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Coupling Landscape Connectedness, Ecosystem Service Value, and Resident Welfare in Xining City, Western China

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Abstract: Landscape connectedness, ecosystem service value (ESV), and resident welfare are intricately interconnected, and understanding their relationships is crucial for promoting regional sustainable development. Utilizing six stages of land use data from 1995, 2000, 2005, 2010, 2015, and 2020 in Xining City, Qinghai Province, this study identified landscape connectedness changes by landscape pattern indices, calculated ecosystem service value by the equivalent factor method, and quantified residents' well-being by comprehensive evaluation indices. To investigate the coupled and coordinated states among the three, a coupling coordination model is adopted. Furthermore, the relative development degree model is employed to reveal the relative developmental level of the three, clarify the lagging factors in their coupling coordination. The gray relational model is employed to identify key factors affecting the coupling mechanism. Key findings include the following: (1) The development trend of landscape types was moving toward diversification and balance, and the total value of ecosystem services has been declining. The comprehensive level of resident welfare has increased annually, but the structure has changed. (2) The coupling relationship among landscape connectedness, ecosystem service value, and resident welfare is strong and has remained at a high correlation level but has been in a state of discord. (3) The main constraint of the discord in the early stage was resident welfare, but the constraining factors in the later stage shifted to ecosystem services and landscape connectedness. The largest patch index and water resource supply were the key influencing factors in the system coupling mechanism. The research findings can provide a reference for the sustainable development of Xining City, regional land use policies, and ecological intervention planning.

Keywords: coupling relationship; ecosystem services; landscape patterns; resident welfare; Xining City

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1. Introduction

The Millennium Ecosystem Assessment (MA) indicates that 60% of global ecosystem services are in a state of degradation or unsustainability [1]. As human activities and climate change continue to intensify, a series of ecological and environmental issues have arisen, including increased carbon emissions, rapid global warming, and rising sea levels, all of which severely damage the environment in which humans live [2,3]. In the context of global environmental change and human disturbance, strengthening the understanding of the relationship between humans and nature is the key to achieving sustainable development [4]. Sustainable development, as a behavioral vector in the complex natural-social-economic system, has focused on the interrelationship between ecosystem services and human well-being. Human well-being is a state of healthy, happy, and materially affluent living. Ecosystem services refer to life-sustaining products and services directly or indirectly derived by humans from ecosystem structures, processes, and functions [5].

These include provisioning, regulating, supporting, and providing cultural services [6]. As the basis for natural environmental conditions formed and maintained by ecosystems and ecological processes, changes in ecosystem services can directly or indirectly affect human well-being [7]. Exploring the impacts of various factors, such as ecosystem processes and land use or landscape pattern changes, on the relationships between ecosystem services and human well-being is very critical [8]. Land use changes not only serve as a significant driving force for global change but also directly affect the structure and function of ecosystems, ultimately influencing their ability to provide ecosystem services [9]. Landscape pattern changes, primarily manifested as land-use/land-cover changes, can impact ecosystem functions and structures by altering surface biophysical parameters, thus affecting the provision of ecosystem services [10,11]. In addition, land use change can directly cause changes in landscape connectedness. Landscape connectedness, as a link between landscape patterns and ecological processes, expresses the degree to which a landscape facilitates or hinders ecological flows. Landscapes with good connectedness can realize their ecological functions more effectively [12–14]. Some studies point out that land use or landscape pattern changes can not only change biodiversity and habitat [15–17] but also alter ecosystem processes, affecting well-being in the process of balancing ecosystem services. Therefore, there is a close relationship between landscape patterns, ecosystem services, and human well-being. This relationship is a complex, nonlinear, multilevel relationship affected by various factors, and studying this relationship as a whole is of great importance for understanding natural ecosystems and socioeconomic systems [18,19], enhancing human well-being [20], and guiding national or regional sustainable development toward increasingly rational and harmonious directions [21].

Following MA's establishment of the connection between ecosystem services and human well-being, the scientific community has been analyzing the relationships between land-use changes and ecosystem services [22,23], landscape patterns and ecosystem services [24], and ecosystem services and human well-being [25,26], with the aim of incorporating ecological, economic, and social aspects into a coordinated global development framework. Landscape indices are simple quantitative indicators that can condense information on landscape patterns at high density, reflecting certain aspects of their structural composition and spatial configuration, and whose change characteristics have a certain degree of significance in terms of the connectedness degree [27,28]. The widely used method for evaluating ESV is the market alternative method, also known as the value equivalent method. Value equivalent factors are essentially the equivalent coefficients that are obtained via a comprehensive scoring system developed by many ecosystem research experts. Human well-being is usually quantified by various evaluation indicators, including subjective, objective, and the combination of subjective and objective. The harmonious development of landscape patterns, ecosystem services, and human well-being has gradually become a frontier of human-earth system research and an important topic for sustainable development [20,29,30]. For example, research assessing the impact of land-use changes in Chile's temperate forests between 1986 and 2011 on the spatial patterns of native forest habitat diversity identified area loss, increased patch numbers, and biodiversity loss as explanations for the decline in ecosystem service provision [31]. Mitchell et al. argued that landscape patterns significantly influenced ecosystem service values, with landscape fragmentation acting as a driver of ecosystem service degradation [32]. High-intensity human activities and accelerated land use transformation have seriously affected ecosystem stability and landscape connectedness, threatening regional ecological security and sustainable development [33]. As landscape fragmentation is becoming increasingly serious due to global environmental changes and human activities, restoring or rebuilding connectivity between landscapes and promoting ecological flows of materials and energy between patches has become one of the most important means to maintain landscape integrity and continuity and to improve regional ecosystem service functions [34–36]. Horcea-Milcu et al. analyzed the relationship between ecosystem services and human well-being in Eastern Europe, concluding that people in impoverished areas are more dependent on ecosystem services [37]. Zhen et al. revealed that changes in urban ecological land use structure led to changes in ecosystem service values, which were mainly affected by urbanization [38]. A few studies revealed that the alpine meadow ecosystems on the Qinghai-Tibet Plateau are severely degraded under the combined effects of climate change and human activities, with both vegetation and soil exhibiting different degradation trends. Long-term neglect of scientific management of grassland resources, extensive operations, and overgrazing have seriously threatened critical biodiversity for human survival, resulting in a significant loss of ecosystem services [39,40]. Li et al. explored the spatiotemporal evolution of ecosystem service values, resident well-being levels, and the coupled relationship between them in the Beijing-Tianjin-Hebei region using a coupled coordination model [41]. While there is extensive literature [42–44] on the coupling relationships and mechanisms between two systems, research on the coupled coordination and interaction mechanisms between landscape connectedness, ecosystem services, and human well-being is still limited. In this context, Hu et al. revealed the complex relationships between landscape patterns, ecosystem service values, and human well-being in the Xishuangbanna Nature Reserve based on coupled coordination [45]. However, the coupling coordination state and mechanism of the three have not been further explored. Many scholars [19,24] argue that clarifying the relationships among landscape pattern, ecosystem services, and human well-being can effectively reveal the intrinsic interactions between human and natural systems, understand ecosystem service processes and mechanisms, and gain insights into regional ecological and environmental changes. This understanding contributes to land-use planning and ecological conservation policy formulation and implementation and promotes sustainable regional development.

Based on the previous research on landscape patterns, ecosystem services, and human well-being, a knowledge gap still exists in current research. The research on the detailed coupling state and the underlying factors of the coupling relationship among the three remains insufficient. Most research focuses on two aspects: landscape pattern, ecosystem services, and human well-being. Few studies consider the interaction among the three systems from an integration perspective. The factor interpretation and mechanism of the coupling relationship among the three are still unclear.

Over the past few decades, China has prioritized economic development, leading to significant environmental and societal changes [46]. The northwest region of China is characterized by a fragile ecological environment and complex ecological conditions. Meanwhile, Qinghai Province is the source of the Yangtze, Yellow, and Lancang rivers, holding crucial ecological significance in China and Asia. Xining City, located at the junction of the Qinghai-Tibet Plateau and the Loess Plateau, serves as the political, economic, and cultural center of Qinghai Province, with a vulnerable yet significant ecological environment [47]. In the 20 years since the implementation of the Western Development Strategy, Xining has experienced rapid development in various aspects, including the economy, society, and resident well-being. However, under the pressure of rapid socioeconomic development and population growth, the local fragile ecological environment faces landscape fragmentation, ecosystem degradation, and an overall unhealthy ecological condition [48]. Therefore, strengthening research on the relationships among landscape pattern changes, ecosystem service values, and resident well-being in Xining City is crucial for reducing regional ecological risks, maintaining ecosystem health, exploring future sustainable development policies, and promoting harmonious coexistence between humans and nature within the context of Chinese modernization. The methodology of this study mainly includes the landscape pattern indices, the equivalent factor method, the comprehensive assessment index system method, the coupling and coordination development model, the relative development degree model, and the gray correlation analysis. The objectives of this study are to (1) quantify the changes in landscape connectedness in Xining City; (2) assess the spatiotemporal variations in ecosystem service values; (3) comprehensively evaluate resident well-being; (4) explore the changes in the coupled coordination state between landscape connectedness, ecosystem service values, and resident well-being; and (5) identify the key coupling factors influencing the harmonious development of these three aspects and reveal the underlying constraints.

2. Materials and Methods

2.1. The Study Area

Xining City (101°77′ E, 36°62′ N) is located in the eastern part of Qinghai Province (Figure 1). As the provincial capital, Xining City administers five districts and two counties, covering an area of approximately 7,660 km^2. Chengzhong, Chengdong, Chengxi, and Chengbei districts are core areas with typically urban character, while other counties or districts have typically natural character but are within city borders. As of the end of 2022, the resident population of Xining City was 2.48 million people, and the regional GDP was CNY 1644.35 billion. The terrain is high in the northwest and low in the southeast, and the altitude range is 2143–4870 m. The city exhibits a "four mountains and three rivers" distribution, with the Huangshui River, a tributary of the Yellow River, running through the city from west to east. Xining has a semiarid plateau continental climate, with an average annual precipitation of 381 mm and strong evaporation, and is generally a water-poor region. Cultivated land, grassland, and unused land are the core types of LUCC, accounting for 73% of the total area [49]. The area of dry land is relatively large, the unused land is dominated by barren grass, and the ecological effect is low. Xining City is a major grain crop production area and an urban development focus in the Qinghai-Tibet region [50]. In the past 20 years, driven by the development of the western region and the construction of an ecological environment, Xining City, as a typical arid area in the west and a typical rapid urbanization area on the Qinghai-Tibet Plateau, has experienced rapid economic growth, and the intensification of human activities has had a great impact on the pattern of land use and ecosystem service functions [51].

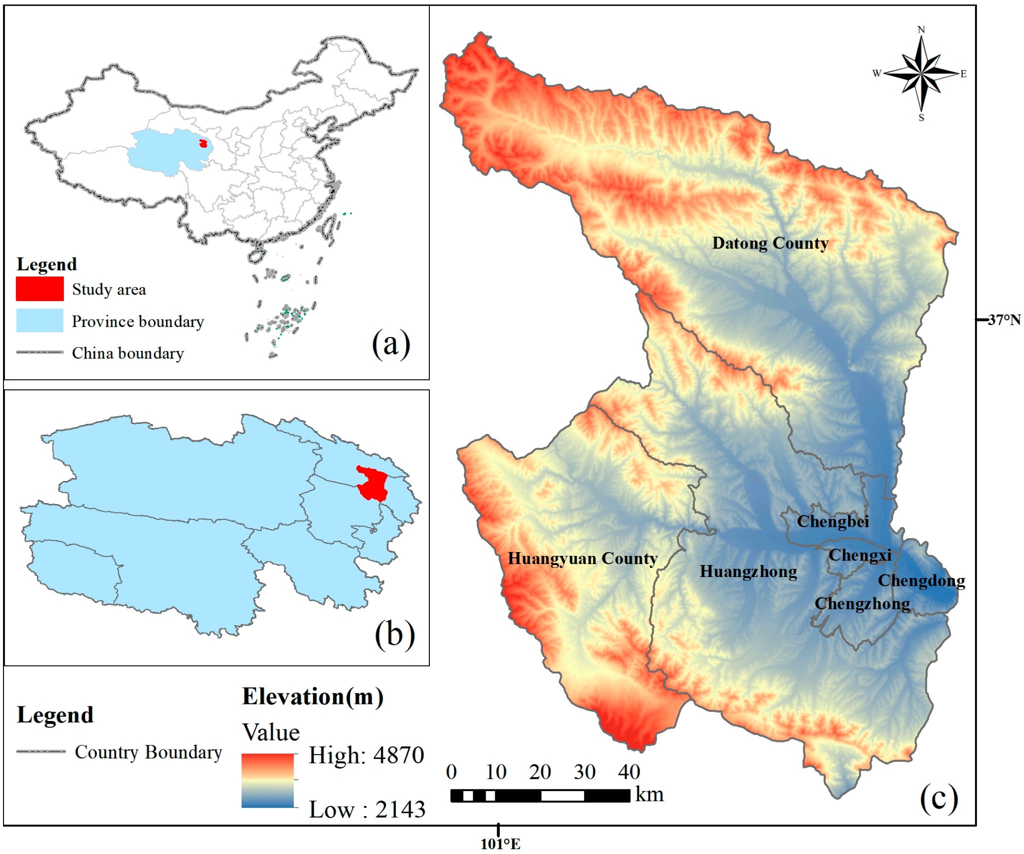

Figure 1. Location of the study area. (**a**) China, (**b**) Qinghai Province and (**c**) Xining City.

2.2. Data Sources

The data used in this study mainly include national administrative boundaries, digital elevation models (DEM), land use/cover change, and socioeconomic statistical data. The DEM is sourced from the Geographic Spatial Data Cloud, while socioeconomic data primarily come from the Xining City Statistical Yearbooks (1995–2020), China Agricultural Product Price Survey Yearbooks, and local records. The land use raster data with a spatial resolution of 30 m in 1995, 2000, 2005, 2010, 2015, and 2020 were from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/, accessed on 5 December 2022). Based on the Chinese Land Use Status Classification, the study area's land use types are divided into six categories: cropland, forestland, grassland, water bodies, construction land, and unused land [52]. For specific data sources, see Table 1.

Table 1. Data sources.

Data Name	Data Format	Data Source	Data Purpose
National Administrative Boundary	Vector data	Geographic Spatial Data Cloud (https://www.gscloud.cn, accessed on 20 December 2022)	The study area
Digital Elevation Models (DEM)	Raster data with a spatial resolution of 30 m	Geographic Spatial Data Cloud (https://www.gscloud.cn, accessed on 20 December 2022)	The study area
Land Use/Cover Change (LUCC)	Raster data with a spatial resolution of 30 m	Resource and Environmental Science and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/, accessed on 5 December 2022)	Statistics of land use type area in 6 periods
Socioeconomic Statistical Data	Statistical data	Xining City Statistical Yearbooks (1995–2020), China Agricultural Product Price Survey Yearbooks, and local records (http://tjj.qinghai.gov.cn/, accessed on 10 December 2022)	Calculate the economic value of ESV and assess the well-being of residents

2.3. Methods

2.3.1. Calculation of Landscape Connectedness

Landscape connectedness is a functional indicator of the extent to which a landscape facilitates ecological flows, describing the organic connections of landscape elements in terms of spatial patterns or ecological processes [27]. This connection may be species flow between biological groups or direct material, energy, and information flow between landscape elements, and it provides a theoretical basis and technical approach for exploring the spatial heterogeneity of landscapes and revealing the relationship between spatial patterns and ecological processes [53,54]. This study employs Fragstats 4.2 software to calculate landscape-level landscape pattern indices and investigate the changing characteristics of landscape connectedness [55,56]. Currently, landscape pattern indices have developed to a stage where there are many indices, few types, and vague ecological significance, and many landscape indices are difficult to interpret ecologically when used individually [57]. Utilizing existing landscape pattern index changes to analyze the landscape connectedness. Based on previous studies [56], the metrics at the land landscape level were selected to characterize the degree of fragmentation and connectedness of the landscape structure with the number of patches (NP), patch density (PD), edge density (ED), largest patch index (LPI), and aggregation index (AI), and the stability of the landscape structure with the landscape shape index (LSI) and Shannon diversity index (SHDI), respectively, with specific meanings [58] presented in Table 2.

Table 2. Landscape pattern metrics for calculating landscape connectedness.

Landscape Metric	Connotation	Weight
Number of Patches (NP) (C1)	Reflects the distribution status of the landscape; higher NP indicates higher fragmentation.	0.2208
Patch Density (PD) (C2)	Represents the number of patches per unit area; higher PD values indicate greater landscape heterogeneity and fragmentation.	0.2014
Largest Patch Index (LPI) (C3)	Proportion of the largest patch's area to the total landscape area; larger values indicate lower fragmentation and greater connectedness.	0.1134
Edge Density (ED) (C4)	Length of edges per unit area; a larger ED indicates a more fragmented landscape.	0.1129
Landscape Shape Index (LSI) (C5)	Describes landscape shape features, reflecting the complexity of landscape spatial patterns; higher LSI values indicate more separated patches, more irregular shapes, or greater fragmentation.	0.1130
Shannon Diversity Index (SHDI) (C6)	Represents landscape heterogeneity, reflecting the richness and complexity of landscape types; higher SHDI values indicate more fragmentation.	0.1264
Aggregation Index (AI) (C7)	Indicates the degree of aggregation of different patch types within the landscape; larger AI values suggest that the patch type has lower fragmentation and greater connectedness.	0.1120

In this paper, the entropy weight method is used to calculate the weight value of each index. This method can largely avoid subjective factors in the calculation of evaluation index weights, making the assessment more realistic and scientifically rigorous. The index weight steps determined by the entropy weight method are as follows: Firstly, the extreme value standardization method is used to eliminate the effects of different dimensions, including positive and negative effects [59].

Index with a positive effect:

$$g_{ij} = \frac{y_{ij} - y_{min}}{y_{max} - y_{min}} \tag{1}$$

Index with a negative effect:

$$g_{ij} = \frac{y_{max} - y_{ij}}{y_{max} - y_{min}} \tag{2}$$

where g_{ij} is the normalized value; and y_{max} and y_{min} represent the maximum and minimum values of the jth index, respectively [45].

Secondly, the information entropy of each index is obtained. In general, the smaller the entropy value, the greater the degree of dispersion between the systems and the greater the weight. The entropy of the jth evaluation index is as follows:

$$H_j = -\frac{1}{\ln n}\left(\sum_{i=1}^{n} f_{ij} \ln f_{ij}\right) \tag{3}$$

where f_{ij} can be calculated as

$$H_j = \frac{1 + g_{ij}}{\sum_{i=1}^{n}(1 + g_{ij})} \tag{4}$$

Finally, the entropy weight of each evaluation index is calculated [55,56]. The entropy weight w_j of the jth evaluation index can be calculated as

$$w_j = \frac{1 - H_j}{m - \sum_{j=1}^{m} H_j} \tag{5}$$

2.3.2. Ecosystem Service Value Assessment

To evaluate the value of ecosystem services, the complex system (structure and process) should be decomposed into different service functions, and these functions should be able to produce direct and indirect benefits for human beings from the ecosystem, including resource supply, environmental regulation, cultural entertainment, and production support [60,61]. In this study, based on the Millennium Ecosystem Assessment (MA), ecosystem services are divided into four categories [5]. Considering China's national conditions and relatively poor water resources in western China, we further subdivided four categories of ecosystem services into 11 services. Water resource supply services are included, and further consideration of ecosystem maintenance services for soil and water conservation and nutrient cycling will make ecosystem service value assessments more comprehensive. Based on Costanza et al.'s method and a questionnaire completed by 500 ecology scholars in China, an equivalent factor of ESV per unit area suitable for an evaluation of ecosystem service value at the Chinese scale was summarized by Xie et al. [62,63]. After that, Xie et al. modified and developed the method for evaluating the value equivalent factor in unit area and proposed an integrated method for dynamic evaluation of the Chinese terrestrial ecosystem service value [64]. The assessment of ecosystem service value differentiated various types of ecosystem services and constructed value equivalents for different types of ecosystem services based on quantifiable standards. The assessment is conducted using the equivalent factor method, which combines these value equivalents with the distribution area of the ecosystem. In this study, the dynamic assessment method for the value of China's terrestrial ecosystem services is applied to estimate the value of 11 ecosystem services in Xining City based on actual conditions [64]. The equivalent factors of cropland, forestland, grassland, water, and unused land are based on the previous research [51,64]. The cropland in the whole area of Xining City is weighted by the value equivalent of dry land and irrigated land. According to the geographical location and climatic conditions of Xining City, the coniferous, broad-leaved, and mixed coniferous and broad-leaved forests in the vegetation cover belong to the forested land, and the three equivalent weights are obtained. The shrub belongs to the shrub forest; the grassland will be the grassland; the meadow value equivalent weighted correction; waters include wetlands and waters; and unused land uses the average of desert and bare land equivalents. Construction land is based on the research results of Liu et al. to obtain the ecosystem service value equivalents per unit area for Xining City [65].

In this study, based on the revised ecological service equivalent table per unit area of China's ecosystems, the economic value created per unit area of grain output was revised based on the grain production and market value of Xining City from 1995 to 2020. The revised method is that a standard economic value equivalent coefficient for ecosystem services is 1/7 of the economic value of food production per unit area of farmland, calculated as follows:

$$E_a = \frac{1}{7}\sum_{i=1}^{n} \frac{m_i p_i q_i}{M} \tag{6}$$

In Equation (6), E_a is the economic value (CNY/ha) of the food production service function provided by the unit area of farmland ecosystem; i is the type of crops; p_i is the national average price (CNY/ton) of crop i in a certain year; q_i is the yield per unit area of crop i (ton/ha); m_i is the planting area of crop i (ha); and M is the planting area of all crops (ha) [64].

Based on the calculation of the planting area and total yield of major grain crops (wheat) in Xining City, the average grain yield per unit area for the city from 1995 to 2020 is obtained, which is 3.12 tons/ha. The average grain price is 3176.28 CNY/ton, resulting in an ecosystem service value of 1414.40 CNY/ha for one standard equivalent factor. The ecosystem service value coefficients per unit area for different land use types in Xining City are shown in Table 3 as follows:

Table 3. Ecosystem service value coefficients per unit area for Xining City (CNY/ha).

Primary Service	Secondary Type	Cropland	Forestland	Grassland	Water	Constructed Land	Unused Land
Provisioning Services	Food Production	1202	294	175	926	14	7
	Raw Material Production	566	668	252	516	0	21
	Water Resource Supply	27	343	141	7694	−10,622	14
Regulating Services	Gas Regulation	948	2193	899	1888	0	92
	Climate Regulation	509	6572	2369	4165	0	71
	Environmental Purification	141	1967	780	6471	3479	290
	Hydrological Regulation	383	4892	1733	89,439	0	170
Supporting Services	Soil Conservation	1456	2673	1094	2291	28	106
	Nutrient Maintenance	170	203	88	177	0	7
	Biodiversity	184	2438	992	7369	481	99
Cultural Services	Aesthetic Landscape	85	1071	441	4682	14	42

The calculation process for the value of ecosystem services is as follows:

$$V_{ij} = A \times VQ_{i,j} \tag{7}$$

In Equation (7), $V_{i,j}$ represents the value of the jth type of ecosystem service for land class i in the study area; A represents the area of land class i; VQ_{ij} represents the coefficient of the jth type of ecosystem service value for land class i; and ESV represents the total value of ecosystem services [64].

Additionally, this study adopts sensitivity analysis to examine the validity of the ecosystem service value coefficients and results. The sensitivity index can verify the accuracy of the selection of ecosystem service value coefficients and the estimation of ecosystem service values. The sensitivity index is used to express the temporal changes and the degree of dependency of ecosystem service values on the per-unit area ecosystem service value coefficients. This reveals the significance of the elasticity between the "value coefficients" and the "total value" for various land-use types [66]. In this study, the value coefficient of one type of land-use category's ecosystem services is adjusted each time (increased or decreased by 50%), and the sensitivity index of each land-use type's ecosystem service values in Xining from 1995 to 2020 is calculated. The smaller the elasticity is, the lower the sensitivity, the more reliable the results, and the more consistent the results are with the actual situation in Xining.

$$CS = \frac{(ESV_b - ESV_a)/ESV_a}{(VC_{bi} - VC_{ai})/VC_{ai}} \tag{8}$$

In Equation (8), CS represents sensitivity; ESV stands for the value of ecosystem services; VC denotes the ecosystem service value coefficient; a and b represent the values before and after adjusting the ecosystem service value coefficient, respectively; and i refers to a specific land-use type. If $CS > 1$, it indicates that ESV is highly elastic with respect to VC, the accuracy of the research results is relatively poor, and the credibility is low. Conversely, if $CS < 1$, it implies that ESV lacks elasticity with respect to VC, the accuracy of the research results is relatively high, and the results are reliable [67].

2.3.3. Assessment of Resident Welfare

The MA defines human well-being as encompassing the basic material needs for a high-quality life: health, good social relationships, security, and freedom of choice and action [68]. Research on human well-being in China focuses on the quantitative assessment of welfare from a sustainability science perspective [44,69]. Referring to the design of human well-being indicator systems both domestically and internationally [41,70–72] and considering the regional characteristics, current ecological and environmental conditions, and economic and social development levels of Xining [73]. Given the multidimensionality and regional differences in residents' welfare, the primary indicators selected for the Xining residents' welfare assessment system are divided into three categories: basic needs, safety and health needs, and psychological needs. The secondary indicators comprise nine aspects, and a total of 32 representative multidimensional assessment indicators were selected [74]. Considering the scale effect and data availability of residents' welfare, macro-statistical indicators characterizing residents' basic needs, such as per capita GDP, per capita income of urban and rural residents, grain output, and total output value of industry and agriculture, are selected. Among them, per capita grassland area, livestock inventory, and meat output are crucial indicators related to the well-being of plateau pastoralists. The total power of agricultural machinery indirectly reflects the level of agricultural modernization. For residents' safety and health needs, we primarily select indicators such as urban green space coverage and per capita park green space area to represent ecological safety levels. Healthcare infrastructure conditions reflect residents' health-related welfare demands. In terms of psychological needs, we primarily select indicators such as rural grassroots organizations and travel agencies to represent social communications. Additionally, multiple indicators, such as education, fiscal expenditure, and television population coverage rate, can better quantify residents' psychological needs. Using statistical analysis methods [44], we establish a relatively comprehensive indicator system for assessing the welfare of Xining residents (Table 4). The weights of each index are assigned using the entropy method.

Table 4. Indicators for Evaluating Resident Welfare in Xining City.

Objective Layer	First-Level Index	Second-Level Index	Third-Level Index	Effect	Weight
Resident Welfare	Basic Needs	Basic economic level	Per Capita GDP (in CNY 10,000 per person) (X1)	+	0.0343
			Urban Resident Per Capita Disposable Income (in CNY 10,000) (X2)	+	0.0314
			Rural Resident Per Capita Net Income (in CNY 10,000) (X3)	+	0.0350
			Total Agricultural Output Value (in CNY 10,000) (X4)	+	0.0423
			Tertiary Industry Share in GDP (X5)	+	0.0169
			Total Industrial Output Value (in CNY 10,000) (X6)	+	0.0374
		Basic material	Per Capita Cultivated Land Area (in hectares per person) (X7)	+	0.0494
			Per Capita Grassland Area (in hectares per person) (X8)	+	0.0686
			Livestock Inventory (X9)	+	0.0132
			Total Grain Output (in 10,000 tons) (X10)	+	0.0131
			Total Meat Production (in tons) (X11)	+	0.0184
			Total Agricultural Machinery Power (in 10,000 kilowatts) (X12)	+	0.0133
		Resource acquisition ability	Fixed Telephone Users (in 10,000 households) (X13)	+	0.0288
			Highway Cargo Turnover (in 10,000 ton kilometers) (X14)	+	0.0289
			Number of Motor Vehicles at Year-End (X15)	+	0.0406
			Cargo Volume (in 10,000 tons) (X16)	+	0.0225
	Security and Health Needs	Health	Per Capita Medical and Health Institutions (per 10,000 people) (X17)	+	0.0175
			Number of Hospital Beds (X18)	+	0.0409
			Number of Old-Age Insurance Participants (in 10,000 people) (X19)	+	0.0622
			Number of Doctors per 10,000 People (X20)	+	0.0242
		Ecological security	Urban Green Space Coverage Rate (NDVI) (X21)	+	0.0183
			Per Capita Park Green Space Area (in square meters) (X22)	+	0.0221
		Personal protection	Basic Medical Insurance Participants (in 10,000 people) (X23)	+	0.0691
			Insurance Income (in CNY 10,000) (X24)	+	0.0423
		Occupation security	Urban Registered Unemployment Rate (%) (X25)	-	0.0275
	Psychological Needs	Social communication	Number of Rural Grassroots Organizations and Committees (X26)	+	0.0278
			Number of Travel Agencies (X27)	+	0.0489
		Culture and Education	Education Fiscal Expenditure (in CNY 10,000) (X28)	+	0.0396
			Number of Primary School Students (X29)	+	0.0131
			Number of Regular High School Students (X30)	+	0.0137
			Number of Regular College and University Students (X31)	+	0.0258
			Television Population Coverage Rate (%) (X32)	+	0.0131

2.3.4. Coupling Coordination Degree Model

The concept of coupling degree originates from physics and refers to the extent to which two or more systems interact and influence each other. The coupling relationship and coordination degree determine the development status of the system. On this basis, this study draws on the methods of other scholars [41,75] to establish a coupling coordination degree model for the landscape connectedness subsystem, ecosystem service subsystem, and resident welfare subsystem (Equation (10)) to explore the temporal changes in the coupling coordination between these three subsystems at the urban scale of Xining from 1995 to 2020. The comprehensive evaluation method is used to calculate the annual comprehensive evaluation values of each subsystem:

$$\begin{cases} R1 = \sum_{j=1}^{m} a_j \times X_j \\ R2 = \sum_{j=1}^{m} b_j \times Y_j \\ R3 = \sum_{j=1}^{m} c_j \times Z_j \end{cases} \tag{9}$$

In Equation (9), R_1, R_2, and R_3 represent the comprehensive evaluation values of the landscape connectedness, ESV, and resident welfare subsystems, respectively; a_j, b_j and c_j represent the weights of the jth index for landscape connectedness, ESV, and resident welfare, respectively; x_j, y_j, and z_j represent the standardized values of the jth index for landscape connectedness, ESV, and resident welfare, respectively.

The calculations for the coupling coordination degree model are as follows:

$$\mathrm{C} = 3 \times \left[\frac{R1 \times R2 \times R3}{(R1 + R2 + R3)^3} \right]^{1/3} \tag{10}$$

$$D = \sqrt{C \times T} \tag{11}$$

In Equations (10) and (11), C represents the coupling degree, R_1, R_2, and R_3 represent the comprehensive development indices of the landscape connectedness, ESV, and resident welfare subsystems, respectively, and D represents the coordination degree. T is the coupling coordination development level index $T = \beta_1 U_1 + \beta_2 U_2 + \beta_3 U_3$, where β_1, β_2, and β_3 represent weights. This study considers that among the three subsystems, landscape connectedness and ecosystem services hold equal positions in the natural ecology, so the weights can be set as $\beta_1 = 0.3$, $\beta_2 = 0.3$, and $\beta_3 = 0.4$ The specific coupling degree standards [76] are presented in Table 5.

Table 5. Evaluation criteria for coupling degree and coupling coordination degree.

Coupling Degree	Coupling Type	Coupling Coordination Degree	Coupling Coordination Type	Coupling Coordination Degree	Coupling Coordination Type
$0 \leq C \leq 0.3$	Low-level Coupling	$0 \leq D < 0.1$	Extremely Uncoordinated	$0.5 \leq D < 0.6$	Barely Coordinated
$0.3 < C \leq 0.5$	Antagonistic Stage	$0.1 \leq D < 0.2$	Severely Uncoordinated	$0.6 \leq D < 0.7$	Primary Coordination
$0.5 < C \leq 0.8$	Running-in Stage	$0.2 \leq D < 0.3$	Moderately Uncoordinated	$0.7 \leq D < 0.8$	Intermediate Coordination
$0.8 < C \leq 1$	High-level Coupling	$0.3 \leq D < 0.4$	Slightly Uncoordinated	$0.8 \leq D < 0.9$	Good Coordination
		$0.4 \leq D < 0.5$	On the Verge of Uncoordination	$0.9 \leq D < 1$	Excellent Coordination

2.3.5. Relative Development Degree Model

The coupling coordination degree model of the systems can reflect the coordinated development relationship of landscape connectedness, ecosystem services, and resident welfare in spatiotemporal development, but it cannot express the relative development degree among the systems [77,78]. Based on this, the relative development degree model is introduced to measure the relative development level between the three systems, with the formula:

$$\beta = B1/B2 \tag{12}$$

We take the relative development degree of resident welfare and landscape connectedness as an example for description. In Equation (12), B1 represents resident welfare, and B2 represents landscape connectedness. The calculation principles for the relative development degree of landscape-connectedness ecosystem services and resident welfare-ecosystem services systems are the same as above. To facilitate the interpretation of the relative development of system coupling, we determine it according to Table 6, based on previous research findings [79,80].

Table 6. Relative development degree evaluation criteria.

Relative Development Degree	Coordinated Development Characteristics
(0, 0.8]	B1 lags behind B2
(0.8, 1.2]	B1 synchronizes with B2
(1.2, ∞]	B1 is ahead of B2

2.3.6. Gray Relational Analysis

Gray theory compares the geometric similarity of two variable time series. The more similar the shape, the higher the correlation between the two variables. This method measures the degree of association between factors based on the similarity or dissimilarity of their development trends and quantifies or orders factors in systems with incomplete information [81]. Therefore, using the gray relational degree method, we determine the dominant objects of coupling association between the two subsystems, analyze the key factors of interaction among the three subsystems, and further reveal the coupling mechanism among them. Since landscape connectedness and ecosystem services reflect the state of the natural ecological system and resident welfare belongs to the social system, this study only identifies the key factors of landscape connectedness and ecosystem services affecting resident welfare [45]. The formulas for the gray relational coefficient and gray relational degree are as follows:

$$\xi_{ij}(t) = \frac{\underset{i}{min}\underset{j}{min}\left|\overline{Z_i(t)} - \overline{Z_j(t)}\right| + \partial \underset{i}{max}\underset{j}{max}\left|\overline{Z_i(t)} - \overline{Z_j(t)}\right|}{\left|\overline{Z_i(t)} - \overline{Z_j(t)}\right| + \partial \underset{i}{max}\underset{j}{max}\left|\overline{Z_i(t)} - \overline{Z_j(t)}\right|} \tag{13}$$

In Equation (13), t represents different years; $Z_{i(t)}$ is the standardized value of human welfare in that year; $Z_{j(t)}$ is the standardized value of landscape connectedness or ESV in that year; and the resolution factor ∂ is the index of distinguishability in the range of (0,1). In most cases, a value of 0.5 is used.

$$r_{ij} = \frac{1}{k}\sum_{j=1}^{k} \xi_{ij}(t) \tag{14}$$

In Equation (14), r_{ij} is the gray relational degree, which numerically represents the impact of a factor on the objective value, ranging from 0 to 1. The closer this value is to 1, the stronger the correlation, indicating that the impact of the indicator on the other system is greater, which is the key factor determining whether the two systems can develop together.

Generally, when r_{ij} falls within the ranges of (0, 0.35], (0.35, 0.6], (0.6, 0.85], and (0.85, 1], the indicators of the two systems have low correlation, medium correlation, relatively high correlation, and high correlation, respectively [45].

3. Results

3.1. Land Use and Land Cover Change

3.1.1. Temporal Characteristics of Land Use and Land Cover Change

The land use types in Xining in 1995 were ranked by area: grassland > forestland > cultivated land > unused land > construction land > water bodies (Table 7). From 1995 to 2020, the area of land use types in Xining showed a pattern of "two increases and three decreases." The areas of grassland and construction land increased. The areas of cultivated land, forestland, and unused land have been continuously decreasing. The proportion of construction land increased from 3.31% in 1995 to 4.47% in 2020, mainly due to the significant reduction in rural settlements and the relocation and merging of herder settlements. The main direction of land use transfer was from forestland to grassland. Overall, the most rapid changes in Xining over the 25 years were the increase in construction land (34.82%) and the decrease in unused land (17.62%).

Table 7. Structure of land use types in Xining from 1995 to 2020 (unit: ha).

Land Use Type	1995	2000	2005	2010	2015	2020	1995–2020
Cropland	1456.63	1459.42	1419.85	1405.64	1365.63	1370.81	−85.82
	19.18%	19.21%	18.69%	18.50%	17.98%	18.05%	−1.13%
Forestland	1758.75	1655.81	1653.48	1654.80	1654.04	1652.66	−106.09
	23.15%	21.80%	21.77%	21.78%	21.77%	21.76%	−1.39%
Grassland	3712.07	3869.27	3876.62	3886.76	3893.12	3886.46	174.40
	48.87%	50.94%	51.03%	51.17%	51.25%	51.16%	2.29%
Water	21.99	20.91	24.41	21.83	22.84	21.55	−0.44
	0.29%	0.28%	0.32%	0.29%	0.30%	0.28%	−0.01%
Constructed land	251.68	248.45	279.52	301.60	344.16	339.31	87.63
	3.31%	3.27%	3.68%	3.97%	4.53%	4.47%	1.16%
Unused land	395.37	342.60	342.60	325.89	316.69	325.69	−69.67
	5.20%	4.51%	4.51%	4.29%	4.17%	4.29%	−0.91%

3.1.2. Spatial Characteristics of Land Use and Land Cover Change

The main land use type in the city is grassland (Figure 2), which accounts for approximately half of the total area of the study region (Table 7) and has the widest distribution. From 1995 to 2020, the area of grassland increased more in western Datong and Huangyuan counties. The construction land in this area has expanded significantly in the past 25 years in the urban area of Xining City, which has a high population density.

3.2. Landscape Connectedness Changes

Overall, the landscape connectedness of Xining City underwent complex changes from 1995 to 2020 (Table 8). At the landscape scale, the number of patches and patch density exhibited an M-shaped change trend. The number of patches and patch density increased, fragmentation intensified (1995–2000), then decreased (2000–2005), followed by another increase (2005–2010), and finally, the landscape structure stabilized (2010–2020). At the same time, the landscape shape index continuously declined over the 25 years, with a more even distribution of patch types. The Shannon diversity index and aggregation index increased annually from 2000 to 2020, indicating that the landscape types in the study area became richer and more diverse and the landscape structure was more stable. Fragmented patches tended to aggregate, and landscape connectivity strengthened, which is related to the growth and aggregation of construction land patches around water bodies during the corresponding time periods (Figure 2). Before 2000, landscape fragmentation intensified, heterogeneity increased, human activities severely disturbed landscape patterns, and land use was disordered, mainly reflected in the large-scale conversion of forestland to grassland (1995–2000). After 2000, the degree of landscape fragmentation weakened, and most of the ecological patches and anthropogenic patch aggregations in the landscape pattern stabilized, as evidenced by increased connectivity in the landscape structure after 2010.

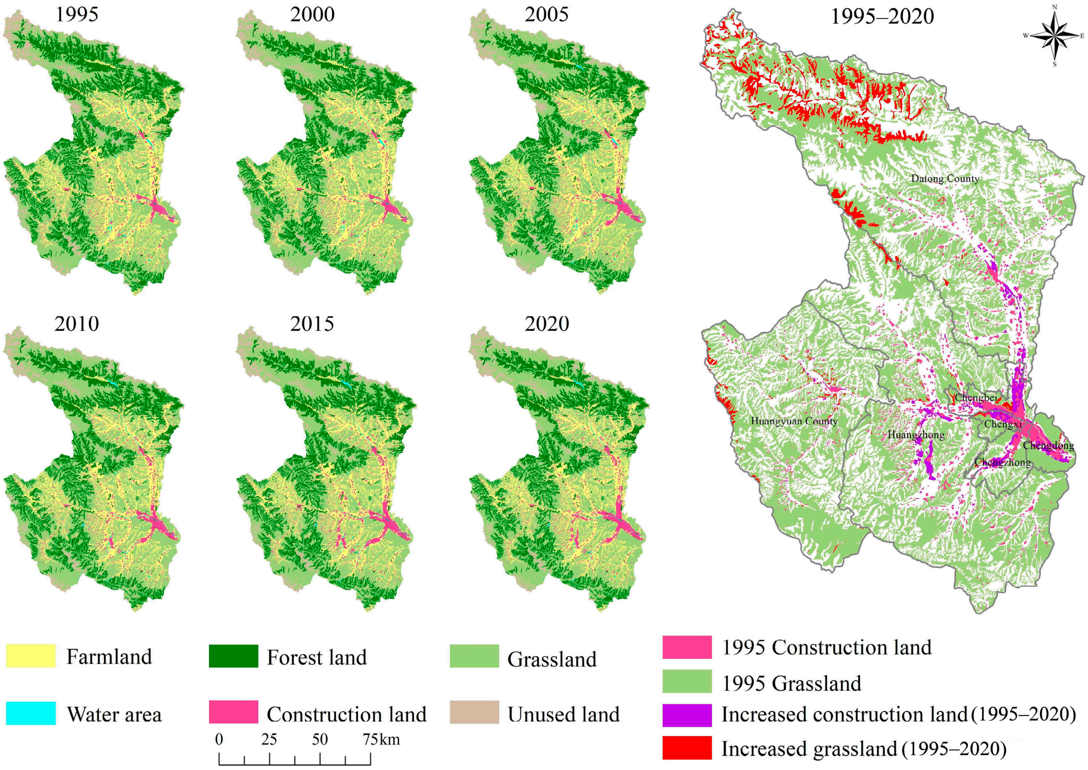

Figure 2. Spatial distribution of land use type changes in Xining from 1995 to 2020.

Table 8. Landscape-level indices in Xining City from 1995 to 2020.

Year	NP	PD	LPI	ED	LSI	SHDI	AI
1995	2628	0.3459	16.2270	30.7104	68.8328	1.2890	95.3954
2000	2675	0.3521	16.5527	30.1886	67.6961	1.2604	95.4730
2005	2652	0.3491	16.5367	30.1744	67.6650	1.2684	95.4755
2010	2681	0.3529	16.5106	30.1535	67.6186	1.2670	95.4786
2015	2660	0.3502	16.5060	30.1459	67.6030	1.2731	95.4799
2020	2633	0.3466	16.5243	30.1364	67.5823	1.2742	95.4814

Note: NP—Number of Patches; PD—Patch Density; LPI—Largest Patch Index; ED—Edge Density; LSI—Landscape Shape Index; SHDI—Shannon Diversity Index; AI—Aggregation Index.

3.3. Ecosystem Service Value Changes and Sensitivity Analysis

3.3.1. Changes in Ecosystem Service Value on a Time Scale

The total ESV in Xining from 1995 to 2020 shows a decreasing trend (Table 9). In 1995, the total ESV of Xining was CNY 8.40 billion, while in 2020, it was CNY 8.19 billion. The total ESV decreased by CNY 0.21 billion over 25 years, a change rate of −2.49%. The ESV of grasslands shows an increasing trend, while the ESVs of other land use types, such as forestland, cultivated land, and construction land, all show a decreasing trend. In terms of the ESV change rate from 1995 to 2020, construction land had the largest change rate at 34.82%, followed by unused land at −17.62%. This shows that human activities have a strong and time-sensitive impact on ecosystem services, and unused land has become a more active part of the ecosystem due to human activities.

Table 9. Changes in ecosystem service value for different land use types in Xining from 1995 to 2020 (billion CNY).

Land Use Type	1995	2000	2005	2010	2015	2020
Cropland	0.8262	0.8277	0.8053	0.7972	0.7745	0.7775
Forestland	4.1000	3.8600	3.8546	3.8576	3.8559	3.8527
Grassland	3.3282	3.4691	3.4757	3.4848	3.4905	3.4845
Water area	0.2761	0.2627	0.3066	0.2742	0.2869	0.2706
Construction land	−0.1662	−0.1641	−0.1846	−0.1992	−0.2273	−0.2241
Unused land	0.0363	0.0315	0.0315	0.0300	0.0291	0.0299
Total	8.4005	8.2870	8.2890	8.2446	8.2096	8.1911

The order of ecosystem service values by primary type is regulating services > supporting services > provisioning services > cultural services (Figure 3). By secondary type, it is climate regulation > hydrological regulation > soil conservation > gas regulation > maintaining biodiversity > environment purification > aesthetic landscape provision > raw material production > food production > maintaining nutrient cycling > water resource supply. In the primary types, the value proportion of regulation services is the highest, with proportions greater than 65% in each research period. The total value decreased from CNY 5.52 billion in 1995 to CNY 5.46 billion in 2020. Support services come next with a proportion of approximately 24%. The total value decreased from CNY 2.05 billion in 1995 to CNY 2.02 billion in 2020. The proportions of supply services and cultural services are relatively small, both below 8%. In the secondary types, from 1995 to 2020, the highest service value in single ecosystem services in Xining is climate regulation, with total values exceeding CNY 2 billion in each research period and proportions above 25% (Table 10). The next highest is hydrological regulation, with total values over CNY 1.7 billion and proportions above 20%. The structure of each single ecosystem service did not change significantly, with only numerical changes. From 1995 to 2020, the value of each ecosystem service in Xining decreased (Table 10). The water resource supply capacity of the ecosystem decreased significantly, with the service value decreasing from CNY −133.09 million in 1995 to CNY −228.02 million in 2020. This is consistent with the results of previous studies [49,51]. The next largest decrease was in food production supply services.

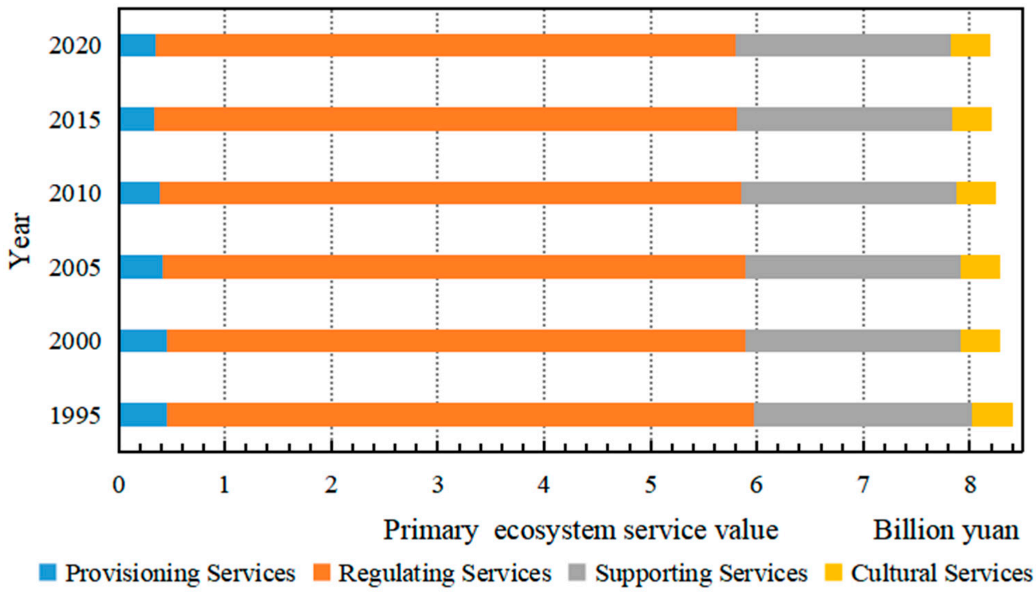

Figure 3. Xining's four ecosystem service values from 1995 to 2020 (unit: billion CNY).

Table 10. Xining's single ecosystem service values from 1995 to 2020 (billion CNY).

Primary Service	Secondary Type	1995	2000	2005	2010	2015	2020	1995–2020
Provisioning Services	Food Production	0.2945	0.2945	0.2901	0.2884	0.2839	0.2842	−3.51%
	Raw Material Production	0.2953	0.2923	0.2903	0.2897	0.2875	0.2875	−2.62%
	Water Resource Supply	−0.1331	−0.1319	−0.1623	−0.1876	−0.2321	−0.2280	−71.32%
Regulating Services	Gas Regulation	0.8652	0.8564	0.8534	0.8527	0.8494	0.8488	−1.90%
	Climate Regulation	2.1215	2.0904	2.0901	2.0914	2.0907	2.0880	−1.58%
	Environmental Purification	0.7695	0.7582	0.7708	0.7772	0.7922	0.7892	2.56%
	Hydrological Regulation	1.7628	1.7294	1.7592	1.7377	1.7458	1.7328	−1.70%
Supporting Services	Soil Conservation	1.0984	1.0876	1.0830	1.0816	1.0766	1.0760	−2.04%
	Nutrient Maintenance	0.0936	0.0929	0.0923	0.0921	0.0915	0.0915	−2.28%
	Biodiversity	0.8562	0.8452	0.8487	0.8488	0.8512	0.8492	−0.81%
Cultural Services	Aesthetic Landscape	0.3767	0.3719	0.3733	0.3726	0.3729	0.3719	−1.27%

3.3.2. Changes in the Ecosystem Service Value on a Spatial Scale

To describe the spatial distribution of ecosystem service values in more detail, this study divides ESV into four levels: low value (0–500 CNY/ha), medium value (500–1500 CNY/ha), high value (1500–2500 CNY/ha), and extremely high value (>2500 CNY/ha). Figure 4 shows the distribution of ecosystem service values in Xining during the research period. High-value areas are mainly distributed in the mountainous areas in the northwest and southwest. Low-value areas are mainly distributed in the eastern part of the city. Most areas have medium ecosystem service values. From 1995 to 2000, the high-value area in the north significantly decreased, the extremely high-value area that had been small in size for many years dropped sharply, and the medium-value area increased. After 2000, the medium-value area further encroached on the high-value area from the periphery and advanced to the west. Low-value areas also gradually expanded at the confluence of many rivers, corresponding to the ecological processes of some forestland being converted to grassland and construction land being concentrated in the eastern valley areas.

3.3.3. Sensitivity Analysis

After adjusting the ecosystem service value coefficients in the study area, the sensitivity index for each land-use category in Xining from 1995 to 2020 is less than 1, indicating that the results are reliable (Table 11). Among them, the sensitivity index of forestland is the highest, ranging from 0.7938 to 0.9253, meaning that when the ecosystem service value coefficient of forestland increases by 1%, the total value of ecosystem services will increase by 0.7938 to 0.9253 percentage points. This is mainly because the ecosystem service value coefficient of forestland in Xining's land-use types is relatively large. The next largest sensitivity coefficient is for grassland, mainly due to its large area. Over the past 25 years, the sensitivity indices of grassland, construction land, and water areas in Xining have all increased to varying degrees, indicating that their impact on the total value of ecosystem services has gradually increased. In contrast, the sensitivity indices of cultivated land, forestland, and unused land have decreased, suggesting that their ecosystem service value coefficients' influence on the total value of ecosystem services has declined. Therefore, paying close attention to the changes of grassland, construction land, water, and other ecosystems is of great significance to exploring the changes in ecosystem service value.

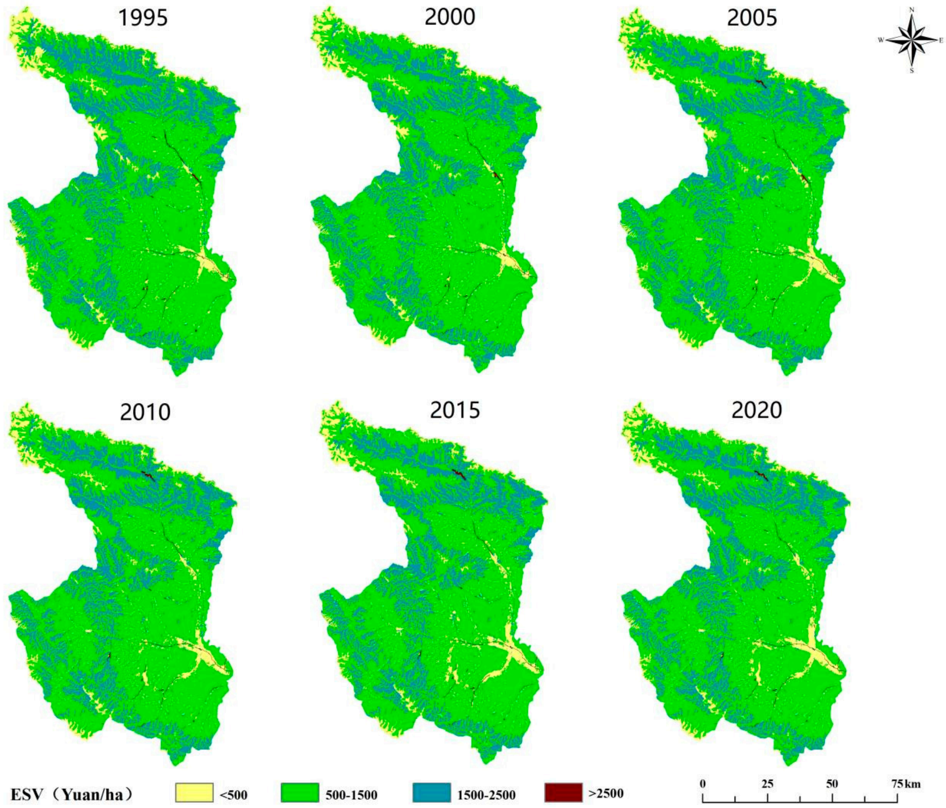

Figure 4. Spatial distribution of ecosystem service values in Xining from 1995 to 2020.

Table 11. Sensitivity index of ecosystem service values in Xining in 1995 and 2020.

Land Use Type	ESV (CNY 10,000) 1995	ESV (CNY 10,000) 2020	Sensitivity Coefficient 1995	Sensitivity Coefficient 2020	Change in Sensitivity Index
Cropland VC + 50%	11,583.57	10,901.09	0.1691	0.1632	0.0059
Cropland VC − 50%	3861.19	3633.70	0.1875	0.1810	0.0065
Forestland VC + 50%	64,002.33	60,141.50	0.8237	0.7938	0.0299
Forestland VC − 50%	21,334.11	20,047.17	0.9253	0.8917	0.0336
Grassland VC + 50%	51,253.22	53,661.12	0.6703	0.7198	0.0494
Grassland VC − 50%	17,084.41	17,887.04	0.7517	0.8071	0.0554
Water area VC + 50%	3242.03	3177.65	0.0580	0.0583	0.0003
Water area VC − 50%	1080.68	1059.22	0.0632	0.0635	0.0003
Construction land VC + 50%	−2162.84	−2915.91	0.0344	0.0476	0.0132
Construction land VC − 50%	−720.95	−971.97	0.0379	0.0523	0.0145
Unused land VC + 50%	432.09	355.95	0.0076	0.0064	0.0012

Note: VC denotes the ecosystem service value coefficient.

3.4. Resident Welfare Changes

The welfare of residents in Xining City has been increasing year by year (Figure 5), with the comprehensive evaluation index rising from 0.1626 in 1995 to 0.8040 in 2020, with the fastest growth occurring from 2015 to 2020. The comprehensive evaluation index of safety and health needs and psychological needs has been increasing significantly each year, while the basic needs evaluation index first declined (1995–2005) and then increased (2005–2020). The comprehensive level of resident welfare has increased annually, but the structure has changed.

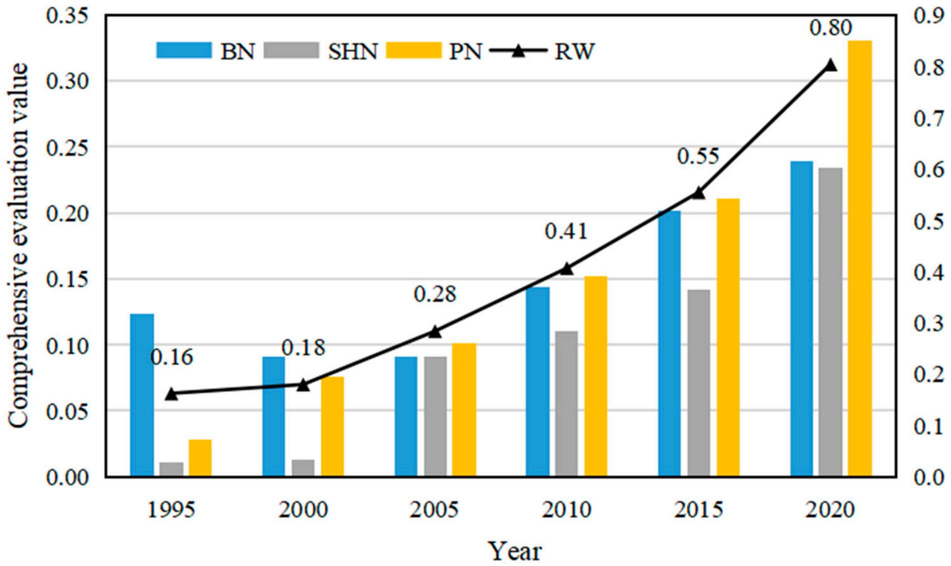

Figure 5. Time-varying changes in the comprehensive evaluation index of resident welfare in Xining City from 1995 to 2020. Note: BN—Basic Needs; SHN—Security and Health Needs; PN—Psychological Needs; RW—Resident Welfare.

3.5. Changes in the Coupling Relationship among Landscape Patterns, Ecosystem Services, and Resident Welfare

3.5.1. Coupling Coordination Degree

Overall, the coupling state of the three systems presents an inverted "U" development trend, with the coupling degree first increasing and then decreasing, and the development relationship of the three systems always in a mismatched state (Table 12). The coupling degree of the three systems in 1995 was 0.27, between 0 and 0.3, at a low-level coupling stage. Then, the adaptation phase began in 2000, starting to balance and cooperate, showing a benign coupling trend. In 2005, it peaked at 0.88, and from 2010 on, the three systems remained in a high-level coupling state, exhibiting a strong mutual influence relationship with strong correlation and driving effects. In 2015, the coupling degree decreased, returning to the adaptation phase until the coupling degree dropped to 0.13, and the three systems returned to the low-level coupling stage. From 1995 to 2020, the coupling coordination degree of landscape pattern, ESV (ecosystem service value), and human welfare in Xining City was in the range of (0.1, 0.4), and the overall development relationship of the three systems was not coordinated, with the three systems in a state of moderate mismatch from 1995 to 2000; mild mismatch from 2005 to 2015; and severe mismatch in 2020.

3.5.2. Relative Development Degree

Considering the uncoordinated development status of the three coupled systems, this study compares and discriminates the pairwise relative development degrees of landscape connectedness, ecosystem services, and resident welfare. We track the analysis of the dominant constraining factors in the overall development stage of Xining City from 1995 to 2020. The unbalanced development of the three systems has experienced a transformation from "resident welfare and landscape connectedness lagging" to "resident welfare and ecosystem services lagging" to "ecosystem services lagging" and finally to "ecosystem services and landscape connectedness lagging" (Table 13). From 1995 to 2000, the primary constraining factor in the uncoordinated coupling of the three systems was the lag in resident welfare. Until 2015–2020, the main constraining factor shifted from the lag in resident welfare to the lag in ecosystem services and landscape connectedness. The coupling of the three systems shows an inverted "U" relationship, and the development relationship has always been in an uncoordinated state. Analyzing the relative development degree reveals that the coordinated development type shifts from the early stage of resident welfare lagging to the later stage of ecosystem services and landscape connectedness lagging. This indicates that resident welfare, ecosystem services, and landscape connectedness are developing in opposite directions.

Table 12. Assessment of the coupling coordination development of landscape connectedness, ecosystem services, and resident welfare in Xining City from 1995 to 2020.

Year	Coupling Degree	Coupling Coordination Degree	Coupling Stage	Coupling Coordination State
1995	0.2770	0.2062	Low-level coupling	Moderate mismatch
2000	0.5401	0.2569	Adaptation phase	Moderate mismatch
2005	0.9584	0.3399	High-level coupling	Mild mismatch
2010	0.8180	0.3469	High-level coupling	Mild mismatch
2015	0.7677	0.3310	Adaptation phase	Mild mismatch
2020	0.1374	0.1421	Low-level coupling	Severe mismatch

Table 13. Comparison of the relative development of the coupling coordination of the three systems: landscape connectedness, ecosystem services, and resident welfare in Xining City from 1995 to 2020.

Year	HWLP	LPESV	HWESV	Development Type	Dominant Constraining Factors
1995	0.4614	0.3651	0.1685	Resident welfare lags behind landscape connectedness, and both lag behind ecosystem services	Resident welfare, landscape connectedness
2000	0.2954	1.6336	0.4826	Resident welfare is ahead of ecosystem services, and both lag behind landscape connectedness	Resident welfare, ecosystem services
2005	0.6246	1.2206	0.7624	Landscape connectedness and resident welfare develop synchronously, and both are ahead of ecosystem services	Ecosystem services
2010	0.6115	2.5237	1.5433	Landscape connectedness is ahead of ecosystem services, and both lag behind resident welfare and ecosystem services	Ecosystem services, landscape connectedness

Note: HWLP represents the relative development degree of resident welfare and landscape connectedness systems; LPESV represents the relative development degree of landscape connectedness and ecosystem service systems; and HWESV represents the relative development degree of resident welfare and ecosystem service systems.

3.6. Gray Relational Degree

The gray relational degrees of various landscape pattern indices with resident welfare range from 0.668 to 0.675 (Table 14). The correlation degree between the two falls within the range of (0.6, 0.85], indicating that the two systems are highly correlated. Among them, the largest patch index has the highest relational degree with resident welfare, with a gray relational degree of 0.675. The patch number and patch density also exhibit relatively high correlations. The gray relational degrees of various ecosystem service indices with resident welfare range from 0.670 to 0.718, indicating a high correlation level between the two systems. The highest correlation coefficient between water supply and resident welfare is 0.718. All ecosystem services in Xining City exhibit relatively high correlations with resident welfare. Among them, the top five services with a higher correlation to resident welfare are water supply, food production, environmental purification, biodiversity, and the provision of aesthetic landscape value.

Table 14. Gray relational degrees and ranking of landscape connectedness and ecosystem services with resident welfare in Xining City.

Landscape Patterns	Relational Degree	Ecosystem Services	Relational Degree	Ecosystem Services	Relational Degree
Patch Number (C1)	0.674	Food Production (Y1)	0.670	Soil Conservation (Y8)	0.670
Patch Density (C2)	0.674	Raw Material Production (Y2)	0.670	Maintaining Nutrient Cycling (Y9)	0.670
Largest Patch Index (C3)	0.675	Water Supply (Y3)	0.718	Biodiversity (Y10)	0.671
Edge Density (C4)	0.669	Gas Regulation (Y4)	0.670	Aesthetic Landscape (Y11)	0.670
Landscape Shape Index (C5)	0.669	Climate Regulation (Y5)	0.670		
Shannon Diversity Index (C6)	0.668	Environmental Purification (Y6)	0.672		
Aggregation Index (C7)	0.672	Hydrological Regulation (Y7)	0.670		

4. Discussion

4.1. Drivers of Landscape Connectedness, ESV, and Resident Welfare Change

The objective of this study was to reveal the interaction coupling mechanisms between landscape connectedness, ESV, and resident welfare and that changes in landscape structure and ecosystem service value are closely related to land-use changes. Ecosystem services are essential sources of various material products and services for humans, contributing to overall well-being [69,82]. However, many human activities exceed the carrying capacity of the natural environment, negatively impacting regional ecology and sustainable development. Excessive agricultural production, mining, and construction activities, for example, have increased the complexity and discontinuity of natural landscapes [83]. This has led to landscape fragmentation and the continuous degradation of ecosystem services [84]. Human activities can alter landscape structure through land-use changes, which in turn affect ecosystem structure and function [85], ultimately influencing the ability of ecosystems to provide services [32].

This paper reveals that changes in landscape connectedness and ecosystem service value have important impacts on changes in resident welfare, mainly through land-use change. We quantified the changes in land-use types in Xining City and observed significant land-use changes during the study period. In terms of land-use transitions, grasslands have been the primary land-use type, but the area of grasslands continues to increase, especially between 1995 and 2000. The increase in grasslands is predominantly due to the conversion of forests (approximately 2/3 of the increase), which decreased by 102.94 ha^2 during the five years, and 1/3 from unused land. After 2000, the amount of cultivated land decreased, with agricultural land being converted to construction land, leading to the partial development of unused land. Between 1995 and 2000, the total value of ecosystem services decreased significantly, with hydrological and climate regulation abilities decreasing the fastest, while other services experienced varying degrees of reduction. This suggests that the ecosystem services of grasslands are far lower than those of forests. The decrease in forest area and the expansion of grasslands have severely damaged the structure of ecosystems and reduced the overall value of ecosystem services. This could be a possible reason for the decline in water resource supply and food production services between 2000 and 2020, as individual ecosystem services interact with each other [86,87]. In general, the early phase saw large areas of high-ecosystem-value forests being transformed into grasslands with slightly lower values, and the impact on ecosystem services cannot be ignored. In the later period, some agricultural land was converted to construction land, negatively affecting the value of ecosystem services. This can also be confirmed in the “M” shape change trend of landscape structure. Before 2000, it was mainly the expansion of grassland and the intensification of human activities that caused the instability and fragmentation of the landscape structure. The overall level of landscape connectedness has declined. After the implementation of the Western Development Strategy in 2000, development became orderly, urbanization reached a certain stage, disturbance decreased, and human activity patches gradually aggregated. The landscape fragmentation weakened, and anthropogenic interference with the overall connectivity of Xining’s landscape structure improved. Consequently, land use change and increasing human activities have a significant correlation with the unstable and fragmented landscape structure [57].

4.2. Coupling State and Factors of Landscape Connectedness, ESV, and Resident Welfare

Based on the coupling coordination model results, the coupling state of the three systems is in a constant state of fluctuation. The early period (1995–2000) exhibited good landscape structure, high connectivity and integrity of patches, high ecosystem service values, low urbanization levels, and generally low resident welfare, with the three systems being in a moderately unbalanced state. During the mid-term (2005–2015), with urgent urban development and increasing resident welfare, landscape connectedness gradually fragmented. However, human activities had a generally improved impact on the landscape structure of Xining City, resulting in mild damage to landscape connectedness and ecosystem structures, with a slight unbalance in the development relationship among the three systems. In the later period (2015–2020), resident welfare experienced significant development, landscape structure underwent substantial changes, dominant patch agglomerations became more apparent, and patch fragmentation and heterogeneity stabilized. Some scholars have argued that landscape structure directly affects ESV and the level of human well-being, leading to an imbalance in the structure of ESV and abnormal development in the structure of resident welfare [88]. Meanwhile, the value of ecosystem services continued to decline, causing the three systems to diverge and even shift to a severely unbalanced state. At the same time, the relative development of the three systems revealed a shift from lagging resident welfare in the early period to lagging ecosystem services and landscape connectedness in the later period, suggesting that resident welfare is moving in the opposite direction from ecosystem services and landscape connectedness. The decline in ecosystem service values negatively impacts resident welfare, and the negative effect caused by the two has far exceeded the positive effect brought by improvements to resident welfare [45].

This study reveals a high correlation between landscape structure and the well-being of residents. Among them, the maximum patch index has the highest correlation with resident well-being, followed by patch number and patch density. Patch number and density have always been the primary factors influencing landscape structure in the process of human-land interaction [89]. The maximum patch index within the landscape pattern indices is a key coupling mechanism factor because forestland has been converted to grassland on a large scale, and cultivated and unused land has been occupied by construction land. Grassland is an essential means of production and production site for the majority of farmers and herders, while the expansion of construction land is an inevitable outcome of urban development. Patches of grassland and construction land types form dominant patches as regional agglomeration degrees increase. At this point, the most advantageous patches tend to highlight their influence, becoming the key factors in coupling. The ecosystem service of water resource supply has the highest correlation with local resident well-being, making it a key coupling impact factor. The prominence of water resource supply among the 11 ecosystem services is closely related to the intensifying contradiction between local water supply and demand, which also reflects the urgent need for improvements in ecological and environmental conditions [90]. Ecosystems provide essential materials for human survival and ensure the operation of human systems [91]. Water is a crucial habitat element for the ecology of the northwestern region, and it is imperative to ensure the amount of water needed to restore and maintain the healthy development of ecosystems [92]. Water resource supply plays a vital role in the stable functioning of other ecosystem services and various ecological environment constructions. Moreover, this study concludes that all ecosystem services have a high correlation with residents' well-being, which is consistent with previous research findings [93].

4.3. Limitations and Implications

This study has certain limitations and can provide a reference for future research. First of all, the description of landscape patterns can be further deepened, and the comprehensive evaluation system of landscape connectedness can be improved. This paper mainly quantifies the change rule of landscape pattern on a macroscale without exploring the internal relationship of ecological indicators. Secondly, it is necessary to improve the comprehensive evaluation index system of residents' welfare to fully reflect the richness and complexity of residents' welfare. The main goal of this study is to evaluate the residents' welfare in the whole region, so we chose the objective indicator evaluation method. The objective indicator evaluation method can quantify and compare residents' welfare at the same time, but it is prone to conceptual absolutism [94]. Traditional factors such as income, material, and spiritual life can be the core drivers of welfare [95], but to avoid the paradox of happiness, we need to refine the meaning and assessment methods of welfare in a more comprehensive and hierarchical way [96]. However, some appropriate social surveys can make the research results more valuable for reference. In the future, social surveys covering happiness levels could be conducted in order to provide a more accurate assessment of residents' well-being. Finally, modern research demonstrates that ecosystem services are the basis for human survival and contemporary civilization, and maintaining ecosystem services is the foundation for sustainable development [97]. Future research can also further reveal the driving mechanism of the coupling of the three by conducting qualitative and quantitative studies of land ecosystem processes and human activity simulations.

In order to quantify the coupling relationship of the system, many research methods and models are used in this paper. Landscape connectedness changes are characterized by landscape pattern indices, ecosystem service changes by value indices, and residents' well-being changes by comprehensive evaluation indices. To investigate the coupled and coordinated states among the three, a coupling coordination model is adopted. Furthermore, the relative development degree model is employed to reveal the relative developmental level of the three, clarify the lagging factors in their coupling coordination, and identify key factors affecting the coupling mechanism through the gray relational model. In terms of research methods, we have carried out a relatively complete research analysis, and this quantitative method will make the correlation between the three more clear.

For decades, grassland has been the primary source of income for residents in Xining City, and promoting local economic development through the livestock industry is essential [38]. In this process, rural towns tend to agglomerate, and human activities have some impact on the landscape structure. Both the spatial expansion of urban growth and the ecological process of landscape change are self-organizing processes, but they can have a significant impact on the course of the system through different development policies and land use control strategies [98]. On the basis of the coupling and coordination relationships and the relative degrees of development among the three systems of landscape connectedness, ecosystem service value, and residents' welfare, we analyzed the main influencing factors of the association-coupling model, which can be used in land use planning by considering ecological protection planning control. At the same time, relying on the concept of sustainable development, the corresponding flexible control and development strategies could be formulated [99].

According to the previous analysis, under the original development pattern of the city, the well-being of the residents may improve for a period of time, but to a rather limited extent. The continuous expansion of construction land and grassland promotes the growth of human activity patches, and the functional demand and value solution for ecosystem services will continue to rise [100]. The shrinking of ecological function patches such as forests and watersheds adversely affects the connectedness of the landscape structure, which in turn affects the flow of ecosystem services and information, and the goods and services provided by ecosystem services become rather limited to meet the relative level of development of the population's well-being. In the future, the polarization between human activities and the ecological environment will become more and more serious, which is not conducive to sustainable development. By carrying out ecological protection in time for the trend of ecosystem service degradation in Xining City over the past 25 years in accordance with the principle of ecological prioritization and prevention, the government could intervene with ecological measures on the lagging landscape structure from the perspective of land use. For example, in this study, grassland, as a relatively concentrated landscape patch occupying a large area, has a greater impact on the ecological landscape structure and ecosystem service function in terms of its change and expansion trend. At the same time, livestock land and water areas play an important role in the local socio-economic ecosystem and the well-being of the residents. Therefore, close attention to, observation, and monitoring of the more connected and ecologically important patch types has become a high priority in the field of ecological and landscape planning. In this scenario, the promotion of forest and grass cultivation to increase the forest area, protect wetlands and water bodies, and avoid excessive encroachment of grasslands into the forest area can prevent further reduction of the forest area. Secondly, the orderly implementation of forest closure and grassland cultivation and the formulation of reasonable ecological compensation standards will help prevent the instability of ecosystem services and landscape structure from negatively affecting the well-being of the population, rectify the continued imbalance in the development relationships between the three systems, and ensure the stable functioning of ecosystem services, contributing to the happiness and ecological security of resident welfare in a more abundant and lasting way.

5. Conclusions

This study evaluates landscape connectedness, ecosystem service value, and residents' well-being quantitatively through comprehensive analysis and mainly uses the coupling coordination model and relative development degree model to reveal the coupled development relationship between landscape connectedness, ecosystem services, and residents' well-being in Xining City from 1995 to 2020. The results show that:

The development trend of landscape types was moving toward diversification and balance, and the total value of ecosystem services has been declining. The comprehensive level of resident welfare has increased annually, but the structure has changed.

The coupling relationship among landscape connectedness, ecosystem service value, and resident welfare is strong and has remained at a high correlation level but has been in a state of discord.

The main constraint of the discord in the early stage was resident welfare, but the constraining factors in the later stage shifted to ecosystem services and landscape connectedness. The largest patch index and water resource supply were the key influencing factors in the system coupling mechanism.

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