

Article

Evaluation and Prediction of Ecosystem Services Value in Urban Agglomerations Using Land Use/Cover Change Analysis: Case Study of Wuhan in China

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Abstract: The evaluation of ecosystem service value (ESV) is crucial for decision making in regional sustainable development. The close relationship between ecosystem services and land use/cover change (LUCC) is well acknowledged. However, the impact of the mutual transformation among different land use types on the temporal and spatial differences in the ESV is still unclear. To fulfill this gap, this study evaluates the ESV in the Wuhan Urban Agglomerations based on LUCC, taking the spatiotemporal characteristics into consideration. The results show that (1) The land use structure in the Wuhan Urban Agglomerations has undergone great changes from 2012 to 2021, and the area of cultivated land converted to forest land is the largest, which may be related to policies such as returning farmland to forests. (2) The total amount of ESV shows a downward trend, and the spatial distribution of ESV is “low in the west and high in the central and eastern regions”, which may be related to the natural factors in study area. (3) The spatial distribution of ESV in the study area will remain unchanged in the future. However, the transformation among land use types may exacerbate the reduction in the total ESV, which will have an adverse impact on the ecological environment and sustainable development of the region. This study initiates a more comprehensive framework to better reflect the real scenario of ESV, which will hopefully provide a reference for regional sustainable development.

Keywords: LUCC; ecosystem service value; value assessment; prediction



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1. Introduction

Ecosystem services are closely related to human well-being [1,2]. With the rapid development of the global economy and society, high-intensity human activities have caused great damage to the ecosystem. There are serious ecological and environmental problems such as global biodiversity loss and land degradation, which threaten the function of the ecosystem and regional sustainable development [3,4]. In the face of increasingly severe ecological and environmental problems, it is necessary to recognize the importance of ecosystem management [5]. The concept of ecosystem services was first proposed in the 1960s [6], from which people initially gained a preliminary understanding of the ecosystem services value (ESV). The value of ecosystem services refers to the monetary value of ecosystem services; that is, the expression of the benefits that humans can obtain from ecosystems in the market [7]. In 1997, Costanza quantitatively assessed the value of global ecosystem services and clarified the principles and methods for estimating the value of ecosystem services [8], which provided a measurement standard reflecting the ecological and environmental conditions of the study area. Subsequently, scholars successively revised and demonstrated the effectiveness of the quantitative evaluation method proposed

by Costanza [9–11]. Within the framework of the study by Costanza et al., Ouyang et al. [12] and others [13] thoroughly assessed and analyzed the service value of China's mainland ecosystems to further explore and quantify the key functions of China's terrestrial ecosystems. In combination with China's actual ecological situation and relevant survey data, Xie et al. [14] made appropriate adjustments to the correlation coefficients in the evaluation method previously proposed by Costanza, and developed the "Table of equivalent factors of the value of terrestrial ecosystem services in China" on this basis, which serves as an important basis for the calculation of the ecosystem service value and evolutionary research, and has been widely used in subsequent research and estimation [4,15]. In recent decades, many scholars have conducted extensive research on ESV, including the response to land use changes [10], spatiotemporal variation characteristics [16], the natural environment [13,17,18], and the estimation and prediction of ESV in combination with socio-economic factors [19–23]. Assessing the evolution of ESV can provide a reference for formulating scientific and rational policies for ecological environmental protection and sustainable development [24] and it helps to achieve the goal of ecological and environmental protection [25,26].

Based on previous research, this study makes the following contributions. Firstly, in response to the problem of large time horizons that do not accurately reflect continuous changes in ESV, higher-frequency data collection and analysis methods are used to allow for smaller yearly time spans. Secondly, spatial analysis and geographic information system (GIS) techniques are introduced, which can better reveal the spatial distribution characteristics of ESV changes. Meanwhile, the temporal dynamic characteristics of ESV changes are analyzed by combining time series and spatial data to provide a more comprehensive understanding of the impact of land use/land cover change (LUCC) on ESV. Finally, in order to predict the future development trends in LUCC and ESV, IDRISI software (17.0) combined with the ESV assessment model are used to predict the potential impacts of LUCC on ESV in the future, which will provide effective support for a more refined management of the national land space.

The Wuhan Urban Agglomerations, also known as the "1 + 8" urban cluster, is the largest economic development consortium in central China. It is also a comprehensive experimental area built to create a "two-type society" under the current strategic deployment. In recent years, rapid industrialization and urbanization have brought about significant changes in the land use structure and methods in this urban cluster, highlighting the contradictions with ecological resource constraints. Therefore, this study takes the Wuhan Urban Agglomerations as an example. The study period lasts from 2012 to 2021. The study is based on the basic accounting theory of land use change combined with remote sensing images from the fourth phase of the Agglomerations, using ArcGIS 10.7 to extract and analyze land use changes. The study compares and analyzes the land use changes in the Wuhan Urban Agglomerations over the past decade from three aspects: overall land use changes, speed and magnitude of changes, and the land use transfer matrix. Additionally, considering the characteristics of the Wuhan Urban Agglomerations, equivalent factors are adjusted. A quantitative assessment of ESV in Wuhan urban agglomeration is carried out by calculating the areas associated with different land types. The study analyzes the impact of LUCC on the ESV of the Wuhan Urban Agglomerations from both temporal and spatial dimensions, as well as at the overall urban area and city levels. Lastly, based on the CA-Markov model and utilizing IDRISI software (IDRISI is a system for the combined application of remote sensing and GIS which integrates GIS and image processing functions, providing strong support for application areas such as remote sensing image processing, GIS analysis, and land use change analysis and prediction), future LUCC and ESV will be predicted and analyzed to provide scientific and rational references for the adjustment of land and space planning and inter-regional ecological compensation in Wuhan Urban Agglomerations [27].

2. Literature Review

LUCC is an important part of global change [28]. Land use change can reflect the impact of human activities on ecosystems [29,30], and directly affects the natural basis for human survival and development. Chen et al. [31] analyzed the patterns and driving factors behind the overall land use changes since 2000 based on a long-term series of remote sensing monitoring data. Focusing on remote sensing images between 2010 and 2015, Liu et al. [32] analyzed in detail the characteristics of the temporal and spatial variability of land use change in China through dynamic monitoring of land use and calculation of interannual rates of change. Wang et al. [33] analyzed the land use changes in Shiyang River Basin from 2005 to 2015, and discussed the temporal and spatial differentiation of ecosystem services in the Shiyang River Basin on this basis. By monitoring and analyzing changes in land use and land cover, the impact of human activities on the Earth's ecosystem can be better assessed, providing a scientific basis for the formulation of policies for sustainable development.

There is a strong link between ecosystem services and LUCC. The concept of ecosystem services can be traced back to the beginning of the 1960s. Ecosystem services are the benefits that humans can derive from ecosystems [34], which encompass those types of goods and services that are directly or indirectly produced and sustained by ecosystems and that are essential to human survival. These services include, but are not limited to, provisioning services, regulating functions, cultural values, and supporting roles, which form the basis for interdependence and harmonious coexistence between humans and the natural environment. Ecosystem services provide support for human land use. The type, pattern, and intensity of land use can, in turn, affect the ability to provide ecosystem services and play a decisive role in maintaining ecosystem services [13]. Ecosystem services evaluation is the process of quantifying and analyzing the value of these services and is essential for coordinating regional economic development, ecological restoration and maintaining regional ecological security [22].

At present, ESV evaluation methods mainly fall into two categories: price based on unit service function (functional value method) and equivalent factors based on unit area value (equivalent factor evaluation method) [35]. In 1997, Costanza et al. [8] proposed the method of equivalent value per unit area, which divided the earth's ecosystem into 17 service functions and assigned a corresponding monetary value to each service function in each unit. Based on this, a table of equivalent value coefficients between different land ecosystems and service functions was established. Garcia-Nieto et al. [36] selected eight European and four North African cities in the Mediterranean region as case studies and examined the impacts of land cover change on ecosystem service provisioning in the peri-urban areas of these cities. The results of the study show a general downward trend in ecosystem service provisioning capacity in peri-urban areas of the Mediterranean over the last 20 to 30 years, a change that poses a significant potential risk to human well-being in the Mediterranean region. Based on this, Xie et al. [37] combined expert knowledge and relevant statistical data to construct an ecosystem service value system conforming to China's actual environmental characteristics, and proposed the "Equivalent Factor Table of China's terrestrial ecosystem Service value" based on LUCC equivalent value assignment in 2003. In 2015, through remote sensing monitoring, Xie et al. [38] used a relevant data model and GIS technology to partially modify the equivalent factor, realized dynamic assessment of ESV, and promoted relevant domestic research [39,40] to a new stage. It has been applied in the evaluation of ecological service value in Beijing-Tianjin-Hebei urban agglomeration [39], Guangxi [41], 25 national key ecological function zones [42], Jiangsu Province [43], Dongting Lake Ecological Economic Zone [44], City Circle [45,46] and many other regions, providing a reference for many LUCC-related ESV studies in China [47–51], which has greatly promoted the development and application of such methods in China. In recent years, with the acceleration of urbanization, significant changes in land use and land cover have become the focus of research. Academics have shown great interest and attention in exploring the correlation between such changes and the value of ecosystem services. A full literature review reveals that the time span of the relevant studies is large,

which cannot accurately reflect the continuous changes in ESV over a period of time. In addition, although most of the studies focus on the general trend and characteristics of ESVs, they often neglect the specific impacts of conversion between different land use types on ESVs in terms of spatial and temporal differences. Lastly, there is little literature on predicting the future trends in LUCC and ESV, which limits our ability to provide scientific support for the refinement of spatial management of the national territory to a certain extent.

Based on this, this study takes the Wuhan urban area as the research object, and explores the impacts of LUCC on the ESV of the Wuhan urban area in the decade from 2012 to 2021. Then, the ESVs of the Wuhan urban agglomeration are predicted for 2035 and 2050, and the future ESVs are quantified on the basis of data extraction and analysis. The future changes in LUCC and ESV in the Wuhan Urban Agglomeration are thus derived with a view to providing a reference for the sustainable development of the region. A flow chart of the main steps of the study is shown in Figure 1.

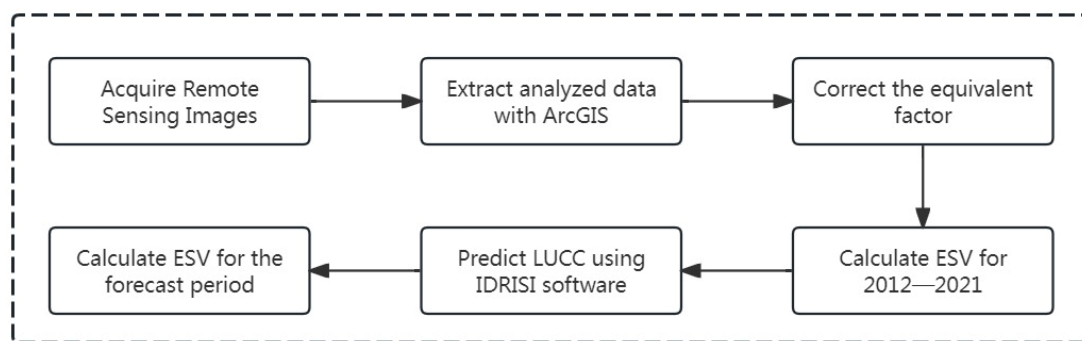


Figure 1. Flowchart on the main steps of the study.

3. Study Area and Research Methodology

3.1. Study Area

The Wuhan Urban Agglomerations is also known as the Wuhan “1 + 8” metropolitan area, and includes the following eight cities besides Wuhan: Huangshi, Xiaogan, Ezhou, Xian’ning, Qianjiang, Tianmen, Huanggang, Xiantao. The study area is located in the east of Hubei Province, towards the middle reaches of the Yangtze River and Jiangnan Plain in the middle east of the country, between 112° and 117° E and 29° N to 33° N, as shown in Figure 2. The city covers about one third of the land and half of the population of Hubei Province, with a total area of about 57,800 square kilometers. The study area is situated in a flat area, dominated by vast plains, a dense river network, and rich soil, with unique natural geographic conditions, a high urban density, and a strong economic foundation, making it the largest city circle in Hubei Province and even in the middle reaches of the Yangtze River. After more than 20 years of integrated construction of the city cluster, the pattern of coordinated development of eight neighboring cities with Wuhan as the core has been initially established. At present, the Wuhan City Circle is steadily moving towards a mature city cluster, realizing the transformation from initial development to maturity and perfection.

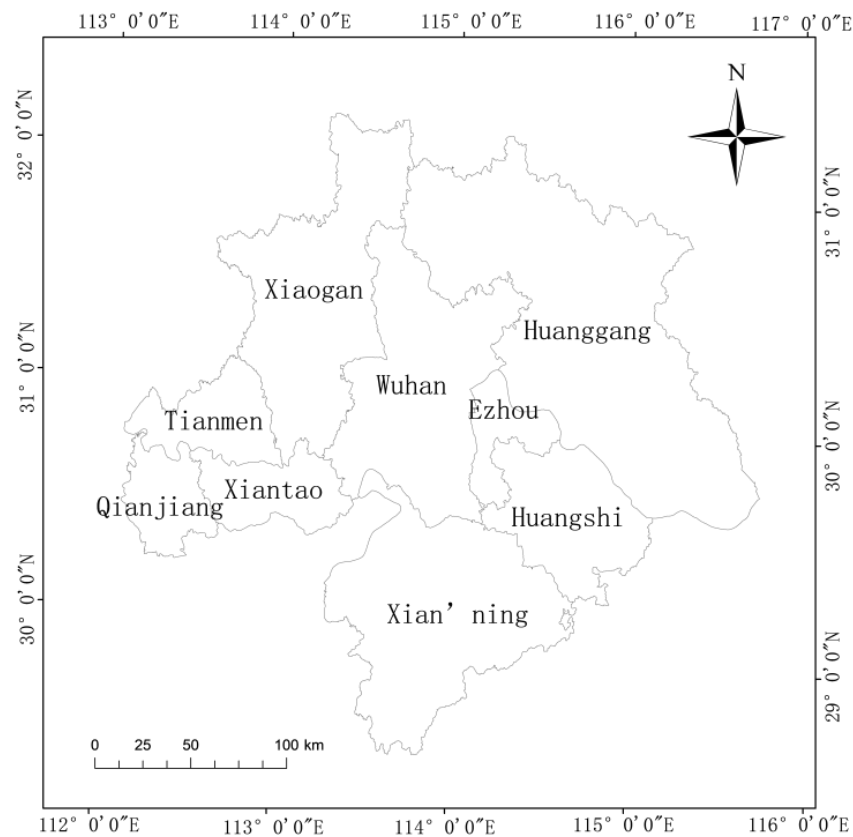


Figure 2. Administrative zoning map of Wuhan Urban Agglomerations.

3.2. Research Methods

3.2.1. ESV Evaluation Method

Land uses in the area differ and the main ecosystem services they produce vary considerably [52]. Based on the actual situation of study area and relevant survey data, this study revises the equivalent factor table proposed by scholar Xie et al. [37]. The revision method of equivalent factor was based on Xie's revision method of Costanza's ecosystem service value scale. First, the original value of the study area was obtained for the scale [13], as shown in Table 1.

Table 1. Equivalent factors of ecosystem services value in the study area.

First Category	Second Category	Farmland	Forestland	Grassland	Water Body	Unused Land
Provision function	Food production	1.11	0.25	0.23	0.66	0.01
	Raw material production	0.25	0.58	0.34	0.37	0.02
	Water supply	1.33	0.30	0.19	5.44	0.01
	Gas regulation	0.89	1.91	1.21	1.34	0.07
Regulation function	Climate regulation	0.47	5.71	3.19	2.95	0.05
	Purify the environment	0.14	1.67	1.05	4.58	0.16
	Hydrologic regulation	1.50	3.74	2.34	63.24	0.12
Maintenance function	Soil conservation	0.52	2.32	1.47	1.62	0.08
	Maintain nutrient circulation	0.16	0.18	0.11	0.13	0.01
	Biodiversity maintenance	0.17	2.12	1.34	5.21	0.07
Cultural function	Esthetic landscape	0.08	0.93	0.59	3.31	0.03

Using a standard equivalent factor, namely, the economic value of annual natural grain output of cultivated land in the region ((average grain output per unit area $\times$ average grain price)/7) [53,54], it was calculated that an ESV equivalent factor in study area is 2735.42 yuan/hm². The revised ESV coefficient of different land use types, namely VC_{fk}

is calculated by multiplying these two above. On this basis, the *ESV* of the study area in phase IV can be further calculated. The specific formula is as follows:

$$ESV_f = \sum (A_k \times VC_{fk}) \quad (1)$$

In the formula, ESV_f refers to the value (yuan) of a certain ecosystem service in the research area. A_k is class k land use area (hm^2) in the study area. VC_{fk} represents the single service value coefficient of type k land use (yuan/hm^2), which is the product of equivalent factor of single service value of type k land use and equivalent factor 2735.42 (yuan/hm^2). The output values of the main grain crops in Wuhan urban agglomeration are shown in Table 2.

Table 2. Output values of main grain crops in Wuhan Urban Agglomerations.

Year	2012	2015	2018	2020
Planting area/ (hm^2)	1385.42	1412.41	1396.34	1314.65
Yield/(t)	9,802,021.00	10,251,400.00	10,191,251.36	9,565,618.49
Yield per unit area/(t/ hm^2)	7075.13	7258.09	7298.53	7276.18

3.2.2. Value Flow Analysis Method

In order to study the impact of different land use types on *ESV*, this paper uses the flow analysis method [55] to calculate the gain and loss of ecosystem service value under LUCC changes. The specific formula is as follows:

$$PL_{ij} = (VC_j - VC_i) \times A_{ij} \quad (2)$$

In the formula, PL_{ij} represents the *ESV* gains and losses in a specific period after the type i land use is changed to type j . A_{ij} represents the area of land use type i converted to type j in this period. VC_j , VC_i represents the *ESV* coefficient of the i and j land use types.

3.2.3. Ca–Markov Model and Prediction Method

In order to make the study of *ESV* more practical, dynamic evaluation and early warning were carried out. In this study, the Ca–Markov model was used to predict the spatial distribution of different land use types and LUCC in 2035 and 2050, and then the *ESV* in the study area in 2035 and 2050 was estimated.

The Markov model uses the state of the system at different time points to build a probability matrix for the conversion from one type of land use to another type of land use. It can predict the state of the system at a certain time in the future. It focuses on analyzing the trends in future land use change in a specific time dimension; however, it is difficult to use traditional Markov model to predict future land use spatial change. The formula of Markov model is as follows:

$$S_{(t+1)} = f(S_{(t)}, N) \quad (3)$$

N is the domain of each cellular unit; S is cellular space; t and $t + 1$ are two different moments; and f is a regular function of cellular state evolution.

The CA model is a local network dynamics model, which predicts the future cellular state based on the previous cellular state and the surrounding neighborhood state according to certain transformation rules. It mainly emphasizes the prediction and analysis in the spatial dimension; however, the CA model also has certain limitations when making prediction. It mainly analyzes local interactions between cells, that is, it only focuses on prediction in the spatial dimension. The formula for the CA model is as follows:

$$S(T) = P_{ij} \times S(T_0) \quad (4)$$

In the formula, $S(T)$ and $S(T_0)$ are the land use states at T and T_0 , respectively. P_{ij} is the transition probability matrix of land use change state, which can be expressed by the following formula:

$$P_{ij} = \begin{pmatrix} P_{11} & \cdots & P_{1n} \\ \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nn} \end{pmatrix} \quad (5)$$

$$(0 \leq P_{ij} < 1, \sum_{j=1}^n P_{ij} = 1 \ (i, j = 1, 2, \dots, n; n \text{ is land use type}).$$

The CA–Markov model combines the advantages of the time dimension analysis carried out by the Markov model and the spatial dimension analysis carried out by the CA model. By combining the two models, the difficulty of making conversion rules can be reduced to some extent, and the workload of performing related calculations can also be reduced. At the same time, it reduces the possible interference caused by human factors on the final prediction results, and can simulate land use change in time and space well [56], and the feasibility and accuracy of the prediction can also be improved as much as possible. Therefore, IDRISI software is used in this paper to simulate and predict land use change in Wuhan Urban Agglomerations by combining the CA and Markov models.

3.3. Data Source and Processing

3.3.1. Data Sources

In order to make a comparative analysis of LUCC changes and ESV response characteristics. In this study, the data came from the geospatial data website (<http://www.gscloud.cn/>, accessed on 27 June 2022), with a spatial resolution of 30 m and an imaging width of 185 km × 185 km. The downloaded product is Level 00 data for a Level 1 T terrain correction image, and the geographic coordinate system used was the WGS-84 reference ellipsoid. Other data, such as agricultural product price, output value and sown area, came from the statistical yearbook, National Agricultural product Cost and Income Data Collection, etc.

3.3.2. Data Processing

The boundary data for the study area were derived from the vector data for counties and districts nationwide and the vector data for the planning boundary of the Wuhan city circle. Firstly, all the data were uniformly projected onto the WGS-84 coordinate system to ensure the consistency and accuracy of the data. Subsequently, a radiometric calibration and atmospheric correction were performed sequentially for the remote sensing data at each stage to eliminate the influence of environmental factors on data quality. On this basis, according to the standard of the Classification of Land Use Status Quo [57], combined with advanced methods such as visual interpretation and the maximum likelihood method, we meticulously classified the land use types into six categories according to the different uses of the land: arable land, forest land, grassland, watersheds, unutilized land, and construction land. Finally, in order to ensure the accuracy of the interpretation results, we further used the high-resolution images of Google Earth to verify and calibrate the interpretation results, and the Kappa coefficients of the remote sensing images of the four periods under study were 0.78, 0.81, 0.88, and 0.81, respectively. Data processing involving equivalent factor modification was completed through Excel (2019) spreadsheet processing. The spatial distribution of land use types in the study area from 2012 to 2021 is shown in Figure 3.

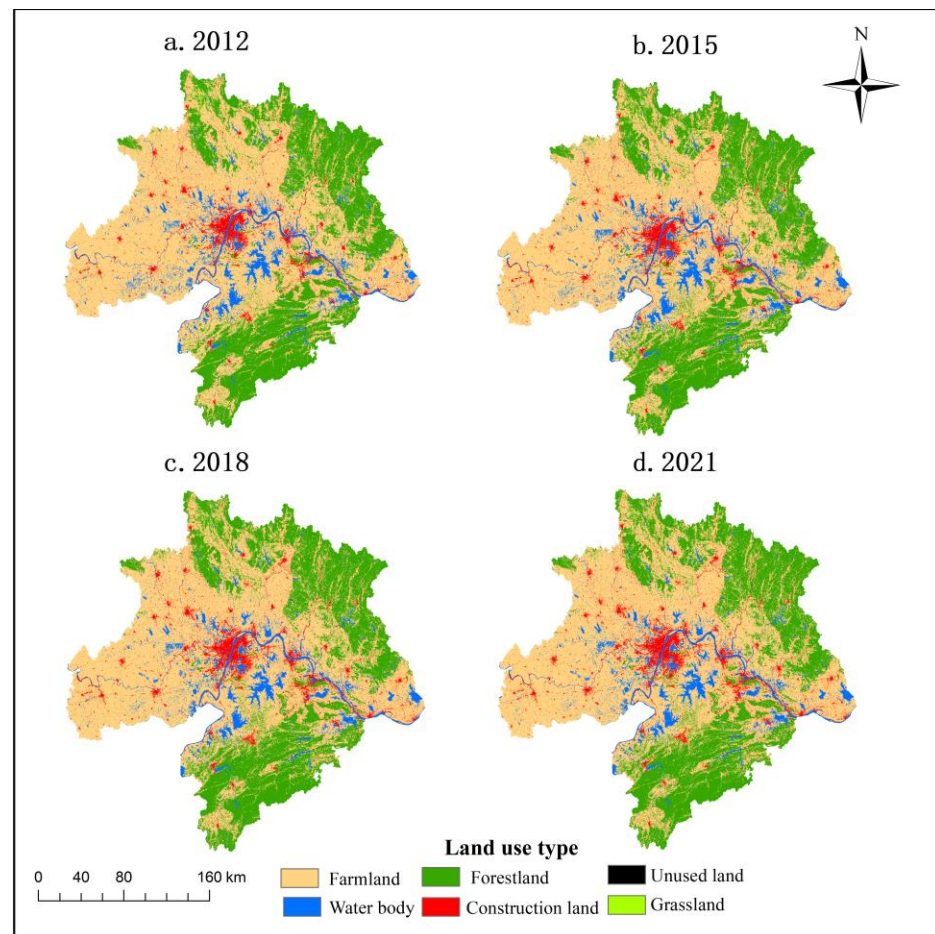


Figure 3. Spatial distribution of land use types in Wuhan Urban Agglomerations from 2012 to 2021.

4. Analysis of Land Use Change

4.1. Analysis of Overall Land Use Change

Land use change is mainly due to the conversion of land to different land use types, such as urban land expansion, new parks, returning farmland to forest and grassland, etc. Based on ArcGIS 10.7, this study analyzed the land use data for 2012, 2015, 2018, and 2021 to obtain the land use situation in study area, as shown in Figure 4. From 2012 to 2021, the area of land that underwent a land use change in the study area was 2188.44 square kilometers, accounting for 3.77% of the area of Wuhan Urban Agglomerations. In 2021, among all land use types, arable land occupied the largest area, accounting for 58.96%, followed by woodland, accounting for 28.60%. Water area, construction land, and unused land occupied less. Arable land and woodland occupied the largest proportion, mainly because the climate and topography of the research area are suitable for the survival of plants.

4.2. Analysis of Land Use Speed and Amplitude Change

As can be seen from Table 3, during the decade from 2012 to 2021, the land use areas in the study area decreased in the following categories: arable land, grassland, water area, and unused land. Among them, arable land decreased the most, with its area decreasing from 60.39% to 58.96%, with a total decreased area of 830.30 km². The water area decreased by 210.03 square kilometers. The grassland area decreased by 52.13 square kilometers. Finally, unused land was reduced by 1.68 square kilometers. The area of forestland and construction land increased, and the scale of construction land expanded significantly, increasing to 777.82 km², accounting for an increase of 5.80% from 4.46%; the woodland area increased by 316.40 square kilometers. The results showed the following: grassland > unused land > construction land > water area > cultivated land > forest land. Grassland had

the highest amplitude and speed change, which reached 73.50%, and decreased by 48.52% in 10 years. The smallest variation was in forestland, which was only 1.94%, increasing at a rate of 0.97% during the decade.

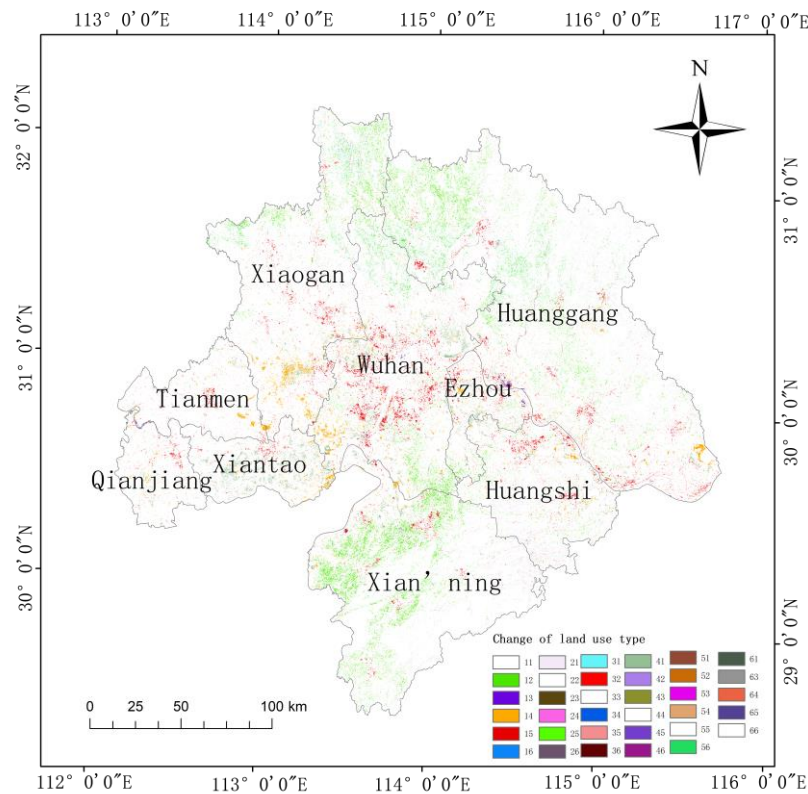


Figure 4. Land use change in Wuhan Urban Agglomerations from 2012 to 2021. (Note: Numbers 1–6 denote arable land, forest land, grassland, waters, construction land, and unused land, respectively. In the legend, 12 represents the area where arable land is converted to forest land, 21 represents the area where forest land is converted to arable land, and so on).

Table 3. Change in land use types in Wuhan Urban Agglomerations from 2012 to 2021.

Year		Farmland	Forestland	Grassland	Water Body	Construction Land	Unused Land
2012	Proportion of area	60.39%	28.06%	0.12%	6.96%	4.46%	0.01%
2015	Proportion of area	58.61%	29.16%	0.07%	7.16%	4.99%	0.01%
2018	Proportion of area	58.47%	29.21%	0.05%	6.72%	5.55%	0.01%
2021	Proportion of area	58.96%	28.60%	0.03%	6.60%	5.80%	0.00%
2012–2015	Amount of change	−1028.50	639.90	−32.00	115.37	306.64	−1.44
	Magnitude of change	−2.94%	3.93%	−45.11%	2.86%	11.85%	−32.96%
	Rate of change	−1.48%	1.95%	−25.91%	1.42%	5.76%	−18.12%
2015–2018	Amount of change	−85.40	25.70	−7.64	−255.83	323.03	0.16
	Magnitude of change	−0.25%	0.15%	−19.63%	−6.16%	11.16%	5.49%
	Rate of change	−0.13%	0.08%	−10.35%	−3.13%	5.43%	2.71%
2018–2021	Amount of change	283.60	−349.20	−12.49	−69.57	148.15	−0.40
	Magnitude of change	0.84%	−2.06%	−39.91%	−1.79%	4.60%	−12.77%
	Rate of change	0.42%	−1.04%	−22.48%	−0.90%	2.28%	−6.60%
2012–2021	Amount of change	−830.30	316.40	−52.13	−210.03	777.82	−1.68
	Magnitude of change	−2.37%	1.94%	−73.50%	−5.20%	30.06%	−38.31%
		−1.19%	0.97%	−48.52%	−2.64%	14.04%	−21.46%

The land use change in study area was analyzed by dividing the two time nodes in 2015 and 2018 into three time periods: from 2012 to 2015, the area of cultivated land, grassland and unused land decreased, while the areas of forest land, water area, and construction land increased. The change in cultivated land area was the most significant,

decreasing by 1028.50 square kilometers, grassland by 32 square kilometers, and unused land by 1.44 square kilometers. From 2015 to 2018, the trend in the change in the extent of the water area changed from growth to decline, and construction land was the largest variable, increasing by 323.03 km². From 2018 to 2021, the area of forestland, grassland, water and unused land decreased, and the decrease in grassland was the most significant, with a change rate of 39.91%.

4.3. Land Use Transfer Matrix

The speed and range of land use change can represent the change in land use type in terms of the amount and speed of the change, but it cannot show the direction of conversion among the various land types. In this paper, the land use transfer matrix is introduced to solve the problem. According to the division of land use type, there are 36 possible land use transformations in the Wuhan Urban Agglomerations during the study time. By combining raster data based on ArcGIS10.7, a land use transfer matrix for each period can be obtained, which are shown in Tables 4–6.

Table 4. Land use transfer matrix for Wuhan Urban Agglomerations from 2012 to 2015/km².

	Farmland	Forestland	Grassland	Water Body	Construction Land	Unused Land	Total
Farmland	-	1115.85	4.51	376.80	310.02	0.00	1807.17
Forestland	479.15	-	0.04	0.00	7.36	0.00	486.55
Grassland	25.05	7.25	-	1.17	3.40	0.21	37.07
Water body	273.96	3.39	0.14	-	26.45	0.10	304.04
Construction land	0.00	0.00	0.00	41.16	-	0.00	41.16
Unused land	0.50	0.00	0.40	0.28	0.58	-	1.75
Total	778.66	1126.48	5.08	419.41	347.80	0.31	2677.74

Table 5. Land use transfer matrix for Wuhan Urban Agglomerations from 2015 to 2018/km².

	Farmland	Forestland	Grassland	Water Body	Construction Land	Unused Land	Total
Farmland	-	547.97	6.00	175.80	306.55	0.00	1036.31
Forestland	519.76	-	0.03	0.00	5.64	0.00	525.43
Grassland	7.44	2.69	-	0.39	2.46	0.74	13.73
Water body	423.52	0.44	0.02	-	19.93	0.36	444.27
Construction land	0.00	0.00	0.00	12.11	-	0.00	12.11
Unused land	0.20	0.00	0.03	0.14	0.57	-	0.94
Total	950.93	551.10	6.08	188.44	335.14	1.10	2032.80

Table 6. Land use transfer matrix for Wuhan Urban Agglomerations from 2018 to 2021/km².

	Farmland	Forestland	Grassland	Water Body	Construction Land	Unused Land	Total
Farmland	-	180.06	2.86	127.42	158.80	0.00	469.13
Forestland	528.26	-	0.38	0.05	2.00	0.00	530.70
Grassland	14.34	1.05	-	0.05	0.66	0.19	16.29
Water body	190.91	0.14	0.07	-	11.57	0.07	202.76
Construction land	19.00	0.25	0.16	5.64	-	0.04	25.08
Unused land	0.14	0.00	0.33	0.03	0.21	-	0.70
Total	752.65	181.50	3.80	133.18	173.23	0.31	1244.67

The results for the conversion among different land use types showed that, from 2012 to 2015, more land was transferred out of the cultivated land category than was transferred into it. During this period, the cultivated land area decreased rapidly and was mainly converted into forest land (1115.85 km²), water area (376.80 km²), and construction land (310.02 km²). Woodland increased the most, mainly from the conversion of farmland (1115.85 km²), accounting for 99.07% of the new area of woodland, mainly due to the impact of the policy of returning farmland to forest. From 2015 to 2018, on the whole,

more land was transferred out of the cultivated land category than was transferred into it. The decrease in cultivated land was mainly converted to forest land (547.97 km²) and construction land (306.55 km²), accounting for 82.46% of the decrease in cultivated land. The new construction land mainly came from cultivated land (306.55 km²), accounting for 91.47% of the increase in the area of construction land. From 2018 to 2021, on the whole, more land was transferred into the cultivated land category than was transferred out of it, and the total area of cultivated land began to increase. The increase in cultivated land mainly came from forest land (528.26 km²), the decrease in the water area was mainly due to its conversion into cultivated land (190.91 km²), and the cultivated land was mainly converted to forest land (180.06 km²) and construction land (158.80 km²), accounting for 72.23% of the reduction in the area of cultivated land.

From 2012 to 2021, the area converted from cultivated land to forest land in the study area was the largest (1368.53 km²), accounting for 30.51% of the total change area in different regions, followed by conversion from forest land to cultivated land, accounting for 23.27%, and conversion from cultivated land to construction land, water area to cultivated land, and water area to water area, accounting for 14.84% and 10.38%. This is shown in Table 7.

Table 7. Main types of land use change and area ratio in Wuhan Urban Agglomerations from 2012 to 2021.

Change in Land Use Type	Area/km ²	Proportion of the Area	Cumulative Area Ratio
From farmland to forestland	1368.53	30.51%	30.51%
From farmland to water body	465.62	10.38%	40.90%
From farmland to construction land	748.45	16.69%	57.58%
From forestland to farmland	1043.44	23.27%	80.85%
From water body to farmland	665.35	14.84%	95.69%

5. Analysis of ESV Evaluation Results

5.1. Temporal Change Analysis of Ecosystem Service Value

5.1.1. Analysis of Overall Changes in the Study Area

Based on the ESV equivalent factor table of Xie Gaodi [37], the value of each single ESV and its change table were calculated by combining them with the actual situation in the study area. As can be seen from Table 8, the total value of ecosystem services in study area in 2021 was 238.581 billion yuan, which decreased by about 5.169 billion yuan from 2012 to 2021. From the data analysis in Table 8, the ESVs of each land use type in the Wuhan City Circle in 2021 are ranked as follows: water occupies the first place, followed by forest land, cropland, grassland, and finally unused land. Further observing the ranking of individual ESVs in Table 9, the hydrological regulation function takes first place, followed by climate regulation, water supply, gas regulation, soil conservation, environmental purification, biodiversity protection, and then food production, aesthetic landscape, and raw material production functions, while the function of maintaining nutrient cycling takes the last place.

Table 8. Changes in ecosystem services and total value of various land uses from 2012 to 2021/10⁸ yuan.

Land Use Type	2012	2015	2018 ESV	2021	2012–2015	2015–2018 Changes in ESV	2018–2021	2012–2021
Farmland	630.26	611.75	610.21	615.31	−18.51	−1.54	5.10	−14.94
Forestland	824.11	856.52	857.82	840.14	32.41	1.30	−17.69	16.03
Grassland	2.37	1.30	1.04	0.63	−1.07	−0.25	−0.42	−1.74
Water body	980.75	1008.78	946.63	929.73	28.03	−62.15	−16.90	−51.03
Unused land	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Total	2437.49	2478.35	2415.71	2385.81	40.86	−62.64	−29.90	−51.69

Table 9. Changes in ESV in Wuhan Urban Agglomerations from 2012 to 2021.

Ecosystem Service Functions	Single Ecosystem Service Value/(10 ⁸ Yuan)				Change Rate/%			
	2012	2015	2018	2021	2012–2015	2015–2018	2018–2021	2012–2021
Food production	124.36	121.88	121.17	121.66	−1.99	−0.58	0.40	−2.17
Raw material production	53.38	53.79	53.51	53.06	0.77	−0.52	−0.83	−0.59
Water supply	200.37	198.87	194.77	194.47	−0.75	−2.06	−0.15	−2.95
Gas regulation	185.14	186.28	185.24	183.81	0.62	−0.56	−0.77	−0.72
Climate regulation	331.69	341.02	339.19	333.43	2.81	−0.54	−1.70	0.52
Purify the environment	138.09	141.99	138.85	136.45	2.82	−2.21	−1.73	−1.19
Hydrological regulation	1008.16	1030.24	985.85	971.33	2.19	−4.31	−1.47	−3.65
Soil conservation	171.34	174.33	173.21	171.03	1.74	−0.64	−1.25	−0.18
Maintain nutrient circulation	21.29	21.08	20.97	20.95	−0.98	−0.56	−0.07	−1.61
Biodiversity maintenance	133.56	136.95	133.33	131.15	2.54	−2.64	−1.64	−1.81
Esthetic landscape	70.11	71.92	69.62	68.46	2.59	−3.20	−1.66	−2.35
Total	2437.49	2478.35	2415.71	2385.81	12.36	−17.82	−10.89	−16.68

The above ranking clearly shows that watershed ecosystems occupy a significant advantage in the value of services provided, while unutilized land ecosystems are relatively low. This difference mainly stems from the differences in the land area occupied by each land use type and its equivalent factor coefficients. In addition, the value contributed by the food production function is relatively low, accounting for only about 5% of the overall service value, which is mainly attributed to the scarcity of high-quality arable land in the Wuhan City Circle and the high dependence on arable land ecosystems for food production. And, among all the individual service values, the hydrological regulation value accounted for the highest share of 40.71%, most of which was provided by forest land and water ecosystems together.

The ESV changes in ecosystem services are shown in Table 9. From 2012 to 2021, only ESV of climate regulation showed an upward trend, while others showed a downward trend. Among them, the hydrological regulation value decreased the most (−3.65%), followed by water resource supply (−2.95%), which was mainly due to the continuous decrease in the water area. The decrease in the food production function value was relatively large, which is mainly related to the decreasing arable land area. The ESV in the study area decreased by 5.169 billion yuan during the decade. It has a huge reduction.

5.1.2. Comparative Analysis of Different Cities

From 2012 to 2021, the ESVs of the nine cities in the study area changed. The ESV of each city in 2012, 2015, 2018, and 2021 is shown in Table 10 below. The order of change in ESV in ten years was as follows: Xiantao > Wuhan > Xiaogan > Huangshi > Ezhou > Huanggang > Xian'ning > Qianjiang > Tianmen. The largest was Xiantao City, with a decrease of about 2.17 billion yuan, while the smallest was Tianmen City, with a decrease of about 36 million yuan. The ESV of each city showed a general downward trend. Compared with other periods, the ESV of each city from 2015 to 2018 showed the largest change and the change range was particularly significant.

Table 10. ESV changes in cities from 2012 to 2021.

Year	Wuhan	Huangshi	Huanggang	Ezhou	Xiaogan	Xian'ning	Xiantao	Tianmen	Qianjiang
2012	442.73	232.27	712.17	98.30	272.84	471.89	96.50	62.74	48.04
2015	448.97	231.74	726.06	99.36	288.97	481.89	87.40	65.84	48.13
2018	428.94	223.99	718.59	93.17	288.87	474.38	77.48	63.61	46.69
2021	422.22	222.16	708.92	92.18	287.38	469.32	74.80	63.11	45.74
2012–2015	6.24	−0.53	13.88	1.05	16.13	10.00	−9.10	3.10	0.08
2015–2018	20.03	−7.75	−7.47	−6.19	−0.11	−7.52	−9.92	−2.23	−1.44
2018–2021	6.72	−1.83	−9.67	−0.99	−1.48	−5.06	−2.68	−0.51	−0.95
2012–2021	20.51	−10.11	−3.26	−6.13	14.54	−2.58	−21.70	0.36	−2.31

By comparing the Wuhan Urban Agglomerations based on land use and ESV, it can be learned that there is only one city whose ESV rate is more than 10% (Figure 5). The rate of change in the other cities is very small. During the study period, the land utilization of most cities does not show sharp fluctuations and changes. According to Table 11, construction land in Wuhan and Huanggang increased the most, leading to a significant decrease in ESV. The growth of ESV in Xiaogan city during this decade is related to the large increase in forest land, because forest land is an important type of ecological land. Tianmen and Qianjiang ensured the balance of ecological land and construction land and realized the stability of ESV while developing economy.

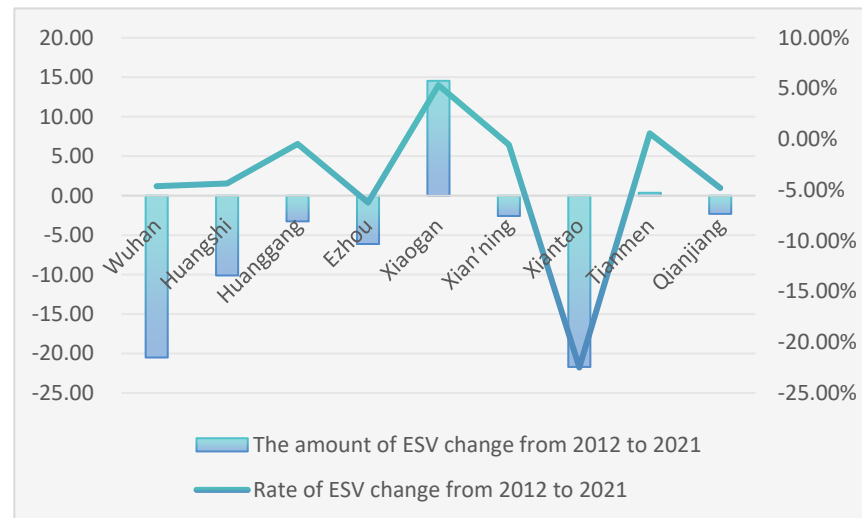


Figure 5. Amount and change rate of change in the ESVs of cities in Wuhan Urban Agglomerations from 2012 to 2021.

Table 11. Change amount of urban land use types/km² in Wuhan Urban Agglomerations from 2012 to 2021.

	Farmland	Forestland	Grassland	Water Body	Construction Land	Unused Land
Wuhan	−277.73	124.18	−1.48	−89.52	244.42	0.13
Huangshi	97.32	−169.38	0.53	−13.59	85.13	0.00
Huanggang	−210.22	55.94	−15.18	−7.41	178.67	−1.80
Ezhou	−21.69	11.40	0.13	−26.01	36.16	0.01
Xiaogan	−232.91	123.31	−36.91	56.48	90.06	−0.02
Xian'ning	−202.33	169.26	0.90	−31.03	63.21	0.00
Xiantao	71.62	0.24	−0.07	−94.67	22.88	0.00
Tianmen	−36.42	1.30	−0.06	3.93	31.25	0.01
Qianjiang	−18.01	0.15	0.02	−8.20	26.05	0.00

5.2. Analysis of Spatial Change in Ecosystem Service Value

In order to clearly reveal the spatial evolution of ESV in different years, this study, based on the ArcGIS 10.7 platform and using the natural discontinuity hierarchy method, conducted an in-depth analysis of the spatial distribution of ESV and its dynamics in the municipalities of the Wuhan City Circle.

According to the spatial distribution characteristics of the ESV in Wuhan City Circle cities shown in Figure 6, it can be seen that in 2012, 2015, 2018, and 2021, the overall spatial pattern of “lower in the west and higher in the east-central part of the city” is shown. Specifically, Huanggang City, Wuhan City and Xianning City are particularly prominent in ESV, with their ESVs exceeding 27.284 billion yuan, 28.897 billion yuan, 28.897 billion yuan, and 28.887 billion yuan in the four years, which are significantly higher than those of other regions. This is followed by Xiaogan and Huangshi, which also have relatively high ESVs,

with four-year ESVs above 9.830 billion yuan, 9.936 billion yuan, 9.317 billion yuan and 9.218 billion yuan, respectively. Further back are Xiantao and Ezhou, which also show a steady increase in ESV, with both four-year ESVs being higher than 6.274 billion yuan, 6.584 billion yuan, 6.361 billion yuan and 6.311 billion yuan, respectively. Finally, the ESVs of Tianmen City and Qianjiang City are relatively low but still show a growing trend, with both four-year ESVs being higher than 4.804 billion yuan, 4.813 billion yuan, 4.669 billion yuan, and 4.574 billion yuan, respectively.

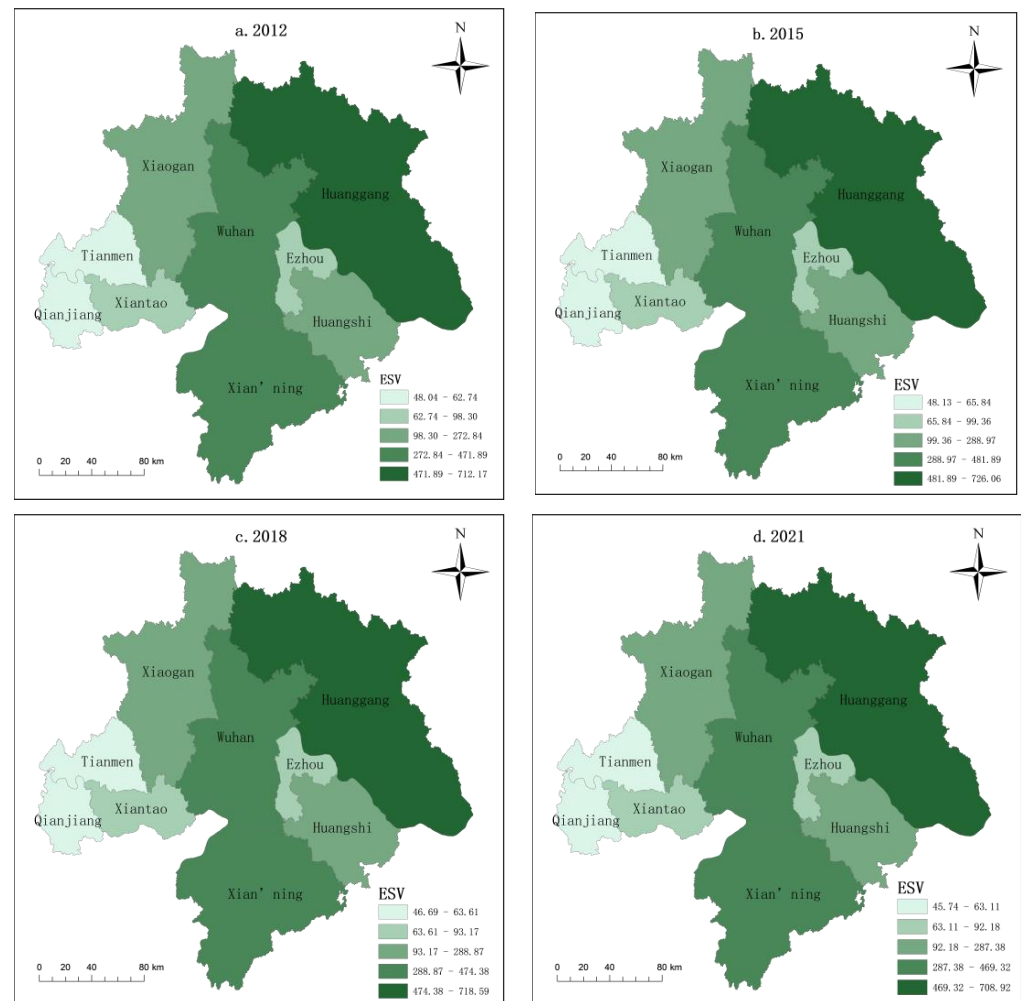


Figure 6. Spatial distribution of ESV in Wuhan Urban Agglomerations from 2012 to 2021.

6. Future Prediction and Analysis of Land Use and ESV

At present, the CA–Markov model is mostly used to predict the spatial development of urban development models [58]. In order to further explore the impact of LUCC on the value of ecological services, we used the LUCC data from 2018 and 2021 extracted from the above analysis, and used the CA–Markov model in the IDRISI software to predict the areas of the different land use types in 2035 and 2050 (as shown in Table 12). The spatial distributions of LUCC and ESV were simulated. The results show that the areas of cultivated land and construction land in the Wuhan Urban Agglomerations will increase (Figure 7), and the ESV of cultivated land will increase, while the areas of forest land, grassland, water area, and unused land will decrease further, and the corresponding ESVs will also decrease. From the perspective of the spatial distribution of ESV (Figure 8), in 2035 and 2050, the ESVs of all cities in study area still show a trend of “low in the west and high in the middle and east”. When comparing the ESVs of different cities, Huanggang City’s ESV is particularly impressive and significantly higher than that of the other regions,

specifically exceeding 44.440 billion yuan and 42.768 billion yuan in the two years examined, respectively. Subsequently, the ESVs of Wuhan and Xianning are also quite impressive, and are expected to exceed 26.653 billion yuan and 25.655 billion yuan in 2035 and 2050, respectively. Xiaogan and Huangshi have lower ESVs than the previous two, but are also at a high level in the region, and are expected to exceed 8.968 billion yuan and 8.630 billion yuan in 2035 and 2050, respectively. Finally, Ezhou City, Xiantao City, Tianmen City, and Qianjiang City have relatively low ESVs compared to the rest of the region, but also have growth potential, and are projected to exceed USD 4.416 billion and USD 4.250 billion in 2035 and 2050, respectively.

Table 12. Prediction of land use patterns and ESV change in Wuhan Urban Agglomerations in 2035 and 2050.

Year		Farmland	Forestland	Grassland	Water Body	Unused Land	Total
2035	Area/km ²	35,574.94	14,391.44	12.14	3729.30	1.41	2275.71
	Ratio	61.34%	24.81%	0.02%	6.43%	0.00%	
2050	ESV/10 ⁸ yuan	640.31	728.97	0.40	906.02	0.00	
	Area/km ²	36,089.29	13,247.40	10.10	3577.68	0.89	
	Ratio	62.24%	22.85%	0.02%	6.17%	0.00%	
	ESV/10 ⁸ yuan	649.57	671.02	0.34	869.18	0.00	

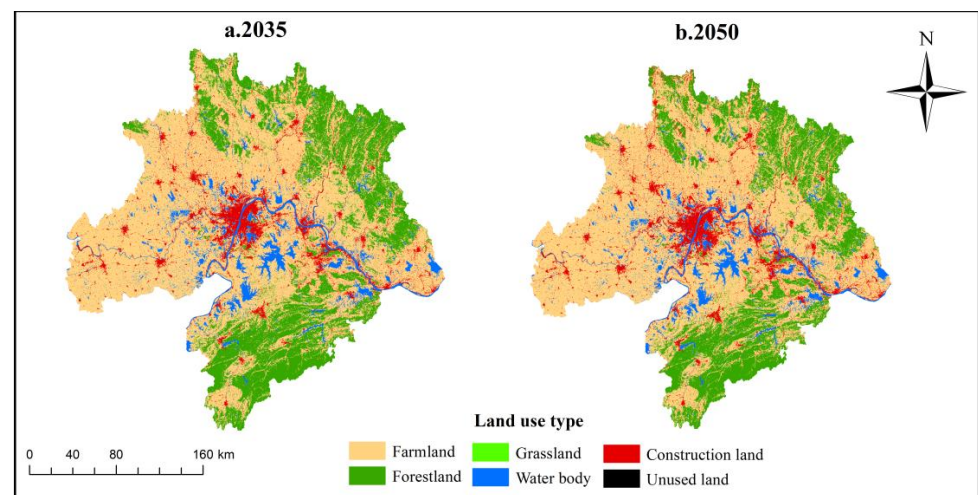


Figure 7. Land use types in Wuhan Urban Agglomerations in 2035 and 2050.

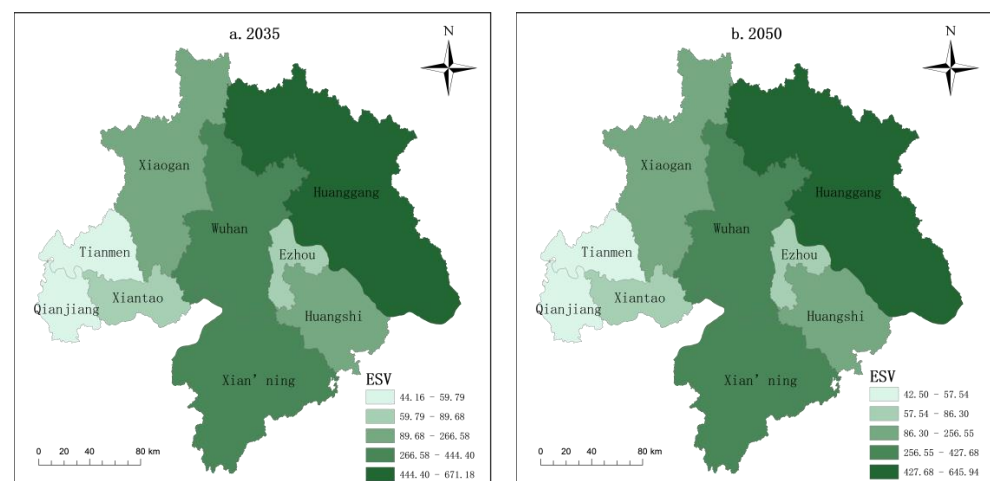


Figure 8. Prediction of ESV spatial distribution in Wuhan Urban Agglomerations in 2035 and 2050.

7. Conclusions and Discussion

7.1. Discussion

From the study of the continuous and dynamic changes in the Wuhan Urban Circle in the four periods of 2012, 2015, 2018, and 2021 in a long time series, our results show that there are irrationalities in the land use structure in the Wuhan Urban Circle, which has a certain negative effect on the overall ecosystem of the region, and that it is necessary to use targeted measures to adjust in the future. In making decisions about the ecological sustainable development strategy of the urban area, the reduction in ESV and the rate of reduction should be gradually reduced on the basis of maintaining an overall smooth change in the ecological service value of the region. For land use types with high ecological values, emphasis should be placed on protection, and conversion to land use types with low ecological values should be avoided as much as possible, and special attention should be paid to circumventing the haphazard expansion of construction land in the process of urbanization, so as to promote the coordinated and sustainable development of socio-economic and ecological systems in the Wuhan City Circle. On the whole, the development of urban areas has taken up too much land with high ecological service values, and the rational use and development of land needs to be strengthened, and we need to be vigilant towards the negative impact of the rapid expansion of land for construction on the ecosystem services such as hydrological regulation and climate regulation. Local governments should formulate detailed land use master plans, clarify land use zoning, and ensure a rational layout of land for agriculture, industry, urban areas, and ecological protection. In the case of Wuhan, while the city is developing economically, special attention should be paid to its ecological construction, with rational planning of the city's spatial layout and an increase in the area of urban greenery; the suburbs should expand the area covered by greenery and nourish the city's water sources, so as to gradually reduce the pollution of the ecological environment caused by the city's development. While protecting the ecological environment, other cities can make reasonable use of the resources provided by the ecosystem, and make moderate use of grasslands and waters, etc., which can not only provide material resources for the city's economic construction, but also allow the optimum economic value of ecological services to be reached. For example, the main reason for the decline in the ESV in Huangshi City is the irrationality of the land use structure, with too much construction land occupying forest land, a type of land with high ecological value; therefore, the city should pay attention to adjusting the land use structure in its development, and take up as little ecologically orientated land as possible. And in the future, the land approval system should be further tightened to increase the cost of non-agriculturalization of arable land, optimize the land use structure, and protect high-quality arable land and ecologically sensitive areas that are of high ecosystem value, such as wetlands, forests, and other land use types. At the same time, based on current big data technology, government departments should establish a cross-sectoral collaboration mechanism and a data-sharing platform. Communication and collaboration between departments such as environmental protection, agriculture, urban planning, transportation, etc., should be enhanced to jointly address the challenges posed by land use changes. In addition, with the talent and scientific research advantages of hundreds of universities in Wuhan City Circle, we can take the initiative to explore ways to incorporate ecological compensation into the evaluation system of social and economic development in a more scientific way, so as to reduce the number of urban construction projects whose environmental cost is greater than the ecological value, to minimize ecological damage at source, and to safeguard the ecological environment in the City Circle. The shortcoming of this study is that the factor correction capacity of the model is limited, mainly because there is no complete and unified set of parameters to measure. Since different methods of calculating the ESV produce different results, we should pay more attention to the relative contribution of ecosystem services and the changes in their increase or decrease in terms of their practical application, so as to carry out quantitative assessments and provide references for the formulation of relevant policies and decisions, thus helping the region to achieve sustainable development.

7.2. Conclusions

Ecosystem service functions and values are dynamic processes [59]. Based on multi-phase remote sensing images, this study monitored and extracted data for LUCC continuity and dynamic changes in Wuhan Urban Agglomerations. By combining these data with the actual situation in the study area, it adopted the revised equivalent factor method to calculate ESV, and studied the influence of LUCC on the spatiotemporal changes in ESV. The CA-Markov model was used to predict the development of and change in LUCC and the corresponding ESV in the future. The main conclusions are as follows:

- (1) The land use changes in the Wuhan city circle from 2012 to 2021 are as follows: the area of land that changed use during this decade is about 2188.44 square kilometers, accounting for about 3.77 per cent of the area of the Wuhan city circle. The decreases in land use areas include arable land, grassland, waters and unused land, and the increase is in construction land. Due to the rapid development of urbanization, the uncontrolled expansion of construction land, and the encroachment of housing conversion and relocation on other land types have caused some of the land with high ESV to be transformed into land with a low ESV, which leads to a decrease in the total ecosystem service value. From the results of the ranking according to the intensity of change in forest land, it can be found that grassland has the largest change rate and speed of change, with a change rate of 73.50 per cent and a decrease of 48.52 per cent in 10 years, which is due to factors such as the cultivation of arable land and the occupation of construction land, leading to a drastic decrease in the area of grassland and other land with ecological nourishment functions, and the protection of ecological land such as watersheds, arable land, and forest land should be strengthened in the future [60].
- (2) The results of the land ESV assessment for the Wuhan urban circle from 2012 to 2021 show that the ESV of the Wuhan Urban Circle will decrease by a total of about 5.169 billion yuan from 2012 to 2021, and only the ESV of climate regulation shows an upward trend, while the others all show a downward trend. Among them, the biggest decrease is in the hydrological regulation value (−3.65%), followed by water supply (−2.95%), which is mainly due to the continuous decrease in water area, and for the Wuhan Urban Circle, due to geographic factors due to the fact that it has a wide distribution of water areas in the region, with a lot of rivers and lakes, which play an important role in regulating the climate and improving the environment for the Urban Circle. The reduction in their area will significantly reduce the ESV. In addition, the reduction in the value of food production function is also relatively large, mainly related to the continuous reduction in the area of arable land. In the ecological service function of Wuhan City Circle, food production is one of the most important functions, the most basic condition for stable food is stable arable land, arable land is the lifeblood of food production, and it is also the type of land use with the highest ecological value; we have to save for a rainy day, and we should always tighten the string of food security in the future, and also should pay more attention to the use and protection of arable land.
- (3) From 2012 to 2021, the ranking of the change in ESV among the nine cities in the Wuhan urban area, from highest to lowest, is as follows: Xiantao City > Wuhan City > Xiaogan City > Huangshi City > Ezhou City > Huanggang City > Xianning City > Qianjiang City > Tianmen City. The cities of Wuhan and Huanggang experienced the highest increase in construction land, leading to a significant decrease in ESV. The growth of ESV in Xiaogan City is attributed to the substantial increase in forest area, as forests are important ecological land. Tianmen and Qianjiang have successfully balanced ecological land and construction land while developing their economies, resulting in stable ecosystem service value. In terms of spatial distribution, there are significant regional differences in the overall change in ESV among the cities in the Wuhan urban area, with a “lower value in the west and higher value in the central-east” pattern. In terms of space, cultivated land in the Wuhan urban area is

mainly distributed in the central-eastern region, where urbanization has progressed rapidly. The expansion of urban construction land has led to the transformation of high-value ESV cultivated land to low-value ESV construction land, resulting in the greatest change. The spatial distribution of ESV in the Wuhan urban area overall exhibits a concentric ring structure with Wuhan City as the center, with higher ESV in the northeast and southeast directions. The significant decrease in ESV in cities such as Xiantao, Ezhou, Huanggang, and Xiaogan between Wuhan and the outer edge of the Wuhan urban area is an important factor contributing to the overall decrease in ESV in the Wuhan urban area during this period.

- (4) The predicted results for LUCC and ESV in the Wuhan Urban Circle in 2035 and 2050 show that the area of cultivated land and construction land will increase, while the area of forests, grasslands, water bodies, and unused land will decrease. The spatial distribution of ESV still exhibits a “low in the west, high in the central-east” trend, with the total ESV amount ranked as follows: Huanggang City > Xianning City > Wuhan City > Xiaogan City > Huangshi City > Ezhou City > Xiantao City > Tianmen City > Qianjiang City. The total future ESV is still decreasing. In the future, it is important to focus on the conversion of land use types in areas with high ESVs in order to reduce their impact on the overall ecosystem services value of the urban circle and promote coordinated development between regions.

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References

1. Fisher, J.C.; Dallimer, M.; Irvine, K.N.; Aizlewood, S.G.; Austen, G.E.; Fish, R.D.; King, P.M.; Davies, Z.G. Human well-being responses to species' traits. *Nat. Sustain.* **2023**, *6*, 1219–1227. [\[CrossRef\]](#)
2. Li, T.; Chen, T.Y.; Hui, B.H. Study on the value of forest ecosystem services in Huangshan City based on Meta-analysis. *Geoscience* **2022**, *42*, 2179–2188.
3. Karger, D.N.; Kessler, M.; Lehnert, M.; Jetz, W. Limited protection and ongoing loss of tropical cloud forest biodiversity and ecosystems worldwide. *Nat. Ecol. Evol.* **2021**, *5*, 854–862. [\[CrossRef\]](#)
4. Promila; Kumar, K.M.; Sharma, P. Assessment of ecosystem service value variation over the changing patterns of land degradation and land use/land cover. *Environ. Earth Sci.* **2023**, *82*, 54. [\[CrossRef\]](#)
5. You, C.; Qiu, H.J.; Guo, L. Spatiotemporal coupling and simulation prediction of socio-ecological system under the concept of “life community of mountains, rivers, forests, fields, lakes, grasslands and sands”. *Acta Ecol. Sin.* **2024**, *44*, 2745–2760.
6. Helliwell, D.R. Valuation of wildlife resources. *Reg. Stud.* **1969**, *3*, 41–47. [\[CrossRef\]](#)
7. Qin, X.C.; Fu, B.H. Spatio-temporal coordination analysis and optimal utilization of ecosystem services and economic development in Qingdao Urban Agglomerations. *Acta Ecol. Sin.* **2020**, *40*, 8251–8264.
8. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; Oneill, R.V.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [\[CrossRef\]](#)
9. Liu, F.; Yu, K.; Zhang, J.L.; Guo, W.Y.; Yin, S.Q. Spatiotemporal changes of land use in Zhundong open-pit coal mine in Xinjiang and its impact on ecosystem service value. *Ecol. Econ.* **2021**, *37*, 169–175.
10. Zhang, T.H.; Tian, Y.; Xu, S.; Tang, L.N.; Guo, W. Evolution of land use patterns in coastal cities and their impacts on the value of ecosystem services. *Acta Ecol. Sin.* **2018**, *38*, 7572–7581.
11. Sun, Z.T.; Yu, Z.W.; Su, S.Q.; Xu, C.S.; Yang, S. Suggestions on the evaluation of ecosystem service value and ecogeological survey at the provincial level in China. *Geol. China* **2023**, *50*, 479–494.
12. Ouyang, Z.Y.; Wang, X.K.; Miao, H. A preliminary study on the service functions of terrestrial ecosystems and their eco-economic value in China. *Acta Ecol. Sin.* **1999**, *5*, 19–25.

13. Yao, C.S.; Zhu, H.J.; Lv, X.; Liu, Y.B. Impacts of socioeconomic drivers of land use change on the value of ecosystem services in Fujian. *J. Nat. Resour.* **2009**, *24*, 225–233.
14. Xie, G.D.; Zhang, C.X.; Zhang, C.S.; Xiao, Y.; Lu, C.X. The value of ecosystem services in China. *Resour. Sci.* **2015**, *37*, 1740–1746.
15. Wang, Z.S.; Zhang, H.P.; Yue, C.; Yang, H.Q.; Zhang, H. Is afforestation for carbon sinks a cost-effective way to achieve carbon neutrality? Take Northwest China as an example. *J. Nat. Resour.* **2024**, *39*, 731–748. [[CrossRef](#)]
16. Xu, X.Y.; Guo, L.; Xue, D.Y.; Sun, S.Q. Spatial-temporal evolution of land use patterns and ecosystem service values in southern Gannan. *Acta Ecol. Sin.* **2019**, *39*, 1969–1978.
17. Hu, F.; Chen, Y.; Zhang, C.C.; Hu, G.H. Spatial and temporal evolution and prediction of ecosystem service value in Taihang Mountains based on MCCA land use scenario simulation. *Environ. Sci. Policy* **2024**, 1–15. [[CrossRef](#)]
18. Wang, H.; Qin, F.; Zhu, J.; Zhang, C.C. Impacts of land use and landscape evolution on the value of ecosystem services. *Acta Ecol. Sin.* **2017**, *37*, 1286–1296.
19. Ding, R.C.; Li, Y.C.; Zhao, C.Z.; Chen, J.P.; Zhu, W.H. Scenario Simulation and Driving Force Analysis of Ecosystem Service Values Based on Land Use/Cover in the Tumen River Basin, China. *Sustainability* **2024**, *16*, 399. [[CrossRef](#)]
20. Li, G.D.; Fang, C.L.; Wang, S.J. Exploring spatiotemporal changes in ecosystem-service values and hotspots in China. *Sci. Total Environ.* **2016**, *545*, 609–620. [[CrossRef](#)]
21. Luo, S.F.; Yan, W.D. Evolution and driving force analysis of ecosystem service values in Guangxi Beibu Gulf coastal areas, China. *Acta Ecol. Sin.* **2018**, *38*, 3248–3259.
22. Xie, L.; Wang, H.W.; Liu, S.H. The ecosystem service values simulation and driving force analysis based on land use/land cover: A case study in inland rivers in arid areas of the Aksu River Basin, China. *Ecol. Indic.* **2022**, *138*, 108828. [[CrossRef](#)]
23. Zhao, Z.G.; Yu, D.; Han, C.Y.; Wang, K.R. Prediction and driving force of ecosystem service value in Poyang Lake Ecological Economic Zone. *Acta Ecol. Sin.* **2017**, *37*, 8411–8421.
24. Hu, Y.; Liu, Y.; Li, C. Multi-Scenario Simulation of Land Use Change and Ecosystem Service Value in the Middle Reaches of Yangtze River Urban Agglomeration. *Sustainability* **2022**, *14*, 15738. [[CrossRef](#)]
25. Christou, M.; Sgardeli, V.; Tsikliras, A.C.; Tserpes, G.; Stergiou, K.I. A probabilistic model that determines the social ecological system (SES) attributes that lead to successful discard management. *Rev. Fish Biol. Fish.* **2020**, *30*, 109–119. [[CrossRef](#)]
26. Dwyer, J.; Short, C.; Berriet-sollic, M.; Déprés, C.; Lataste, F.G.; Hart, K.; Prazan, J. Fostering resilient agro-food futures through a social-ecological systems framework: Public-private partnerships for delivering ecosystem services in Europe. *Ecosyst. Serv.* **2020**, *45*, 101180. [[CrossRef](#)]
27. Shen, M.S.; Zheng, H.; Liu, Y.Y.; Wang, W.H.; Xie, G.T. Spatial transfer network of ecological service value in Dongjiang Basin in 2020. *Water Resour. Hydropower Eng.* **2022**, *53*, 124–134.
28. Wang, J.; Dun, Y.L. A review of research on the impacts of land use change on ecosystem services. *Resour. Environ. Yangtze Basin* **2015**, *24*, 798–808.
29. Sun, D.Z.; Liang, Y.J. Multi-scenario simulation of land use on the Loess Plateau based on improved Markov-CA model. *J. Geo-Inf. Sci.* **2021**, *23*, 825–836.
30. Zuo, L.L.; Peng, W.F.; Tao, S.; Zhu, C.; Xu, X.L. Dynamic changes of land use and ecosystem service value in the upper reaches of the Minjiang River. *Chin. J. Ecol.* **2021**, *41*, 6384–6397.
31. Chen, C.; Park, T.; Wang, X.H.; Piao, S.L.; Xu, B.D.; Chaturvedi, R.K.; Fuchs, R.; Brovkin, V.; Ciais, P.; Fensholt, R.; et al. China and India lead in greening of the world through land-use management. *Nat. Sustain.* **2019**, *2*, 122–129. [[CrossRef](#)]
32. Liu, J.Y.; Ning, J.; Kuang, W.H.; Xu, X.L.; Zhang, S.W.; Yan, C.Z.; Li, R.D.; Wu, S.X.; Hu, Y.F.; Du, G.M.; et al. Spatial and temporal patterns and new characteristics of land use change in China from 2010 to 2015. *Acta Geogr. Sin.* **2018**, *73*, 789–802.
33. Wang, B.; Zhao, J.; Zhong, J.T. Spatial-temporal differentiation of ecosystem services in the Shiyang River Basin from 2005 to 2015. *Arid. Zone Res.* **2019**, *36*, 474–485.
34. Xie, G.D.; Cao, S.Y.; Leng, Y.F.; Zhang, C.S.; Gai, L.Q.; Lu, C.X.; Zhang, S.Y. China's Sustainable Development Functional Zone. *Resour. Sci.* **2012**, *34*, 1600–1609.
35. He, N.; Zhou, Y.; Wang, L.; Li, Q.; Zuo, Q.; Liu, J. Spatiotemporal differentiation and the coupling analysis of ecosystem service value with land use change in Hubei Province, China. *Ecol. Indic.* **2022**, *145*, 109693. [[CrossRef](#)]
36. Garcia-Nieto, A.P.; Geijzendorffer, I.R.; Baro, F.; Roche, P.K.; Bondeau, A.; Cramer, W. Impacts of urbanization around Mediterranean cities: Changes in ecosystem service supply. *Ecol. Indic.* **2018**, *91*, 589–606. [[CrossRef](#)]
37. Xie, G.D.; Lu, C.X.; Leng, Y.F.; Zheng, D.; Li, S.C. Value assessment of ecological assets on the Qinghai-Tibet Plateau. *J. Nat. Resour.* **2003**, *2*, 189–196.
38. Xie, G.D.; Zhang, C.X.; Zhang, L.M.; Chen, W.H.; Li, S.M. Improved value-of-ecosystem services based on value equivalent factor per unit area. *J. Nat. Resour.* **2015**, *30*, 1243–1254.
39. Lei, J.C.; Wang, S.; Wang, J.M.; Wu, S.Q.; You, X.B.; Wu, J.; Cui, P.; Ding, H. Effects of land use change on ecosystem services value of Xunwu County. *Acta Ecol. Sin.* **2019**, *39*, 3089–3099.
40. Zhang, X.Q.; Mansur, S.; Ma, G.F. Analysis of Eco-Economic Harmonious Development in Yarkant River Plain Oasis based on Ecosystem Service Value. *Res. Environ. Sci.* **2018**, *31*, 1114–1122.
41. Qiu, H.H.; Hu, B.Q.; Zhang, Z. Research on the value of ecosystem services in Guangxi in the past 20 years based on land use change. *J. Environ. Eng. Technol.* **2022**, *12*, 1455–1465.

42. Liu, H.M.; Gao, J.X.; Liu, X.; Zhang, H.Y.; Xu, X.L. Assessment of changes in the value of ecosystem services in national key ecological function areas from 2010 to 2015. *Acta Ecol. Sin.* **2020**, *40*, 1865–1876.
43. Jiang, H.; Wu, Q. Research on the value assessment of ecosystem services in Jiangsu Province based on LUCC and the characteristics of spatiotemporal evolution. *Resour. Environ. Yangtze Basin* **2021**, *30*, 2712–2725.
44. Chen, R.; Yang, C.; Yang, Y.; Dong, X.Z. Spatial-temporal interpretation of ecosystem service value and its driving factors in Dongting Lake Eco-economic Zone. *Chin. J. Appl. Ecol.* **2022**, *33*, 169–179.
45. Chen, S.L.; Liu, X.T.; Yang, L.; Zhu, Z.H. Variations in Ecosystem Service Value and Its Driving Factors in the Nanjing Urban Agglomerations of China. *Forests* **2023**, *14*, 113. [[CrossRef](#)]
46. Guo, X.M.; Fang, C.L.; Mu, X.F.; Chen, D. Coupling and coordination analysis of urbanization and ecosystem service value in Beijing-Tianjin-Hebei urban agglomeration. *Ecol. Indic.* **2022**, *137*, 108782.
47. Chen, W.X.; Li, J.F.; Zhu, L.J. Spatial differentiation and sensitivity analysis of ecosystem service values in the middle reaches of the Yangtze River. *J. Nat. Resour.* **2019**, *34*, 325–337.
48. Deng, C.X.; Zhong, X.L.; Xie, B.G.; Wan, Y.L.; Song, X.W. Spatial and temporal changes of land ecosystem service value in Dongting Lake region. *Geogr. Res.* **2019**, *38*, 844–855.
49. Ding, L.L.; Wang, Q.; Chen, X.; Tang, J.J. Response of ecosystem service value to land use change in Dianshan Lake area in the past 30 years. *Acta Ecol. Sin.* **2019**, *39*, 2973–2985.
50. Liu, G.L.; Zhang, L.C.; Zhang, Q. Impacts of spatiotemporal changes in land use on the value of ecosystem services in the Yangtze River Delta. *Chin. J. Appl. Ecol.* **2014**, *34*, 3311–3319.
51. Xie, M.; Wu, W.C. Impacts of land use and landscape pattern changes on the value of ecosystem services in northeastern Gan. *Soil Water Conserv. Res.* **2024**, *31*, 331–341.
52. Fu, B.J.; Zhang, L.W. Land-use change and ecosystem services: Concepts, approaches and progress. *Prog. Geogr.* **2014**, *33*, 441–446.
53. Xie, G.D.; Zhang, C.X.; Zhang, L.M.; Chen, W.H.; Li, S.M. Improvement of Ecosystem Service Value-based Method Based on Unit Area Value Equivalent Factor. *J. Nat. Resour.* **2015**, *30*, 1243–1254.
54. Wang, Z.F.; Xu, J. Impacts of land use evolution on ecosystem service value of national parks: A case study of Sanjiangyuan National Park. *Acta Ecol. Sin.* **2022**, *42*, 6948–6958.
55. Wang, C.; Li, W.; Sun, M.; Wang, Y.; Wang, S. Exploring the formulation of ecological management policies by quantifying interregional primary ecosystem service flows in Yangtze River Delta region, China. *J. Environ. Manag.* **2021**, *284*, 112042. [[CrossRef](#)] [[PubMed](#)]
56. Zhong, S.Z.; Sun, H.Y. Spatial and temporal changes in ecosystem services and trade-offs and synergistic relationships in Qilian Mountain National Nature Reserve under different scenarios. *Soil Water Conserv. Res.* **2023**, *30*, 358–369.
57. GB/T21010-2017; Current land use classification. Ministry of Natural Resources, People's Republic of China: Beijing, China, 2017.
58. Tan, D.M.; Ding, S.Y.; Han, B.L.; Pan, X.L. Effects of Different Development Models on the Value of Urban Ecosystem Regulation Services. *Acta Ecol. Sin.* **2022**, *42*, 6554–6564.
59. Fu, B.J.; Tian, H.Q.; Tao, F.L.; Zhao, W.W.; Wang, S. Research progress on the impact of global change on ecosystem services. *Basic Sci. China* **2020**, *22*, 25–30.
60. Liu, F.L.; Yang, R.Y. Land use change and its impact on ecosystem service value in Wuhan. *Res. Soil Water Conserv.* **2021**, *28*, 177–183+193+172.

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