# Spatial-Temporal Evolution of ESV In The Yellow River Basin And Its Response To Land Use Change

**Jie Yang**
Gansu Agricultural University
**Baopeng Xie**
Gansu Agricultural University
**Degang Zhang** (zhangdg@gsau.edu.cn)
Gansu Agricultural University

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# Spatial-temporal Evolution of ESV in the Yellow River Basin and Its Response to Land Use Change

**Jie Yang[1], Baopeng Xie[2], Degang Zhang[1]***

[1] College of Pratacultural Science, Gansu Agricultural University, Lanzhou 730070, China

[2] College of Management, Gansu Agricultural University, Lanzhou 730070, China

* Correspondence: zhangdg@gsau.edu.cn; Tel.: +86-182-9389-3322

**Abstract:** Evaluating the value of ecosystem services and clarifying their temporal and spatial characteristics can effectively assist regions in formulating targeted and localized sustainable ecological management strategies. This study takes the Yellow River Basin (YRB）in China as the research area, analyzes the ecosystem service value (ESV) and its spatial-temporal variation characteristics in this region, using the equivalent factor method and geospatial exploration method, introduces the elasticity coefficient, and explores the response of ESV change to land use change, based on the land use cover data from 1990 to 2020. The results show that from 1990 to 2020, the ESV of the YRB showed an overall increasing trend, mainly because the ecological construction project increased the forest land and grassland in the region, thus the ecosystem service function was improved. In the past 28 years, the spatial characteristics of ESV in the YRB are relatively stable. The high-value areas are mainly distributed in the upper Yellow River, while the low-value areas are mainly distributed in the lower Yellow River, but the cold spots and hot spots are reduced. The ESV barycenter coordinates show the direction of the transfer trajectory, which is first to the southwest, then to the northeast, and then to the southwest. From 2000 to 2010, the land use change in the YRB had a greater impact on ESV. Since 2010, the disturbance of ecosystem services by land use change has decreased. The elastic index of the upstream region and the Loess Plateau region is significantly higher than that of other regions, and the impact of land use change on ecosystem services is more obvious, which is mainly because the large-scale implementation of ecological construction projects has significantly improved the ecological function of the region. Our results is conducive to promoting the coordination of sustainable development and ecological protection in YRB, which is based on a comprehensive spatial-temporal assessment of ESV.

**Keywords:** ecosystem service value; spatial-temporal characteristics; elastic coefficients; Yellow River Basin

## 1. Introduction

Ecosystem services refer to the benefits ecosystems that humans obtain directly or indirectly from ecosystems, including providing services, regulating services, cultural services and supporting services. Ecosystem services are related to human well-being and are the foundation of human survival and socioeconomic development. After the release of the United Nations Millennium Ecosystem Assessment report, ecosystem services and assessment research has become a global academic hotspot. Grasping the external spatial-temporal evolution and internal impact mechanism of ecosystem services is of great significance for identifying regional ecosystem service problems, maintaining regional ecological balance, and promoting regional sustainable development. ESV, as a quantitative method for evaluating regional ecosystem services [2], has attracted much attention from academia, government and the public. Among them, the value of ecosystem services in the form of currency is the most widely used, which is easy for the public to understand and to be used by decision makers, and which can also effectively assist spatial planning, ecological regulation and ecological restoration.

The ESV estimated by using the ecological parameter model based on emergy [9-10] or the equivalent method based on value per unit area [11-13]. Since Costanza tried to measure the value of global ecosystem services, the equivalent factor of global ecosystem value proposed by him has been widely used in the assessment of ESV around the world [14]. Xie et al established an ESV assessment system for different terrestrial ecosystems in China on this basis [15-16]. Because of its simple operation and easy comparison of results, it has been widely used in China. On this basis, many scholars make corrections and improvements according to the actual study area's ecosystem and socioeconomic development status [17-19], which can relatively accurately assess the regional ecosystem status. The value of ecosystem services is the basis for describing the spatial-temporal evolution of ecosystem services, and its accurate accounting is very important, which is of great significance to scientific management of ecosystems and the realization of sustainable development.

At present, the research on ESV mainly focuses on three aspects. First, it focuses on the spatial-temporal variation characteristics of ESV, explores the impact of land use/cover on ESV, and combines spatial regression and geographic detector methods to analyze the driving factors of the spatial-temporal variation of ESV. For example, Hu et al. used the InVEST model to explore the response of ESV to land use/cover change in the Pearl River Basin [3]; Huang et al. studied the spatial distribution of ESVs in the Lhasa River Basin [4]; Song et al. studied the Northeast Regional wetland ESV changes, identified the driving factors of ESV changes, and clarified the contribution of different driving factors to ESV changes [5]. The second is to focus on using ESV as the determining basis for ecological compensation standards. For example, Wu et al. took the Changtian Basin in Xixiu District, Anshun City as the study area, calculated the ESV in the study area and determined the compensation standards for cultivated land, forests, water areas and orchards［6］. Tian et al. calculated the total ESV based on the meteorological data, remote sensing data and socio-economic data of Chishui River in 2000, 2010 and 2015, using carbon fixation and oxygen release and InVEST model, and determined the compensation standards and priority compensation level in different areas of the basin[7]. The third is to use FLUS, CA-Markov and other models to predict and simulate future land use changes and estimate the profit and loss of ecosystem services value under different scenarios, so as to optimize the spatial layout of land use. For example, Hu et al. simulated the land use change in Anhui Province under the ecological optimization scenario based on the GM and FLUS models. In addition, they estimated the ESV of Anhui Province from 1995 to 2030 using the revised model [8].

In the YRB, there is a vast territory and it is characterized by complex geomorphological units, diverse ecosystem types, and obvious regional climate differences. The ecological environment of the YRB is fragile and it is one of the areas sensitive to global climate change; it is an ecological corridor connecting the Qinghai-Tibet Plateau, Loess Plateau and North China Plain; it is an important area with ecological functions such as water conservation, windbreak and sand fixation, and biodiversity protection, etc. It plays a very important role in maintaining regional ecological security and is an important ecological barrier in our country. In recent years, the status of the YRB as an important ecological barrier and an important economic zone in my country has been further clarified from the national level. The complex and diverse topography and climate provide natural advantageous conditions for the diversity of ecosystems and land use types, and it is a representative area for studying ESV and its equilibrium characteristics. What is more worth mentioning is that in the past few decades, the Chinese government has implemented large-scale ecological engineering measures in response to vegetation degradation in the upper reaches of the YRB and soil erosion in the middle reaches, such as the ecological protection and construction projects of the Three Rivers Sources, the comprehensive management projects of mountains, rivers, forests, fields, lakes and grasses, and the projects of returning farmland to forests and grasslands, the transforming of degraded farmland and wasteland, and other water and soil conservation measures, such as the restoring of forest and grassland ecosystems. The land use/cover types in this region have changed significantly, resulting in spatial-temporal changes in ecosystem services. Therefore, it is necessary to further explore the spatial-temporal evolution characteristics of the ESV of the YRB from the past to the present.

In this study, based on the land use cover change from 1990 to 2020, the researchers evaluated the ESV of the corresponding year and explored its spatial-temporal change characteristics, identified the cold and hot spots of the

ESV, as well as the transfer path and distance of barycenter, further revealed the changing law of ESV in the YRB, and analyzed the response of ESV to land use changes, in order to provide scientific reference for rational use of land and protection of ecosystems.

## 2. Materials and Methods

### 2.1 Study Area

The Yellow River originates from the Yoguzonglie Basin at the northern foot of the Bayan Har Mountains on the Qinghai-Tibet Plateau, flows through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong, and flows into the Bohai Sea in Kenli County, Shandong Province, with a total length of 5464 km for the main stream and 4480 m for the drop. The YRB is located between 96° -119° east longitude and 32° -42° north latitude (Fig. 1), with a length of about 1900 km from east to west, a width of about 1100 km from north to south, and a drainage area of 79.5×104 $km^2$. The upper reaches of the Yellow River is located above Hekou Town, with a length of 3472 km and a drainage area of 42.8 × 104 $km^2$; the middle reaches is from Hekou Town to Taohuayu, with a length of 1206 km and a drainage area of 34.4 × 104 $km^2$; the lower reaches is below Taohuayu , with a length of 786 km and a drainage area of only 2.3 × 104 $km^2$. In the YRB, there is a vast territory, and many mountains. The height difference between the east and the west is very different. The topography of each region is also very different, and the climate of different regions in the basin is significantly different. The seasonal difference in the YRB is large, and the annual precipitation in most parts of the basin is between 200 and 650 mm, and it is more than 650 mm in the southern of the middle upper reaches, and the lower reaches, especially the northern slope of the Qinling Mountains in the southern boundary, which is greatly affected by topography, the precipitation can generally reach 700-1000 mm, and it gradually increases from northwest to southeast. The distribution of precipitation is uneven, and the ratio of north-south is greater than 5. According to the water resources zoning of the YRB (slices), the YRB can be divided into 8 secondary basins and 29 tertiary basins. As of 2020, the resident population in the basin reached 152 million, the regional GDP was 9,642.276 billion yuan, and the urbanization rate reached 46.70%. The whole urbanization is in a period of accelerated development, and the contradiction between the development and protection of land space is becoming more and more serious.

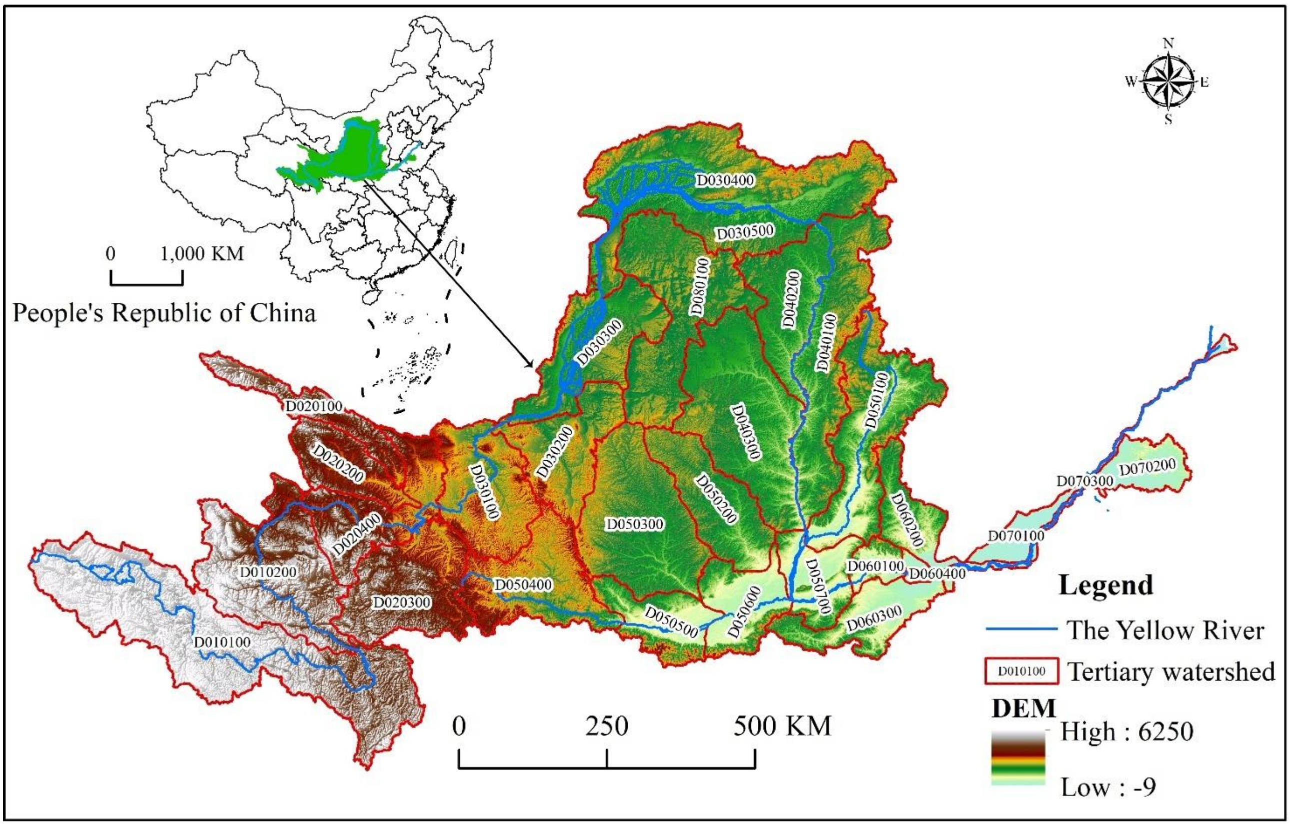


**Fig. 1 Scope of YRB and distribution of drainage system**

## 2.2 Date Source

The land use type data of the YRB in 1990, 1995, 2000, 2005, 2010, 2015 and 2020 with a spatial resolution of 1 km are all from the Resource Science Data Center of the Chinese Academy of Sciences (http://www.resdc). .cn/) remote sensing monitoring database of China's land use status. The data production takes the Landsat TM/ETM remote sensing images of each phase as the main data source, and is interpreted and produced through human-computer interaction. The land use change classification system is used to divide land use into 6 categories: cultivated land, forest land, grassland, water area, construction land and unuseland. Considering that the negative effects of construction land on the ecosystem of the YRB far exceed the positive effects, so its ESVs are not included. Statistical data such as grain output and grain prices are taken from the Statistical Yearbook of 9 provinces including Gansu, Qinghai, and Shandong, etc. and The National Agricultural Product Cost and Benefit Data Compilation in 2020.

## 2.3 Evaluation methods of ESV

According to the research results of Constanza et al. [14], ecosystem services can be divided into 9 types. This study is based on the “ecosystem equivalent table perunit area of ecosystems in China” proposed by Xie et al. in 2007 [20]. Through correcting the socio-economic development status of the YRB and the economic value of the annual natural grain yield per unit area of farmland, the researchers can obtain the ESV coefficient (VC) table of each land use type in the YRB. The specific correction process is as follows: the average grain yield per unit of grain is 4626.55 kg·hm$^{-2}$ and grain market price is 0.35 USD·kg$^{-1}$ in the YRB from 1990 to 2020, taking the formula that shows the ecological service value of farmland per unit area is equal to the market economic value of the average grain yield per unit of land 1/7 calculation [15], the researcher can get the result that the equivalent factor of an ESV in the Yellow River is 232.16USD·hm$^{-2}$·a$^{-1}$, and finally they obtain the ESV coefficient of the YRB, which is showed in Tab.1.

Tab.1 ESV coefficients per unit area of land use categories in YRB/（USD·hm$^{-2}$·a$^{-1}$）

| | Forest | Grassland | Cultivated land | Water | Unuselan |
|---|---|---|---|---|---|
| Food production | 812.55 | 185.73 | 116.08 | 0.00 | 0.00 |
| Raw materials | 626.82 | 208.94 | 206.62 | 106.79 | 0.00 |
| Water conservation | 742.90 | 185.73 | 139.29 | 4731.35 | 6.96 |
| Soil conservation | 905.41 | 452.71 | 338.95 | 2.32 | 4.64 |
| Waste disposal | 304.13 | 304.13 | 380.74 | 4220.61 | 2.32 |
| Gas regulation | 756.83 | 253.05 | 164.83 | 578.07 | 78.93 |
| Climate regulation | 23.22 | 69.65 | 232.16 | 23.22 | 2.32 |
| Biodiversity conservation | 603.61 | 11.61 | 23.22 | 2.32 | 0.00 |
| Entertainment | 297.16 | 9.29 | 2.32 | 1007.56 | 2.32 |
| Total | 5072.62 | 1680.81 | 1604.20 | 10672.25 | 97.51 |

Finally, the ESV of the study area is calculated as follows:

$$\mathrm{ESV} = \sum \mathrm{S_k} \times \mathrm{VC_k}$$

In the formula, ESV represents the value of ecosystem services (USD), Sk represents the area (hectare) of the kth land use type in the study area, and $VC_k$ represents the ESV coefficient per unit area of the ecosystem type k (USD/hectare).

## 2.4 Local Spatial Autocorrelation of ESV

Spatial autocorrelation analysis (Moran's I) is generally used to express the degree of spatial correlation of a geographic thing or phenomenon at different locations in a certain region[21], and can measure whether the distribution of ESV has agglomeration. Hot Spot Analysis (Getis-Ord Gi*) is used to measure the aggregation and differentiation characteristics of spatial changes in ESV (ESV), and to explore whether the spatial changes of ESV have high-value agglomeration (hot spot) and low-value agglomeration (cold spots) phenomenon [22]. Through the analysis of hot spot, it is possible to determine the location where the ESV high-value area or low-value area clustered in space [23]. The calculation formula is as follows:

$$Moran's\ \mathrm{I}=\frac{\mathrm{n}\sum_{\mathrm{j=1}}^{\mathrm{n}}\mathrm{w_{ij}}\left(\mathrm{x_i}-\bar{\mathrm{x}}\right)\left(\mathrm{x_j}-\bar{\mathrm{x}}\right)}{\sum_{\mathrm{i=1}}^{\mathrm{n}}\left(\mathrm{x_i}-\bar{\mathrm{x}}\right)^2\left(\sum_{\mathrm{i}}\sum_{\mathrm{j}}\mathrm{w_{ij}}\right)}$$

$$Z\left(G_{\mathrm{i}}^{*}\right)=\frac{n\sum_{j=1}^{n}w_{i,j}x_j - X\sum_{j=1}^{n}w_{i,j}}{\mathrm{s}\sqrt{\frac{\left[\mathrm{n}\sum_{\mathrm{j=1}}^{\mathrm{n}}\mathrm{w}_{\mathrm{i},j}^{2}-\left(\sum_{j=1}^{n}w_{i,j}\right)^2\right]}{(n-1)}}}$$

$$X=\frac{1}{n}\sum_{j=1}^{n}x_i,\ S=\sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{j=1}}^{N}\mathrm{x_j^2}-\left(X\right)^2}$$

In the formula: n is the number of spatial grid units in the study area, $x_i$ and $x_j$ are the observed values of spatial unit i and spatial unit j, respectively, ($x_i-\bar{x}$) is the deviation of the observed value from the mean value on the ith spatial unit, $w_{ij}$ is the weight matrix of space units i and j.

## 2.5 Land use change response resilience of ESV

Resilience is a measure of how responsive one variable is to changes in another variable.This paper uses this method to measure the percentage change in ESV caused by land use/land cover change . The formula is as follows:

$$E=\left|\frac{(ESV_{t1}-ESV_{to})/ESV_{t0}}{LUP}\right|,\ LUP=\frac{\sum_{i=1}^{n}\Delta L_i}{\sum_{i=1}^{n}L_i}$$

In the formula: E is the elasticity index of ESV in response to land use change; t0 is the initial stage of the study, t1 is the end stage of the study; LUP is the percentage of land use change; $\Delta L_i$ represents the land use change area of i land use types, and Li represents the total area of i land use types.

### 2.6 The barycenter shift of ESV

The center of gravity of ESV draws on the principles of population gravity center and economic gravity center, and explores the temporal and spatial evolution process of ESV from space. It also analyzes the barycenter of the ESV and its change trajectory in the YRB from four aspects: the barycentric coordinates, the moving direction, the distance, and the location of the administrative region in 1990, 1995, 2000, 2005, 2015 and 2020. The calculated formula is as follows:

$$X=\frac{\sum_{i=1}^{n}M_iX_i}{\sum_{i=1}^{n}M_i},\quad Y=\frac{\sum_{i=1}^{n}M_iY_i}{\sum_{i=1}^{n}M_i}$$

The moving distance of the barycenter of ESV in the s Among them, $M_i$ is the attribute value of a certain element in the sub-region, which is the ESV of the region in this study; $X_i$ and $Y_i$ represent the geographic coordinates of the region, respectively, and X and Y represent the barycentric coordinates of the ESV in the study area. tudy area in 1990, 1995, 2000, 2005, 2015 and 2020 can be calculated by the following formula:

$$d=\rho\sqrt{(x_{i+t}-x_i)^2+(y_{i+t}-y_i)^2}$$

In the formula, d represents the moving distance of the barycenter; ($x_i$, $y_i$) and ($x_{i+t}$, $y_{i+t}$) are the coordinates of the barycenter of the ESV in the ith and i+t-th years, respectively; and $\rho$ is the conversion rates between the plane coordinates and the geographic coordinates. Generally, researchers take the constant of 111.11km.

## 3. Results

### 3.1 Analysis of changes in the value of ecosystem services in the YRB

According to Tab. 2, the researcher obtains a raster image of ESV in the YRB, and obtains the total value of ecosystem services in the YRB by using spatial statistical tools. The results show that from 1990 to 2020, the total value of ecosystem services in the YRB showed a dynamic trend of decrease-increase-decrease, and the overall trend was increasing trend , with a total increase of $31.85\times10^{10}$USD, and an average annual increase of $1.14\times10^{10}$USD. This change trend is consistent with the land use cover change in the study area. In 30a, the cultivated land in the YRB decreased by 8,663 km2, because with the rapid urbanization, part of the cultivated land was occupied by construction land. In addition, after 2000, my country began to implement the policy of returning farmland to forest and grassland on a large scale, which accelerated the reduction of cultivated land. The forest area increased by 30933093km$^2$, indicating that the implementation of the policy of "returning farmland to forest and grassland" has achieved great results, which increased the value of ecosystem services generated by forest land by $167.66\times10^{10}$USD. The grassland increased by 738km$^2$, the corresponding ESV increased by $28.73\times10^{10}$USD, the unuseland decreased by 8131km$^2$, and the ESV decreased by 9.52×10$^{10}$USD. In general, the ecological protection and management measures in the YRB have achieved remarkable results, and the value of ecosystem services has been significantly improved due to the increase in forest land and grassland areas.

Tab. 2 The value of ecosystem services in the YRB from 1990 to 2020

| land use types | ESV(X10$^{10}$USD) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 1990-2020 |
| Cultivated land | 3738.89 | 3740.72 | 3740.72 | 3738.89 | 3660.55 | 3644.44 | 3586.73 | -152.16 |
| Forest | 5833.27 | 5534.97 | 5788.60 | 5833.27 | 5997.59 | 5986.55 | 6000.93 | 167.66 |
| Grass land | 7131.05 | 7319.22 | 7151.14 | 7131.05 | 7162.28 | 7151.32 | 7159.78 | 28.73 |
| Water | 1646.70 | 1488.80 | 1595.52 | 1646.70 | 1602.87 | 1615.91 | 1643.84 | -2.86 |
| Unuseland | 75.73 | 71.60 | 75.73 | 75.73 | 68.07 | 67.75 | 66.21 | -9.52 |
| total | 18425.65 | 18155.32 | 18351.72 | 18425.65 | 18491.37 | 18465.96 | 18457.50 | 31.85 |

In terms of the structure of ecosystem services in the YRB (Tab.3), the relative proportions of various ESVs did not change significantly, and the ESV structure was relatively stable. Among them, soil conservation and waste disposal are the most prominent, accounting for about 37% of the total value of ESV. It can be seen that the YRB ecosystem mainly reflects the importance of soil conservation and waste disposal in the basin, while the sum of Climate regulation, Biodiversity conservation and Entertainment only accounts for 11.99% of the total. During the study period, various services have changed to varying degrees. Among them, Waste disposal and Climate regulation have suffered losses, with losses of 22.23×10$^{10}$USD and 20.29×10$^{10}$USD respectively. The rest of the services showed an increasing trend, among which the value of the Food production service increased the most, which was 19.03 ×10$^{10}$USD, mainly due to the obvious increase of the forest land and grassland area in the YRB.

Tab. 3 The value of individual ecosystem functions in the YRB from 1990 to 2020

| Service category | ESV (10$^{10}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 1990-2020 |
| Food production | 1992.89 | 1966.04 | 1991.24 | 1992.89 | 2017.00 | 2012.85 | 2011.92 | 19.03 |
| Raw materials | 2105.32 | 2090.50 | 2104.73 | 2105.32 | 2118.97 | 2114.30 | 2109.98 | 4.66 |
| Water conservation | 2702.36 | 2609.32 | 2671.39 | 2702.36 | 2703.09 | 2704.62 | 2714.93 | 12.57 |
| Soil conservation | 3755.78 | 3753.38 | 3753.91 | 3755.78 | 3776.60 | 3768.25 | 3760.84 | 5.06 |
| Waste disposal | 3180.43 | 3134.48 | 3156.27 | 3180.43 | 3159.82 | 3158.50 | 3158.20 | -22.23 |
| Gas regulation | 2478.59 | 2450.71 | 2472.27 | 2478.59 | 2491.18 | 2486.67 | 2484.43 | 5.84 |
| Climate regulation | 868.65 | 874.91 | 2478.59 | 868.65 | 859.08 | 856.27 | 848.36 | -20.29 |
| Biodiversity conservation | 797.83 | 763.63 | 797.56 | 797.83 | 816.46 | 814.84 | 815.78 | 17.95 |
| Entertainment | 543.79 | 512.36 | 537.03 | 543.80 | 549.16 | 549.65 | 553.06 | 9.27 |

## 3.2 Spatial distribution and variation characteristics of ecosystem services in the YRB

The total value of ESV in the study area and changes in the value of each individual service cannot reflect their spatial differences. In order to describe the temporal and spatial distribution pattern of ESV in the study area, the natural breakpoint method was used to classify ESV with reference to the existing studies, and it was divided into four levels: low-value area, lower-value area, higher-value area and high-value area. The analysis was carried out with the three-level watershed of the YRB as the statistical unit. The result showed that the higher the level, the higher the ESV. As shown in the Fig. 2 , from 1990 to 2020, the spatial characteristics of ESV were relatively stable. The high-value areas are mainly distributed in the upper reaches of the YRB, from Shizuishan to the north bank of

Hekou Town, the Fenhe River Basin, from Hekou Town to Longmen and the Jinghe River Basin. The forest and grassland in the above-mentioned areas are relatively concentrated, the ESV coefficient is high, and the watershed area is large, which makes the total ESV high. The higher value areas are mainly distributed in the the areas from Longyang Gorge to Lanzhou main stream basin, the Daxia River and Tao River basin, and the Wei River basin. The area above Baoji Gorge and the inflow area are in the transition area between the high-value area and the lower-value area, and are also important geographical transition areas. For example, the transition area between the Loess Plateau and the Qinghai-Tibet Plateau is a higher-value area. The lower-value area mainly includes the Huangshui River Basin, the Datong River Basin, the basin below Lanzhou, and the Guanzhong Plain area. The unuseland in this area is widely distributed. Due to the large area of construction land in the Guanzhong Plain, the value of ecosystem services has shrunk. The low-value area is distributed in the lower reaches of the YRB, which is the area with the most extensive and large area of construction land in the basin, in which the ecosystem service function is poor, and which is also the economically developed area of the YRB. From 1990 to 2020, the number of watersheds at the ESV level did not change significantly, from the perspective of changes in the value of watershed ecosystem services. The average ESV of the watershed is $40.52\times10^{10}$USD. There are 7 high-value watersheds, 5 higher-value watersheds, 12 lower-value watersheds, and 5 low-value watersheds respectively.

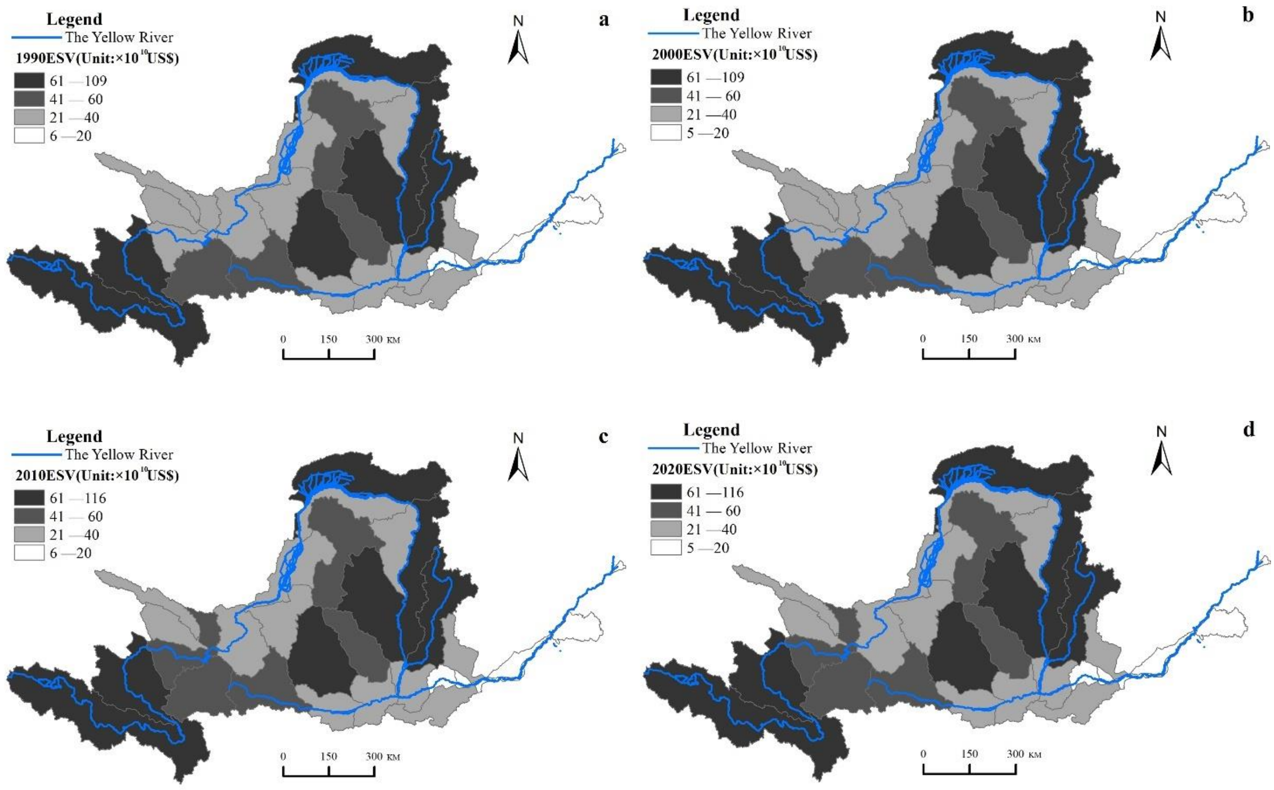


Fig. 2 Spatial distribution of ESV changes in YRB from 1990-2020 (a.1990 b.2000 c.2010 d. 2020)

This paper further reveals the spatial agglomeration characteristics and evolution law of ESV in the YRB from 1990 to 2020 through hotspot analysis (Fig. 3). The ESV accumulation characteristics in most of the YRB are not significant in space, and the significant areas are dominated by high ESV and low ESV accumulation. The high-value areas of ESV are concentrated in the five core areas of the Maqu-Longyangxia River Basin, the Daxia River and Tao River Basin, the Datong River Basin, and the Fen River Basin. The low-value agglomeration areas are mainly distributed in the Inner River, the northern and eastern margins of the YRB and the lower reaches. From 1990 to 2020, the high-value agglomeration area and the low-value agglomeration area did not change significantly in space, but the number of grids in the high-value agglomeration area and the low-value agglomeration area decreased from 647 to 627, and from 699 to 681, respectively. In general, the high-value agglomeration areas in the YRB are distributed in a large scale, while the low-value agglomeration areas are scattered.

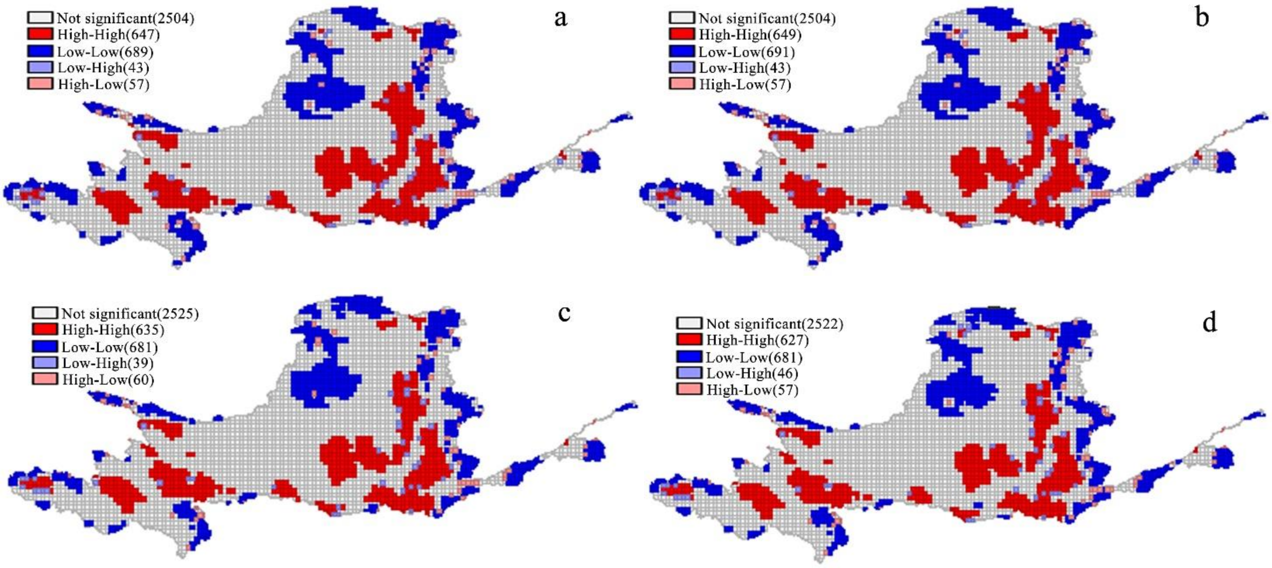


Fig. 3 Spatial agglomeration characteristics of ESV in the YRB from 1990 to 2020. (a.1990 b.2000 c.2010 d. 2020)

From 1990 to 2020, the barycenter coordinates of the ESV in the YRB remained stable between 106.78° ~106.94° E and 36.40° ~36.65° N (Fig. 4). During the study period, the barycenter coordinates of the ESV showed a transfer trajectory of first to the southwest, then to the northeast, and then to the southwest. From the perspective of the overall transfer direction, the barycenter of ESV shifted from the northeast of Huanxian County to the southwest from 1990 to 2020. The ESV in the northeast decreased, while the ESV in the southeast increased. From 1995 to 2000 and from 2000 to 2005, the migration distance of the barycenter of ESV in the YRB was longer, which were 16.33 km and 15.75 km, respectively, while the migration distance of the barycenter of ESV from 2005 to 2020 was shorter.

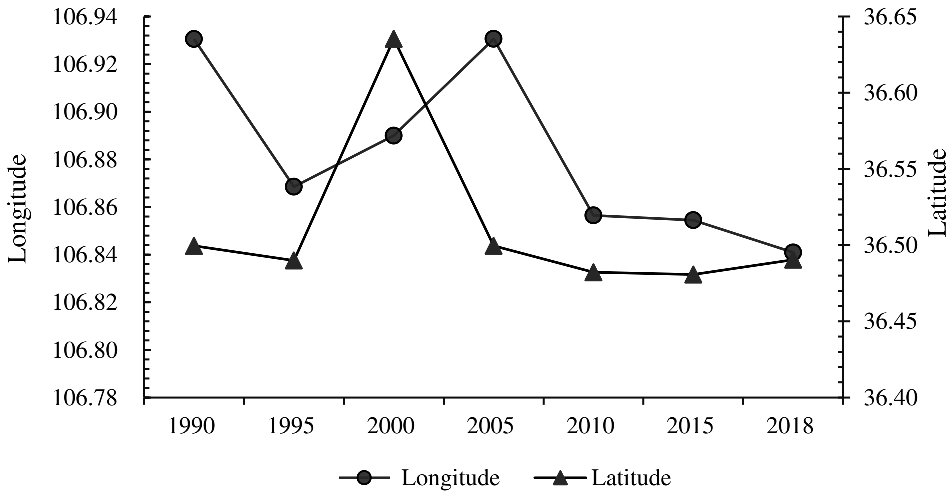


Fig. 4 Barycenter coordinates in the value of ecosystem services in the YRB from 1990 to 2020

### 3.3 Response of ecosystem services to land use change

From 1990 to 2020, the area of land use type change in the YRB reached 64356km$^2$. The area of each land type has changed to varying degrees. Among them, the land types with the largest changes are cultivated land and construction land. The cultivated land decreased by 8663 km$^2$ and the construction land increased by 13109 km$^2$. Compared with water, forest and grassland, the unuseland has also undergone great changes. In 2020, it decreased by 8131 km$^2$ compared with that of in 1990. The forest increased by 3093 km$^2$ and the grassland increased by 738 km$^2$. Changes in land use types have significant impacts on ecosystem services. In this paper, the researcher introduces a resilience index to reflect the response of ESV to land use change, using spatial analysis method. The average elasticity of ESV change in the YRB relative to land use change during 1990-2000 and during 2000-2010 was 0.27 and 0.44, respectively, but it dropped to 0.04 during 2010-2020. This indicates that the disturbance capacity of land use change on ecosystem services was weak during 1990-2000, while the disturbance capacity increased during 2000-2010. Since 2010, land-use change has had less disruption to ecosystem services. During this period, the range of changes in land use types was large, but the average elasticity index was relatively low, because there were many types of land use changes at this time, including the conversion of forest land and cultivated land to construction land, and the conversion of forest land and water area to cultivated land. The reduction of ESV brought by the change of land use per unit area was relatively small. In addition, due to the implementation of a series of ecological construction projects, the forest land and grassland in the river basin have been effectively increased, and the ESV has increased. On the whole, the value of ecosystem services did not change much.

Then, the researcher carries out accurate spatial statistics on the elasticity index from 1990 to 2020 (Fig. 5). The results show that the elastic index of the upper YRB and Loess Plateau is higher, and the impact of land use change on ecosystem services is more obvious in this region. This is mainly because since around 2000, the Chinese government has implemented large-scale ecological engineering measures in response to vegetation degradation in the upper reaches of the YRB and soil erosion in the middle reaches (Loess Plateau), such as the ecological protection and construction projects of the Three River Sources, and the comprehensive management projects of mountains, rivers, forests, fields, lakes and grasses and the projects of returning farmland to forests and grasslands, and other water and soil conservation measures such as the renovation of degraded farmland and wasteland, the restoration of forest and grassland ecosystems, etc., which have significantly increased the service value of ecosystems in the above-mentioned regions. In addition, Lanzhou New District, Guanzhong Plain and the lower Yellow River region also show higher elasticity index. Due to the rapid advancement of urbanization, the above-mentioned regional development and construction and human activities have led to a rapid increase in construction land, thus resulting in a significant decline in ecosystem services and a higher resilience index.

In general, the land use types in the YRB have changed a lot, and the conversion between land types is very common. The conversion of ecological land to urban construction land and the conversion of unuseland and cultivated land to ecological land have brought strong changes in the value of ecosystem services. This shows that the ecological construction projects implemented in the basin have achieved good ecological benefits.

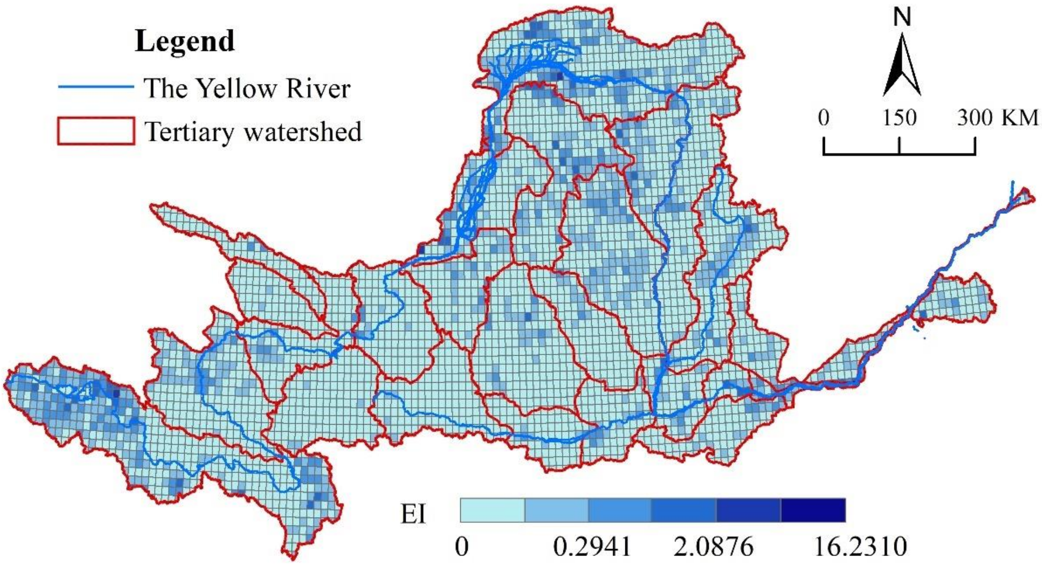


Fig. 5 Spatial distribution of elastic coefficients in the YRB from 1990 to 2018.

## 4. Discussion

According to literature reports, different scholars use different evaluation index systems and calculation methods to calculate the value of ecosystem services.The research results of Yin et al. show that the ESV in the YRB from 1990 to 2020 showed a dynamic change of first increasing and then decreasing, with an overall increasing trend [26], which is consistent with the trend of this study. However, due to the different evaluation index systems selected, the accounting methods differences lead to numerical differences. This paper evaluates the ESV of the YRB based on the method of unit area value equivalent factor. This method has a relatively simple and comprehensive evaluation system, is especially suitable for evaluating the value of ecosystem services in larger areas, and has proved to be a more effective method than evaluating benefits. Considering the availability of data, the grain yield and price in each county were not used in the calculation of the equivalent factor, which weakened the spatial heterogeneity of the counties in the study area and may have an impact on the estimation results [27]. The evaluation of ESV needs to ensure accuracy and adaptability. With the continuous evolution of the relationship between human beings and the natural environment, the equivalent factor table needs to adapt to the dynamic update of the times; considering the locality of ESV research, more time-sensitive and local ecological indicators and high-precision remote sensing data should be incorporated into the evaluation system; the ESV evaluation model can fully consider ecological processes and will become the future research direction of value evaluation. Some scholars have found that the reduction of farmland and forest area can lead to the decline of ESV [28]. Since urban construction land tends to occupy high-quality farmland, forest land and grassland, the reduction of these land types will lead to the loss of ESV. From 1990 to 1995, ESV decreased due to the reduction of forest land and water area. From 1995 to 2010, ESV continued to increase, mainly due to the increase of forest land and water area. Due to the implementation of policies such as “returning farmland to forests”, natural forest protection plan, and the Three North Protection Plan [29], ESV decreased from 2010 to 2020. After 2010, with the improvement of social and economic level and the acceleration of urban development, the construction land for residences, industrial parks, and public service facilities has increased significantly, and the area of grassland and cultivated land has decreased, resulting in a decrease in ESV. The research findings are consistent with Xin et al. [30].

In this study, using the hot and cold spot analysis method can well characterize the spatial difference of ESV. Many scholars have applied it to the spatial analysis of ESV [31]. Because the economy in the upstream areas such as Qinghai, Lanzhou and Sichuan is lagging behind that of the downstream areas, there is less construction land, grasslands are widely distributed, and these areas have higher altitudes and lower accessibility to human activities. The water source produced by melts snow and ice all year round nourishes the local grassland [32], and mainly undertakes ecological service functions such as soil and water conservation [33]. The northern Qilian Mountains, Taihang Mountains and Qinling Mountains are rich in grassland forest resources. Hot spots such as mediation services, habitat services, and human services are concentrated, and these areas are listed as ecological protection barriers. Delineate the ecological corridor protection areas of the YRB, formulate a system of nature reserves, and give full play to the regulating role of ecological barriers to ensure regional ecological security. The cold spots are mainly concentrated in the middle and lower reaches of the YRB, such as the Mu Us Sandy Land and the Loess Plateau. These areas are crisscrossed with ravines, hills and beams, with fragile ecological environment, low forest and grass coverage, serious soil erosion, mostly unuseland and cultivated land, and weak ecosystem services, resulting in low ESV. In the downstream provinces such as Henan and Shandong, in these regions, there is flat terrain, convenient transportation, developed economy, and a lot of construction lands, resulting in the loss of ESV, represented by the reduction of biodiversity, fragmented habitat distribution due to land use changes, and species threatened with extinction [34]. Species are threatened with extinction due to the fragmentation of habitat distribution caused by land use change [34]. In this regard, the low-yield and poor-quality arable lands in the region are included in the new round of the project of returning farmland to forest and grassland, insisting on sand control and afforestation, planting grass, and eliminating desertification; and doing a good job in the intensification of urban and industrial lands. At the same time, the gravity model was used to study the changing trend of the ESV “center of gravity” in the YRB. The researcher can comprehensively analyze the temporal and spatial changes of ESV, combining with the changes of ESV in different periods, so that the ecological impact and laws of government decision-making can be fed back and analyzed, which is conducive to finding problems and providing support for the formulation of ecological and environmental protection policies.

The results of the study finds that water area contributes the most to total ESV. However, in recent years, due to the accelerated urbanization, the sharp increase in water consumption, the discharge of industrial sewage, and the use of chemical fertilizers and pesticides have aggravated the severity of water pollution. Although the government has formulated the “Transboundary Water Body Joint Protection Action” to make up for the deficiencies of the environmental protection law, the penalties for illegal sewage discharge are still insufficient, and the problem of water pollution still exists and is serious. Therefore, the state should increase the penalties for violations. From 1990 to 2020, the total ESV in the YRB showed an increasing trend, which was mainly due to the policies issued by the national government in recent years, such as returning farmland to forest and returning farmland to grassland. These policies have made great contributions to the promotion of ESV in the YRB and the security of regional ecological assets, and have effectively improved the regional ecosystem, and the sustainable benefits of ecosystem services have also been significantly improved. At the same time, due to the frequent human activities and the increase of urban construction land, part of the cultivated land is also consumed and occupied greatly. Therefore, cultivated land not only bears the role of ecologically returning farmland and protecting ecology, but also makes huge sacrifices for social and economic development. Therefore, in the process of regional land development and utilization, it is still very important to maximize the safety of cultivated land. In response to this, several suggestions are put forward: first, we should strengthen the protection of basic farmland, check the red line of cultivated land, and do a good job in the balance of cultivated occupation and compensation; second, when formulating regional land use planning policies, ESV should be included in decision-making; the third is to improve the management efficiency of the project of returning farmland to forest and grassland, consolidate the results of the project implementation, and strictly prevent the occurrence of reclamation and grazing. Fourth, in the land use planning, we should do a good job in the planning of construction land, avoid disorderly development of construction land, do a good job in evaluating the economical and intensive use of construction land, digest and revitalize the stock land, and improve the efficiency of urban land use. In addition, because the upper, middle and lower reaches of the YRB are the ecological center, the energy center and the economic center respectively [36], the proposal of ecological protection countermeasures in the YRB needs to classify the river basin according to the different protection priorities of the region and adapt measures to local conditions, in order to strive to achieve ecological Balanced development of relationships with humans.

## 5. Conclusion

This study evaluated the ESV of the YRB using the equivalent factor method, revealed the numerical changes and spatial distribution characteristics of the ESV in the YRB, and deeply explored the response of the ESV to the change of land use types. The researcher has drawn the following conclusions:

(1) In terms of time, from 1990 to 2020, the ESV in the YRB showed an overall increasing trend, with a total increase of $31.85\times10^{10}$USD, with an average annual increase of $1.14\times10^{10}$USD. The value of ecosystem services increased by $167.66\times10^{10}$USD and $28.73\times10^{10}$USD, indicating that the value of ecosystem services increased significantly, mainly because the implementation of large-scale ecological construction projects has increased forest land and grassland; In space, from 1990 to 2020, the spatial characteristics of ESV were relatively stable. The high-value areas were mainly distributed in the upper reaches of the YRB, from Shizuishan to the north bank of Hekou Town, the Fenhe River Basin, Hekou Town to Longmen and the Jinghe River Basin; the low-value areas were distributed in the lower reaches of the YRB, which was the most widely distributed and larger area of construction land in the basin. In this area, it had poor ecosystem services and was also an economically developed area in the YRB. The ESV of the YRB has the characteristics of spatial agglomeration in space. The barycenter coordinates of the ESV show a transfer trajectory of first southwest, then northeast, and then southwest.

(2) From 2000 to 2010, the land use change in the YRB had a greater impact on ESV, showing a high elasticity coefficient. Since 2010, the disturbance of ecosystem services caused by land use change has become smaller. Spatially, the upper reaches of the YRB and the Loess Plateau have higher elastic indices, and the impact of land use change on ecosystem services is more obvious, mainly because the large-scale implementation of ecological construction projects has significantly improved the ecological functions of the region.

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