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The Influence of Landscape Pattern Evolution on the Value of Ecosystem Services

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ABSTRACT. Ecosystem services (ES) can link natural ecosystems with socioeconomic systems. The Yi River basin is one of the most important sub-basins of the Yellow River basin, and the landscape pattern of this basin has changed dramatically in recent years. However, the assessment of landscape patterns on ecosystem services value (ESV) in such basin has been little studied. Therefore, the temporal-spatial evolution of the landscape pattern and ESV of the Yi River basin was evaluated through the landscape indices analysis method and the method for evaluating the value equivalent factor in unit area, based on land cover data from 1987 to 2020. The effects of changes in landscape patterns on ESV were then quantified. The results show that (1) Forest was the dominant landscape type in the Yi River basin, followed by grassland, with the total area of both accounting for 80% of the basin area. From 1987 to 2020, the area of forest and construction land has increased, while that of farmland and grassland has decreased. In addition, the stability of the landscape within the basin was low, and the fragmentation of patches was serious. The landscape shape index (LSI) for 2015 and 2020 was 52.57 and 42.38, respectively, and Shannon's diversity index (SHDI) value increased from 1.04 to 1.17 in the same period, indicating that the degree of heterogeneity in the landscape of the Yi River basin was considerably reduced and the dominant patches were well connected. (2) From 1987 to 2020, the total ESV (supply, regulation, support, and cultural services) in the Yi River basin showed an “N” pattern of variation. Specifically, such total ESV increased noticeably from 1987 to 2005, decreased after 2005, bottomed out in 2015, and began to recover by 2020. Forest regulating services contributed the most to the total ESV at 77%. (3) The results of correlation analysis displayed that total ESV was negatively correlated with LSI and positively correlated with SHDI. Moreover, water supply services had a significant inverse relationship with the largest patch index (LPI), LSI, and SHDI. The LSI and patch density index (PD) had a strong positive correlation with biodiversity. Human activities (e.g., urbanization) were found to be the main drivers of a landscape pattern change and ESV decline in the Yi River basin, thus the level of biodiversity and overall ecosystem service provision in such basin can be improved by increasing the degree of landscape heterogeneity and reducing the complexity of landscape shape. The assessment of the evolution of landscape patterns and the quantification of its impact on ESV can help provide scientific information for improving the ecological qualify and supporting sustainable development in the Yi River basin.

Keywords: ecosystem services; value assessment; landscape pattern index; the environmental law regime

1. Introduction

A basin is a relatively complete physical geographic unit that includes the landscape components necessary for ecological security and sustainable development. Landscapes are spatial units consisting of different mosaics of ecosystems (Peng et al., 2015). Landscape pattern refers to the spatial arrangement of landscape elements of various sizes and shapes (Liu et al., 2010), and is also a manifestation of landscape heterogeneity (Zhou, 2000). The appropriate configuration of the landscape pattern is considered essential for the supply and maintenance of ecosystem services (ES). Ecosystem services, also known as goods and services that humans derive directly or indirectly from ecosystem functions, are the environmental conditions and utilities that enable ecosystems to form and sustain human survival and development (Daily, 1997; Costanza et al., 1998). Human well-being is generated by ES, which consists of energy, logistics, and information flows of natural capital (Liu et al., 2017a). In recent years, terrestrial ecosystems on earth have been destroyed by human activities (Fu et al., 2017; Li and Xie 2021). For example, urbanization and human social economic activities have caused large-scale land use changes and further affected the composition, structure, function, and services of landscape ecosystems within the basins (Hu et al., 2020). Such changes will have significant impacts on ES and produce inhibitory effects that ultimately pose risks to human well-being. Therefore, the investigation of the relationship between landscape pattern evolution and ecosystem service value (ESV) is crucial for land use planning, ecological security protection, and sustainable development of basins.

Previously, landscape patterns and ES have received more

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attention nationally and internationally as research hotspots in ecology and geography (Lin et al., 2014; Tang et al., 2016; Guo et al., 2020). Single types of landscape pattern changes have been examined, including forests (Li et al., 2020a), grasslands (Guo et al., 2020), wetlands (Lei et al., 2020), urban green spaces (Tang, 2020), and coal sites (Xu et al., 2017). In addition, how changes in landscape pattern affect soil carbon pools (Li et al., 2011), water-sediment processes (Li et al., 2017), ecological security (Huang et al., 2012), and watersheds runoff (Lin et al., 2014) have also been investigated. Multiple tools or techniques, including landscape ecological risk assessment (Li et al., 2019), and numerous algorithms and models (Tang et al., 2016; Ou et al., 2017; Wang et al., 2022) were used to optimize landscape patterns. In detail, after 2004, techniques such as trade-offs and coordination (Chen et al., 2021), assessment and mapping (Nikodinoska et al., 2018), and supply and demand of ES (Zhao et al., 2018) began to be brought into focus. In recent years, the process, mechanism, and realization path of ES flows (Liu et al., 2017b), ES bundles (Tao et al., 2018), and land sense creation of ES (Qi et al., 2020; Qin et al., 2022) has become the subject of scholarly attention. Ecosystem processes are altered by changing landscape patterns, resulting in impacts on the ability of ecosystems to produce goods and services (Fu et al., 2014; Li et al., 2015; Zou et al., 2017., Xiong et al., 2018; Xiao et al., 2022). A considerable number of studies have examined the relationship between landscape patterns and ES in the last decade, including exploring the type and quantity of ES through different land use landscape patterns. For instance, Su et al. (2023) simulated land use/cover change (LUCC) in the Fenhe River basin under four scenarios from 2020 to 2030, based on multi-source remote sensing data and land-use data, the spatial distribution model, the Markov model, and the patch-generating land use simulation (PLUS) model. They found that the total ESV of such basin showed a decreasing trend over time, with the economic development priority scenario displaying the largest decrease in total ESV and the ecological protection priority exhibiting the least decrease. The landscape type with the highest contribution to total ESV was forest, accounting for 58.54%. In addition, the effects of different intensities of landscape change or land use on ES were also investigated. For example, Tesfay et al. (2023) analyzed the trend of LUCC in the Chacha watershed in the central Ethiopia highlands for 1997 to 2021 and then estimated the total ESVof such watershed based on a supervised image classification technique with a maximum likelihood classifier. The results showed that increasing the land cover of forest, grassland, and canal in the study watershed would maximize the total ESV. Furthermore, the interaction between changes in landscape patterns and ES values was evaluated. For example, the evolution of landscape patterns and ESV of wetlands in Haikou and the response relationship between them were studied by Chen et al. (2023) through landscape pattern index, equivalent factor method, and correlation analysis. It can be found that ESV in Haikou wetlands was significantly and positively correlated with landscape shape and Shannon diversity, and negatively correlated with spreading index, mean patch area, and aggregation indices were positively correlated with ESV in wetlands.

In general, previous studies have mostly focused on the impact of landscape area change on ES. However, it is rare to quantify the spatial-temporal evolution of landscape patterns within basins in terms of their impact on ES. The Yi River basin is a representative typical basin in terms of its geographical location, topography, and ecosystem dispersion. The impact of landscape pattern evolution on ES values is explored in such a typical catchment, which can not only facilitate scientific decision-making services to land use planners but also inform ecological conservation and high-quality development in the Yellow River basin.

The objective of this study is to investigate the impact of changing landscape patterns in the Yi River basin on ES. In detail, (1) The spatial and temporal variations of the landscape pattern in the Yi River basin from 1987 to 2020 were examined through the landscape pattern indices based on land use data. (2) The changes in ESV (i.e., total ESV and 11 categories of individual ESV) in the Yi River basin were evaluated using the method of equivalence factor per unit area between 1987 and 2020. (3) The relationship between the evolution of landscape patterns and ESV, and the response of ESV change to the landscape indices of the Yi River basin were investigated by a statistical approach. Exploring the impact of basin landscape pattern evolution on ESV can help optimize the basin landscape pattern, build ecological barriers, and improve environmental benefits.

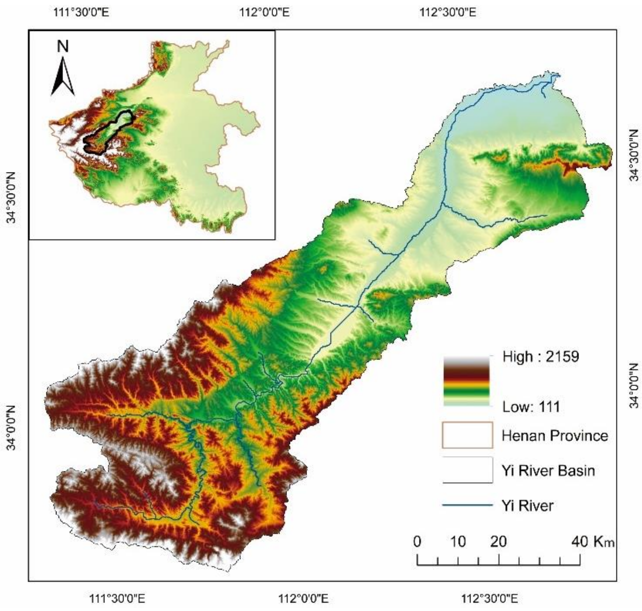

Figure 1. Location of the study area.

2. Overview of the Study Area

The Yi River basin (33°39′ ~ 34°17′N, 111°20′ ~ 112°11′E) is located in the middle and lower reaches of the Yellow River and flows through the southern and western parts of Henan Province. The total length of the mainstream of the Yi River is 237.9 km, and the basin area is approximately 5,846 km^2. The geography of such a basin is high in the southwest and low in the northeast, with elevations extending from 110 to 2,200 m (Figure 1). The Yi River basin has a mild temperate continental monsoon climate with high summer temperatures and heavy rainfall, and colder, drier winters. The basin includes a wide range of soil types, a diversity of plant and animal species, and good ecological conditions. The upper, middle, and lower sections of the basin transition from hills to mountains to plains. The upper section of the Yi River basin is densely forested, the middle section has some reservoirs for water supply, and the lower section is mainly farmland scattered in densely populated areas. With rapid economic and social development, as well as accelerated urbanization, the landscape pattern of the Yi River basin has changed dramatically in recent years, and such change has had a significant impact on the ecological environment of the basin (Liu et al., 2019). The total value of ecosystem services generated in the Yi River basin is on a declining trend, and the spatial distribution of its decreasing area of value is more fragmented, and these are mainly due to landscape level changes such as decreasing landscape aggregation, increasing fragmentation, and increasing levels of landscape richness and diversity (Wei et al., 2021).

3. Methodology

3.1. Data Sources

The land use/cover change (i.e., LUCC) data in 1987, 1995, 2005, and 2020 over the Yi River basin were attained from the Scientific Data Center (http://henu.geodata.cn/). The LUCC data of 2015 was obtained based on the Landsat TM remote sensing image data. The remote sensing data was then imported into ENVI 5, and cropped, geometrically calibrated, and configured for interpretation. Based on the obtained land use/cover data from 1987 to 2020 and the actual needs of the Yi River basin study, the landscape was divided into seven categories, including forest, grassland, farmland, canal, reservoir, construction land, and bare land. The specific land use classifications and their descriptions are shown in Table 1. Land cover maps of the Yi River basin from 1987 to 2015 are shown in Liu et al. (2022a), and the cover map for 2020 is presented in Figure 2.

Table 1. Classification and Descriptions of Land Use in the Yi River Basin

Land Use Type	Definition
Farmland	Including water fields, and dry land
Forest	Forestry land with trees, shrubs, bamboo, etc., which includes woodlands, shrubbery, dredging land, and other woodlands
Grassland	Including natural grassland, improved grassland, artificial grassland
Canal	Including a naturally formed or man-made river
Reservoir	Including reservoirs, pits, lakes, beaches, and beaches
Construction Land	Including settlements, industrial and mining land, and transportation land
Bare Land	Including sand, Gobi, saline land, bare land, bare rock, gravel, etc.

The variability of landscape patterns at temporal and spatial scales can be visually characterized by Landscape Indices (Chen et al., 2008). Based on previous studies, six commonly used landscape pattern indices were selected for this study, including the largest patch index (i.e., LPI), landscape shape index (i.e., LSI), patch density index (i.e., PD), Shannon's diversity index (i.e., SHDI), contagion index (i.e., CONTAG), and aggregation index (i.e., AI) (Wu et al., 2021; Liu et al., 2022b). The meaning of these indices is shown in Table 2. In addition, to investigate the evolution of landscape patterns in the Yi River basin, several landscape pattern indices were chosen at both landscape and type levels. At the landscape level, LPI, LSI, PD, SHDI, and CONTAG were selected; at the type level, LPI, LSI, PD, and AI were chosen.

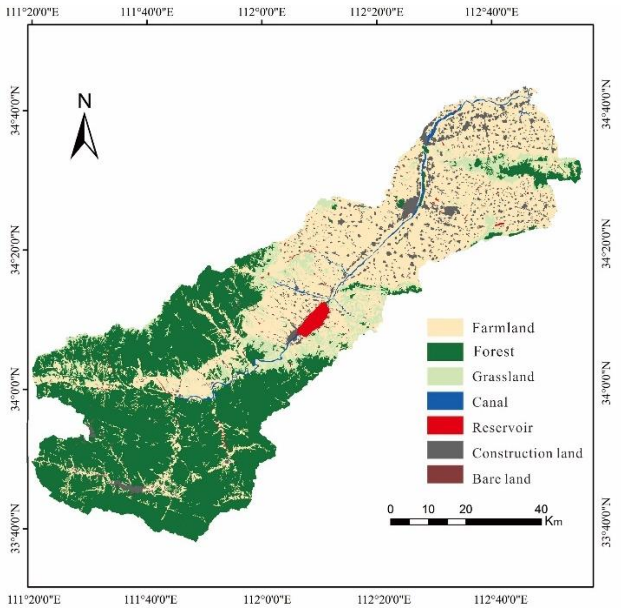

Figure 2. The LUCC of the Yi River basin in 2020.

3.2. Evaluation Method of Equivalence Factor per Unit Area

There are numerous approaches to evaluating ES. For example, the real market method, alternative market method, hypothetical market approach, market value method, conditional value method, and simulated market approach (Li et al., 2018). Among them, the value equivalent factor in the unit area is considered one of the most effective valuation tools due to its ability to directly monetize the value of ES. Based on quantitative criteria, such methodology creates value equivalents for the various ES generated by ecosystems, which are then evaluated in proportion to the size of the landscape (Xie et al., 2003, 2008, 2015a, 2015b). The method of calculating the value equivalent factor per unit area is based on a standard equivalent, which is the net profit of food production (i.e., rice, wheat, and corn) per unit area of farmland. Data on the sown area of rice, wheat, and corn for 1987, 1995, 2005, 2015, and 2020 in Luoyang City, Henan Province were obtained from the official website of the Statistics Bureau of Luoyang City and Henan Province (http://lytjj.ly.gov.cn/index.htm, https://tjj.henan.gov.cn/). The average net profit per

Table 2. The Meaning of Landscape Pattern Indicators

Landscape Pattern Index	Representational Significance
LPI	Reflecting the proportion of the largest patch area in the landscape to the total area of the study area can reflect the intensity and frequency of human activities in the region.
LSI	Reflecting the overall structural complexity of the landscape system, the smaller the landscape shape index, the simpler the structure of the ecosystem, and the higher the overall stability of the landscape.
PD	Reflecting the density size of patches in the landscape ecosystem, and its ecological significance can reflect the fragmentation degree of the landscape.
SHDI	Reflecting the degree of heterogeneity of the landscape, the larger the value the higher the degree of landscape heterogeneity and the higher the degree of fragmentation.
CONTAG	CONTAG, which ranges from 1 to 100, indicates the degree of aggregation between diverse regions in the terrain. A higher value indicates more connectedness and stronger aggregation of the landscape ecosystem.
AI	The degree of patch aggregation and dispersion in the landscape is reflected by AI. The landscape is more inclined to be made up of numerous small, distinct regions the smaller the value. The patches are more noticeable and connected the higher the value.

Table 3. Share of Rice, Wheat, and Corn Sown Area, Average Net Profit, and D-Value in the Yi River Basin

	Crop Area Ratio (%)					Average Net Profit per Unit Area (RMB/h·m^2)				
	1987	1995	2005	2015	2020	1987	1995	2005	2015	2020
Rice	1.18	0.77	0.46	0.33	15.54	2,672.70	10,204.65	4,405.20	5312.25	6,388.43
Wheat	67.52	68.46	58.49	55.88	47.17	1,108.35	3,453.45	1,811.40	1,525.20	–730.50
Corn	31.30	30.77	41.05	43.78	37.29	1,024.80	5,446.50	2,534.70	–978.15	2,463.60
D-value	1,100.66	4,118.70	2,120.32	441.58	1,566.86	1,100.66	4,118.70	2,120.32	441.58	1,566.86

Note: Values in the last row represent D-value.

unit area of crops in Henan Province in 1987, 1995, 2005, 2015, and 2020 was calculated using the National Compilation of Information on Costs and Benefits of Agricultural Products (Department of Prices, National Development and Reform Commission, 1988, 1996, 2006, 2016, 2021). The ES value of a standard equivalent can be expressed as follows:

$$D = S_r \times F_r + S_w \times F_w + S_c \times F_c \tag{1}$$

where D denotes one standard equivalent of ES in RMB/h·m^2. S_r, S_w, and S_c represent the percentage of sown area of rice, wheat, and corn in the country for the entire study period (i.e., 1987 ~ 2020), respectively; F_r, F_w, and F_c characterize the average net profit per unit area (RMB/h·m^2) of rice, wheat, and corn during the same period, respectively.

Standard equivalence factors can be used to measure ESV nationally wide. However, the standard equivalence factors must be modified to ensure the accuracy of ESV assessment in the Yi River basin. Data for rice, wheat, and corn in Henan Province and Luoyang City were utilized to correct the six parameters in the traditional equivalence factor calculation. The D-values calculated through Equation (1) are displayed in Table 3.

The ecological value coefficients of various landscape types in the study area in that year can be calculated through the standard equivalence factors of the study year, and the value of the regional ES can be calculated by adding them to the ESV calculation formula, as follows:

$$ESV = \sum A_k \times VC_k \tag{2}$$

$$ESV_k = A_k \times VC_k \tag{3}$$

$$ESV_f = \sum A_k \times VC_{fk} \tag{4}$$

where ESV (RMB, unit: yuan) denotes the total value of all ecosystem services, A_k refers to the area (h·m^2) of the kth land use type in the study area, and VC_k represents the value coefficient (RMB/h·m^2·a). ESV_k indicates the value of the kth ES of the ecosystem in the study area. ESV_f denotes the value of a single service function in the study area, and the tits coefficient is expressed by VC_{fk}.

3.3. Correlation Analysis Method

Correlation analysis methods have been used to develop links between ecosystem service values and landscape patterns. Correlation analysis is the process of determining the strength of linear relationships between variables and expressing them using appropriate statistical indices (Song et al., 2008). In this study, the landscape indices were used as the independent variable, and the single ES value was used as the dependent variable. The data for the independent and dependent variables were collected from 1987 to 2020. The association between ESVs and different landscape pattern indices in the Yi River basin was investigated through the correlation analysis method.

4. Results

4.1. Landscape Changes in the Yi River Basin

To evaluate the impact of landscape change on ESV, the changes in the landscape and the value of ecosystem services in the Yi River basin are presented. In detail, the changes in landscape area and landscape pattern are analyzed to help understand how the landscape would change from 1987 to 2020,

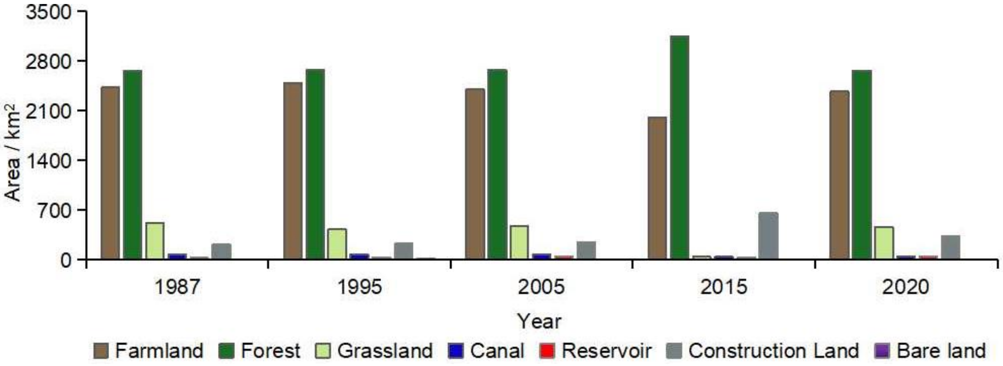

Figure 3. Changes of land cover types in the Yi River basin from 1987 to 2020.

as shown in Table 4 and Figures 3 and 4. Moreover, the changes in landscape patterns are displayed at the landscape level and type level. Figure 3 shows the changes in land cover types in the Yi River basin in the period of 1987 to 2020. The major landscape type in the Yi River basin is forest, followed by farmland, both of which account for 80% of the entire basin area. From 1987 to 2020, the area of farmland and grassland decreased while the area of forest and construction land increased. From 1987 to 2005, the area of canal and reservoir increased, but by 2015, the area of both landscape types began to decline. The proportion of bare land has changed rarely over the past few decades. As far as the spatial distribution of LUCC, the area of forest and grassland in upstream of the basin has increased significantly. In recent years, the area of artificial surface (e.g., construction land) and farmland in the middle and lower reaches of the basin has also increased rapidly. Grasslands in the lower part of the basin have been largely degraded and covered mainly by farm-land and forests.

Table 4 shows the characteristics of the five landscape pattern indices between 1987 and 2020. It can be found that landscape pattern indices at the landscape level have changed dramatically in the Yi River basin. The magnitude of the LPI value fluctuates in a wave-like pattern, reaching a peak in 2015. This indicates that the intensity and frequency of human activity have fluctuated considerably over the past 30 years. It has had a continuous impact on the landscape change in the Yi River basin. In 2015, the intensity of landscape patches and human activities were more separated. The average value of LSI in the Yi River basin was 43.73 during 1987 to 2020, but the value in 2015 was much higher than the average, which indicates that the spatial structure of the landscape ecosystem was relatively stable from 1987 to 2005 and relatively less stable from 2015 to 2020. Moreover, LSI was found to be highly correlated with the increase of construction land area in the Yi River basin. From 1987 to 2005, there was little change in PD with a value of 0.4, while it increased to 3.12 in 2015, indicating that the patch density in the Yi River basin increased and the landscape fragmentation increased in 2015. This shift can be attributed to the outward expansion of rural communities and towns resulting from increased population density in the Yi River basin. From 1987 to 2005, SHDI decreased and then increased, reaching its lowest level in 2015. This indicates a significant change in the landscape type of the Yi River Basin, with a high level of fragmentation in 2005. However, from 2005 to 2015, the degree of landscape variability decreased dramatically, which may be due to the increased agricultural intensification and urbanization of the Yi River basin in recent years. The CONTAG index showed an increasing trend from 1987 to 1995, then decreased from 1995 to 2005, and peaked in 2015, indicating the presence of major patches of high connectivity in the Yi River basin.

Table 4. Landscape-Level Changes in the Yi River Basin from 1987 to 2020

Landscape Pattern Index	Year				
	1987	1995	2005	2015	2020
LPI	29.35	35.29	29.31	44.99	29.19
LSI	41.50	36.41	41.80	56.57	42.38
PD	0.44	0.41	0.45	3.12	0.55
SHDI	1.14	1.13	1.16	1.04	1.17
CONTAG	66.49	67.30	66.08	67.94	65.81

As shown in Figure 4, the pattern indices at the type level in the Yi River basin have changed dramatically over the past 30 years. Compared with other landscape types, the LPI and AI of forests are in the dominant position. From 1987 to 2020, the LPI of the forests shows a trend of increasing, then declining and finally increasing. This suggests the dominant position and influence of forests in the landscape of the Yi River basin. The results in Figure 2 display that the forest landscape patches are densely distributed and highly aggregated. Forests are mainly distributed in the upper reaches of the Yi River basin, with a total area of 2,912 km^2, of which up to 2,300 km^2 is forested. From 1987 to 2005, the LSI and PD of the forest did not change much, while in 2015, the values of these two variables increased slightly. These results suggest that as the size of forest patches grows, so does the number and shape complexity of patches, which is good news for the Yi River basin in its efforts to limit erosion and preserve its biodiversity. Farmland has dominated the area and influence of the Yi River basin for nearly 30 years, with LPI values second only to the forests. The AI of farmland tends to increase and then decrease indicating that the farmland is becoming more scattered. From 1987 to 2005, farmland has the largest LSI compared to other landscapetypes until 2015, when the LSI of construction land replaced farmland. The results

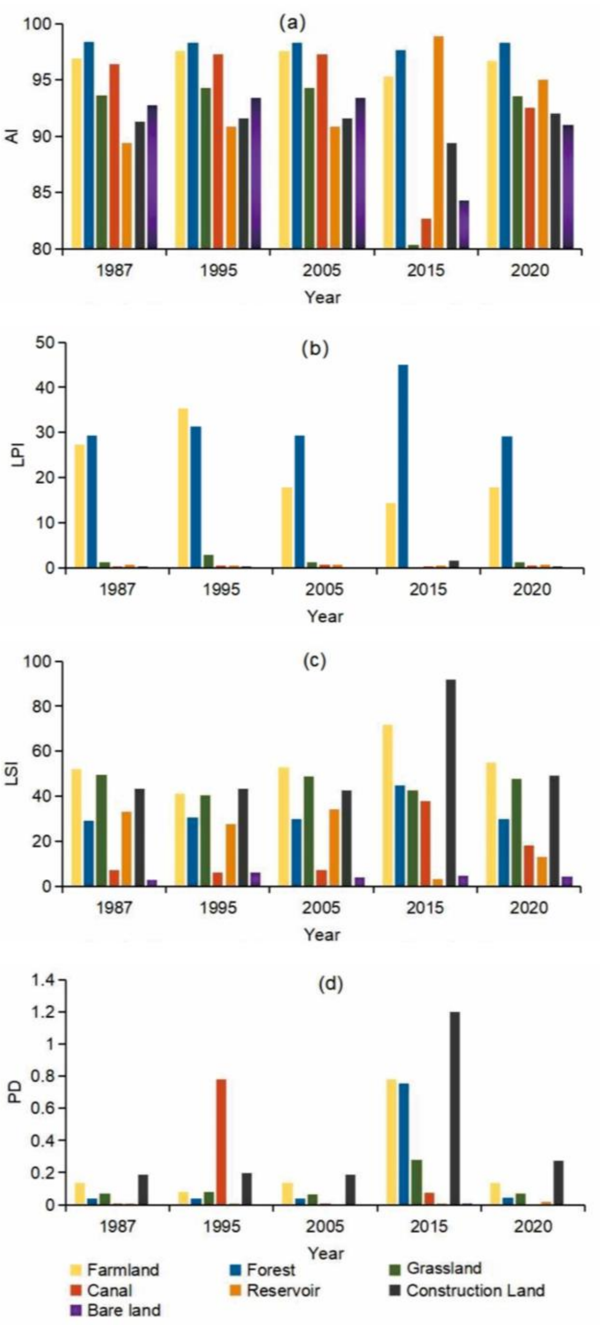

Figure 4. AI, LPI, LSI, and PD at the type level in the Yi River basin from 1987 to 2020.

suggest that the distribution of farmland in the Yi River basin has further fractured with the economic and social development of the region. It shows that the density growth of farmland patches became larger and the level of heterogeneity increased after 1995, and the PD value of farmland was the lowest in 1995 and gradually increased afterward. In the past 30 years, the LPI, LSI, and PD of construction land have gradually increased, indicating that the area, density, and quantity of construction land increased, and spatial distribution became more dispersed and fragmented. These may be related to the overall population and urbanization process in the Yi River basin. In addition, the LPI of reservoirs, canals, grassland, and bare land is low. From 2005 to 2015, the LSI of the reservoir decreased while the AI increased, indicating that their discrete state decreased, and reservoir patches tended to be regular.

4.2. Changes in the Value of Ecosystem Services in the Yi River Basin

The eleven ESs (including good, material, water supply, gas regulation, climate regulation, purify environment, hydrological regulation, soil conservation, nutrient cycle, biodiversity, and aesthetic landscape) selected in this study can be divided into four categories: supply services, regulation services, support services, and cultural services (Xie et al., 2015). The overall ESV and the ESV created by each category in the Yi River basin in 1987, 1995, 2005, 2015, and 2020 were calculated through Equations (2) to (4). As shown in Table 5, the total ESV in 1987 was 7.787 billion yuan and the total ESV in 1995 was 3.7 times higher than that in 1987. However, the total ESV in 2005 decreased by more than 50% compared to that of 1995, and the total ESV in that year was 15.070 billion yuan. By 2015, the total ESV in the study area had dropped to the lowest level in the past 30 years, with a total reduction of 11.960 billion yuan in the Yi River basin compared to 2005. From 1987 to 2020, the total ESV showed a trend of increasing and then decreasing, with a large decrease in the Yi River basin. The ESV generated by various landscape ecosystem types varies considerably. The ESV of forests shows an increasing trend from 1987 to 2020, and it contributes between 60% and 70% to the total ESV of the Yi River basin. The ESV value of farmland contributes between 10% and 20% and is the second largest contributor to total ES after forests. The ESV of farmland increased from 1.071 billion yuan in 1987 to 4.117 billion yuan in 1995, then gradually decreased from 2005 to 2015, reaching a low point of 355 million yuan in 2015. The grasslands and reservoirs cover a small area and contribute a similarly small amount to the overall ESV, contributing no more than 5% from 1987 to 2020. There is no significant change in the contribution of canals to ESV in the Yi River basin from 1987 to 2020.

The ESV composition of the Yi River basin is dominated by one of the four selected ES categories, i.e., regulating services. Among all ES outputs, gas control services and biodiversity rank fourth and fifth, respectively, while hydrological regulation, climatic regulation, and soil conservation services constantly occupy the top three positions. From 1987 to 2020, these five services accounted for more than 80% of the total services in the Yi River basin. Both hydrological regulation and climate regulation services contribute more than 21% to the total services in the Yi River basin, while soil conservation and biodiversity services maintain a contribution of 9% to the total services. This shows that the contribution of providing services and cul- tural services in the Yi River basin is significantly lower than that of regulating and supporting services, which dominate the output of ESV and ES flows. It can be found that from 1987 to 2020, the individual ESVs of the Yi River basin show a trend of increasing and then decreasing (Figure 5). In 1987, the food pro-

Table 5. Composition Characteristics of ESVs in the Yi River Basin from 1987 to 2020

Landscape Type	ESV (billion/year)					ESV Change Amount (billion/year)			
	1987	1995	2005	2015	2020	1987 ~ 1995	1995 ~ 2005	2005 ~ 2015	2015 ~ 2020
Farmland	10.72	41.17	20.40	3.55	30.45	30.45	–20.77	–16.85	26.90
Forest	51.30	193.08	99.56	24.43	141.78	141.78	–93.52	–75.13	117.35
Grassland	2.92	8.93	5.57	0.092	6.01	6.01	–3.36	–5.45	5.92
Canal	11.35	39.38	20.39	2.26	28.03	28.03	–18.99	–18.13	25.77
Reservoir	1.56	7.12	4.59	0.77	5.56	5.56	–2.53	–3.82	4.79
Construction Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare Land	0.01	0.04	0.18	0.04	0.03	0.03	0.14	–0.14	–0.01
Total	77.87	282.50	150.67	31.07	105.48	204.63	–131.83	–119.60	74.41

Note: Unit of values in the row of Bare Land is 10^{-2} billion/year.

Table 6. Correlation Coefficients between Landscape Indices and ESV

Individual ESV	Landscape Pattern Index				
	LPI	LSI	PD	SHDI	CONTAG
Food	–0.215	–0.601	–0.472	0.455	–0.174
Material	0.644	0.046	0.301	–0.514	0.832
Water Supply	–0.955*	–0.930	–0.995*	–0.984*	–0.840
Gas Regulation	0.983*	0.881	0.977*	–0.991*	0.896
Climate Regulation	0.938	0.948	0.999*	–0.977*	0.811
Purify Environment	0.919	0.96*	0.998*	–0.959*	0.773
Hydrological Regulation	0.959*	–0.922	–0.992*	0.978*	–0.840
Soil Conservation	0.997*	0.807	0.937	–0.983*	0.949
Nutrient Cycle	0.330	–0.253	–0.012	–0.230	0.599
Biodiversity	0.910	0.950*	0.987*	–0.933	0.746
Aesthetic Landscape	0.840	0.922	0.938	–0.846	0.635
Total ESV	–0.303	–0.806	–0.636	0.521	–0.128

Note: * indicates a significant correlation.

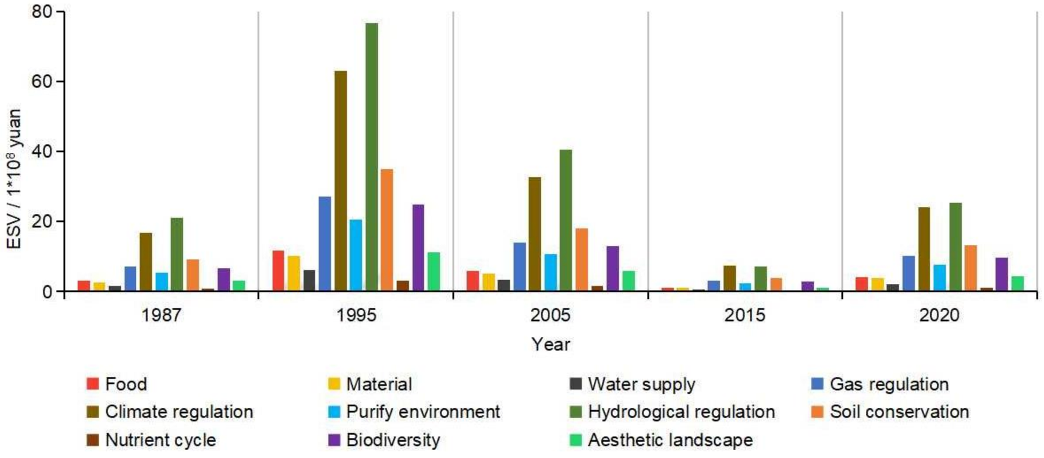

Figure 5. The Individual ESV in the Yi River Basin from 1987 to 2020.

duction and water supply were 306 and 172 million yuan, respectively. By 1995, their ESVs increased to 1,165 and 627 million yuan, respectively. At the end of 2005, the ESV of food production and water supply decreased to 585 and 332 million yuan, respectively. Compared to the former, water supply services provided by canals and reservoirs have changed much less over the past 30 years. In 1987, the value of hydrological control services and climate regulation services were 2,103 and 1,689 million yuan; in 1995, the increases were huge at 7,666 and 6,311 million yuan; in 2005, they declined to 4,039 and 3,271 million yuan and were 711 and 705 million yuan in 2015, respectively. This trend is mainly caused by the initial expansion of forest patches and the subsequent reduction in total services due to urbanization. When nutrient cycling and biodiversity support services were selected, their costs were 83 and 664 million yuan in 1987, 313 and 2,491 million yuan in 1995, 160 and 1,308 million yuan in 2005, and 33 and 291 million yuan in 2015, respectively. Cultural services were chosen to quantitatively evaluate the landscape aesthetics services, and the results indicated that their costs in 1987, 2005, 2015, and 2020 were 301, 1,133, 601, and 103 million yuan, respectively.

4.3. Impact of Landscape Change on ESV

As shown in Table 6, there is a correlation between the total ESV and the landscape indices in the Yi River basin from 1987 to 2020. Besides, some individual ESs (e.g., water supply, hydrological regulation, and soil conservation) were strongly correlated with the landscape pattern indices. Among the landscape indices, IPI has a high negative correlation with water supply services and a significant positive correlation with soil conservation, climate, and hydrological regulation services. This implies that the largest patches in the landscape represent an increasing proportion of the total basin area, which promotes some of the regulation services while limiting water supply services. LSI has a significant favorable association with waste dissipation and biodiversity conservation, which implies that increasing the complexity of the landscape structure contributes positively to waste dissipation and biodiversity conservation. Water supply services and hydrological regulation services have a considerable and inverse connection with PD, while gas regulation services, climate regulation services, environmental purification services, and biodiversity have a significant and positive relationship. This implies that greater patch density in the landscape negatively affects both water supply and hydrological regulation services, while increasing the value output of some regulation services. SHDI is substantially connected with water supply services, gas regulation, climate regulation, environmental purification, and soil conservation, but not with hydrological regulation services. This shows that the value of numerous of these ESs can be reduced by landscape variability and fragmentation. As a result, over-concentration of residential areas and industrial intensification should be avoided, and a reasonable allocation of different land types should be made to ensure their scientific and balanced development in the future since the diversity of landscape patches also contributes to the improvement of the total ES of the Yi River basin.

5. Discussion

A multidimensional investigation of the impacts of the developing landscape pattern on ESV in the Yi River basin would help clarify their interrelationships at various spatial-temporal scales. The results showed no significant changes in the area of forests, farmland, grassland, and other ecosystems, but changes in structure pattern resulted in significant variations in ESV (Li et al., 2020b). To assure future ES value improvement, continued ES flow output, and human well-being in the Yi River basin, it is vital to focus on changes in ecosystem and landscape patterns within the basin. For example, long-term processing of photographs of basin landscape patterns through GIS and RS technologies have enabled researchers to better understand trends in the evolution of landscape patterns in the Yi River basin and to assess the health of its ecosystems. Excessive human intervention may compromise the stability of the ecosystem within a basin (Cao et al., 2021). Therefore, avoiding concentrated construction sites and intensive industrial developmentis critical to constracting scientific landscape development patterns (Qin et al., 2020), maintaining the diversity of landscape patches, and reducing landscape fragmentation (Yu et al., 2021).

It is important to continuously revise and optimize the policy guidelines for ecological development in the Yi River basin constantly and to implement a systematic and coordinated management mechanism in the management process. Land use patterns should build an integrated bridge between regional ecosystem health, economic development, and environmental performance (Peng et al., 2015) to better support sustainable development in the middle and lower reaches of the Yellow River basin and achieve harmony between humans and nature.

The Yi River basin is an important sub-basin in the middle and lower reaches of the Yellow River basin. Investigating such sub-basin from multiple perspectives, such as changes in landscape pattern, ESV assessment and mapping, ES trade-offs and synergies, and ES supply and demand, can help to clarify the ecological status of the sub-basin, and also enrich the database of ecological conservation in the Yellow River basin. The above research perspectives also help to illuminate the current status of different regions in the Yellow River basin and also provide data to support the exploration of high-quality development and ecological management in the Yellow River basin.

The results of this study can provide a reference for the valuation of ecosystem services and the evolution of landscape patterns in the sub-basins of the Yellow River basin. However, the use of different assessment methods, the choice of models, the accuracy of the obtained data, and unexpected field conditions in the study area can all affect the accuracy of the assessment results. The influence of landscape pattern evolution on ES is a complex process, and it is difficult to address the problem fundamentally by only analyzing the correlation between the landscape indices and ESV without taking into account the internal mechanism of landscape pattern changes on ES change. As a result, more research and analysis with a large number of actual cases would be one future extension of this study.

6. Conclusions

In this study, the landscape indices analysis method and the equivalent factor evaluation method were used to evaluate the spatial and temporal evolution of the landscape pattern and ESV. In addition, the correlation analysis was used to explore the impact of landscape pattern changes on ESV in the Yi River basin from 1987 to 2020. The results show that:

(1) Forest is the dominant landscape type in the Yi River basin, followed by farmland, with both accounting for up to 80% of the total basin area. From 1987 to 2020, the area of forest and construction land increased, while the farmland and grassland decreased.

(2) From 1995 to 2020, the overall stability of the landscape in the Yi River basin gradually declined, and the fragmentation of patches was serious. From 2005 to 2015, landscape

heterogeneity declined dramatically, and large areas of connectivity were prominent, such as the canals in the basin. This was due to the increased intensity and frequency of human activities in the basin, and the concentration of patches of construction land in the basin from 2005 to 2015.

(3) In the Yi River basin, the value of total ES (including provisioning, regulating, supporting, and cultural services) increased from 1987 to 1995 and then decreased from 1995 to 2015, with regulating services being the largest contributor to total ESV and forests being the main source of regulating service value.

(4) Total ESV has been demonstrated to be connected with the landscape indices, negatively correlated with LSI, and positively correlated with SHDI. In the Yi River basin, some individual ESVs were strongly correlated with the landscape pattern indices. For example, LPI was significantly positively correlated with gas regulation, temperature regulation, and soil con- servation, while water supply and hydrological regulation were highly negatively correlated with PD.

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