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Research on the Coupling Co-ordination between Quality of County-Level New Urbanization and Ecosystem Service Value in Shaanxi Province

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Abstract: Rapid urbanization has significantly impacted the structure of ecosystem services, accelerating the pressure on natural resources and ecological space. The clarification of the interdependent relationship between new-type urbanization (NTU) and ecosystem services (ESs) has contributed to ecological conservation and high-quality co-ordinated development, in contrast to traditional urbanization. This study focuses on the counties in Shaanxi Province as the research subjects, develops a new urbanization evaluation model for county-level areas, and utilizes Section data at the county level in Shaanxi Province for the years 2000, 2010, and 2020. (To analyze land cover change, we selected four data periods: 1990, 2000, 2010, and 2020, to capture significant spatial trends.) This study employed the comparative analysis method and the Coupled Co-ordination Model (CCDM) to assess the correlation between traditional urbanization and the value of ecosystem services, as well as between new urbanization and the value of ecosystem services. Additionally, the study utilizes the ArcGIS platform to analyze the spatiotemporal characteristics of the two types of urbanization evolution and the spatiotemporal relationship between urbanization and ecosystem co-ordination. The study findings suggest the following: (1) a "low-level coordination" coupling relationship exists between traditional and new urbanization in county-level areas of Shaanxi Province and the value of ecosystem services. (2) The coupling co-ordination of traditional and new urbanization with the value of ecosystem services shows a spread of low-value areas in space, leading to a pattern of low disorder assimilation and significant spatial aggregation. (3) From 2000 to 2020, traditional and new urbanization in various counties of Shaanxi Province consistently exhibited a steady increase, with spatial patterns of "Guanzhong region > Northern Shaanxi region > Southern Shaanxi region". Both types of urbanization have displayed a "low-level coupling" with ecosystem services. (4) During the same period, the new urbanization index in different counties of Shaanxi Province showed a steady increase, demonstrating an advantage of Guanzhong. Its impact on the ecosystem was significantly weaker than that of traditional urbanization. (5) The development of new urbanization can be more effectively co-ordinated with ecosystem services compared to traditional urbanization. However, currently, its co-ordination with the ecosystem service system is relatively poor. The study's results suggest that enhancing new urbanization from multiple dimensions is beneficial for promoting the integrated coherence between urbanization development and ecosystem service systems.

Keywords: county area; new urbanization; ecosystem service value; coupled co-ordination

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1. Introduction

The harmonious coexistence of humans and the environment is the central objective pursued throughout the development of human society [1–8]. The rapid expansion of urbanization has intensified the strain on natural resources and ecological space, posing significant threats to the sustainable development of urban ecosystems and urbanization [9–11].

In China, urbanization has experienced rapid progress, accompanied by swift development in both urban and rural economies. Projections indicate that China's urbanization rate will reach 70–75% by 2030, which will pose a series of substantial challenges [12,13]. Co-ordinating the sustainable development of urbanization and the ecosystem becomes an utmost priority.

Therefore, China has introduced a new approach to urbanization construction. This new model places emphasis on people-centered development, prioritizes ecological environment protection, and strives for sustainable development throughout the urbanization process [14–18]. The present state of new urbanization construction and the co-ordinated development between new urbanization and ecosystems have emerged as prominent areas of research [19–22].

This study investigates the status, development, assessment, and modeling of ecosystem environments in the context of new urbanization. Western countries have made significant contributions in terms of fundamental theoretical research, beginning with early theories such as the Garden City theory proposed by Robert Owen and Ebenezer Howard. Subsequent models, including Berger's "pressure-state-response" model [23], the Environmental Kuznets Curve, and the "decoupling" theory [24,25], have investigated the interplay between urbanization processes and the ecological environment. Subsequently, Jiang et al. proposed the theory of the "social-economic-natural" composite ecosystem [26–29], which holds valuable reference value for the subsequent development of urbanization and ecosystems. Building on the foundation of theoretical research, scholars have conducted empirical studies on the coupling between urbanization and ecosystems in countries such as the United States, Pakistan, South Korea, and China [30–34], providing empirical evidence of the intricate interactions between ecosystems and urbanization systems [16,19,35–37]. There is a significant body of research exploring the interrelationship between urbanization and ecosystem services. The primary studies can be categorized into three areas: (1) the impact of urban land expansion on ecosystems, with a particular focus on land use changes and spatial patterns of urbanization. For instance, Seto, K. et al. conducted a study examining the direct impact of urban expansion on biodiversity and carbon stocks [7,38–41]. (2) Trade-offs, interactions, and assessment of ecosystem services. Additionally, several related studies have explored the modeling framework and assessment of ecosystem service values [42–45]. (3) The interaction between human activities and ecosystems involves examining the impact of urbanization on ecosystems, as well as exploring methods for incorporating ecological principles into future urban planning and management [34,40,45].

Overall, the academic community has made considerable progress in studying the relationship between urbanization and ecosystems. Furthermore, researchers have expanded their research focus from studying the "human-land relationship" to examining "coupled human and natural systems" (CHANS). The research methodology has also evolved, incorporating coupling indexes, magic squares, loops, and couplers. Moreover, pioneering explorations have been conducted. However, certain shortcomings persist: (1) research tends to focus on national or urban agglomeration scales [37,46], neglecting the county level to some extent; (2) existing empirical studies primarily concentrate on individual examinations of urbanization or new urbanization's impact on ecosystems, lacking comparative research on the co-ordinated coupling of traditional urbanization and new urbanization with ecosystems. Based on the previous literature, this paper starts from the research level of counties and compares the interrelationships between traditional urbanization, new urbanization, and ecosystems, respectively, using the Coupled Co-ordination Degree Model (CCDM).

Located in the northwest part of China within the Yellow River Basin, Shaanxi province serves as the core region for the Western Development strategy, benefiting from its abundant natural resources and cultural landscapes. The current urbanization rate in Shaanxi has surpassed 60%. Nevertheless, the extensive expansion of urbanization, large-scale urban construction, and land expansion have led to land resource wastage and several environmental concerns, including soil erosion, soil and water loss, and a decline in biodiversity.

The continuous increase in the urban population has further strained water resources and energy demands. Therefore, it is crucial to comprehend the current state of new urbanization construction, as well as the interplay between urbanization and ecosystems, in the counties and districts of Shaanxi Province. This understanding is vital for the development of counties and the protection of the ecological environment.

In this context, the co-ordinated development between new urbanization and ecosystem service value at the county level in Shaanxi Province holds substantial implications for urbanization construction. Therefore, this study employs panel data at the county level in Shaanxi Province from 2000, 2010, and 2020 to construct an assessment model for county-level new urbanization. The model is used to evaluate the development of new urbanization in Shaanxi Province from 2000 to 2020. Using the principle of system coupling co-ordination, the ArcGIS platform is utilized to analyze the evolutionary characteristics and spatial aggregation of the coupling co-ordination among the subsystems of new urbanization, traditional urbanization, and the ecosystem service value.

2. Materials and Methods

2.1. Study Area

Shaanxi Province, located in the northwest of China, is bordered by Shanxi and Henan to the east, Ningxia and Gansu to the west, Sichuan, Chongqing, and Hubei to the south, and Inner Mongolia to the north. It is located between 105°29′ E and 111°15′ E longitude and 31°42′ N and 39°35′ N latitude, covering a total area of 205,624.3 square kilometers. The region features a narrow and elongated terrain, with higher elevations in the north and south and lower elevations in the middle. It encompasses diverse landforms, including plateaus, mountains, and basins.

Shaanxi Province, located in the northwest of China, is divided administratively into 10 prefecture-level cities, 30 districts, 5 county-level cities, and 72 counties (refer to the Figure 1). As of the end of 2022, the permanent resident population of Shaanxi Province reached 39.56 million, increasing by 20,000 compared to the previous year. The level and quality of urbanization in Shaanxi Province have steadily improved, with the urbanization rate of the permanent resident population reaching 64.02%. Geographically, Shaanxi Province can be divided into three regions: the northern Shaanxi Loess Plateau, the central Guanzhong Plain, and the southern Shaanxi Qinba Mountainous Area. The northern Shaanxi Loess Plateau is characterized by grasslands and arable land, supporting a well-developed economy based on abundant mineral resources. The Guanzhong Plain is a flat platform dominated by arable land and construction land, serving as a significant economic hub in Shaanxi Province. The southern Shaanxi region mainly consists of hilly and mountainous areas, with the majority of land being forests. Due to its geographical location and terrain, this region exhibits a relatively low level of economic development.

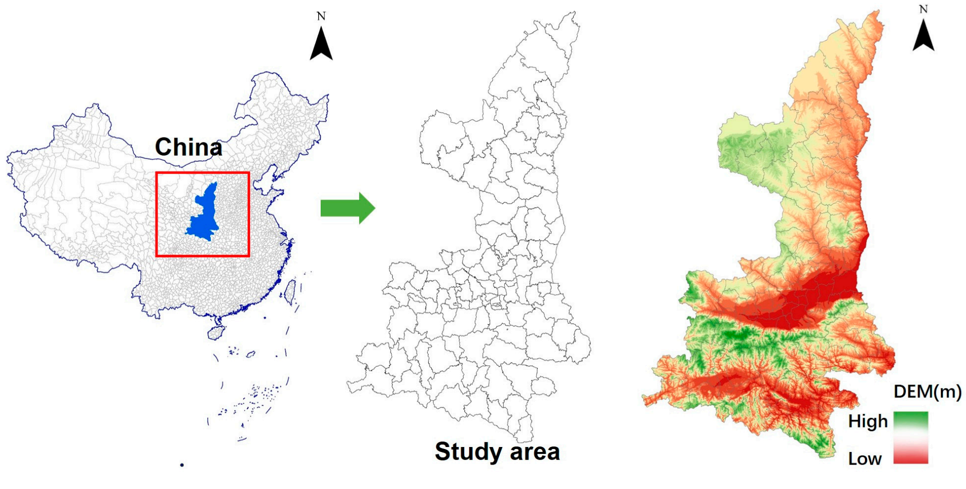


Figure 1. The study area. (The red square is the index of the Shaanxi province on the right).

2.2. Data Resource

This study utilizes various data sources, including remote sensing, terrain, and socio-economic data. The land use data (1990–2020, 30 × 30 m), population density, and GDP spatial distribution dataset were acquired from the Resource and Data Cloud Platform. The majority of socio-economic data are obtained from the Statistical Yearbooks of different counties within Shaanxi Province. The study utilizes DMSP/OLS data, sourced from the NOAA website, to represent the stable annual grid impact of nighttime lights. The data are denoised and calibrated before being utilized for research purposes. The table below displays the specific data sources (Table 1).

Table 1. Data and relevant sources used for the valuation of ecosystem services and the quality assessment of new urbanization.

Data	Type	Source	Note
Land use map	Raster	Resource and Environment Science and Data Center (https://www.resdc.cn/, accessed on 10 August 2023). (30-m resolution)	resolution is 30 × 30
Population and GDP	Number	Shaanxi Statistical Yearbook (2000–2020); Seventh National Population Census	-
Population density and GDP spatial distribution datasets	Raster	resource and Environment Data Cloud Platform (http://www.resdc.cn/, accessed on 10 August 2023);	resolution is 30 × 30
Shaanxi Province PM2.5 dataset	Shape file	Shaanxi Province Department of Ecology and Environment (http://sthjt.shaanxi.gov.cn/, accessed on 10 August 2023); https://sites.wustl.edu/acag/datasets/surface-pm2%E2%80%935/#V5.GL.02, accessed on 10 August 2023	resolution is 30 × 30
Nighttime Lighting Dataset for Districts and Counties in Shaanxi Province	Raster	NOAA website (www.ngdc.naoo.gov, accessed on 15 August 2023); Geographic Data Sharing Infrastructure, global resources data cloud (www.gis5g.com, accessed on 15 August 2023)	resolution is 30 × 30

2.3. Research Framework

This study first assesses the quality of traditional urbanization and the value of ecosystem services in different counties of Shaanxi Province from 2000 to 2020. It then examines the spatiotemporal variations in traditional urbanization and the value of ecosystem services during the research period, followed by conducting a co-ordinated analysis between traditional urbanization and the ecosystem. Subsequently, within the framework of new urbanization, a novel evaluation system for assessing the quality of new urbanization in each county of Shaanxi Province is developed. The results of new urbanization at the county level are then analyzed in conjunction with the value of ecosystem services to investigate their co-ordination. A comparative analysis is performed to assess the development of both traditional and new urbanization, as well as explore the interrelationship between the two and the value of ecosystem services. Finally, conclusions are formulated (Figure 2).

2.4. Evaluation of Traditional Urbanization and Construction of Evaluation Index System for New Urbanization Quality

Urbanization is a multifaceted process that involves population, economy, space, society, and land use [47–51]. However, traditional urbanization primarily focuses on population migration and the proportion of urban residents. Therefore, in this study, the traditional urbanization rate F_i is defined as:

$$F_i = \frac{P_{\text{city}}}{P} \tag{1}$$

The term P_{city} refers to the total urban population in the study area, while P represents the total population in the region.

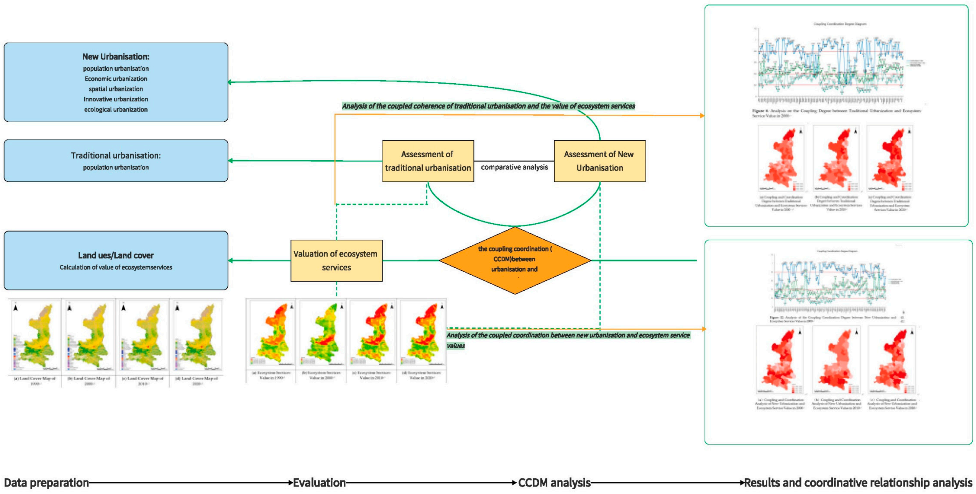


Figure 2. A framework diagram of ideas for analyzing the coupled co-ordination of the quality of new urbanization and the value of ecosystem services.

The concept of "New Urbanization" is proposed as an extension of the urbanization concept. Based on previous definitions of new urbanization [52–57], this paper develops an evaluation system comprising 20 indicators across five dimensions: population urbanization, economic urbanization, spatial urbanization, innovation urbanization, and ecological urbanization (refer to the Table 2). By utilizing panel data at the county level, this paper standardizes multiple indicators and applies a dynamic spatial panel model combined with the entropy method to determine the weights of the evaluation indicators for assessing the quality of new urbanization. Empirical research is conducted on new urbanization in different counties of Shaanxi Province.

Table 2. Table of quality evaluation indicator system for new urbanization.

Target Layers	Dimension	Indicator Layer	Indicator Attributes	Weights (%)
Evaluation of the quality of new urbanization	population urbanization	Total population at the end of the year	+	1.593
		population of cities and towns	+	4.497
		densitization of the population	+	11.193
		Number of people with high school education and above	+	3.801
		Percentage of urban population	+	2.726
		Urban population density	+	9.737
	Economic urbanization	Total social consumption	+	2.869
		Share of value added in secondary and tertiary industries	+	1.314
		Secondary and tertiary value added	+	4.671
		GDP per capita	+	5.119
		GDP	+	6.092
		Percentage of population in secondary and tertiary sectors	+	1.397
		Night time light index	+	3.702
	spatial urbanization	Percentage of built-up land	+	7.845
		Housing area per capita	+	8.206
		Built-up area	+	2.446
	Innovative urbanization	Number of national patent applications	+	18.188
	ecological urbanization	Ecological land area	+	3.211
		Percentage of ecological land	+	1.079
		PM2.5	-	0.336

2.5. Calculation of Value of Ecosystem Services

The value of ecosystem services corresponds to the products obtained directly or indirectly from ecosystem functions. Costanza et al. (1997) evaluated the global ecosystem service value (ESV) using the equivalence factor method [44,58]. Since then, numerous scholars have employed various methods to assess the value of ecosystem services [59–62]. Among these methods, the equivalence factor method is widely used due to its simplicity and scientifically calculated results. This study builds upon the research of Xie Gaodi et al. [44] and modifies the ESV by incorporating the Normalized Difference Vegetation Index (NDVI), drawing upon the methods of Geng Tianwei et al. [63,64]. The equivalent values of ecosystem services in the counties of Shaanxi Province are obtained (as shown in the Table 3), followed by the application of the equivalent factor method to calculate the service value of county-level ecosystems in Shaanxi Province using panel data. Furthermore, GIS tools are utilized to calculate ecosystem service values at the raster level.

$$\mathrm{ESV} = \sum_{k=1}^{6} A_k \times C_k \quad \mathrm{k} = 1, 2, \ldots, 6$$

The term "ESV" stands for ecosystem service value, A_k represents the area of the kth land class, and C_k represents the coefficient for adjusted ecological value of the kth land class. The table below presents the specific calculation equivalents for the adjusted ecosystem service value in Shaanxi Province.

Table 3. Calculation of the equivalent value of ecosystem services for various land-use types in Shaanxi Province [63].

Classification	Gas Regulation	Climate Regulation	Water Conservation	Soil Formation and Conservation	Waste Disposal	Biodiversity Conservation	Food Production	Value of Raw Materials	Entertainment and Cultural Value	Sum
arable land	225.6	401.6	270.8	658.9	740.1	320.4	451.3	45.1	4.5	3118.3
forest land	1579.5	1218.4	1444.1	1760.0	591.21	1471.1	45.1	1173.3	577.6	9860.3
Grassland	361.0	406.2	361.0	880.0	591.2	491.9	135.4	22.5	18.1	3267.3
Water	0	207.6	9196.9	4.5	8204.2	1123.7	45.1	4.5	1958.5	20,745
Urban and rural industrial, mining, and residential land	0	0	0	0	0	0	0	0	0	0
Unused land	0	0	13.5	9	4.5	153.4	4.5	0	4.5	189.4
Ocean	0	207.6	9196.9	4.5	8204.2	1123.7	45.1	4.5	1958.5	20,745

2.6. Evaluation of the Coupled Co-ordination between Urbanization Level and the Value of Ecosystem Services

This study adopts the concept of coupling from physics to evaluate the interactions and impacts between the new urbanization system and the traditional urbanization system with the ecosystem, as coupling refers to the phenomenon where two or more systems achieve co-ordinated consistency through mutual interactions [65,66]. The specific calculation formula is as follows:

$$C = \{Y_1 \times Y_2 / [(Y_1 + Y_2) \times (Y_1 + Y_2)]\}^{1/2} \tag{2}$$

Among them, C represents the coupling degree between the quality of new urbanization and the value of ecosystem services, with a value ranging from 0 to 1. A higher value indicates a better positive resonance between the two systems; Y_1 represents the quality of new urbanization and Y_1 represents the value of ecosystem services.

The co-ordination degree is a metric that evaluates the level of co-ordination among internal elements within two or more systems, aiming to determine if the coupling between systems is favorable. This paper integrates the co-ordination degree with the coupling degree and proposes an objective model to accurately depict the level of co-ordinated development between the "new urbanization" system and the "ecosystem services" system. The model is presented as follows:

$$D = \sqrt{C \times T}, T = \alpha Y_1 + \beta Y_2 \tag{3}$$

D represents the co-ordination degree, T represents the comprehensive co-ordination index, α and β are undetermined coefficients, and their sum equals 1. In this study, the ecosystem and the new urbanization system are regarded as mutually influential and equally significant; hence, $\alpha = \beta = 0.5$ in the formula. Drawing on pertinent studies [67,68], a higher co-ordination degree indicates better co-ordination. Specifically, the co-ordination degree is categorized into nine levels(refer to the Table 4).

Table 4. Correspondence table for coupling co-ordination results [69].

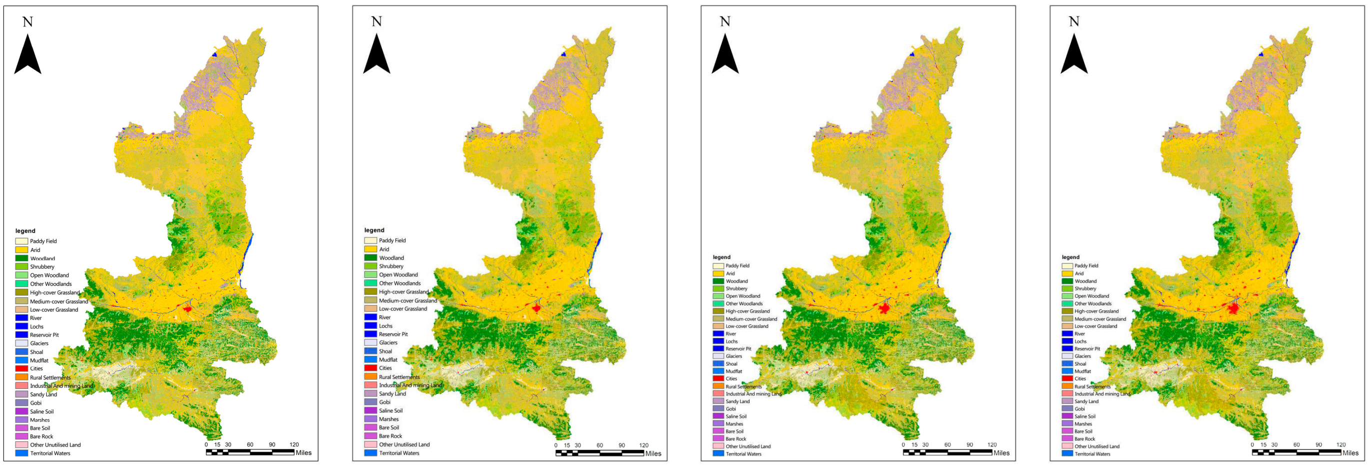
	$0 \leq D \leq 0.2$	$0.2 \leq D \leq 0.3$	$0.3 \leq D \leq 0.4$	$0.4 \leq D \leq 0.5$	$0 \leq D \leq 0.2$	$0.5 \leq D \leq 0.6$	$0.6 \leq D \leq 0.7$	$0.7 \leq D \leq 0.8$	$0.8 \leq D \leq 0.9$
degree of co-ordination	severe disorder	Moderate disorder	Mild disorder	On the verge of becoming dysfunctional	Barely co-ordinated	Elementary co-ordination	Intermediate co-ordination	Good co-ordination	Quality co-ordination

3. Results

3.1. Analysis of Ecosystem Service Valuation Results

3.1.1. The Analysis of Land Use Change

From 1990 to 2020, the study area had the highest proportions of grassland, cultivated land, and forestland, accounting for 94.93%, 95.38%, and 94.42%, respectively. Unused land and construction land had the lowest proportions. In terms of spatial distribution, grassland was mainly distributed in southern and northern Shaanxi. Forestland was primarily found in the southern foothills of the Qinling Mountains, as well as the Ziwuling and Huanglong Mountains in northern Shaanxi. Cultivated land was predominantly located in the Guanzhong Plain, while construction land was mainly concentrated in the Guanzhong region represented by Xi'an. During the study period, land use in Shaanxi Province exhibited an increasing trend. Grassland, forestland, construction land, and water bodies all experienced growth. Construction land had the highest growth rate, expanding from 2762.4429 km² in 1990 to 5280.81 km^2 in 2020. The Guanzhong Plain region saw the most significant increase in construction land (as shown in the Figure 3).



(**a**) (**b**) (**c**) (**d**)

Figure 3. Land cover maps from 1990 to 2020. (**a**) Land Cover Map of 1990. (**b**) Land Cover Map of 2000. (**c**) Land Cover Map of 2010. (**d**) Land Cover Map of 2020.

The largest reduction in land during the period from 1990 to 2020 occurred in cultivated land, which decreased from 71,668.69 km² to 66,733.07 km², representing a decrease of

2.41%. This reduction can be attributed to the urbanization trend during this period, which has led to inefficient land utilization and wastage of resources. For instance, an analysis of urbanization and ecological restoration from 2000 to 2010 reveals the following changes: a 1.04% increase in grassland, a 2.18% decrease in cultivated land, a 0.79% increase in forest land, and a 0.40% increase in construction land. These figures demonstrate the gradual effectiveness of ecological restoration efforts during this period. However, it is important to note that the rapid pace of urban development has also contributed to these trends.

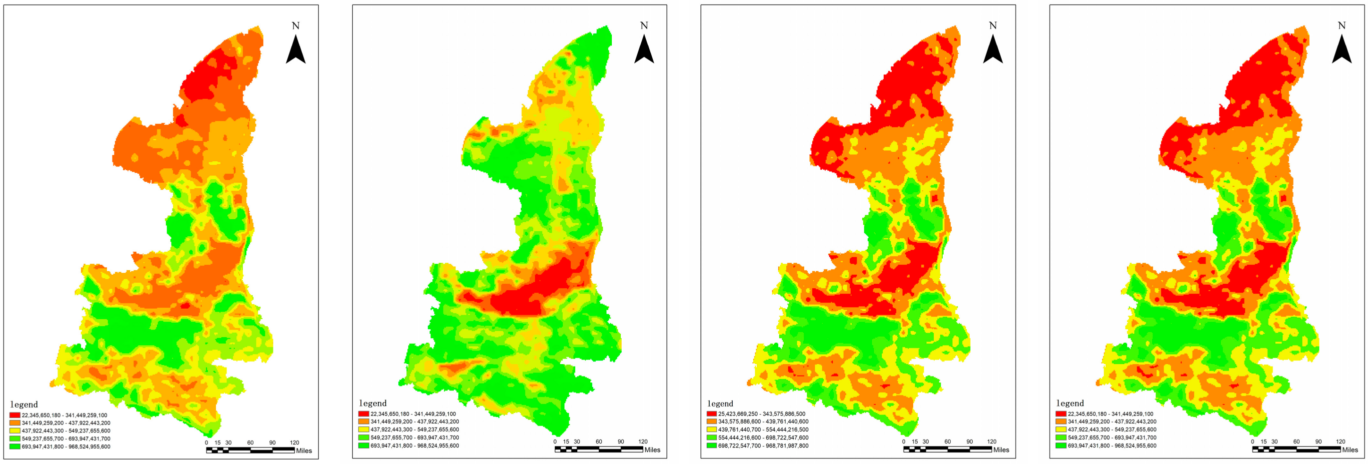
3.1.2. The Evaluation of Ecosystem Services Value

The total ecosystem service value (ESV) of Shaanxi Province was calculated for four periods from 1990 to 2020 using the research method described above. The ESV in Shaanxi Province exhibited an overall increasing trend, with a 1.04% growth rate from 1990 to 2020. During the period from 1990 to 2000, the ESV of Shaanxi Province experienced a 0.35% increase. The most significant increase was observed between 2000 and 2010, with a growth rate of 1.04%. From 2010 to 2020, the ESV of Shaanxi Province declined by 0.35%.

The spatial distribution pattern of ecosystem service value (ESV) in Shaanxi Province, as depicted in the figure, demonstrates a relatively stable multi-center distribution pattern characterized by lower values in the north and higher values in the south (as shown in the Figure 4). This pattern can be attributed to the unfavorable natural conditions and significant land desertification issues in northern Shaanxi, whereas the southern region of Shaanxi is characterized by abundant forest land, high vegetation coverage, and a greater ecosystem service value. Specifically, the low-value areas are concentrated in the urban agglomeration of the Guanzhong Plain centered on Xi'an, the transitional region with wind and sand in northern Shaanxi encompassing Yuyang District and Dingbian County, and the county-level agglomeration in the Han River Basin of southern Shaanxi consisting primarily of Chenggu County and Hanyin County. The high-value areas are primarily located in the central region of the Loess Plateau in northern Shaanxi, encompassing Baota District, Yichuan County, Fuxian County, Huangling County, the Qinling Mountains region consisting mainly of Feng County and Taibai County, and the county-level agglomeration in the Daba Mountains in the south, mainly comprising Zhenba County and Ziyang County. Regarding the evolution of the spatial pattern, the spatial distribution of ecosystem service value experienced a reverse evolution trend during the periods of 1990–2000 and 2000–2010, with the most significant changes observed. However, since 2010, the spatial pattern has reached a relatively stable state. More specifically, the northern Shaanxi region centered around Yulin City and the county-level agglomeration in the Daba Mountains with Hanzhong City and Ankang City as the regional cores experienced the most significant changes in ecosystem service value, displaying a "low-high-low" evolution trend.

3.2. The Analysis of Traditional Urbanization

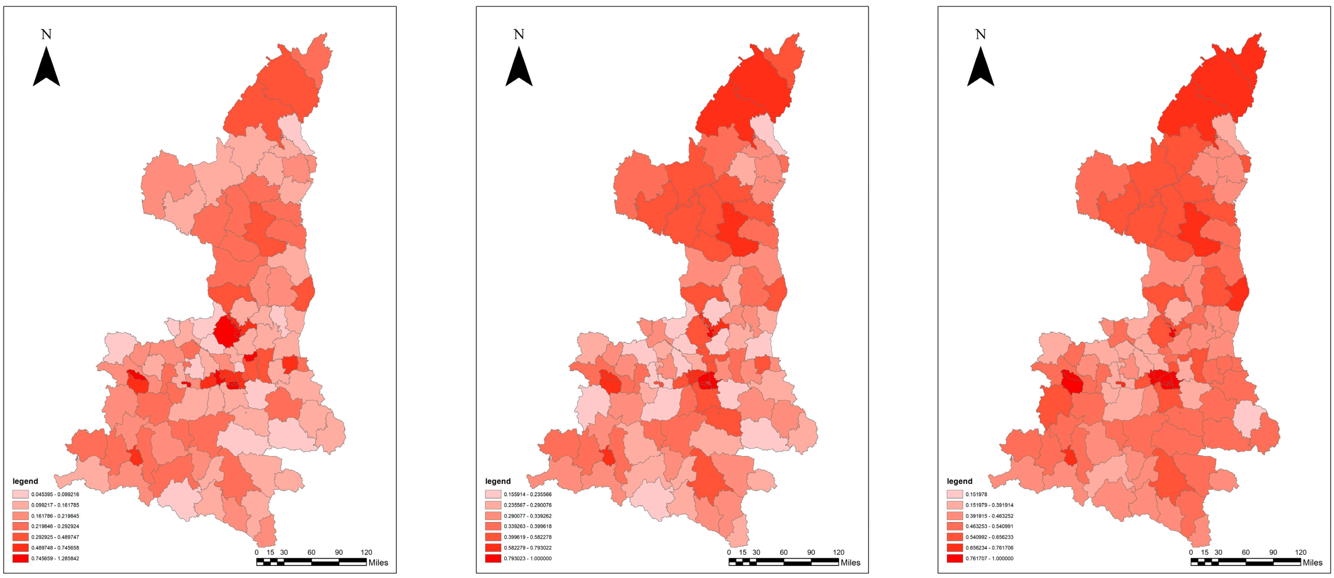
The calculation results of traditional urbanization from 2000 to 2020 are obtained using Formula (1). Throughout the research period, the traditional urbanization level in Shaanxi Province exhibited a steady upward trend, although it remained relatively low. The average value of the traditional urbanization index in various counties in Shaanxi Province increased from 0.2926 to 0.5333 during the period of 2000 to 2020. The overall growth rate remained stable, with a growth rate of 36.07% from 2000 to 2010 and 32.33% from 2010 to 2020. From 2000 to 2010, the lowest value range of the traditional urbanization index increased from [0.045, 0.099] to [0.156, 0.236], indicating a substantial disparity in urbanization levels among different research units. From 2010 to 2020, the highest and lowest value range of the traditional urbanization index remained relatively stable, but there was a general improvement in the traditional urbanization level across various counties, resulting in a gradual narrowing of the gap.



(**a**) (**b**) (**c**) (**d**)

Figure 4. Ecological service value from 1990 to 2020. (**a**) Ecosystem Services Value in 1990. (**b**) Ecosystem Services Value in 2000. (**c**) Ecosystem Services Value in 2010. (**d**) Ecosystem Services Value in 2020.

The traditional urbanization level in Shaanxi Province exhibits a pattern of multiple central locations in terms of spatial distribution, which aligns with the spatial distribution of ecosystem services value (as shown in the Figure 5). Regions with a lower ecosystem services value generally exhibit relatively higher levels of traditional urbanization. The areas with medium to high values experience a gradual increase in terms of the evolution of spatial distribution, and the proportion of counties with urbanization rates exceeding 50% has risen from 16.67% to 42.59%. These areas are primarily located in the northern part of Shaanxi, centered around Yulin and Yan'an, as well as the Guanzhong Plain region centered around Xi'an.



(**a**) (**b**) (**c**)

Figure 5. Results of traditional urbanization from 2000 to 2020. (**a**) Traditional Urbanization in the Year 2000. (**b**) Traditional Urbanization in the Year 2010. (**c**) Traditional Urbanization in the Year 2020.

3.3. Analysis of the Coupling Co-ordination between Traditional Urbanization and Ecosystem Service Value

By analyzing the coupling degree, co-ordination index, and coupling co-ordination level of county units in Shaanxi Province in 2000, 2010, and 2020, the coupling degree values indicate the strength of interaction between the systems. In terms of the coupling degree, the proportion of county units in the high coupling degree interval (0.9–1.0) is the largest in all three time periods, with the number gradually increasing from 35.51% to 68.22%. This indicates a gradual strengthening of the interaction between the two systems in the study area.

Since the degree of coupling only indicates the strength of interaction between systems without reflecting the mutual promotion or constraint at different levels, further analysis of the evolution characteristics of the coupling co-ordination level between the two systems in the research area is necessary. Overall, the coupling co-ordination level between traditional urbanization and ecosystem service value in Shaanxi Province has gradually shifted from imbalance to co-ordination. However, it still remains at a low level of coupling co-ordination, with only a few counties, such as Shenmu City and Yuyang District, maintaining a good and high-quality co-ordination level during the study period. From 2000 to 2020, 92.52% of the counties showed an upward trend in coupling co-ordination, while only a few counties, including Xincheng District, Yanliang District, Yanta District, Zizhou County, Danfeng County, Lintong District, Suide County, and Yaozhou District, experienced a decrease in the coupling co-ordination level (as shown in the Figures 6–8). The majority of counties, accounting for 74.76% in 2000 and 54.94% in 2010, had coupling co-ordination indexes in the range of (2.0, 0.5), indicating that the traditional urbanization and ecosystem service value in most counties of Shaanxi Province were generally imbalanced during the period of 2000–2010. Among them, the largest number of counties were in the range of (0.4, 0.5), indicating that most counties were on the verge of imbalance. In 2020, 63.55% of the counties had coupling co-ordination indexes in the range of (0.5, 1.0), with the highest number of counties falling in the range of (0.6–0.7), accounting for 25.23%. This indicates that the coupling co-ordination level of most counties has progressed from being on the verge of imbalance to a preliminary level of co-ordination.

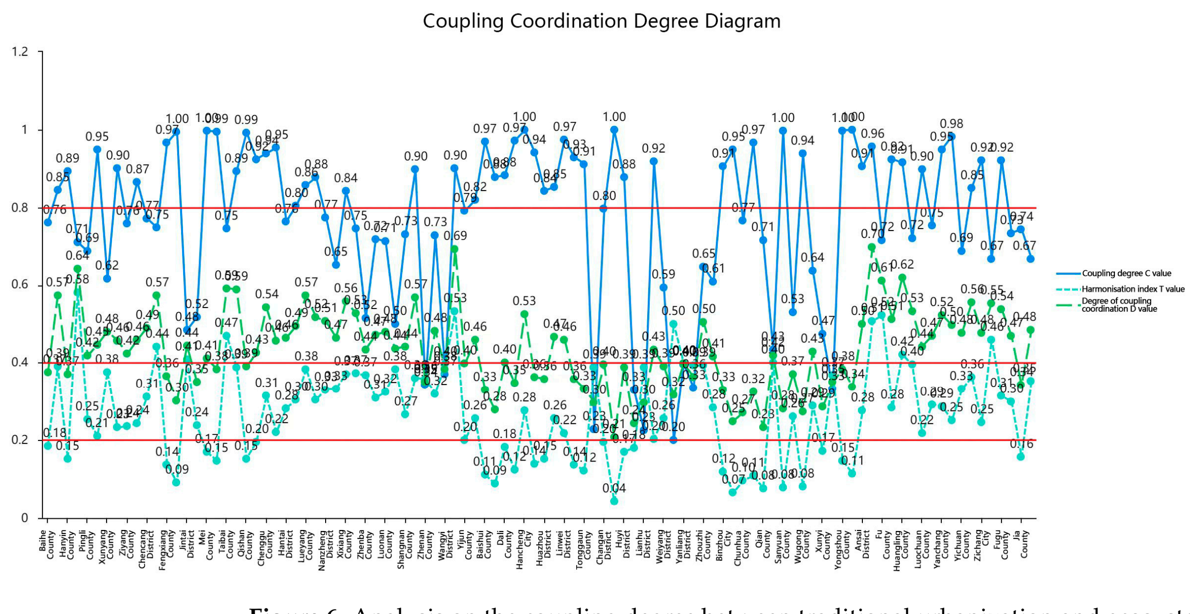


Figure 6. Analysis on the coupling degree between traditional urbanization and ecosystem service value in 2000.

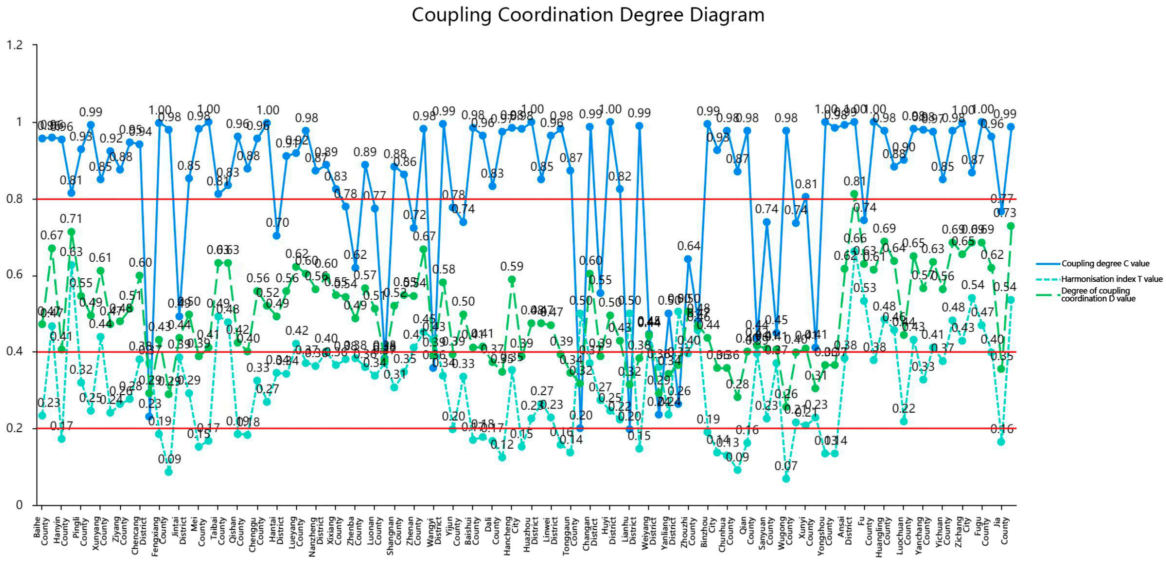


Figure 7. Analysis on the coupling degree between traditional urbanization and ecosystem service value in 2010.

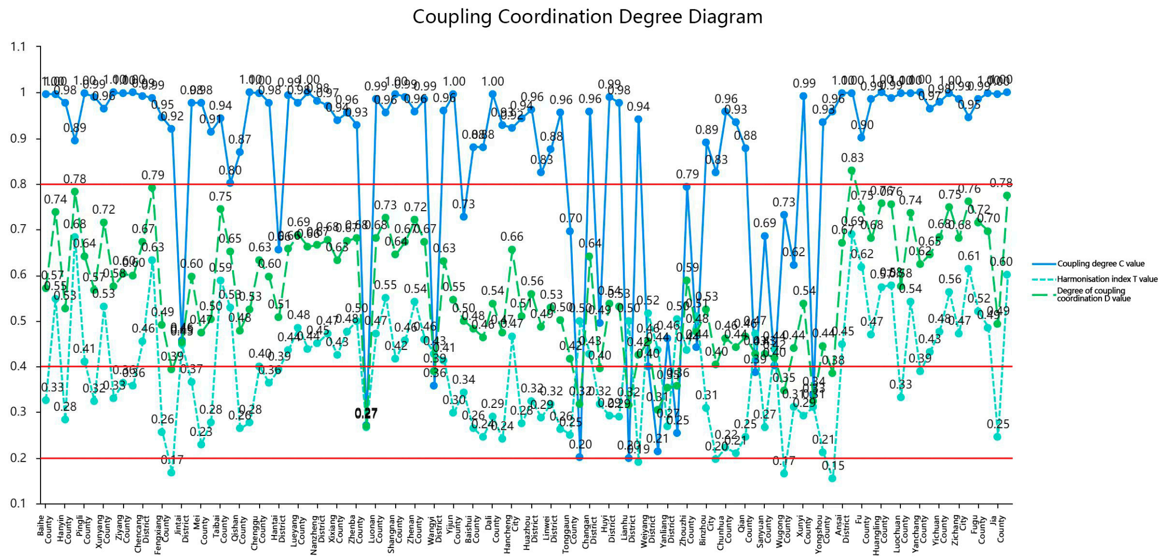
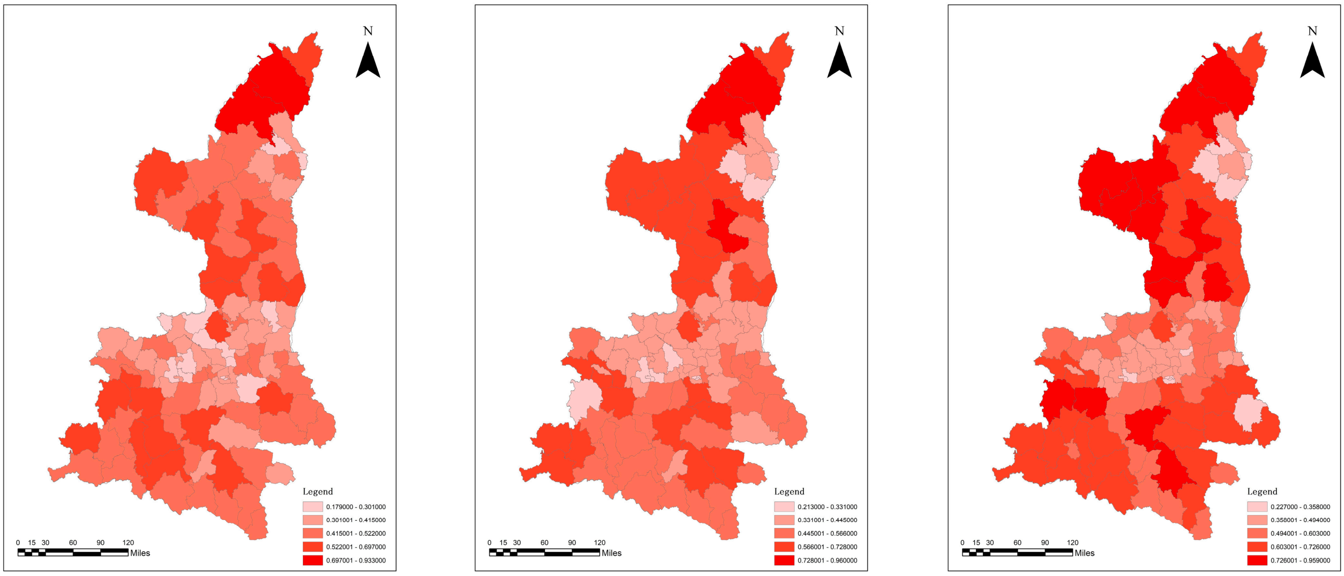


Figure 8. Analysis on the coupling degree between traditional urbanization and ecosystem service value in 2020.

Considering the level of coupling, the co-ordination between traditional urbanization and ecosystem service value was calculated using the previously mentioned model formula. We analyzed the spatial distribution of the co-ordination between county-level ecosystem services and traditional urbanization in Shaanxi Province using ArcGIS10.5 software (Figure 9). Coupling co-ordination indicates the relationship between two systems. From a spatial perspective, significant differences exist between counties, showing a consistent pattern of low values in the central region and higher values in the north and south, with the north having higher values than the south. The high-value areas are predominantly located in southern and northern Shaanxi. These areas include county groups in the transitional area between wind and sand, primarily consisting of Shenmu City, Yuyang District, and Dingbian County. Additionally, there is a county group in the Loess Plateau centered around Baoji District, and another county group in the mountainous region of southern Shaanxi with Ningshan County as the central point.



(**a**) (**b**) (**c**)

Figure 9. Coupling and co-ordination between traditional urbanization and ecosystem service value from 2000 to 2020. (**a**) Coupling and Co-ordination Degree between Traditional Urbanization and Ecosystem Services Value in 2000. (**b**) Coupling and Co-ordination Degree between Traditional Urbanization and Ecosystem Services Value in 2010. (**c**) Coupling and Co-ordination Degree between Traditional Urbanization and Ecosystem Services Value in 2020.

3.4. Analysis of the Effects of New Urbanization

This article presents an evaluation system consisting of five dimensions: population urbanization, economic urbanization, spatial urbanization, innovation urbanization, and ecological urbanization. The figure below illustrates the changes in urbanization levels in different counties of Shaanxi Province from 2000 to 2020(Figure 10). The evaluation results for the dimension of population urbanization increased from 0.0143 to 0.0349, representing a growth of 143.83%. The growth of population urbanization in the Guanzhong region is greater than in the various counties of southern Shaanxi as well as in northern Shaanxi. The highest growth rate is observed in Langu County of Ankang City in southern Shaanxi. The level of economic urbanization increased from 0.001 in 2000 to 0.0455 in 2020, representing a growth of 3.34%. The growth rate is relatively fast, averaging at 4.00%. The overall level of spatial urbanization exhibited an upward trend, with only five counties experiencing a decrease. The level of spatial urbanization in Shaanxi Province increased by 34.91% from 2000 to 2020. The level of innovation urbanization has continuously increased, with the mean value rising from 0.000061 to 0.0092, resulting in an overall increase of 150.41%. Certain districts and counties in the Guanzhong region (e.g., Chang'an District and Beilin District in Xi'an City) exhibited significant increases in innovation urbanization, with growth rates of 4022.41% and 953.85%, respectively. The average annual growth rate of county-level innovation urbanization is 7.52%. The average value of the ecological urbanization dimension showed a slight increase, with an overall growth of 24.70% from 2000 to 2020. The average growth rate is 1.23% per year. A total of 18.69% of the counties experienced a decrease in the level of ecological urbanization, primarily concentrated in the Guanzhong region.

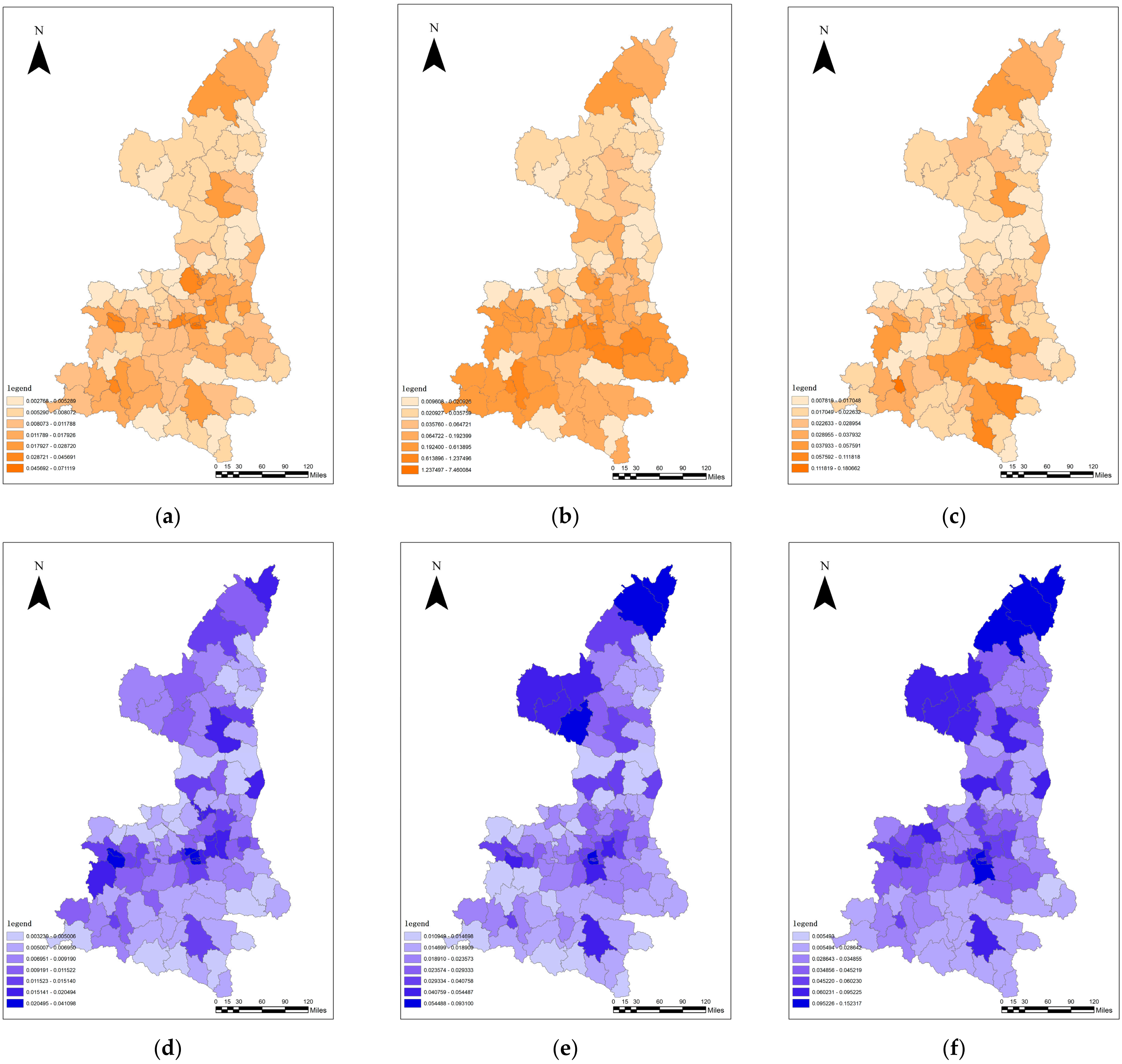
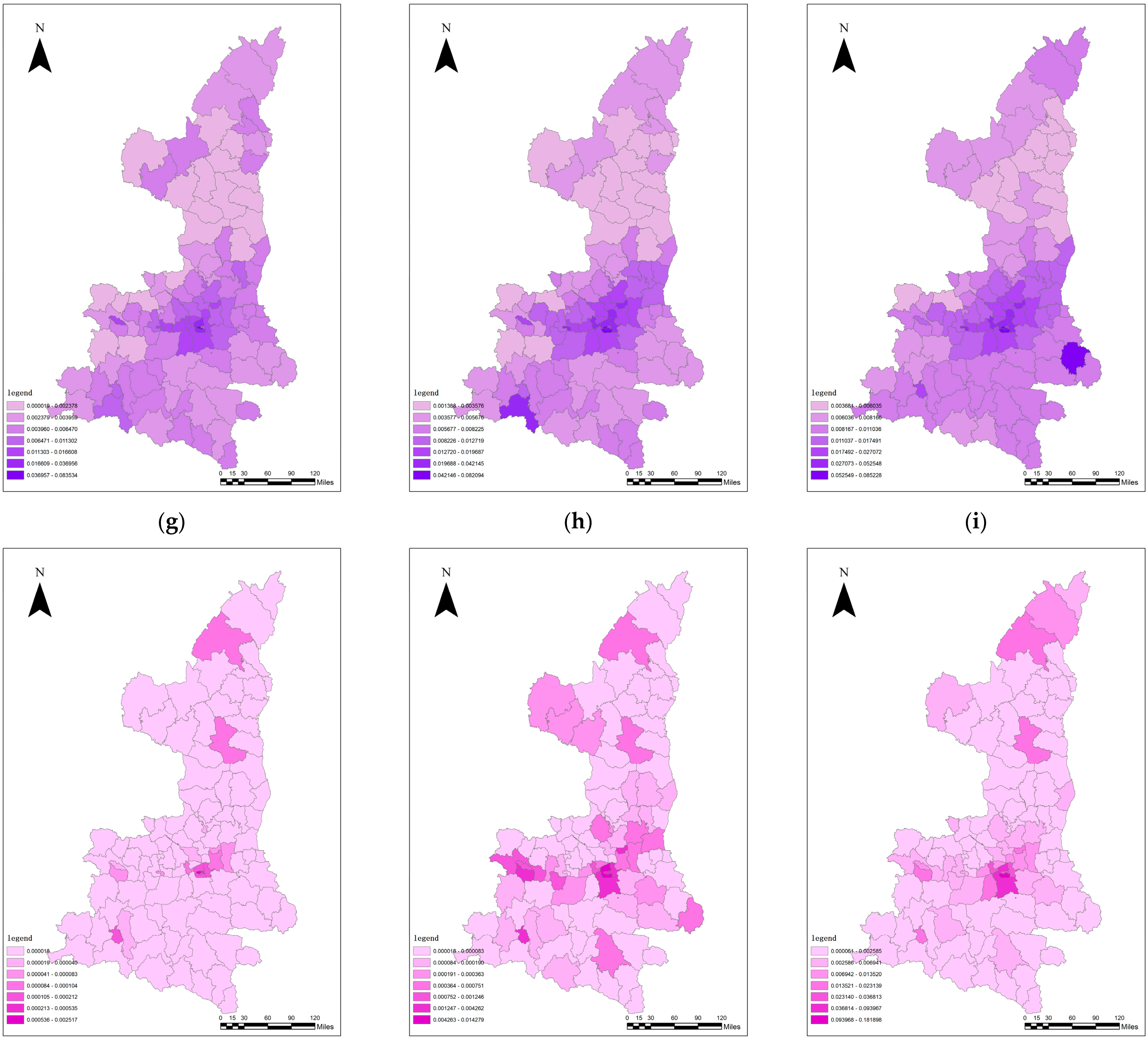


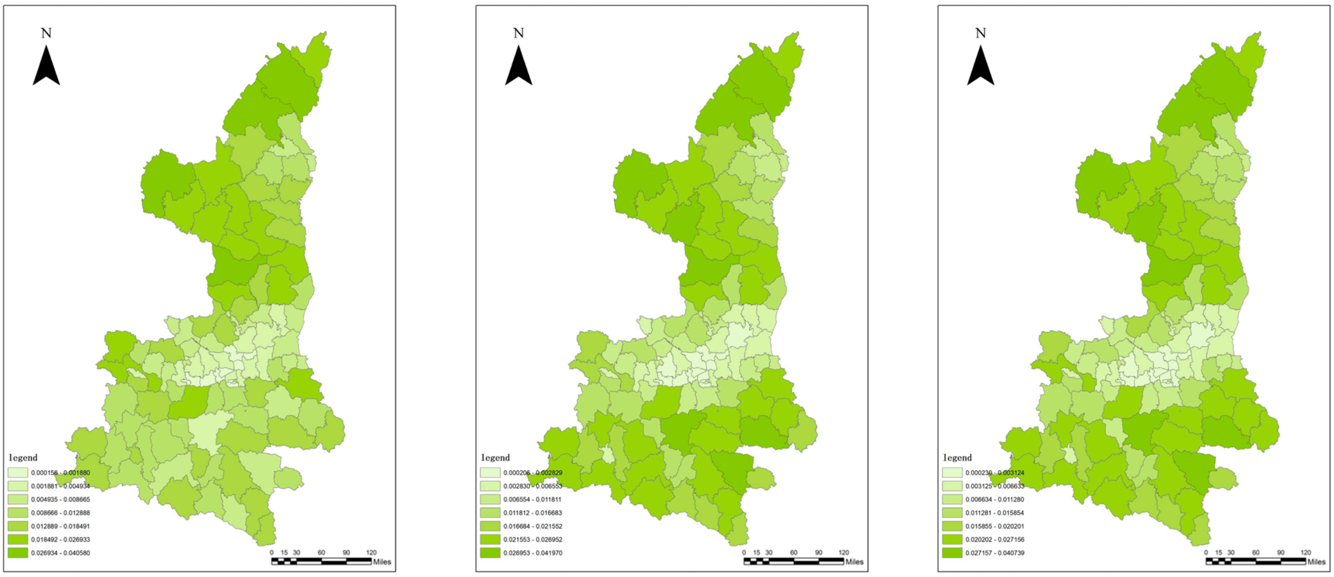
Figure 10. *Cont.*



(**g**) (**h**) (**i**)

(**j**) (**k**) (**l**)

Figure 10. *Cont.*



(**m**) (**n**) (**o**)

Figure 10. Dimensions of new urbanization results from 2000 to 2020. (**a**) Urbanization of the Population in the Year 2000. (**b**) Urbanization of the Population in the Year 2010. (**c**) Urbanization of the Population in the Year 2020. (**d**) Urbanization of the Economic in the Year 2000. (**e**) Urbanization of the Economic in the Year 2010. (**f**) Urbanization of the Economic in the Year 2020. (**g**) Urbanization of the Spatial in the Year 2000. (**h**) Urbanization of the Spatial in the Year 2010. (**i**) Urbanization of the Spatial in the Year 2020. (**j**) Urbanization of the Innovative in the Year 2000. (**k**) Urbanization of the Innovative in the Year 2010. (**l**) Urbanization of the Innovative in the Year 2020. (**m**) Urbanization of the Ecological in the Year 2000. (**n**) Urbanization of the Ecological in the Year 2010. (**o**) Urbanization of the Ecological in the Year 2020.

Generally, in terms of the growth rate of urbanization across the five dimensions, the order of priority is as follows: innovative urbanization > economic urbanization > population urbanization > spatial urbanization > ecological urbanization.

In terms of the spatiotemporal changes in urbanization indicators, the overall level of population urbanization exhibited a polycentric pattern from 2000 to 2020. Additionally, the average level of urbanization in the Guanzhong region surpassed that in both the Shaannan and Shaanbei regions. Specifically, in the Guanzhong region, there was a phenomenon of decreasing urbanization levels from the core area of Yanta District to its surrounding regions. In the Shaannan region, the levels of urbanization across different counties were relatively balanced. In the Shaanbei region, significant spatial disparities in urbanization were observed, with Shenmu County and Yuyang District exhibiting higher values compared to other areas, resulting in substantial spatial differentiation.

In terms of economic urbanization, the overall level of economic urbanization in Shaanxi Province exhibited a steady increase from 2000 to 2020. The regions with relatively good economic urbanization indexes expanded over time. The development pattern shifted from a single center in Xi'an in 2000 to the formation of an economic urbanization belt in the northern part of the study area, encompassing Dingbian County, Jingbian County, and Hengshan District by 2010. By 2020, two development cores, namely "Northern Shaanxi" and "Guanzhong", gradually formed.

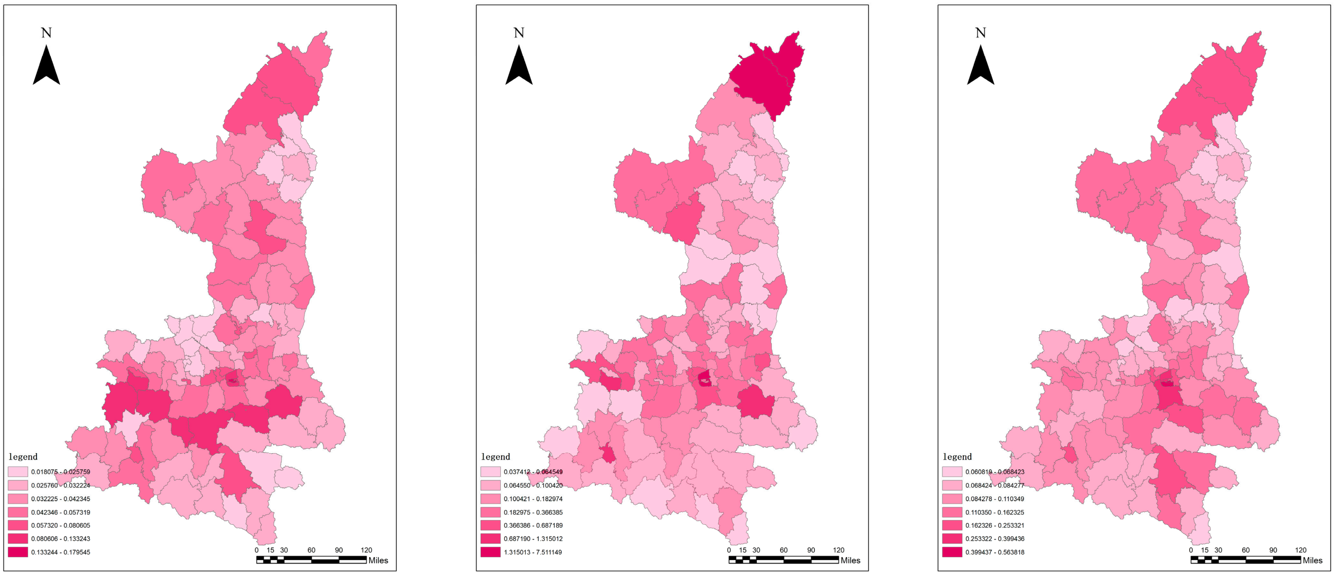
In terms of spatial urbanization, the levels of spatial urbanization in different counties of Shaanxi Province are relatively balanced, with higher levels of intensification observed in the Guanzhong region, followed by the Southern Shaanxi region and then the Northern Shaanxi region.

The areas with high levels of innovative urbanization exhibit significant spatial–temporal expansion, with the expansion rate being highest in the Guanzhong region of Shaanxi

Province, followed by the Northern Shaanxi region and then the Southern Shaanxi region. The single-center form, centered around "Xi'an", is gradually becoming prominent.

In terms of ecological urbanization, Shaanxi Province experienced steady improvement from 2000 to 2020, maintaining a spatial pattern characterized by higher levels in the north and south and lower levels in the central region.

As illustrated in the figure below, the results demonstrate a spatial distribution pattern characterized by a central high and peripheral low, with notable spatial disparities (as shown in the Figure 11). On average, the level of comprehensive urbanization in the counties of the Guanzhong region surpasses that in the northern and southern Shaanxi regions. The development of the Guanzhong region is driven by its locational advantages, with the Yanta District, Beilin District, and Weiyang District serving as focal points of comprehensive urbanization. Shenmu County stands out as the top-performing county in the northern Shaanxi region, whereas, in the southern Shaanxi region, the Hantai District of Hanzhong City takes the lead.



(**a**) (**b**) (**c**)

Figure 11. Comprehensive review of new urbanization from 2000 to 2020. (**a**) Comprehensive Assessment of New Urbanization in 2000. (**b**) Comprehensive Assessment of New Urbanization in 2010. (**c**) Comprehensive Assessment of New Urbanization in 2020.

3.5. Analysis of the Coupling Co-ordination between the Quality of New Urbanization and Ecosystem Service Value

The degree of coupling and co-ordination between new urbanization and ecosystem services value can be calculated. The degree of coupling indicates the strength of interaction between systems. An analysis of the numerical values of the degree of coupling between new urbanization and ecosystem services value from 2000 to 2020 reveals that, in 2000, the degree of coupling between new urbanization and ecosystem services value in various counties was predominantly distributed in the high coupling range of (0.8–1.0) (Figure 12). However, from 2010 to 2020, the degree of coupling between new urbanization and ecosystem services value gradually decreased to the range of (0.4–0.8) (Figure 13). In 2020, around 55.14% of counties had a degree of coupling value in the range of (0.4–0.8), while only 21.49% of counties were in the range of (0.9–1.0) (Figure 14). The overall degree of coupling weakened, suggesting that new urbanization is gradually reducing its impact on the strength of ecosystem services value.

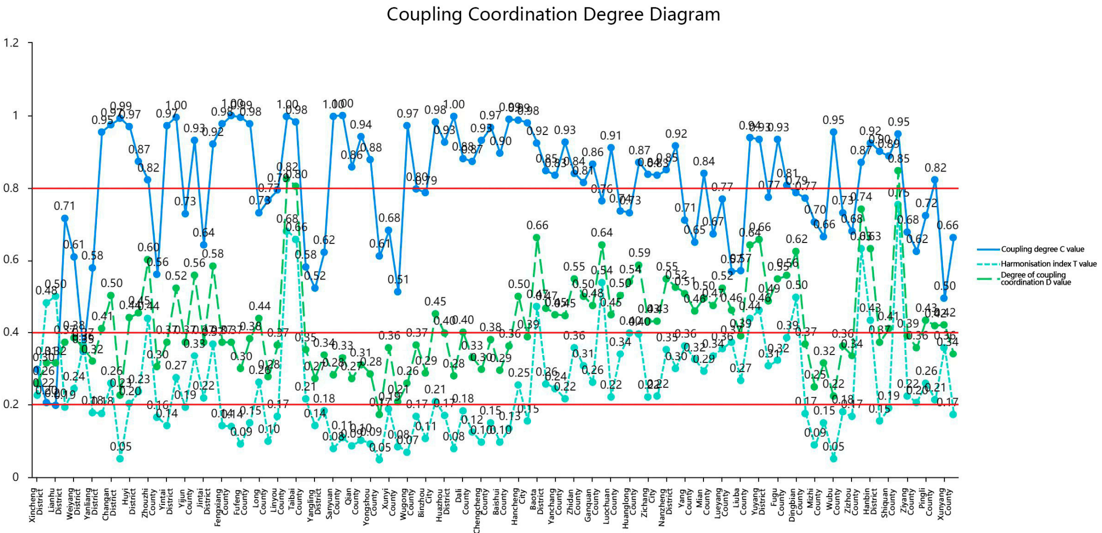


Figure 12. Analysis of the coupling co-ordination degree between new urbanization and ecosystem services value in 2000.

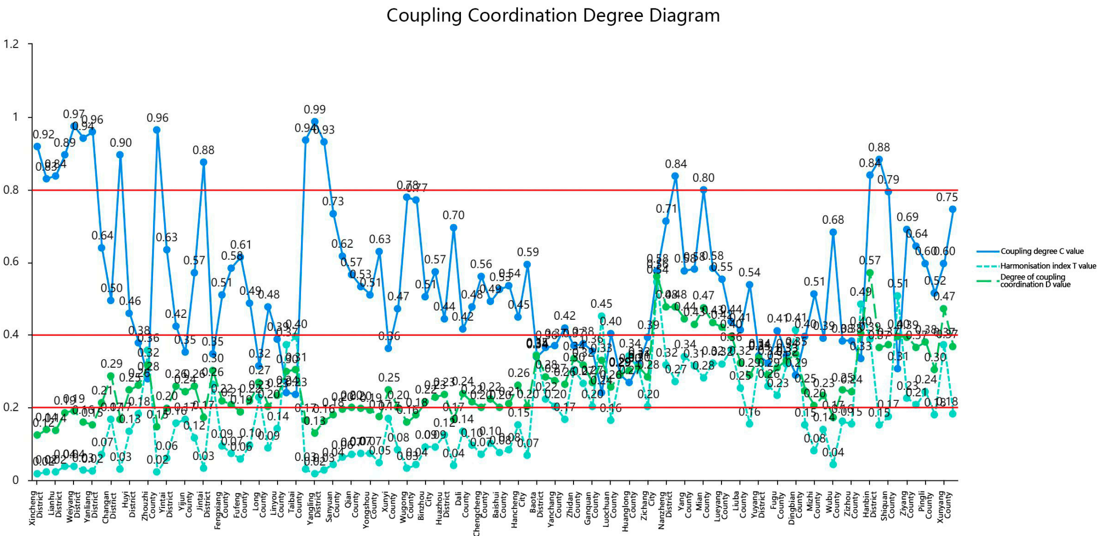


Figure 13. Analysis of the coupling co-ordination degree between new urbanization and ecosystem services value in 2010.

The level of coupling co-ordination represents the degree of co-ordination and development between two systems. As shown in the figure below, in the year 2000, 74.76% of county-level areas exhibited an imbalance in the coupling co-ordination between new urbanization and ecosystem services value. Specifically, Changwu County and Shangnan County in southern Shaanxi Province experienced a severe imbalance. In 2010, the coupling co-ordination index remained below 0.6 (indicating a primary level of co-ordination), suggesting a generally poor level of co-ordination. From 2000 to 2020, the overall coupling co-ordination between new urbanization and ecosystem services in the research area showed a declining trend, with only 18.69% of county-level areas exhibiting an increase in coupling co-ordination.

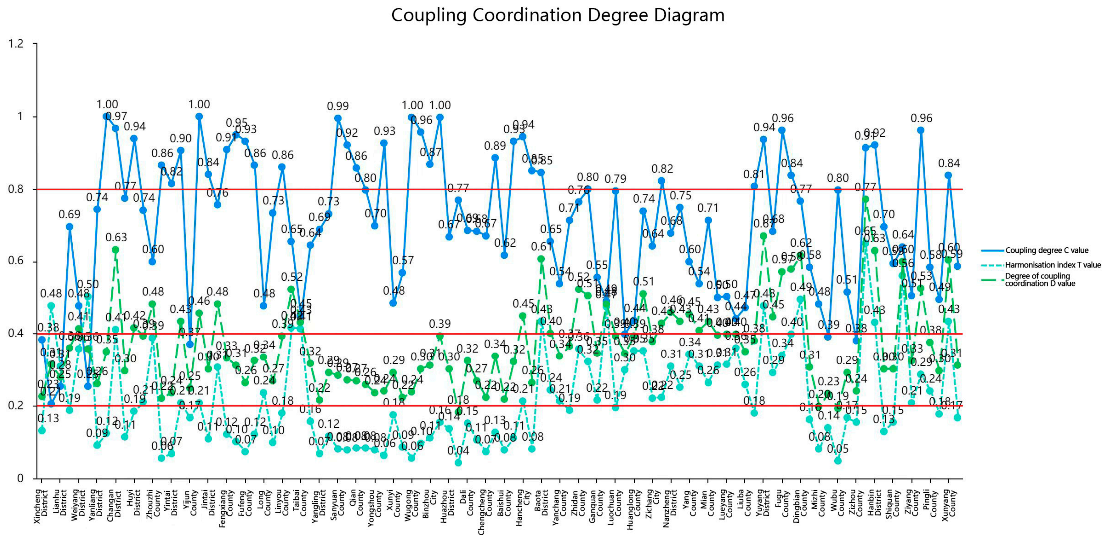
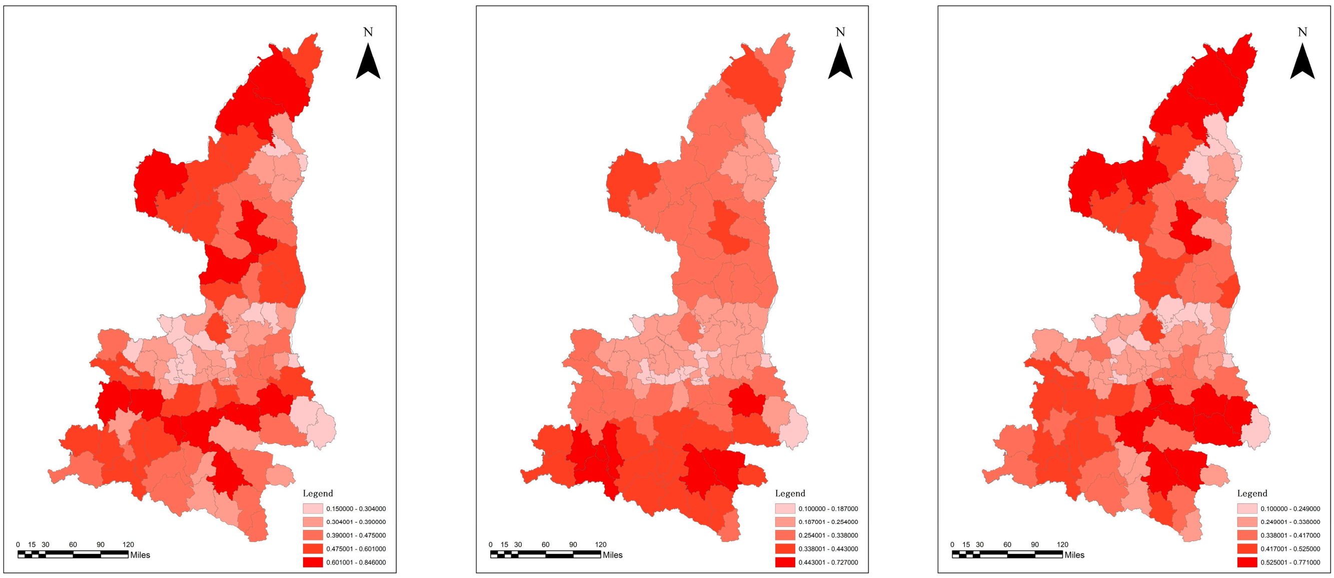


Figure 14. Analysis of the coupling co-ordination degree between new urbanization and ecosystem services value in 2020.

The figure illustrates the coupling co-ordination between visualized new urbanization and ecosystem service value(Figure 15). From 2000 to 2020, various counties in Shaanxi Province exhibited a significant spatial disparity in the coupling co-ordination between new urbanization and ecosystem service value. There is a prominent spatial agglomeration, characterized by a phenomenon of high values in the south and north and low values in the middle. The coupling co-ordination between new urbanization and ecosystem services in the Guanzhong region of Shaanxi Province is imbalanced.



(**a**) (**b**) (**c**)

Figure 15. Analysis of the coupling co-ordination degree between new urbanization and ecosystem service value from 2000 to 2020. (**a**) Coupling and Co-ordination Analysis of New Urbanization and Ecosystem Service Value in 2000. (**b**) Coupling and Co-ordination Analysis of New Urbanization and Ecosystem Service Value in 2010. (**c**) Coupling and Co-ordination Analysis of New Urbanization and Ecosystem Service Value in 2020.

Generally, the development status of new urbanization and ecosystem services in different counties of Shaanxi Province from 2000 to 2020 has exhibited a trend of “lagging new urbanization—synchronized development—lagging ecological environment development”. For instance, the Yan Ta District in Xi’an City is a case in point. In summary, the contribution of new urbanization to the value of ecosystem services in the study area is gradually decreasing compared to traditional urbanization. However, due to the inadequate development of new urbanization, the co-ordination between new urbanization and the ecosystem remains imbalanced.

4. Discussion and Conclusions

The aim of this study is to examine the interconnected and co-ordinated relationship between ecosystem services and urbanization, in contrast to previous studies [7,31,40,70]. It seeks to clarify whether new urbanization development is more favorable to the co-ordinated development of urbanization and ecosystems, as opposed to traditional urbanization. The study developed a “new urbanization evaluation index system” focused on the county-level evaluation scale. The results indicated that the level of low coupling, characterized by strong spatial clustering, in counties of Shaanxi Province had increased convergence and a significantly low level of disordered assimilation. The findings are generally consistent with the research on the relationship between ecosystems and urbanization [71–76]. Moreover, the findings indicate that, in comparison to traditional urbanization, new urbanization affects ecosystem services through five dimensions: economic, ecological, population, spatial, and innovative urbanization. The comprehensive system includes both positive and negative effects. The overall results show that the adverse impact of new urbanization on ecosystem services is relatively minor. Drawing on these findings, this paper seeks to enhance the co-ordinated coupling system of “urbanization-ecological”. This paper argues that both urbanization and ecological systems affect the ecosystem through two distinct pathways (as depicted in the Figure 16). Compared to traditional urbanization, the new urbanization weakens the impact on the ecosystem from five dimensions, resulting in relative stability between the two systems. However, the co-ordination between them is still inadequate and it is essential to enhance future development of new urbanization, as depicted in the figure.

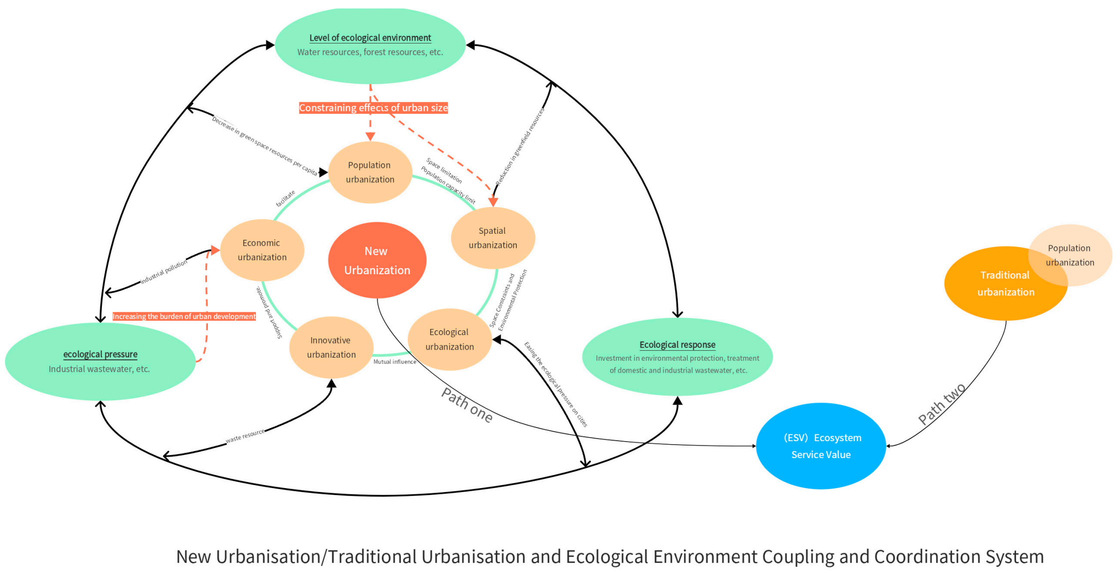


Figure 16. Analysis of the ecological impact pathways of new urbanization and traditional urbanization.

This study focuses on the counties of Shaanxi Province as its research subjects. It develops an evaluation model for the new urbanization of these counties, computes the values of both traditional urbanization and new urbanization, and determines the ecosystem service value (ESV) of Shaanxi Province from 2000 to 2020. It employs a coupled co-ordination model to conduct a comparative analysis of the traditional urbanization–ecosystem coupling and the new urbanization–ecosystem coupling. The key findings are as follows:

(1) Between 2000 and 2020, traditional urbanization in Shaanxi Province exhibited a consistent increase, with the average urbanization rate in each county rising by 169.55%. The highest growth rate occurred in the Guanzhong region. Spatially, traditional urbanization in Shaanxi Province follows a "high in the middle, low on the periphery" pattern. Research on coupling relationships suggests a "spread of low-value areas" resulting in a low-discrepancy assimilation pattern, characterized by significant spatial agglomeration and clear spatial differences. Significant urbanization disparities exist among the counties.

(2) Between 2000 and 2020, the interaction between traditional urbanization and ecosystems has gradually intensified, leading to a shift from "disorder" to "coordination" in their coupling. Nevertheless, the overall level of coupling co-ordination remains low. Spatially, the coupling co-ordination demonstrates a stable pattern of being "low in the middle, high in the north and south, with higher levels in the north than in the south."

(3) In this paper, a new urbanization assessment model is developed based on population, economy, space, ecology, and innovation. The average value of urbanization has steadily increased from 2000 to 2020, with an average annual growth rate of 168.24%. Economic urbanization and innovation urbanization show the highest growth rates of 334.32% and 752.05%, respectively. The research results show a significant "Guanzhong advantage" in terms of spatial distribution across all five urbanization dimensions, where novel urbanization in the Guanzhong region is notably superior to other areas, demonstrating strong spatial agglomeration.

(4) The relationship between the new urbanization of counties in Shaanxi Province and the value of ecosystem services demonstrates a distinct pattern, indicating a "low-level coupling". Between 2000 and 2020, the ecosystems and new urbanization in each county of the study area have consistently experienced a condition of "mild imbalance". Nevertheless, the comprehensive analysis of new urbanization and the co-ordination between the value of ecosystem services reveals an overall declining trend, suggesting a general reduction in the negative impact of new urbanization on ecosystems.

(5) Compared to traditional urbanization, the new urbanization takes into account a wide range of interactions within the "ecology-urbanization" system. The connection between new urbanization and the value of ecosystem services is relatively weak. In other words, the adverse impact of new urbanization on the value of ecosystem services can be considered relatively minor.

Author Contributions: Concepts, Q.N. and X.M.; methodology, Q.N.; software, Q.N.; validation, R.D.; formal analysis, Q.N.; investigation, Q.N.; resources, Q.N. and X.M.; formal analysis, Q.N. and X.M.; investigation, Q.N.; resources, Q.N.; data collation, Q.N.; writing—original draft preparation, Q.N. and X.M.; writing—review and editing, P.C. and Y.L.; visualization, Q.N.; supervision, R.D.; project management, P.C.; funding acquisition, P.C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The land use data (1990–2020, 30 × 30 m), population density, and GDP spatial distribution dataset were acquired from the Resource and Data Cloud Platform (https://www.resdc.cn, accessed on 10 August 2023). The majority of socio-economic data were obtained from the Statistical Yearbooks of different counties within Shaanxi Province. The Shaanxi Province PM2.5 dataset was obtained from the Shaanxi Province Department of Ecology and Environment (http://sthjt.shaanxi.gov.cn/, accessed on 10 August 2023).The DMSP/OLS data was sourced from the NOAA website (www.ngdc.naoo.gov, accessed on 15 August 2023).

Conflicts of Interest: Authors Qingsong Ni and Yan Liang were employed by the company POWERCHINA Chengdu Engineering Corporation Limited. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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