2003) used some of the results of Costanza's assessment of global ecosystem service values as a reference, and also integrated the results of ecological questionnaire surveys conducted on Chinese professionals to develop a table of ecological service values per unit area of different terrestrial ecosystems in China, and assessed the ecosystem service values of the Qinghai-Tibet Plateau, so that the study of Chinese ecosystems began to mature and diversify. Liu et al. (2020) estimated the value of ecosystem services in the Poyang Lake basin from 1990–2015, using land use as the main data source, and analyzed the trade-off synergistic relationships among ecosystem services; Yang et al. (2022) selected six important ecosystem service functions in Beijing and used models such as InVEST and ROS to quantitatively assess the spatial and temporal distribution of ecosystem services from 1990 to 2018; Qiao et al. (2023) used the InVEST model and GIS spatial analysis methods to assess the spatial and temporal characteristics of five ecosystem services: water production, soil conservation, carbon storage, food supply, and vegetation net primary productivity, based on land use, meteorological data, and socioeconomic data in the Huaihe River basin from 1995 to 2020. There have been successful results for the assessment of watershed or regional ESV,

but there are few studies on the assessment of ESV in ecological water replenishment areas. With the opening of the South-to-North Water Diversion (it is abbreviated to SNWD later) Project, research on the value of ecosystem services in ecological recharge areas has begun to increase, but most studies have explored large-scale and wide-scale changes, while there has been less discussion of changes at the county level, making it difficult to provide specific guidance on the construction of economic and ecological civilisations in smaller areas. As a typical water-scarce city in the SNWD Central Project, Anyang County has a particularly severe groundwater shortage. After the SNWD Project was commissioned, Anyang County's water resources were greatly replenished and its land cover and ESV changed. Therefore, assessing the ESV of Anyang County and analysing its evolutionary characteristics can provide some reference value for other water-scarce cities in the SNWD Central Project and promote the construction of ecological civilisation in the relevant cities. This paper takes Anyang County as the research object, based on the ESV equivalent factor method (Pan et al. 2021), analyses land use type changes in Anyang County using GIS and ENVI, establishes an ecosystem value evaluation system based on the actual situation in Anyang County, and assesses the ESV and its evolutionary characteristics in Anyang County from 2008 to 2021. Using the land use images of 2017 and 2021, the FLUS model (Future Land Use Simulation) proposed by Liu et al. (2017) was used to simulate the land use situation of Anyang County in 2025, so as to obtain the ecosystem service value of Anyang County in 2025, to provide some reference for the future urban construction and ecological environment protection of Anyang County.

## Research methodology

### Land use dynamic degree

The dynamic degree of land use can be used to depict a change in land use. The dynamic degree of a particular land use more accurately captures the rate at which various land types change over time and captures regional variations in land use changes (Xie et al. 2020; Zhao et al. 2019). The single land use dynamic degree formula is:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

where  $K$  is the dynamic attitude of a land use type;  $U_a$  and  $U_b$  are the area of a land use type at the beginning and end of the study period, respectively; and  $T$  is the study period for a land type.

### Valuation of ecosystem services

Anyang County’s ecosystem services are broken down into four categories: supply services, regulation services, support services, and cultural services. These categories include food production, raw material production, water supply, gas conditioning, climate regulation, water purification, hydrological regulation, soil and water conservation, maintenance of biodiversity, and aesthetic landscape maintenance (Xie et al. 2015). For the classification of forest land types in Anyang County, coniferous forests account for 12%, broad-leaved forests for 86% and mixed coniferous forests for 2%; arable land is divided into paddy and dryland with a ratio of 1:3.68; grassland types are mainly scrub, accounting for 65% and meadows for 35%; water systems are dominant in the watershed; and indicators of ecosystem service functions of bare land are taken for unused land. The equivalence factor for construction land was set to zero in this paper because there are no reliable methods for estimating the value of artificial ecosystem services on construction land in existing studies. Finally, the ESV per unit area equivalence of the study area was determined using the “Chinese ecosystem service value per unit area equivalence table” (Xie et al. 2015), as shown in Table 1.

The equivalence factor table suggested by Xie et al. has to be changed because it is based on the national average of ecosystem service functions and is not applicable to the study area. Referring to the study by Xie et al. (2003), the value of ecosystem services for food production per unit area of farmland (1 standard equivalent factor) is equivalent to 1/7 of the national average market value of food production per unit. the revised formula is:

$$E = \frac{1}{7} \times \frac{M}{H} \tag{2}$$

where  $E$  is the economic value per unit area of agro-ecosystem providing food production services (yuan/hm<sup>2</sup>);  $M$  is the

total annual value of food in the study area (yuan); and  $H$  is the area of cultivated land in the study area (hm<sup>2</sup>).

Based on its land use, Anyang County’s ecosystem services value was determined using the formula below.

$$ESV = \sum_n^{i=1} (A_k \times VC_k) \tag{3}$$

where  $ESV$  is the total value of ecosystem services in the study area (yuan);  $A_k$  is the area of the  $k$ th land-use type (hm<sup>2</sup>); and  $VC_k$  is the coefficient of  $ESV$  for the  $k$ th land-use type (yuan/hm<sup>2</sup>).

### Land use change simulation

In this paper, FLUS model coupled with Markov model is used to simulate and predict the land use in Anyang County in 2025. The FLUS model was developed by Liu et al. (2017). The principle is to use the ANN neural network to calculate the land use data and driving factors of each period, and obtain the probability of conversion from each land type to other land types. Then, the conversion probability is combined with the neighbourhood influence factor, adaptive inertia coefficient and conversion cost. Based on the principle of cellular automata, the overall conversion probability of the cell is obtained. Finally, the simulation results are obtained through the adaptive inertia competition mechanism selected by roulette.

The FLUS model can effectively deal with the uncertainty and complexity of the mutual transformation of various land use types under the influence of natural and human activities. It has high simulation accuracy and can obtain similar results to the real land use distribution. Considering that Anyang County, as one of the water receiving areas of the Middle Route of the SNWD Project, has been promoted by policies such as returning farmland to forests and returning farmland to lakes, this paper sets up a scenario of ecological

**Table 1** Ecosystem service value equivalent per unit area in the study area

Ecological service value		Woodland	Waters	Farmland	Grassland	Unused land
Supply service	Food production	0.28	0.80	0.96	0.32	0.00
	Production of material	0.64	0.23	0.33	0.48	0.00
	Supply of water resources	0.33	8.29	− 0.54	0.26	0.00
Regulating service	Gas conditioning	2.12	0.77	0.76	1.68	0.02
	Climate control	6.34	2.29	0.40	4.44	0.00
	Water purification	1.88	5.55	0.11	1.47	0.10
	Hydrological regulation	4.55	102.24	0.78	3.26	0.03
Support services	Water and soil conservation	2.58	0.93	0.82	2.05	0.02
	Maintaining biodiversity	2.35	2.55	0.15	1.86	0.02
Cultural service	Aesthetic landscape	1.03	1.89	0.07	0.82	0.01

protection to simulate, prohibiting the conversion of water areas to other land types, and the area of cultivated land continues to decrease and is converted into ecological land such as forest land.

## Example application

### Overview of the study area

Anyang County, which belongs to Anyang City, has geographical coordinates of longitude 113° 53′–114° 45′ East and latitude 35° 57′–36° 21′ North. The county is adjacent to Tangyin County and Hebi City in the south, across the river from Magnetic County, Linzhang County and Shibian County in Hebei Province in the north, bordered by Beiguan District and Wenfeng District in the west, and connected to Neihuang County in the east. Anyang County is 73.75 km long from east to west and 44 km wide from north to south, with an administrative area of 1189 km<sup>2</sup> (Fig. 1). Anyang is the first municipality in Henan Province to start work on the SNWD Project, and the SNWD Project has brought rare water resources opportunities to Anyang, providing solid water resources to support the city's economic and social development.

### Data source

The remote sensing images of Anyang County in 2008, 2011, 2014, 2017 and 2021 are from the China Geospatial Data Cloud website, which are Landsat5 TM and Landsat8 OLI-TIRS remote sensing data in the Landsat series. The

economic data used in the research comes from the statistical yearbook issued by the Anyang municipal government.

### Land use change characteristics

Landsat imagery was used to classify six different types of land in Anyang County, including those used for construction, forestry, water, crops, grassland, and unused land. Table 2 and Fig. 2 provide statistics on the area of various land types in Anyang County.

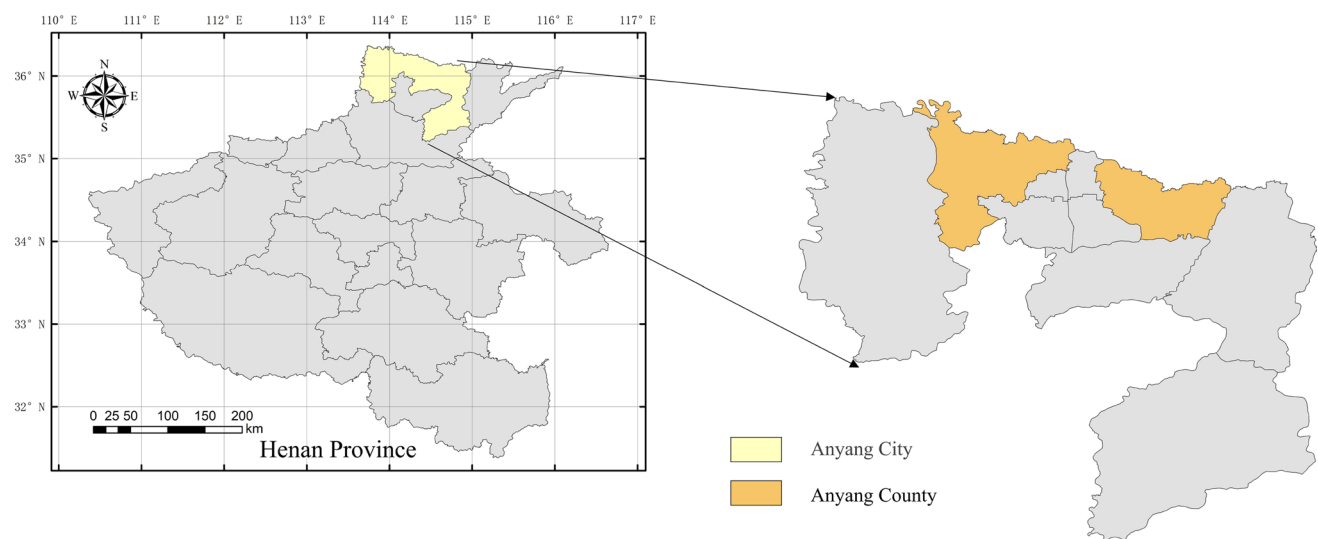
### Land use change

The dynamic degree of single land use in Anyang County was calculated by formula using remote sensing interpretation data from 2008 to 2021. Table 3 presents the outcomes.

In terms of single land use dynamics, the dynamics of construction land, forest land, water and grassland are positive between 2008 and 2021, indicating that the area of these four land types is growing. The largest single dynamic for water area is 9.21%, indicating that the opening of the

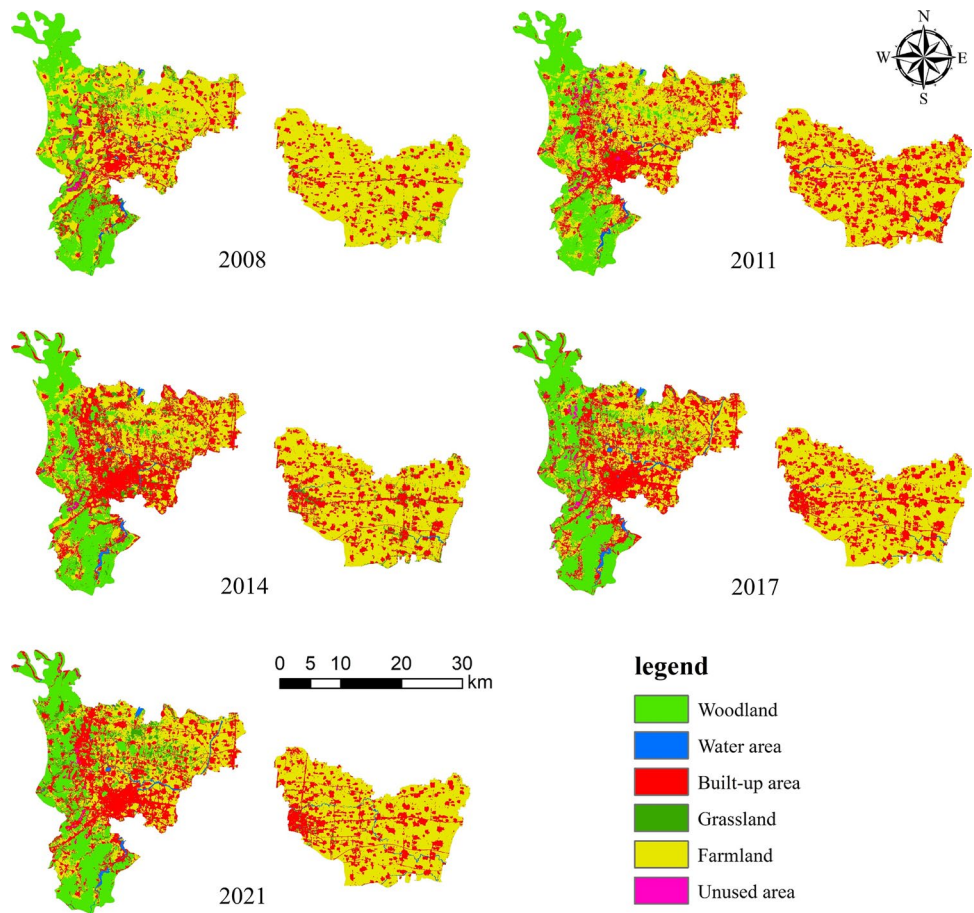
**Table 2** Results of land use classification in Anyang County from 2008 to 2021

	2008	2011	2014	2017	2021
Construction land (km <sup>2</sup> )	181.58	205.83	258.93	254.46	258.8
Woodland (km <sup>2</sup> )	229.75	231.73	249.82	258.97	264.73
Waters (km <sup>2</sup> )	6.68	8.96	9.28	14.54	14.68
Farmland (km <sup>2</sup> )	667.98	653.39	580.95	567.14	559.73
Grassland (km <sup>2</sup> )	35.67	37.75	41.68	50.10	57.52
Unused land (km <sup>2</sup> )	28.44	17.42	9.42	5.19	5.61



**Fig. 1** Location map of the study area

**Fig. 2** Results of land use classification in Anyang County from 2008 to 2021



**Table 3** Land use dynamics in the study area

Time period	Single land use dynamics (%)					
	Construction land	Woodland	Waters	Farmland	Grassland	Unused land
2008–2011	4.45	0.29	11.38	− 0.73	1.94	− 12.92
2011–2014	8.6	2.6	1.19	− 3.7	3.47	− 15.31
2014–2017	− 0.58	1.22	18.89	− 0.79	6.73	− 14.97
2017–2021	0.43	0.56	0.24	− 0.33	3.7	2.02
2008–2021	3.27	1.17	9.21	− 1.25	4.71	− 6.17

SNWD Project has had a significant impact on the growth of water area in the study area; the single dynamic for construction land is 3.27%, indicating that the expansion of urbanisation and development and construction activities in Anyang County have continued steadily over the past decade or so. The single-motion attitude of arable land and unused land is always negative, indicating that the area of these two land types is gradually decreasing, with the area of arable land decreasing all the time, but at a gradually decreasing rate, indicating that arable land is still the mainstay of land use in Anyang County, despite the impact of urban expansion.

**Land use transfer analysis**

The Anyang County land use type map in 2008 and 2021 was processed using a GIS software platform, and the data were exported to produce the location’s land use type transfer matrix and a statistical analysis table of land use transfer (see Table 4).

Analysis of the above table shows that a total of 313.68 km<sup>2</sup> of land in Anyang County has been transferred from 2008 to 2021, accounting for 37.50% of the total land area in the region; in addition, among the various land use

**Table 4** Land use transfer matrix in the study area

Land use type	Area in 2008 (km <sup>2</sup> )	Area in 2021 (km <sup>2</sup> )	Stable area (km <sup>2</sup> )	Transferred area (km <sup>2</sup> )	Type transfer rate (%)	Regional transfer rate (%)
Construction land	181.58	258.8	163.49	18.09	11.06	5.77
Woodland	229.75	264.73	173.16	56.59	32.68	18.04
Waters	6.68	14.68	3.90	2.78	71.28	0.89
Farmland	667.98	559.73	478.22	189.76	39.68	60.49
Grassland	35.67	57.52	12.73	22.94	180.20	7.31
Unused land	28.44	5.61	4.92	23.52	478.05	7.50
Total	1150.1	1150.1	836.42	313.68	37.50	100

**Table 5** Production of main crops in Anyang County in 2021

Crop type	Output (tonnes)	Average price (yuan/ton)
Wheat	226,130	2840
Maize	215,976	2760
Peanut	496	11,200

types, the type transfer rate of unused land is the largest, reaching 478.05%, but due to its small distribution and small area base, the transferred area is only 23.52 km<sup>2</sup>; in addition, the type transfer rate of grassland also reached 180.20%, while the type transfer rate of cropland, although 39.68%, reached 189.76 km<sup>2</sup>; in terms of regional transfer rate, due to the wide distribution of forest land and cropland in Anyang County, the total regional transfer rate of the two types reached 78.53%, while the contribution of other land use types to land transfer in the study area was low, all below 10% or less, with insignificant transfer changes. The conversion of arable land to construction land, forest land and grassland, and the conversion

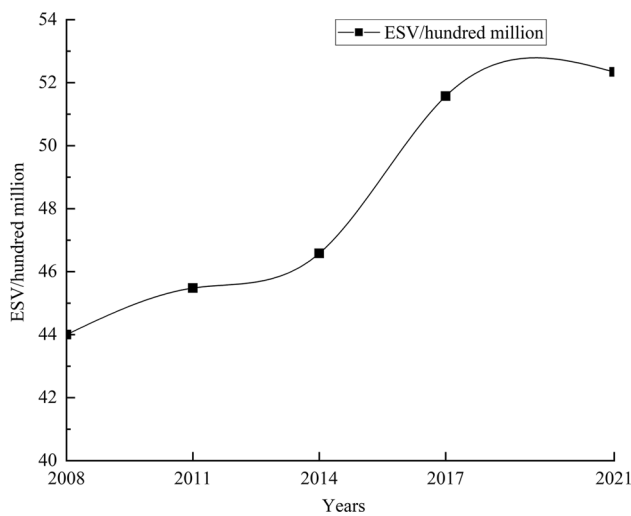
of unused land to construction land are the main inter-transfers of various lands, according to the land use distribution map. Due to the opening of the South–North Water Transfer Project, the conversion of water areas is primarily distributed around various water bodies, while the conversion of grassland is more sporadic and variable. Construction land is primarily distributed in urban fringe areas and close to the original rural settlements.

### Spatial and temporal characteristics of ESV

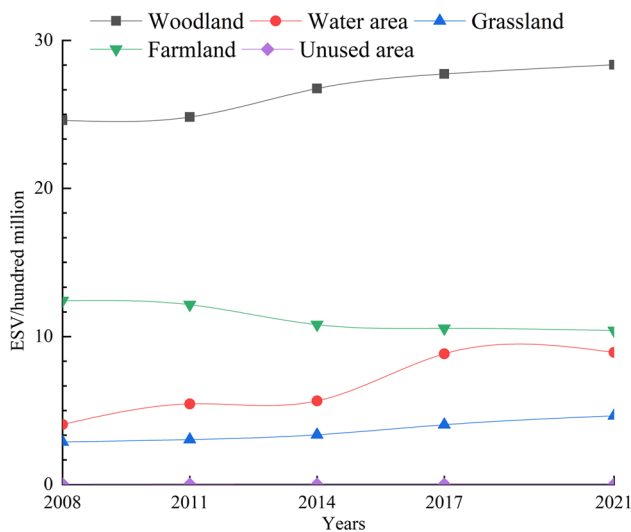
The economic value of the equivalent factor of ecosystem services in Anyang County can be calculated from Eq. (2) as 3486 yuan hm<sup>-2</sup> a<sup>-1</sup> with reference to the 2021 Anyang City Statistical Yearbook, which identifies its main crops (Table 5). This was multiplied by the equivalent value of every ecosystem service in Anyang County to determine the value coefficient of ecosystem services per unit area. The equivalence factor was corrected to obtain the value coefficients of ecosystem service functions (Table 6) for various land use types in Anyang County in light of the actual situation there and the knowledge that the biomass factor of farmland ecosystems in Henan Province is 1.39 (Xie et al. 2015).

**Table 6** Table of service value coefficients per unit area of ecosystems in Anyang County (yuan hm<sup>-2</sup> a<sup>-1</sup>)

First class type	Secondary type	Waters	Woodland	Grassland	Farmland	Unused land
Supply service	Food production	3876.43	1356.75	1550.57	4651.72	0
	Production of material	1114.47	3101.15	2325.86	1599.03	0
	Supply of water resources	40,169.53	1599.03	1259.84	-2616.59	0
Regulating service	Gas conditioning	3731.07	10,272.54	8140.51	3682.61	96.91
	Climate control	11,096.29	30,720.72	21,514.20	1938.22	0
	Water purification	26,892.75	9109.62	7122.94	533.01	484.55
	Hydrological regulation	495,408.01	22,047.21	15,796.46	3779.52	145.37
Support services	Water and soil conservation	4506.35	12,501.49	9933.36	3973.34	96.91
	Maintaining biodiversity	12,356.13	11,387.02	9012.70	726.83	96.91
Cultural service	Aesthetic landscape	9158.07	4990.91	3973.34	339.19	48.46



**Fig. 3** Changes in the value of ecosystem services in the study area from 2008 to 2021



**Fig. 4** 2008–2021 Changes in the service value of various types of ecosystem services in the study area

**Table 7** Ecosystem service value of various types in Anyang County from 2008 to 2021 (hundred million yuan)

Land use type	2008	2011	2014	2017	2021
Waters	4.06	5.45	5.65	8.84	8.93
Woodland	24.6	24.82	26.75	27.73	28.35
Grassland	2.88	3.04	3.36	4.04	4.64
Farmland	12.43	12.16	10.81	10.55	10.41
Unused land	0.03	0.02	0.01	0.01	0.01
Total	44.00	45.48	46.58	51.57	52.34

### ESV variation characteristics of land use types

From 2008 to 2021, the ESV of various land use types in Anyang County was determined using the equivalent factor technique. Figures 3 and 4, and Table 7 display the computation results.

Analysis shows that

- (1) In the past 10 years or so, Anyang County has seen an increase in the value of ecosystem services, which went from RMB 4.400 billion in 2008 to RMB 5.234 billion in 2021, an increase of 18.95%.
- (2) Forest land makes up the majority of Anyang County’s ESV, making up about 55% of the county’s ESV, backed by cropland and waters. Overall, the ESV of forest land, waters and grassland increased, while that of cropland and unused land decreased, in line with the changes in the area of each land use type (Fig. 4).
- (3) The main factor contributing to the decrease in the value of ecosystem services in Anyang County over the past decade or so, as seen from changes in the value of ecosystem services by category in the county, is the decline in the value of cropland ecosystem services brought on by the reduction in cropland area, and the main factor driving the increase in the value of ecosystem services in Anyang County is the rise in the value of the corresponding ecosystem services brought on by the expansion of water and woodland areas. Cropland, forests, and water are thus not only the primary components of Anyang County’s land use, but also the primary causes of changes in the perceived value of the county’s ecosystem services.

### ESV variation characteristics of single ecological service function

Changes in the value of individual ecosystem service functions by period in Anyang County from 2008 to 2021 are shown in Table 8.

The analysis shows that

- (1) Among the various types of ESV in Anyang County (Table 8), hydrological regulation and climate regulation were dominant, followed by gas regulation and soil and water conservation, among others. In addition, the largest change in individual ESVs during the study period was hydrological regulation, which increased by 467 million yuan, or 40.70%, followed by climate regulation, which increased by 142 million yuan, a change of 15.48%. The high proportion of arable land in Anyang County has kept the value of its water sup-

**Table 8** Changes in the value of ecosystem services in the study area from 2008 to 2021

Classification of ecological services		Single ecosystem service value (RMB 10 <sup>8</sup> )				
Primary classification	Secondary classification	2008	2011	2014	2017	2021
Supply service	Food production	3.50	3.45	3.14	3.12	3.11
	Production of material	1.87	1.86	1.81	1.84	1.87
	Supply of water resources	- 1.07	- 0.93	- 0.70	- 0.42	- 0.38
Regulating service	Gas conditioning	5.14	5.13	5.08	5.21	5.30
	Climate control	9.19	9.30	9.80	10.29	10.62
	Water purification	2.90	2.98	3.14	3.41	3.52
	Hydrological regulation	11.47	12.62	12.96	15.85	16.13
Support services	Water and soil conservation	5.91	5.91	5.89	6.05	6.17
	Maintaining biodiversity	3.51	3.57	3.76	3.99	4.12
Cultural service	Aesthetic landscape	1.58	1.61	1.69	1.82	1.87
Total		44.00	45.48	46.58	51.17	52.34

ply negative for over a decade, but there was an overall upward trend, with an increase of RMB 69 million and a change of 64.47%.

- (2) Because the water's ESV coefficients for hydrological regulation, water supply, and water purification are larger and its area has grown throughout the study period, the overall ESV in the study area has increased as a result; the area of forest land increased steadily during the study period, and the coefficients of climatic regulation and hydrological regulation are larger in the ESV coefficients of forest land, which also had a greater influence on the increase of the overall ESV in the study area; the area of arable land accounted for the largest proportion in the study area, and the area of arable land decreased year by year, which is an important reason for the decrease of the overall ESV in the study area.
- (3) Overall, the evolution of ecosystem service functions in Anyang County over the last decade or so has increased slowly from the beginning of the study (2008–2014) to a rapid increase in the middle of the study (2014–2017) to a levelling off in the latter part of the study (2017–2021), indicating that the evolutionary pattern of its land use types tends to be progressively optimised, the value of ecosystem services generated gradually levelled off (Fig. 3).

Due to the official opening of the SNWD Project at the end of 2014 and the major national decision to build an ecological civilisation at a strategic level, the ecological restoration of the waters of Anyang County has achieved significant results and the area of woodland and grassland has increased steadily, which has had a very positive effect on the rise in the value of ecosystem services in Anyang County.

### Spatial variation analysis of ecosystem services value

This paper calculates the ESV of each network based on the GIS spatial analysis method, and obtains the spatial distribution pattern of ecosystem service functions in Anyang County for five periods to study the spatial distribution of ESV in Anyang County and its change pattern (Fig. 5).

From Fig. 5, it can be seen that

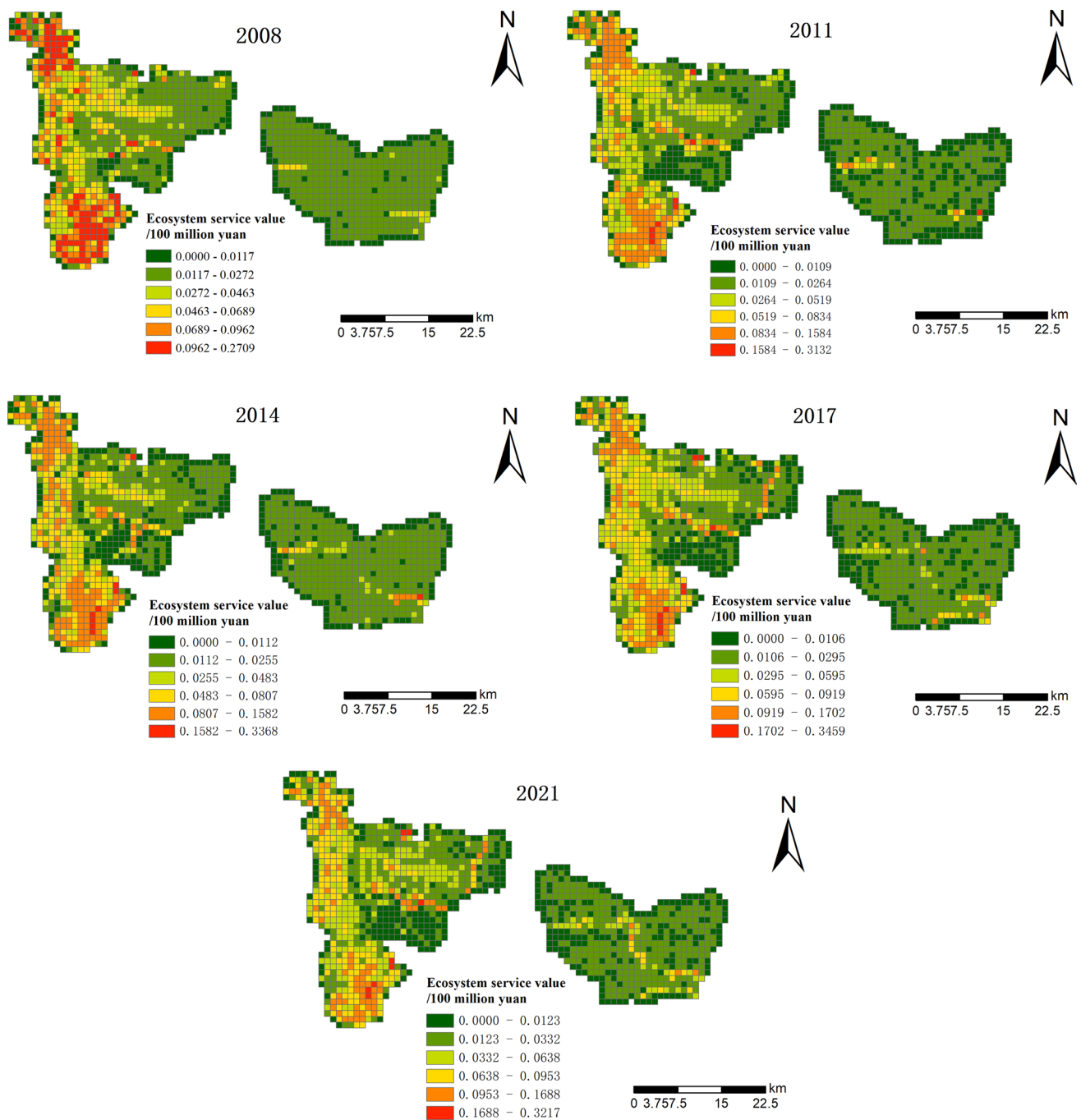
- (1) On the whole, the spatial pattern of ESV in Anyang County remained basically stable from 2008 to 2021.
- (2) In Anyang County as a whole, the value of ecosystem services exhibits a tendency of being high in the west and low in the east, with the high value regions being located in the western half of Anyang County, primarily in woodland and water areas.
- (3) In terms of changes in the spatial pattern, the high-value cells of ESV in Anyang County show a decreasing trend from 2008 to 2021, while the rest of the area is more stable.

### Discussion

#### Ecological contribution rate

Ecological contribution rate refers to the proportion of the change in ESV of each species to the total ESV change in the study area during the study period. Calculating the ecological contribution of each category to changes in the value of ecosystem services, overall, water contributed the most to changes in the value of ecosystem services over the last decade or so of the study period, with an ecological contribution of 39.21%; woodland followed, with 30.19%; grassland and cropland had smaller ecological contributions of 14.17% and





**Fig. 5** Spatial distribution of ecosystem service value in the study area from 2008 to 2021

16.26%, respectively. By stage, the ecological contribution of water was the highest from 2008 to 2011, reaching 67.80%. As there is more movement between the four land types of water, woodland, grassland and arable land, it leads to a greater variation in the ecological contribution of the four land types, with

a maximum variation of 62.55%. The sum of the ecological contribution of water and woodlands is around 70% and the amount of change in the value of ecosystem services in water and woodlands has a large impact on the change in the total value of ecosystem services in the study area and is, therefore, the main contributing and sensitive factor (Table 9).

**Table 9** Ecological contribution rate of various species to ESV changes in Anyang County from 2008 to 2021 (%)

Period	Waters	Woodland	Grassland	Farmland	Unused land
2008–2011	67.80	10.73	7.80	13.17	0.49
2011–2014	5.25	50.66	8.40	35.43	0.26
2014–2017	62.43	19.18	13.31	5.09	0.00
2017–2021	6.21	42.76	41.38	9.66	0.00
2008–2021	39.21	30.19	14.17	16.26	0.16

**Future land use simulation and ecological service value prediction in the study area**

Considering the construction of the SNWD Project and the promotion of ecological protection policies, combined with the actual situation of Anyang County, elevation, slope, aspect, distance to the city center, distance to the town center, distance to the main road and distance to the railway were selected as driving factors. After several simulations and comparison with the actual land use situation in Anyang County, the model parameters are set as follows: the number of iterations is set to 300, the neighborhood size is 3, the neighborhood factor is 1, and the model factor is 0.1. After the model is run, Kappa meets the requirements, indicating that the model simulation results are good. The final results are shown in Fig. 6 and Table 10.

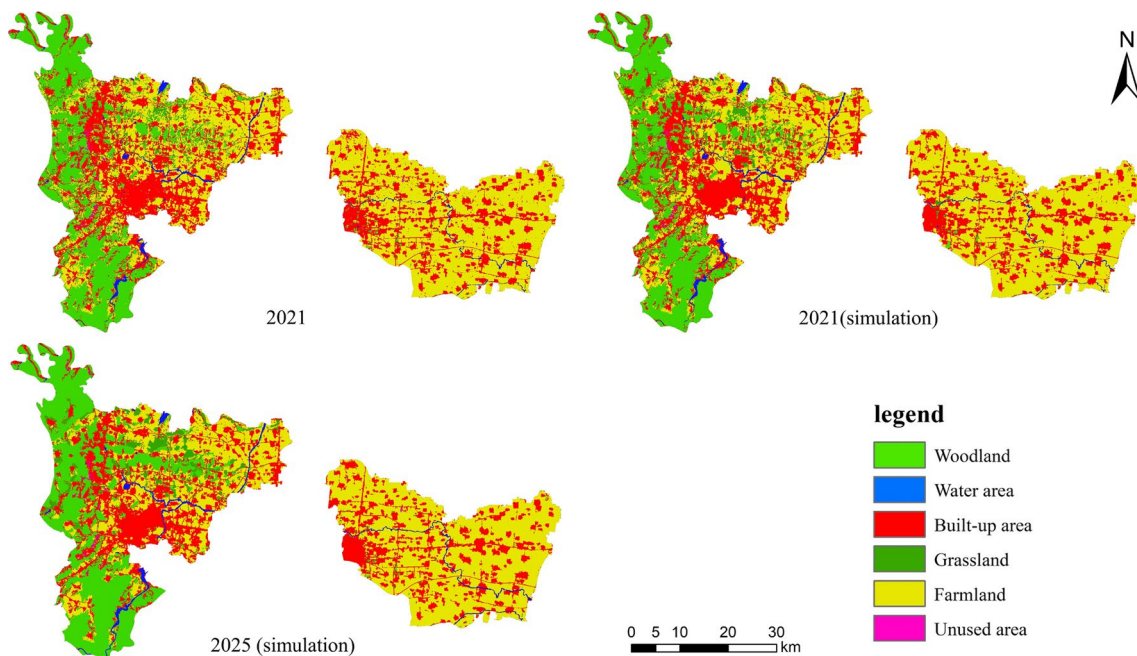
**Table 10** Land use simulation results of Anyang County in 2025

	2021	2021 (simulation)	2025 (simulation)
建设用地 (km <sup>2</sup> )	258.8	262.09	254.29
林地 (km <sup>2</sup> )	264.73	275.26	288.95
水域 (km <sup>2</sup> )	14.68	16.85	19.95
耕地 (km <sup>2</sup> )	559.73	537.34	523.66
草地 (km <sup>2</sup> )	57.52	63.47	69.23
未利用地 (km <sup>2</sup> )	5.61	6.06	4.99

**Table 11** Ecosystem services of Anyang County in 2025 (hundred million yuan)

土地利用类型	2021	2021 (simulation)	2025 (simulation)
水域	8.93	10.25	12.14
林地	28.35	28.48	30.94
草地	4.64	5.12	5.58
耕地	10.41	10	9.74
未利用地	0.01	0.01	0
总计	52.34	53.86	58.4

The analysis of the results obtained from the simulation shows that: similar to the trend of previous years, the area of construction land in Anyang County shows a stable trend without large fluctuations; the ecological land such as



**Fig. 6** Land use simulation results of Anyang County in 2025

forest land, water area and grassland showed an increasing trend, which was consistent with the development of Anyang County in recent years and local policies. As an agricultural city, cultivated land has always been the main body of land use in Anyang County. In 2025, the area of cultivated land will show a small decrease and no significant change. There was no significant change in the location and area of unused land. By consulting the development direction and policy of Anyang County in recent years, it is known that the land use change from 2021 to 2025 is consistent with it. Therefore, the results of FLUS model simulation have certain credibility.

Based on the simulated land use results of Anyang County in 2025, the ecosystem service value of Anyang County in 2025 was calculated. The calculation results are as follows: Table 11.

Analysis of Table 11, the simulated ecosystem service value of Anyang County in 2021 is very close to the actual value, indicating that the results have certain credibility. This land use simulation has made certain restrictions on the transformation of ecological land, prohibiting the conversion of forest land into cultivated land, and setting the water surface as a restricted change area, so there will be a certain deviation from the actual situation. It is expected that the ecosystem service value of Anyang County will be less than 5.84 billion yuan in 2025. In the next few years, the ecosystem service value of Anyang County will continue to rise.

Differences in ecological and environmental conditions and social development levels among regions in Anyang County have led to significant spatial and temporal differences in the value of ecosystem services within the region. Spatially, the western part of Anyang County is dominated by forest land, while the central and eastern parts are dominated by arable land; therefore, the western part of Anyang County has a higher ESV than the eastern part; temporally, with people's increased awareness of ecological and environmental protection, and the vigorous implementation of important initiatives such as returning farmland to forest, pollution control and ecological restoration, the ecological environment of Anyang County has been continuously improved, and the value of ecosystem services has shown a trend of increasing year by year.

Although the ecological environment of Anyang County has been continuously improved, there is still much room for improvement. Most of the woodlands in Anyang County are on the mountainous areas in the west. As one of the main contributors to the value of ecosystem services, woodlands should be protected in the future and the expansion of towns around woodlands needs to be reasonably controlled to reduce people's interference with them. The water area in Anyang County is relatively small and the largest contributors to the water area are the Huan River and the

Xiaonanhai Reservoir in the region. After the SNWD Project was opened, the water surface was greatly expanded and as the land type that contributes most to the value of ecosystem services, the water surface area in Anyang County will be further increased in the future. However, there are more settlements and arable land near the Huan River, which is more likely to be disturbed by man, so it needs the relevant departments to strengthen the protection, suggest the agricultural planting area to strictly control the amount of pesticide and chemical fertilizer, advocate the use of organic fertilizer, and at the same time, strengthen the management of point source and surface source pollution to avoid the ecological environment pollution of the Huan River and damage to the ecosystem of Anyang County.

As a typical water-scarce city in the SNWD Central Project, the study of the ESV of Anyang County is of great reference value to other water-replenishing cities in the SNWD Central Project. In the future, the environmental management experience of Anyang County may also provide some guidance to other cities. The time span of this study includes the period before and after the transfer of water from the South–North Water Transfer Project, and the use of highly visualised spatial raster data, which can show not only changes in time scale but also spatial differences within the region, has good visualisation and practicality, and is expected to provide some reference value for the future environmental management of Anyang County.

## Conclusions

Based on land use data and the equivalent factor method, this paper measures, analyzes, and explores the spatial and temporal changes in land use and ESV in Anyang County over five time periods: 2008, 2011, 2014, 2017, and 2021. The land use situation of Anyang County in 2025 was simulated, and the ecosystem service value of Anyang County in 2025 was calculated. These conclusions were reached:

- (1) The value of ecosystem services in the study area increased by RMB 834 million (18.95%) between 2008 and 2021, with cropland and forest land making up the majority of the value of ecosystem services in Anyang County. The single ESV is dominated by hydrological regulation and climate regulation, followed by gas regulation and soil and water conservation. The largest change in the single ESV is hydrological regulation, which increased by RMB 467 million, or 40.70%. The main factor driving the rise in the study area's total ESV was the expansion of Anyang County's water area, which increased the value of specific ecosystem services like hydrological regulation and water supply.

- (2) Anyang County has essentially maintained a stable spatial pattern of ESV over the study period, which runs from 2008 to 2021, in terms of the spatial distribution of ESV. The high value areas are primarily found around woodlands and water, with the overall distribution showing a trend of high in the west and low in the east.
- (3) From 2008 to 2021, water has the largest contribution to ESV change with an ecological contribution of 39.21%, followed by woodland with an ecological contribution of 30.19%. The sum of the ecological contribution of water and woodlands is around 70%, which is the main contributor and sensitive factor to ESV change.
- (4) Analyze the ecosystem service value of Anyang County from 2008 to 2021, and combine the ecosystem service value simulation of Anyang County in 2025 to give the following assumptions: as water transfer from the South–North Water Transfer Project continues to increase, the area of water bodies in Anyang County will grow and the value of ecosystem services provided by waters will continue to rise. In the future, Anyang County's ecosystem services will have a slow and steady increase in value.

**Author contributions** All authors contributed to the study conception and design. Writing and editing: SG and JH; chart editing: YW; preliminary data collection: XZ and GZ. All authors read and approved the final manuscript.

**Funding** This work was supported by the Key Scientific Research Project of Colleges and Universities in Henan Province (CN) (Grant numbers 17A570004).

**Availability of data and materials** Data and materials are available from the corresponding author upon request.

## Declarations

**Conflict of interest** We have no financial interests, non-financial interests, or conflicts of interests related to the content of this article.

**Ethical approval** Not applicable.

## References

- Adnan M, Islam W, Gang L, Chen HYH (2022) Advanced research tools for fungal diversity and its impact on forest ecosystem. *Environ Sci Pollut Res Int* 29(30):45044–45062
- Cornejo A, Pérez J, López-Rojo N, Tonin AM, Rovira D, Checa B, Jaramillo N, Correa K, Villarreal A, Villarreal V, García G, Pérez E, Ríos González TA, Aguirre Y, Correa-Araneda F, Boyero L (2020) Agriculture impairs stream ecosystem functioning in a tropical catchment. *Sci Total Environ* 745:140950
- Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG (1997) The value of the world's ecosystem services and natural capital. *Nature* 387:253–260. <https://doi.org/10.1038/387253a0>
- Gao X, Wang J, Li C, Shen W, Song Z, Nie C, Zhang X (2021) Land use change simulation and spatial analysis of ecosystem service value in Shijiazhuang under multi-scenarios. *Environ Sci Pollut Res Int* 28(24):31043–31058. <https://doi.org/10.1007/s11356-021-12826-9>
- Lheureux A, David V, Del Amo Y, Soudant D, Aubry I, Bozec Y, Conan P, Ganthy F, Grégori G, Lefebvre A, Leynard A, Rimmelin-Maury P, Souchu P, Vantrepote V, Blondel C, Cariou T, Crispi O, Cordier MA, Crouvoisier M, Duquesne V, Savoye N (2023) Trajectories of nutrients concentrations and ratios in the French coastal ecosystems: 20 years of changes in relation with large-scale and local drivers. *Sci Total Environ* 857(Pt 3):159619
- Liu X, Liang X, Li X, Xu X, Ou J, Chen Y, Li S, Wang S, Pei F (2017) A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects. *Landsc Urban Plan* 2017:16894–17116
- Liu H, Zheng L, Wu J, Liao Y (2020) Past and future ecosystem service trade-offs in Poyang Lake Basin under different land use policy scenarios. *Arab J Geosci* 13(2):46
- Malone DP, Davis K, Lonhart SI, Parsons-Field A, Caselle JE, Carr MH (2022) Large-scale, multidecade monitoring data from kelp forest ecosystems in California and Oregon (USA). *Ecology* 103(5):e3630
- Ouyang Z, Wang X, Miao H (1999) A primary study on Chinese terrestrial ecosystem services and their ecological-economic values. *Acta Ecol Sin* 05:19–25
- Pan D, Yan H, Han T, Sun B, Jiang J, Liu X, Li X, Wang H (2021) Evaluation of the service function value of grassland ecosystems in Gansu Province using the equivalence factor method. *Pratacult Sci* 38(09):1860–1868
- Qiao X, Yang Z, Yang Y (2023) Trade-off and synergy of ecosystem services and their scale effects in the Huaihe River basin from 1995 to 2020. *Areal Res Dev* 42(02):150–154+166
- Sannigrahi S, Chakraborti S, Joshi PK, Keesstra S, Sen S, Paul SK, Kreuter U, Sutton PC, Jha S, Dang KB (2019) Ecosystem service value assessment of a natural reserve region for strengthening protection and conservation. *J Environ Manag* 244:208–227. <https://doi.org/10.1016/j.jenvman.2019.04.095>
- Steenberg JW, Millward AA, Nowak DJ, Robinson PJ, Ellis A (2017) Forecasting urban forest ecosystem structure, function, and vulnerability. *Environ Manag* 59(3):373–392
- Weiskopf SR, Rubenstein MA, Crozier LG, Gaichas S, Griffis R, Halofsky JE, Hyde KJW, Morelli TL, Morissette JT, Muñoz RC, Pershing AJ, Peterson DL, Poudel R, Staudinger MD, Sutton-Grier AE, Thompson L, Vose J, Weltzin JF, Whyte KP (2020) Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Sci Total Environ* 733:137782
- Xie G, Lu C, Leng Y, Zheng D, Li S (2003) Ecological assets valuation of the Tibetan Plateau. *J Nat Resour* 02:189–196
- Xie G, Zhang C, Zhang C, Xiao Y, Lu C (2015) The value of ecosystem services in China. *Resour Sci* 37(09):1740–1746
- Xie H, He Y, Choi Y, Chen Q, Cheng H (2020) Warning of negative effects of land-use changes on ecological security based on GIS. *Sci Total Environ* 704:135427

- Yang W, Yang P, Sun X, Han B (2022) Changes of landscape pattern and its impacts on multiple ecosystem services in Beijing. *Acta Ecol Sin* 42(16):6487–6498
- Zhao Q, Wen Z, Chen S, Ding S, Zhang M (2019) Quantifying land use/land cover and landscape pattern changes and impacts on ecosystem services. *Int J Environ Res Public Health* 17(1):126. <https://doi.org/10.3390/ijerph17010126>
- Zhao X, Wang J, Su J, Sun W (2021) Ecosystem service value evaluation method in a complex ecological environment: a case study of Gansu Province, China. *Plos One* 16(2):e0240272. <https://doi.org/10.1371/journal.pone.0240272>

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.