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Prediction of Ecosystem Service Value (ESV) Based on Grey System Theory Model: A Case Study of Hanzhong City

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Abstract

Ecosystem services play an important role in human survival and development. The prediction and evaluation of ecosystem service value (ESV) can provide scientific basis and guidance for the protection and restoration of the ecosystem, and provide decision-making support for policy formulation and resource allocation. It has significant practical and long-term significance, and is an important means to promote the construction of ecological civilization and sustainable development. Taking Hanzhong City, Shaanxi Province, China as an example, based on the land use data from 2010 to 2020, this paper analyzes the temporal and spatial evolution of the ESV in Hanzhong City, and uses the grey system theory model to forecast and analyze the ecosystem value in the region from 2025 to 2030. The results show that: (1) The main land-use types in Hanzhong are grassland, forestland and farmland. From 2010 to 2020, the area of farmland, water area and grassland decreased, while the area of forestland, built-up land and barren land increased. (2) From 2010 to 2020, the ESV of Hanzhong City showed a trend of decreasing first and then increasing, and Zhenba County had the highest proportion of increasing ESV. From the perspective of different ecosystem service types, the value provided by soil conservation service is the largest, while the value provided by water supply service is the least. From the perspective of different land use types, the value provided by forestland is the largest, and the value provided by built-up land is the least. (3) It is predicted that the ESV in Hanzhong will continue to increase from 2025 to 2030, but due to the insufficient protection of water sources and the expansion of built-up land, the ESVs in some regions will decrease year by year. The future planning of Hanzhong should pay attention to the coordinated development of a new urbanization process and ecological civilization construction to build a green ecological city.

Keywords: *Ecosystem Service Value (ESV), Prediction Model, Grey System Theory, Hanzhong City.*

Introduction

With the rapid development of human economy and society, human activities, such as over-exploitation of natural resources and change in land-use type, have destroyed the function of ecosystem, resulting in the decline of biodiversity, degradation of ecosystem, degradation of land resources and other problems. These problems not only seriously affect the structure, process and function of ecosystem, but also have a serious impact on human well-being. With the continuous development of ecological science and the improvement of human cognition of ecosystems, more and more stakeholders begin to realize the importance of protecting and restoring natural ecosystems to maintain the health and survival of human society (Morandín-Ahuerma et al., 2019). Ecosystem services refer to the direct or indirect benefits that ecosystems provide to human beings, including material and immaterial benefits, which can be evaluated or estimated as economic or non-economic values (Marcos et al., 2021). According to the Millennium Ecosystem Assessment report, ecosystem services are divided into four categories: support services, provisioning services, regulatory services and cultural services (Assessment, 2005). (Costanza et al., 1997) further categorize ecosystem services into 17 categories, which include only renewable services and exclude non-renewable resources such as fuels and minerals. Ecosystem services play an important role in human survival and development, so it is of great significance to evaluate the ESV. The impact of land use and land cover change on the ESV is significant (Ongsomwang et al., 2019). Different types of land use have

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different impacts on the supply and demand of ecosystem services, thus impacting the ESV. (Costanza et al., 1997) propose a method for estimating the value of global ecosystem services and natural capital, and provide monetization valuation data for different types of ecosystems around the world. (De Groot et al., 2012) estimate the value in monetary units of different ecosystems, such as forests, wetlands, oceans, grasslands, etc., and find that the value of global ecosystems and their services is much higher than previously thought. (Xin et al., 2023) evaluate and simulate changes in the ESV based on land use/cover change in Shanghai. (Admasu et al., 2023) examine the impact of land use/cover change on the ESV in the Dire and Legedadi watersheds in the Central Plateau region of Ethiopia and provide information support for landscape management decisions in the region. (Knoke et al., 2024) propose the concept of "land cover elasticity" and introduce it to improve the valuation of ecosystem services for large-scale land use change. However, most of the existing studies are based on the evaluation of the past or present ESV, and the research on the prediction of the future ESV remains to be in-depth. In the research on the future prediction of ESV, most scholars use the Markov-CA model to predict the future land use/cover situation, and further predict the ESV indirectly (Chen et al., 2022; Xi et al., 2021), and some scholars use trend analysis method to predict the future trend of ESV qualitatively (Guo & Yang, 2014; Hou et al., 2021). This study introduces a grey system theory model to predict ESV. Grey system theory does not require a large amount of data, is suitable for small samples, and has high accuracy. It is currently a very novel method for predicting ESV.

This study selects Hanzhong City as the research subject. Hanzhong City is an important ecological protection barrier in China and a major water source protection area for the South-to-North Water Diversion Project's central route. The selection of the study area is typical and representative. However, in recent years, with the development of the social economy, Hanzhong City is facing a contradiction between the rapid expansion of the city scale and the ecological environment improvement of the Qinling Mountains. (Feng et al., 2020) study the temporal and spatial changes of land use in Hanzhong City, Shaanxi Province, China, and analyze the effects of different land use types on ESV. (Wang et al., 2014) mainly use 3S technology (remote sensing, geographic information system and global positioning system) to quantitatively analyze and evaluate the value of land use, ecosystem and ecological service in the three cities of southern Shaanxi (Hanzhong, Ankang and Shangluo). Using remote sensing image interpretation and agricultural statistical data analysis, (Zhang & Zhou, 2020) study the special-temporal variation of land use and its impact on agroecosystem service value in Hanzhong Basin. The existing research has a good reference significance for the assessment of ESV in Hanzhong City. However, there are still many limitations, such as incomplete data, inconsistent calculation methods and inaccurate results. At the same time, few existing studies are involved in predicting the change of ESV in the future, so it is still valuable to explore its change rule. This study is based on land use data from three periods between 2010 and 2020. It provides a detailed analysis of the spatial and temporal evolution of ESV in Hanzhong City and future predicts ESV for 2025 to 2030. Such continuous data analysis over this time span and future prediction is relatively rare in related fields of research.

This study expands the research methods for predicting ESV, enriches the application of grey system theory in ESV prediction, and provides new ideas and methods for the study of ESV. The research results can provide scientific evidence for local governments in formulating land use plans and ecological protection policies. This can help achieve the coordinated development of economic growth and ecological protection, promoting sustainable development in the region.

Methodology and Data

Study Area

Hanzhong is located in the geographical and geometric center of China, in the southwest of Shaanxi Province, between 105°30'50" ~ 108°16'45" east longitude and 32°08'54" ~ 33°53'16" north latitude. It has jurisdiction over 9 counties, 2 districts and 1 national economic and technological development zone, covering an area of 27,200 square kilometers. Hanzhong belongs to the subtropic climate zone, with Qinling Mountain in the north, the cold current is not easy to invade, and the climate is mild and humid.

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All the rivers in Hanzhong belong to the Yangtze River Basin. In terms of water system composition, the main water system is the east-west Han River system and the north-south Jialing River system. The location of the research area is shown in Figure 1.

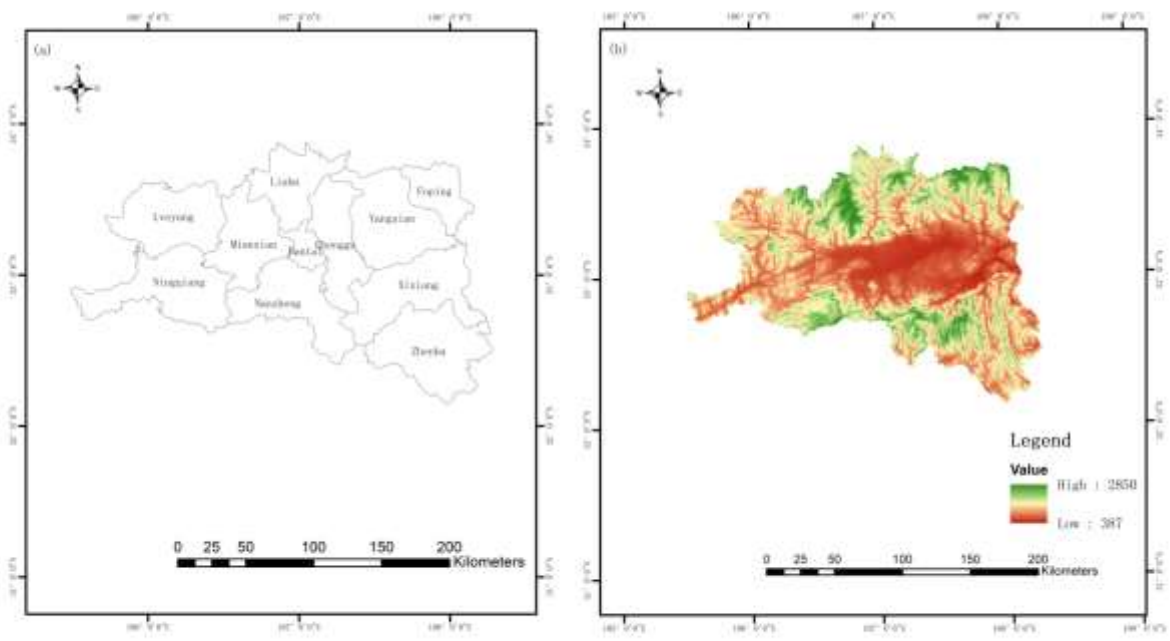

Fig. 1. Location Of Hanzhong City, Shaanxi Province, China: (A) 11 Counties Of Hanzhong City; (B) Digital Elevation Model (DEM).

Data Sources

The data of the study area Digital Elevation Model (DEM) used in this paper are from the Geospatial Data Cloud (http://www.gscloud.cn/). The land use data of Hanzhong for 2010, 2015 and 2020 are derived from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (http://www.resdc.cn). Based on the National Resources and Environment Database of China, the data is generated by manual visual interpretation using the Landsat remote sensing image data of the United States as the main information source. Combined with the actual situation of the study area, according to the research requirements and image accuracy, the land use in Hanzhong City is divided into 6 types, including farmland, forestland, grassland, water area, built-up land and barren land. The accuracy test of remote sensing interpretation results shows that the comprehensive evaluation accuracy of the first-level type reaches more than 92%, which met the research requirements. The average grain yield data and grain planting area data of Hanzhong City come from Shaanxi Statistical Yearbook, and other social and economic statistical data come from the National Agriculture Products of Cost-Benefit Data Compilation.

Research Methods

Accounting for the ESV

At present, the accounting methods for the ESV can be roughly divided into two categories. The first method is based on the price of the unit service function, also known as the function value method. The second method is based on an equivalent factor of unit area value, also known as the equivalent factor method. The function value method is a method to calculate the total value by quantifying the number of ecosystem service functions and the unit price of each function. It usually establishes a production function to simulate the relationship between ecosystem service functions and environmental variables in a particular area (Ouyang et al., 2020). However, this method requires a large number of input parameters, and the calculation process is relatively complex. More importantly, it is difficult to reach an agreement on the

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evaluation methods and parameter standards of each ESV (Müller et al., 2020). The equivalent factor method is based on distinguishing different ecosystem service function types, using quantifiable criteria to construct the value equivalent of different ecosystem service function types, and then combining it with the distribution area of the ecosystem for assessment (Li et al., 2021). Essentially, the equivalent factor method is the product of the ESV per unit area of each ecosystem type multiplied by the area of that type. Compared with the function value method, the equivalent factor method is more intuitive and easier to use, requires fewer data, and is particularly suitable for assessing ESV at regional and global scales (Zhao et al., 2021). This study evaluates the ESV of Hanzhong City using the equivalent factor method. The equivalent factor method, as a tool for evaluating ESV, has certain advantages, such as ease of operation and intuitiveness. However, its limitations cannot be overlooked. Equivalent factors cannot reflect regional differences. Since the equivalent factor method is usually based on the equivalent factors of a specific region or context, applying it to other regions may result deviations. Different regions have varying ecosystem types, environmental conditions, and socio-economic backgrounds, so using uniform equivalent factors may not accurately reflect the actual situation in each region. Therefore, to improve the accuracy and reliability of the assessment, this paper has modified the equivalent factors based on the specific conditions of Hanzhong City and developed regionally differentiated equivalent factors. This avoids a one-size-fits-all approach, thereby enhancing the role of the equivalent factor method in evaluating ESV and providing scientific support for ecological protection and sustainable development.

Based on the measurement method of ESV proposed by (Costanza et al., 1997), (Xie et al., 2008) compiled the equivalent factor table of ESV in China to adapt to the actual situation in China. The ESV of the standard equivalent factor is defined as the value of grain production per unit area (ha) of the farmland ecosystem. In this study, by referring to the Shaanxi Statistical Yearbook and compiling the cost-benefit data of China's agricultural products, it is concluded that the average price of grain in Hanzhong City is 0.33 USD/kg, and the average yield is 4039.67 kg/ha. Therefore, the total income per unit area of grain production in Hanzhong City during 2010 – 2020 is 1342.64 USD/ha. Total inputs per unit area (including seeds, fertilizers, pesticides, machinery use, energy and labor costs, etc.) are 962.94 USD/ha and shadow leases for land acquisition for food production are estimated at 248.56 USD/ha. According to this calculation, the equivalent factor of ESV of one standard unit in Hanzhong City during the study period is 131.13 USD/ha. Then, based on the equivalent factor table of ESV in China based on (Xie et al., 2008), and referring to the research of (Li & Zhang, 2022), the equivalent factor is modified to obtain the ESV coefficient of each land use type in Hanzhong City (Table 1).

Table 1. Ecosystem Value Coefficient of Each Land Use Type in Hanzhong City (Usd/Ha).

Ecosystem services		Farmland	Forestland	Grassland	Water area	Built-up land	Barren land
Provisioning services	Food production	131.13	43.27	56.39	69.50	32.78	2.62
	Raw materials	51.14	390.78	47.21	45.90	35.41	5.25
	Water supply	-342.26	157.36	74.75	1,370.34	-441.92	2.62
Regulating services	Gas regulation	94.42	566.49	196.70	66.88	0	7.87
	Climate regulation	127.20	533.71	204.57	270.13	0	17.05
	Hydrologic regulation	100.97	536.33	199.32	2,461.36	-637.30	9.18
	Environment purification	182.27	225.55	173.10	1,947.32	-292.43	34.09
Support services	Soil conservation	192.76	527.15	293.74	53.76	2.62	22.29
	Nutrient cycle maintenance	40.65	93.10	30.16	9.18	0	1.31
	Biodiversity maintenance	133.76	591.41	245.22	449.78	40.65	52.45
Cultural services	Aesthetic landscape	22.29	272.76	114.09	582.23	142.93	31.47

Grey Prediction Model

To carry out an in-depth analysis, it is necessary to use the existing data to predict the further ESV of

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Hanzhong City. Since there are only three periods of data in this paper, the amount of data is small, and short-term prediction is needed, the grey system theory model is chosen to forecast the ESV of Hanzhong City from 2025 to 2030.

Firstly, the ESV of Hanzhong City in 2010, 2015 and 2020 is input into the model GM (1,1) as the original series $X^{(0)}$:

$$X^{(0)} = \left\{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3)\right\} \tag{1}$$

where, $x^{(0)}(1)$ is the ESV of Hanzhong in 2010, $x^{(0)}(2)$ is the ESV of Hanzhong in 2015, and $x^{(0)}(3)$ is the ESV of Hanzhong in 2020.

Based on the original data in Equation (1), a new series $X^{(1)}$ is obtained by summing it:

$$X^{(1)} = \left\{x^{(1)}(1), x^{(1)}(2), x^{(1)}(3)\right\} \tag{2}$$

where, $x^{(1)}(k) = x^{(0)}(1) + \cdots + x^{(0)}(k)$, $k = 1,2,3$.

Secondly, the adjacent mean of $X^{(1)}$ is taken to generate the sequence $Z^{(1)}$:

$$Z^{(1)} = \left\{z^{(1)}(2), z^{(1)}(3)\right\} \tag{3}$$

where, $z^{(1)}(k) = \frac{\left[x^{(1)}(k) + x^{(1)}(k-1)\right]}{2}$, $k = 2,3$.

Construct the accumulation matrix B and the constant term vector Y as follows:

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{1}(3) & 1 \end{bmatrix} \tag{4}$$

$$Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \end{bmatrix} \tag{5}$$

At this time, the grey prediction model can be established:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \tag{6}$$

where, a and b are parameters.

The time response equation of Equation (6) is:

$$\hat{x}^{(1)}(k) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-a(k-1)} + \frac{b}{a} \tag{7}$$

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To obtain the time response equation (7) of the grey prediction model (6), the least squares estimation of the parameters is carried out, thus:

$$\hat{a} = [a,b]^T = \left(B^T B\right)^{-1} B^T Y \tag{8}$$

Finally, the cumulative reduction value can be obtained:

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) \tag{9}$$

where $k = 2,3,4,5$; $\hat{x}^{(0)}(2)$, $\hat{x}^{(0)}(3)$, $\hat{x}^{(0)}(4)$ and $\hat{x}^{(0)}(5)$ are the predicted values of ESV in Hanzhong in 2015, 2020, 2025 and 2030, respectively.

Data Validation

Before establishing a grey prediction model, it is necessary to first validate the data to determine whether the grey system theory model GM(1,1) can be used to predict the ESV of Hanzhong City. This study uses the smoothness ratio test to validate the data.

To determine whether the data is a quasi-smooth sequence, smoothness ratio analysis is used to assess the smoothness of the original data. The more stable the data changes, the smaller the smoothness ratio. The calculation method is as follows:

$$\rho_k = X^{(0)}(k) / X^{(1)}(k-1) \tag{10}$$

If the data sequence meets the following two conditions, it can be considered a quasi-smooth sequence and can be used for the GM(1,1) prediction model.

a) $\frac{\rho_{k+1}}{\rho_k} < 1$, where $k = 2,3,4,\ldots,n-2,n-1$.

b) $\rho_k \in [0,\delta]$, $\delta < 0.5$, where $k = 2,3,\ldots,n$.

Accuracy Check of Prediction Results

In this paper, the accuracy of the prediction results of ESV is tested by the posterior error test method, which is used to evaluate the prediction results.

After calculating the sequence of reduced values through Equation (9), calculate the residual:

$$\varepsilon(k) = x^0(k) - \hat{x}^0(k) \tag{11}$$

where, $k = 1,2,3$.

Calculate the variance S_1 of the original sequence $X^{(0)}$ and the variance S_2 of the residual $\varepsilon(k)$:

$$S_1 = \frac{1}{n}\sum_{k=1}^{n}\left(x^0(k) - \overline{x}\right)^2 \tag{12}$$

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$$S_2 = \frac{1}{n}\sum_{k=1}^{n}\left(e(k)-\bar{e}\right)^2 \tag{13}$$

Calculate the posterior difference ratio C:

$$C = \frac{S_2}{S_1} \tag{14}$$

When $C \leq 0.35$, the accuracy level of the model is level 1 (good), indicating that the prediction results are very reliable. When $0.35 < C \leq 0.5$, the accuracy level of the model is 2 (qualified), indicating that the prediction results are credible. When $0.5 < C \leq 0.65$, the accuracy level of the model is level 3 (barely qualified), indicating that the prediction results are barely credible. When $C > 0.65$, the accuracy level of the model is level 4 (unqualified), indicating that the prediction results are not credible.

Results

Analysis of land use change

Table 2 and Figure 2 show the area and proportion of land use types in Hanzhong from 2010 to 2020. Hanzhong's main land use types are farmland, forestland and grassland, and the land area of these three types accounts for more than 98%. Water area, built-up land and barren land account for the smallest proportion, and the three together accounts for only about 2%. From 2010 to 2020, the general trend of land use change in Hanzhong City is as follows: (1) The area of farmland and water area continues to decrease. (2) Built-up land area continues to increase. (3) The area of forestland decreases first and then increases, showing an overall increasing trend. (4) The area of grassland and barren land increase first and then decrease, and the overall area of grassland shows a downward trend, while the overall area of barren land still shows an upward trend.

Table 2. Land-Use Type Area of Hanzhong City From 2010 To 2020.

Land-use type	2010		2015		2020	
	Area (ha)	Proportion	Area (ha)	Proportion	Area (ha)	Proportion
Farmland	741,963.70	27.39%	740,121.20	27.32%	725,385.80	26.79%
Forestland	821,939.46	30.34%	821,740.25	30.33%	869,121.39	32.10%
Grassland	1,098,823.74	40.56%	1,099,024.12	40.56%	1,063,456.04	39.27%
Water area	17,514.09	0.65%	17,366.49	0.64%	17,110.26	0.63%
Built-up land	28,867.05	1.06%	30,390.84	1.12%	32,327.01	1.19%
Barren land	222.57	0.01%	661.68	0.03%	552.06	0.02%

From the perspective of spatial distribution, farmland and built-up land are mainly concentrated in the central area of Hanzhong City (Figure 3). Over time, built-up land changes obviously, and its area shows a trend of continuous increase, while farmland area gradually decreases, which indicates that built-up land is occupying farmland, which may be related to the acceleration of urbanization and urban population growth of Hanzhong City. The large area of forestland and grassland is mainly distributed in the northern and southern mountains of Hanzhong City, which shows the excellent ecological background of Hanzhong City. The water area is small, mainly distributed along the Han River basin. The barren land area is the smallest.

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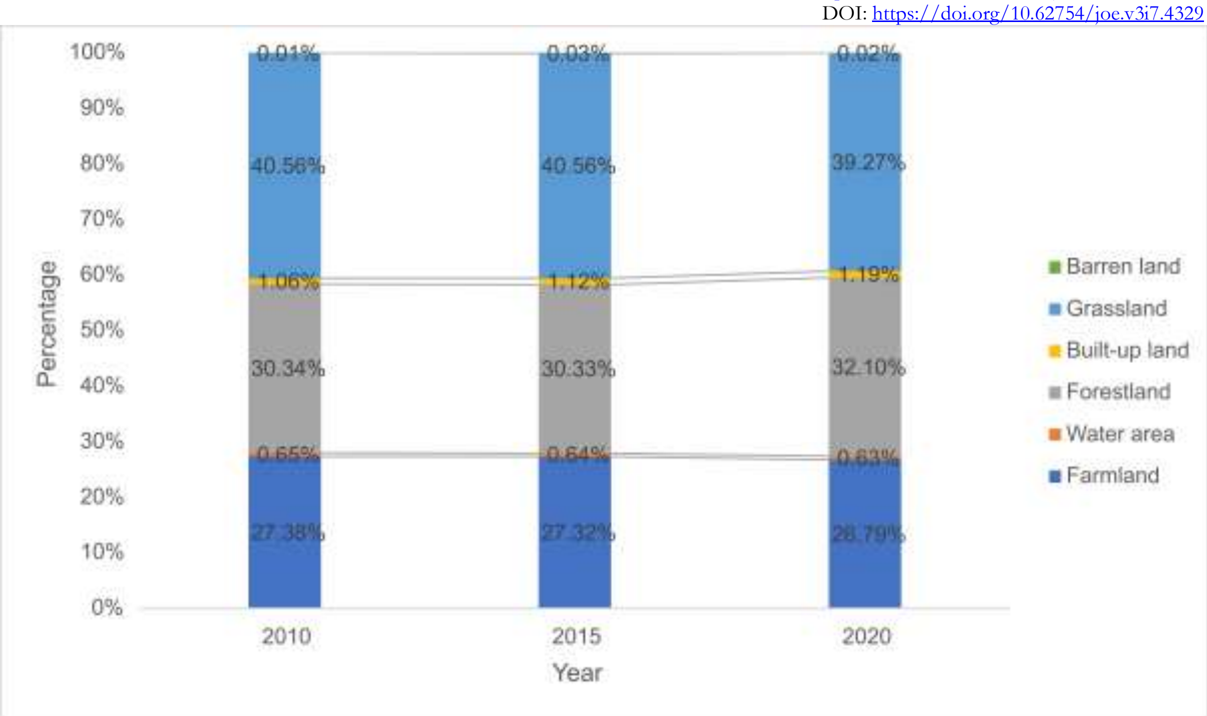

Fig. 2. Proportion of Land-Use Types in Hanzhong From 2010 To 2020.

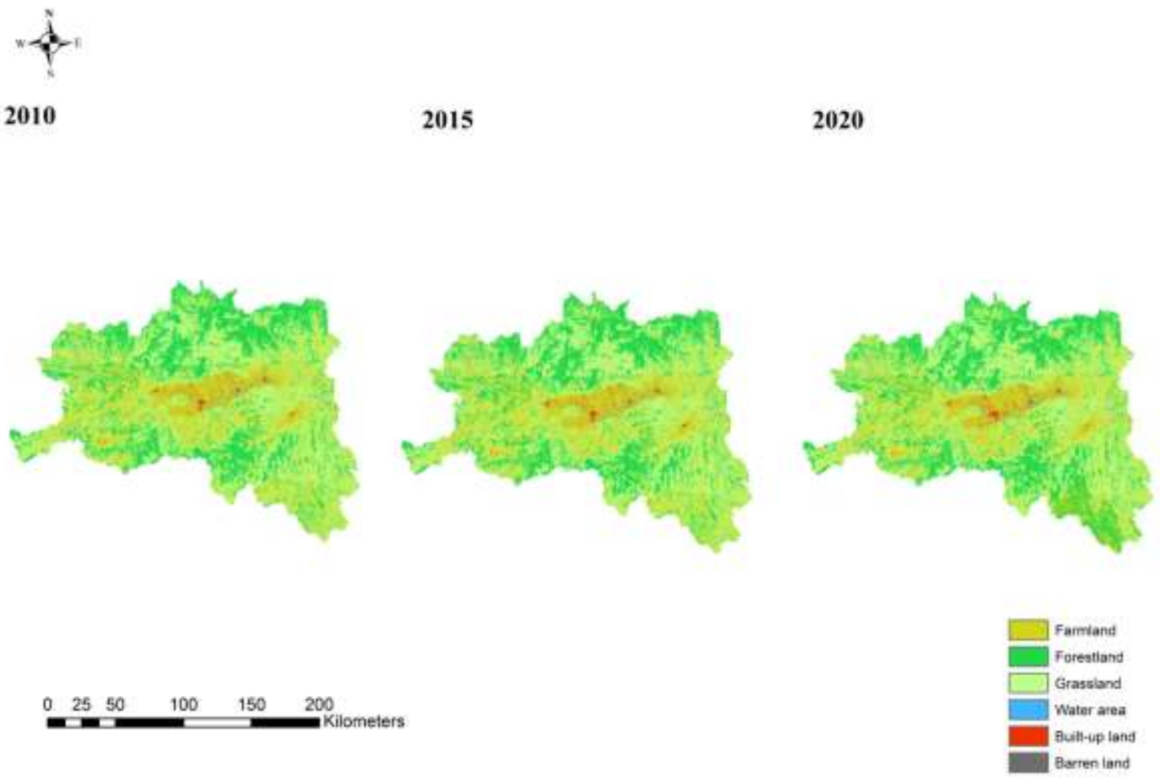

Fig. 3. Land-Use Change Map of Hanzhong City From 2010 To 2020.

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Analysis of Accounting Results of ESV in Hanzhong City

Temporal Evolution of ESV in Hanzhong City

In terms of ESV of different indicators (Table 3), from 2010 to 2020, the ESV of Hanzhong City shows a trend of first decline and then increase. Overall, the ESV in the city increases by 1.92% during the study period, showing an upward trend. Among them, the value of provisioning services increases by 3.86%. Over the past 10 years, Hanzhong has gradually enhanced its capacity to supply ecological products to meet the growing material needs of local and surrounding people. The growth of the regulating services value is 1.67% and the value of support services increases by 1.62%. Although the value of both regulating services and support services increase, the growth rates are lower than that of provisioning services value. This may be because human activities have certain impacts and risks on the ecological system of Hanzhong City, and it is necessary to strengthen the attention and protection of the natural ecological system of Hanzhong City. The value of cultural services increases by 2.29%. This shows that Hanzhong City has achieved certain achievements in tourism development in the past 10 years.

In terms of individual ecosystem services (Table 3), the proportion of each ecosystem service value is relatively stable in the order of soil conservation > biodiversity maintenance > climate regulation > hydrology regulation > gas regulation > waste disposal > raw materials > aesthetic landscape > food production > nutrient cycle maintenance > water supply. During the whole study period, the ESV of raw materials, water supply, gas regulation, climate regulation, hydrological regulation, soil conservation, nutrient cycle maintenance, biodiversity maintenance and aesthetic landscape increase, and the ESV of water supply increases the most. The ESVs decline in both food production and environment purification, with the former declining more sharply.

Table 3. Accounting Results of ESV Of Different Indexes in Hanzhong City From 2010 To 2020 (Unit: USD Million).

Ecosystem services		2010	2015	2020
Provisioning services	Food production	196.99	196.79	194.95
	Raw materials	412.84	412.73	428.87
	Water supply	-31.22	-31.48	-22.85
	Subtotal	578.61	578.04	600.97
Regulating services	Gas regulation	752.99	752.73	771.17
	Climate regulation	762.58	762.24	778.31
	Hydrology regulation	759.48	757.89	772.86
	Environment purification	536.50	535.44	536.22
	Subtotal	2,811.55	2,808.30	2,858.56
Support services	Soil conservation	900.10	899.70	911.38
	Nutrient cycle maintenance	139.98	139.90	142.63
	Biodiversity maintenance	863.86	863.57	880.85
	Subtotal	1,903.94	1,903.17	1,934.86
Cultural services	Aesthetic landscape	380.43	380.50	389.16
	Subtotal	380.43	380.50	389.16
Total		5,674.53	5,670.01	5,783.55

In terms of land-use type (Table 4), the ESV provided by different land-use types in Hanzhong is ranked as forestland > grassland > farmland > water area > barren land > built-up land from high to low. Among them, the ESV provided by farmland, water area and built-up land continues to decrease, which may be related to the acceleration of the urbanization process. Although the ESV provided by forestland has a certain decline trend at first, it still shows an upward trend on the whole. The ESVs provided by grassland and barren land increase first and then decrease, mainly because the area of grassland and barren land increase first and then decreases. It can be seen that different land use types and intensities affect the

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increase or decrease of ESV. This is mainly because changes in land use impact the structure, processes, and functions of ecosystems, leading to changes in the value of regional ecosystem services.

Table 4. Accounting Results of ESV Of Different Land-Use Types in Hanzhong City From 2010 To 2020 (Unit: USD Million).

Land-use type	2010	2015	2020
Farmland	544.85	543.49	532.67
Forestland	3,236.72	3,235.94	3,422.52
Grassland	1,796.85	1,797.18	1,739.02
Water area	128.31	127.23	125.36
Built-up land	-32.23	-33.95	-36.12
Barren land	0.01	0.12	0.10
Total	5,674.49	5,670.01	5,783.55

Spatial Evolution of ESV in Hanzhong City

In terms of spatial evolution characteristics, this paper uses ArcGIS 10.8 software to classify the ESV per unit area of different land-use types in Hanzhong in 2010, 2015 and 2020 by using the Natural Jenks method, and obtaining the spatial distribution map of ESV per unit area of Hanzhong (Figure 4). As can be seen from Figure 4, the overall region distribution pattern of ESV in Hanzhong is higher in the north and south, and lower in the middle, and the spatial distribution characteristics of ESV in Hanzhong have little change during the study period. Based on the land use characteristics, it can be seen that forestland and grassland are mainly distributed in the north and south areas of Hanzhong City, which will directly lead to the increase of ESV. The central area is mainly the urban area of Hanzhong City. With the continuous acceleration of urbanization, the built-up land is increasing gradually, but the ESV provided by the built-up land is negative. Therefore, from 2010 to 2020, the low ESV area in the central area of Hanzhong City is gradually expanding.

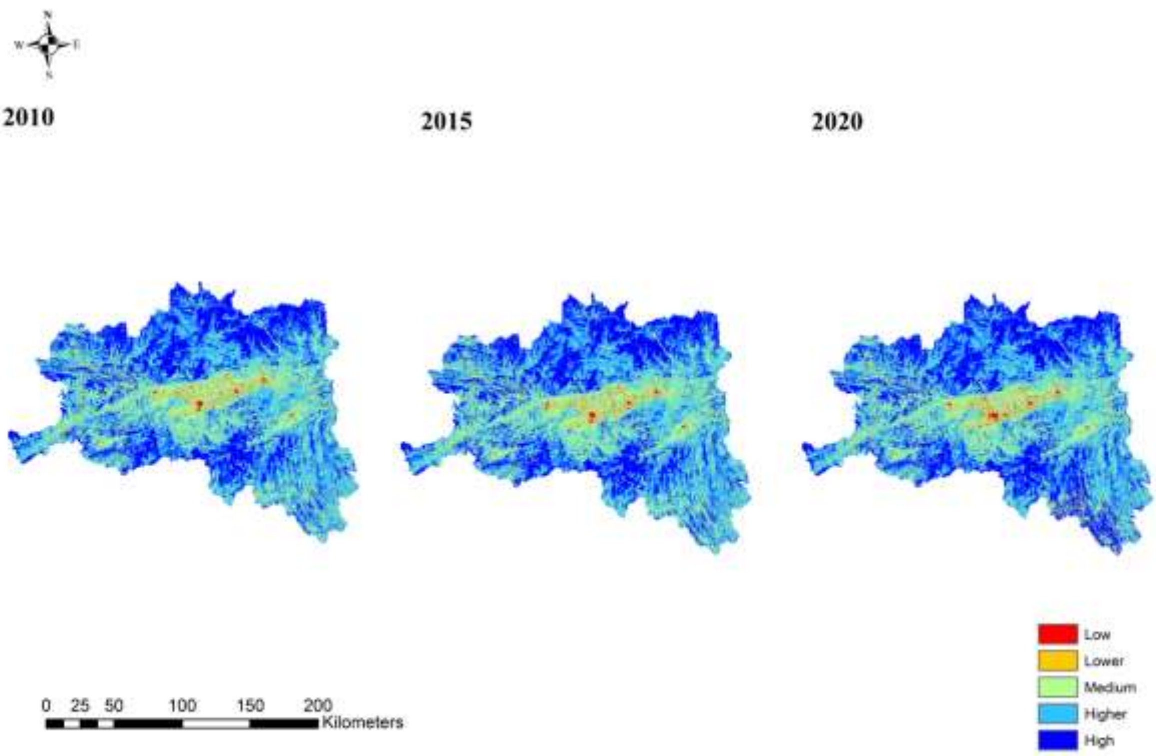

Fig. 4. Spatial Distribution of ESV Per Unit Area in Hanzhong City From 2010 To 2020.

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The ESV per unit area of Hantai District is always in the low-value area in the 3 calculation time points in this paper. As can be seen from Table 5, during 2010 – 2020, the ESV in Hantai District decreases by 3.49 million USD, with a decline rate of 4.26%. This is mainly because Hantai District is the central urban area of Hanzhong City, with high population density, a good opening foundation, economic development zone and free trade zone (under construction) and other functional areas. Therefore, Hantai District's ability to provide products such as agriculture, forestry, fishery and animal husbandry is relatively weak, while the built-up land area accounts for a relatively high, and the regulating services and support services that can be provided by farmland, forestland and grassland can be limited. On the contrary, the ESV per unit area of Zhenba County is in the high-value area, and the high-value area expands significantly. From 2010 to 2020, the ESV in Zhenba County increases by 120.48 million USD, with a growth rate of 19.25%. This is mainly caused by the increase of forestland area in Zhenba County, which may be related to the effective implementation of the policy of returning farmland to forest. Although most counties and districts show a steady rise in the ESV of cultural services during the study period, the overall proportion is still low, which indicates that the tourism attraction rate of Hanzhong is still weak. Therefore, it is necessary to accelerate the upgrading and optimization of tourism-related industries under the premise of guaranteeing ecological tourism.

Table 5. Accounting Results of ESV of Counties and Districts in Hanzhong City From 2010 To 2020 (Unit: USD Million).

Year	Administrative division	Provisioning services	Regulating services	Support services	Cultural services	ESV
2010	Hantai District	3.32	43.47	29.04	6.11	81.95
	Nanzheng District	60.44	296.64	200.82	39.92	597.82
	Chenggu County	44.05	224.53	148.78	30.64	448.00
	Yang County	68.27	333.72	221.73	44.90	668.62
	Xixiang County	58.65	312.04	212.18	41.25	624.12
	Mian County	44.11	235.73	160.64	31.52	472.00
	Ningqiang County	56.66	314.18	215.80	41.16	627.80
	Lveyang County	71.89	318.01	212.41	43.54	645.85
	Zhenba County	55.76	311.15	218.07	40.89	625.86
	Liuba County	76.19	267.35	179.62	38.80	561.95
	Foping County	39.26	154.73	104.87	21.70	320.55
2015	Hantai District	3.18	42.73	28.86	6.16	80.93
	Nanzheng District	60.39	296.36	200.75	39.92	597.42
	Chenggu County	43.73	223.15	148.56	30.66	446.10
	Yang County	68.20	333.42	221.68	44.88	668.18
	Xixiang County	58.64	311.96	212.15	41.26	624.01
	Mian County	44.11	235.41	160.49	31.54	471.54
	Ningqiang County	56.55	313.70	215.47	41.10	626.82
	Lveyang County	71.89	317.93	212.36	43.54	645.71
	Zhenba County	55.79	311.13	218.06	40.90	625.87
	Liuba County	76.20	267.35	179.62	38.80	561.97
	Foping County	39.25	154.70	104.85	21.69	320.48
2020	Hantai District	2.95	40.76	28.40	6.35	78.46
	Nanzheng District	59.82	293.55	199.70	39.88	592.95
	Chenggu County	43.70	222.76	147.87	30.61	444.94
	Yang County	68.17	332.38	221.85	44.81	667.21
	Xixiang County	59.23	313.00	213.03	41.38	626.65
	Mian County	44.29	235.21	160.46	31.56	471.52
	Ningqiang County	57.58	314.85	216.22	41.39	630.05
	Lveyang County	72.38	318.34	212.36	43.66	646.74
	Zhenba County	77.97	367.62	251.48	49.27	746.34
	Liuba County	75.79	265.96	178.98	38.63	559.36

Journal of Ecohumanism
2024
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	Foping County	39.07	154.12	104.52	21.62	319.33

Analysis of Prediction Results of ESV in Hanzhong City

First, the smoothness ratio test is used to validate the data, and the results show that the data sequence is a quasi-smooth sequence, so it can be used for the GM(1,1) prediction model.

According to the established prediction model of the ESV of Hanzhong City, the ESV in 2025 and 2030 is predicted. The specific prediction results are shown in Table 6, Table 7 and Table 8. As can be seen from the tables, although the ESV predicted by different criteria is slightly different, the overall ESV in Hanzhong will continue to rise from 2025 to 2030. It is expected that the ESV in 2030 will increase by about 6.57% compared with that in 2010.

In terms of the ESV of different indicators, it is estimated that the ESV of food production will decline from 2025 to 2030. This trend may be due to the continuous implementation of the policy of returning farmland to forest, resulting in the reduction of farmland area, or it may be due to the reduction of agricultural production efficiency and other reasons. However, it is expected that the value of other indicators of ecosystem services will be on the rise. The increase in the value of regulating services and support services indicates that the productivity and self-regulation ability of the ecosystem in Hanzhong is improving. The increase in the value of cultural services indicates that the natural environment and cultural landscape of Hanzhong are becoming more attractive to tourism and leisure activities. It is expected that the increase in these ESVs may be related to the implementation of environmental protection policies, and may also complement Hanzhong's economic development and social progress.

Table 6. Prediction Results of ESV Of Different Indexes in Hanzhong City From 2025 To 2030 (Unit: USD Million).

Ecosystem services		2025	2030
Provisioning services	Food production	193.13	191.32
	Raw materials	445.58	463.00
	Water supply	-16.56	-12.05
Regulating services	Gas regulation	790.02	809.37
	Climate regulation	794.69	811.44
	Hydrology regulation	788.10	803.67
	Environment purification	537.00	537.78
Support services	Soil conservation	923.20	935.18
	Nutrient cycle maintenance	145.41	148.25
	Biodiversity maintenance	898.44	916.42
Cultural services	Aesthetic landscape	398.00	407.06
Total		5897.01	6011.44

It is expected that the ESV of different land-use types will change to different degrees between 2025 and 2030. The ESV of farmland, grassland, water area, built-up land and barren land may decrease, while that of forestland is expected to increase. Specifically, the expansion of built-up land may destroy the ecosystem and weaken its ecological service function, which is one of the important reasons leading to the decline of ESV. With the implementation of the policy of returning farmland to the forest and strengthening the protection of forest resources, the area of forestland will gradually increase, which will promote the ESV.

Table 7. Prediction Results of ESV Different Land-Use Types in Hanzhong City From 2025 To 2030 (Unit: USD Million).

Land-use types	2025	2030
Farmland	522.05	511.66
Forestland	3,618.78	3,827.38

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2024
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Grassland	1,682.60	1,628.16
Water area	123.52	121.70
Built-up land	-38.41	-40.87
Barren land	0.08	0.07
Total	5,908.62	6,048.10

From 2025 to 2030, it is predicted that the ESV of Hantai District, Nanzheng District, Chenggu County, Yang County, Mian County, Liuba County and Foping County will slightly decline, while that of Xixiang County, Ningqiang County, Lveyang County and Zhenba County will be improved. Especially in Zhenba County, the growth of ESV is the most obvious. This trend may be because Hantai District, Nanzheng District, Chenggu County, Yang County and Mian County have more plain areas and rapid urbanization development. Built-up land will be developed along traffic lines and residential areas, leading to the decline of ESV. Zhenba County is rich in forest resources, and it is expected that the area of forestland will continue to increase from 2025 to 2030, which will significantly improve the ESV.

Table 8. Prediction Results of ESV Of Counties and Districts in Hanzhong City From 2025 To 2030 (Unit: USD Million)

Administrative division	2025	2030
Hantai District	76.06	73.74
Nanzheng District	588.51	584.11
Chenggu County	443.78	442.63
Yang County	666.24	665.27
Xixiang County	629.30	631.96
Mian County	471.50	471.48
Ningqiang County	633.30	636.56
Lveyang County	647.77	648.80
Zhenba County	886.70	1,056.89
Liuba County	556.76	554.18
Foping County	318.18	317.04
Total	5918.10	6082.66

In this paper, 28 grey prediction models are constructed according to different indicators, different land-use types and different counties. After the posterior difference test, the results show that the posterior difference ratio (C) of all models is less than 0.35, and the accuracy level of all models is level 1 (good). Therefore, the prediction results of ESV using this model are scientific and accurate.

Discussion

Forecasting ESV is of great significance for realizing sustainable development, maintaining ecological security and promoting economic development. Based on the grey system theory model and the analysis of the temporal and special changes of the ESV in Hanzhong City from 2010 to 2020, this paper predicts the ESV in Hanzhong City from 2025 to 2030, and makes an in-depth of the prediction results.

It can be seen from the prediction results that the overall ESV of Hanzhong City has a continuously rising trend, especially the ESV of forestland has been effectively improved, while the ESV of the water area has been declining year by year. Both forestland and water area are important for ecosystem services. Hanzhong City is located in the Qinling-Bashan mountain area, which is a biological source area with intensive ecological resources and an important water source protection area for the South-to-North Water Diversion project. Although the government has carried out the policy of returning farmland forest to forest in recent years, which has made some achievements, the protection of water sources is still insufficient. In addition, the increase in the built-up land area will lead to the decline of ESV in some regions. Therefore, the future development planning of Hanzhong City should carry out systematic ecological remediation of the broken farmland, provide financial subsidies for the policy of returning farmland to forest, and strengthen the

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2024
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protection of water sources while ensuring the quantity of farmland, to avoid the rapid expansion of built-up land.

In terms of model selection, most existing studies use the Markov-CA model to simulate land-use change, and then indirectly calculate ESV. This paper tries to use a new way to predict ESV, that is, using the grey system theory model to predict ESV directly. Compared with the Markov-CA model, the grey system theory model can transform uncertain factors into certain factors, which has high reliability and accuracy, and has lower requirements on the number of samples. However, how to take future policy factors into account at the same time is a problem worth further consideration.

In this paper, considering that the function value method requires a large number of parameters and a complex calculation process, the equivalent factor method, which is easier to calculate, is selected to calculate the ESV. However, the ecosystem itself is a complex comprehensive system, the spatial heterogeneity cannot be explained by the equivalent factor method, and the selection of coefficient is subjective, which may affect the evaluation results to a certain extent. In the future, we should devote ourselves to exploring a more scientific and perfect evaluation system.

Conclusion

The main land-use types in Hanzhong are grassland, forestland and farmland, which have superior ecological environments. Between 2010 and 2020, the area of farmland, water area and grassland decrease, while the area of forestland, built-up land and barren land increase.

From 2010 to 2020, the ESV of Hanzhong City shows a trend of first decline and then increase, among which the overall increase rate of Zhenba County is as high as 19.25%. In 2010, 2015 and 2020, forestland is the land-use type that contributes the most to ESV, accounting for 57.04%, 57.07% and 59.18%, respectively. Compared with other accounting indicators, the ESV of soil conservation is always the highest from 2010 to 2020, accounting for 15.86%, 15.87% and 15.76%, respectively.

According to the forecast results, the ESV in Hanzhong will continue to increase from 2025 to 2030, and the increase in forestland area is an important reason for the growth. The ESV of food production will decline, while the ESV provided by all other indicators will rise. The high-value areas will still be mainly distributed in the south and north, and the land-use type is mainly grassland and forestland. The low-value areas will still be mainly distributed in the middle of the city, and the land-use type is mainly built-up land. In addition, the ESV of some low-value areas will also show a trend of decline year by year. Therefore, relevant government departments need to improve the land resource planning system and actively adjust the land-use structure to promote efficient, green and sustainable development of the region. In addition, in the process of urban construction, it is necessary to strictly observe the boundaries of urban development, pay attention to the secondary development of abandoned built-up land, and carry out new urbanization that takes into account ecological protection.

The grey system theory model is used to predict the ESV of Hanzhong City, and the prediction accuracy level reaches level 1 (good), indicating that the model has a high prediction accuracy and can be used as a reference for the future ESV.

Credit Authorship Contribution Statement

Yan Feng: Conceptualization, Formal analysis, Methodology, Resources, Software, Visualization, Writing – original draft. **Fathin Faizah Said:** Conceptualization, Methodology, Resources, Supervision, Validation, Writing – review & editing. **Norlida Hanim Mohd Salleh:** Resources, Software, Supervision, Validation, Writing – review & editing. **Naziatul Aziah Mohd Radzi:** Supervision, Validation, Visualization, Writing – review & editing. **Yunqiao Li:** Data curation, Visualization, Writing – original draft.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

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