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Research on Zoning and Carbon Sink Enhancement Strategies for Ecological Spaces in Counties with Different Landform Types

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Abstract: Ecological carbon sinks, pivotal in mitigating carbon emissions, are indispensable for climate change mitigation. Counties, as the fundamental units of ecological space management, directly impact the achievement of regional dual carbon targets through their levels of carbon sink. However, existing research has overlooked the intricate relationship between terrain features and ecological spaces, leading to a lack of specific guidance on enhancing the carbon sink for counties with diverse landform characteristics. This study focused on Jingbian County (Loess Plateau), Fuping County (Guanzhong Plain), and Chenggu County (Qinba Mountains), each characterized by distinct landform characteristics. This study proposes a comprehensive identification model for ecological space within the context of dual carbon targets. Utilizing this model as a basis, the land use structure, carbon sink potential, and ecological spatial patterns of different counties were systematically analyzed. The results indicated substantial disparities in land use structure, carbon sink capabilities, and ecological space distributions among counties with different landform types. Specifically, Jingbian County was predominantly covered by grassland, exhibiting a moderate overall carbon sink capacity, with baseline ecological spaces playing a significant role. Conversely, Fuping County, dominated by cultivated land and construction land, exhibited the lowest carbon sink capacity, with non-ecological spaces accounting for a staggering 85.93%. Chenggu County, on the other hand, was characterized by the dominance of forestland, with nearly all its carbon sink originating from forestland, and core ecological spaces occupying a leading position. Tailored optimization strategies are recommended based on varying terrain features: Jingbian County should prioritize ecosystem restoration and conservation, while Fuping County should concentrate on optimizing land use structure and promoting urban greening. Reinforcing the carbon sink capacity of existing ecosystems is crucial for Chenggu County. This study broadens the perspective on ecological space optimization and provides scientific guidance and pragmatic insights tailored to regional disparities, which are instrumental in assisting various regions to achieve their dual carbon targets.

Keywords: ecological space; carbon sink; land use; landform types; dual carbon targets

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1. Introduction

As global climate change intensifies, strategies for carbon sink enhancement and climate change adaptation have become pivotal subjects in contemporary geographical scientific research [1–3]. In the quest to achieve the dual carbon goals—namely peaking carbon emissions and achieving carbon neutrality—counties, which are pivotal administrative

units for carbon management, are of substantial theoretical and practical value to conduct research on sustainable strategies for enhancing carbon sinks [4,5]. The county's ecological space, as a vital carrier for the interaction between natural systems and socio-economic activities, is directly influenced by alterations in land use configurations and spatial layouts, thereby impacting the regional carbon sink capacity [6,7]. Diverse landform regions exhibit varying ecosystem characteristics due to their distinct natural environmental conditions and primary functional roles [8–10]. Therefore, by thoroughly considering local landform characteristics, elucidating the underlying principles governing ecological space distribution, and proposing tailored carbon sink enhancement strategies, it is possible not only to enhance the regional carbon sink potential and effectively address the challenges posed by global warming, but also to maintain regional ecological stability and promote comprehensive development in both socio-economic and ecological realms.

Recent years have witnessed considerable advancements in the study of ecological spaces, largely due to the advent of technologies such as remote sensing, geographic information systems, and computer science [11–13]. Scholars have conducted extensive and in-depth research explorations into theories related to ecological functional zoning [14], dynamic analysis of land use changes [15,16], and the evaluation of ecosystem service values [17,18]. These efforts have provided a solid scientific foundation for the effective identification and rational partitioning of ecological space. Among them, representative achievements include: establishing a comprehensive system of ecological zoning methods and introducing core concepts such as ecological source and sink areas and the ecological security layout [19–21]; conducting research on the identification and comprehensive evaluation of different spatial scales and types of ecological space [12,22,23]; evaluating the ecosystem service values for different land uses; and exploring the mechanism through which human activity influences the evolution of ecological space [24–26]. Current research hotspots in ecological space predominately concentrate on multi-scale distribution patterns and functional characteristics of ecological space, precise assessment and realization mechanisms of ecosystem service values, as well as optimized configuration and refined management strategies for ecological space [27–29]. Despite these advancements, significant deficiencies remain that require further investigation. A major shortfall involves the frequent neglect of the complex interplay between topographic features and the distribution and functionality of ecological spaces. This neglect results in a lack of comprehensive carbon sink enhancement strategies tailored to varying topographical regions. Moreover, existing research fails to adequately understand the intricate relationship between the multidimensional properties of ecological spaces and their carbon sink capabilities. This flaw results in a failure to systematically integrate carbon sink potential into the identification framework for ecological spaces. These limitations not only impede a holistic understanding of ecological spaces but also constrain the sustainable management and enhancement of carbon sink potential in county-level ecological spaces.

In this study, Jingbian County (Loess Plateau), Fuping County (Guanzhong Plain), and Chenggu County (Qinba Mountains) were selected as study areas because they exemplify the prevalent geomorphological categories found in Shaanxi Province and throughout China. This research focused on scrutinizing the characteristics of land use structure, the current status of carbon sinks, and disparities in the distribution patterns of ecological spaces across counties with diverse landforms. Based on these analyses, the study developed and proposed landform-specific strategies to enhance carbon sinks within ecological spaces. The primary objective of this research was to provide valuable solutions for the effective management of ecological spaces and the enhancement of carbon sink capabilities in counties with varied landform types.

2. Materials and Methods

2.1. Study Area

This study selected Jingbian County, Fuping County, and Chenggu County in the Shaanxi Province as representative research areas, each epitomizing a distinct region within

the province's three major geomorphic types: the Loess Plateau in the north, the Guanzhong Plain in the center, and the Qinba Mountains in the south. Jingbian County, situated in the northern part of Shaanxi Province, serves as a microcosm of the Loess Plateau geomorphology, characterized by deep loess deposits and a landscape marked by an intricate network of gullies and ravines. This region is ecologically fragile and faces severe soil erosion challenges. Simultaneously, due to its abundant energy resources, it primarily relies on the energy industry for economic growth. Fuping County, located in the Guanzhong Plain region of central Shaanxi, boasts fertile land and a humid climate, making it a crucial agricultural production base not only for the province but also nationally. In addition to agriculture, the county has developed a diversified industrial structure encompassing manufacturing, modern services, and high-tech industries. Chenggu County, located in the Qinba Mountains, boasts a diverse ecosystem, abundant natural resources, and considerable potential for eco-tourism development. The intricate topography and diverse ecosystem types found in the Qinba Mountains are of great significance in maintaining regional carbon balance. The locations of these study areas are depicted in Figure 1.

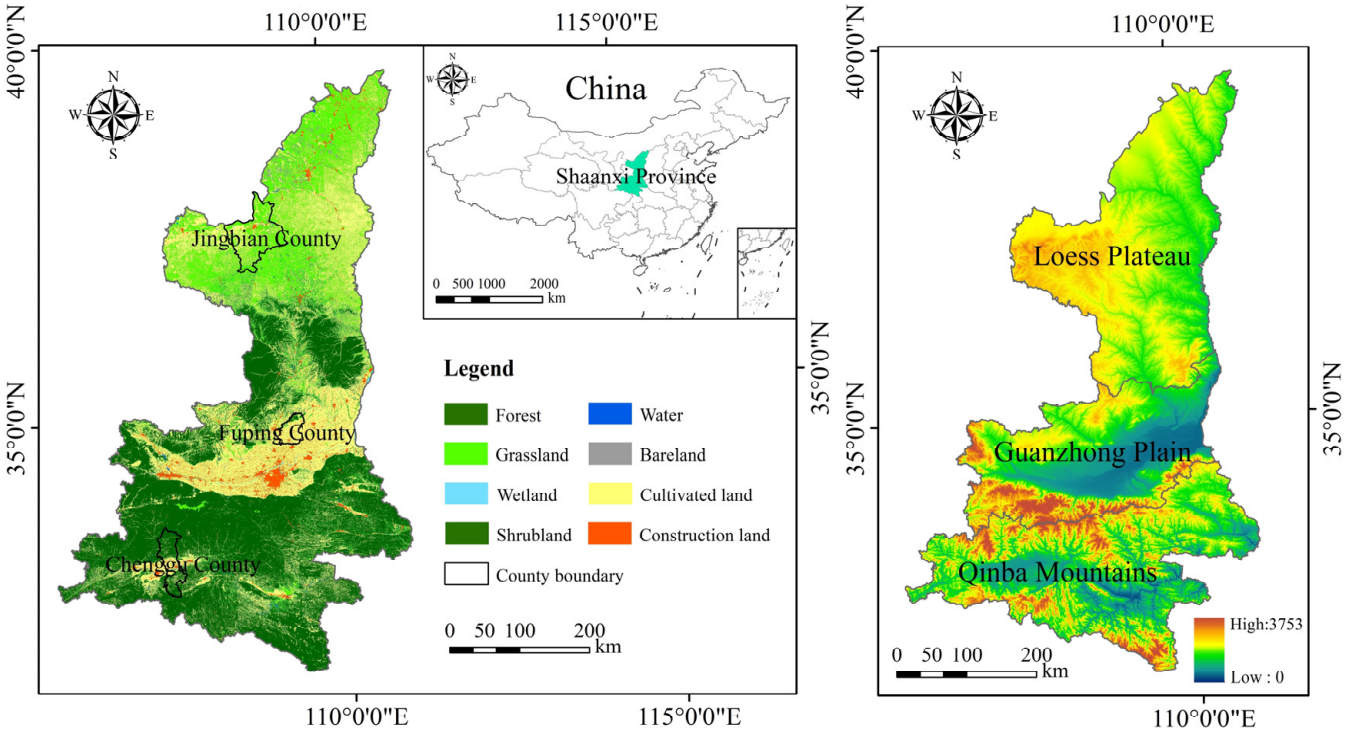


Figure 1. The locations of the study areas.

2.2. Data

This study collected eight types of data in the research area, including land use, elevation, population, nighttime light imagery, road network, surface temperature, vegetation, and administrative boundaries. All datasets, except for elevation data, corresponded to the year 2020. Table 1 provides specific details for all datasets utilized and their corresponding calculated indicators.

Table 1. The specific details of the data and their corresponding indicators.

Name	Resolution	Calculated Indicators	Source
GlobeLand30 [30]	30 m	habitat quality, carbon sink intensity	http://www.globallandcover.com (accessed on 18 June 2023)
SRTM DEM	30 m	elevation, slope, relief degree	https://earthexplorer.usgs.gov (accessed on 27 July 2023)
Woldpop [31]	100 m	population density	https://www.worldpop.org.uk (accessed on 27 July 2023)
NPP-VIIRS-like NTL data [32]	500 m	nighttime light intensity	http://nnu.geodata.cn/data (accessed on 27 July 2023)
OpenStreetMap [33]	\	traffic network density	https://www.openstreetmap.org (accessed on 18 August 2023)
1-km monthly mean temperature dataset for China [34]	1000 m	surface temperature	https://poles.tpdc.ac.cn/zh-hans (accessed on 18 August 2023)
MOD13Q1	250 m	normalized difference vegetation index (NDVI)	https://ladsweb.modaps.eosdis.nasa.gov (accessed on 18 August 2023)
Administrative boundary	\	\	http://www.dsac.cn (accessed on 15 June 2023)

3. Methodologies

3.1. Carbon Sink Coefficient Method

The amount of carbon sequestered per unit area and time is defined as the carbon sink coefficient, representing the carbon absorbed and stored by ecosystems through photosynthesis and other biogeochemical processes [35]. In assessing total carbon sinks across various land use categories, the primary focus is on forest, grassland, shrub, wetland, etc. Cultivated land, recognized as a carbon source [36], is deliberately excluded from this study. The carbon sink coefficient method has gained widespread practical application due to its simplicity, intuitiveness, ease of operation, and cost-effectiveness [37,38]. Its expression is as follows:

$$C_t = \sum_{i=1}^{n} A_i S_i \quad (1)$$

The total carbon sink (C_t) is determined by the area of each land use type (A_i) and the corresponding carbon sink coefficient (S_i). Referencing the findings of the existing literature [38–40] and considering the current situation of Shaanxi Province, the carbon sink coefficients for forest, grassland, shrubland, wetland, water and bareland in this study are 0.8700 t/hm^{2}a^{-1}, 0.1380 t/hm^{2}a^{-1}, 0.2300 t/hm^{2}a^{-1}, 0.5670 t/hm^{2}a^{-1}, 0.6710 t/hm^{2}a^{-1}, and 0.0005 t/hm^{2}a^{-1}, respectively.

3.2. Multivariate Comprehensive Identification Model of Ecological Space under the Dual Carbon Targets

Building upon our previously established ecological space identification system for dual carbon targets [41], this study further refined and presented a comprehensive recognition model for ecological space (Figure 2). The realization process of the model was segmented into three primary steps. In the initial step, ecological space indicators were computed. Commencing from the inherent functions of urban ecological patches and considering the mutual interactions between patches and the surrounding landscape environment, while also incorporating the carbon sink capacity of the ecological space, this study established ten indicators. The second step involved estimating the ecological space comprehensive index. The analytic hierarchy process (AHP) method was applied to determine the weights of different ecological spatial indicators. Subsequently, spatially weighted overlay analysis was conducted using ArcGIS 10.3 software to derive the ecological space comprehensive index. Finally, in the third step, the delineation of ecological space zones

was executed. Drawing on existing research findings on ecological space partitioning [42], this study categorized ecological space into four types using the natural breakpoint method.

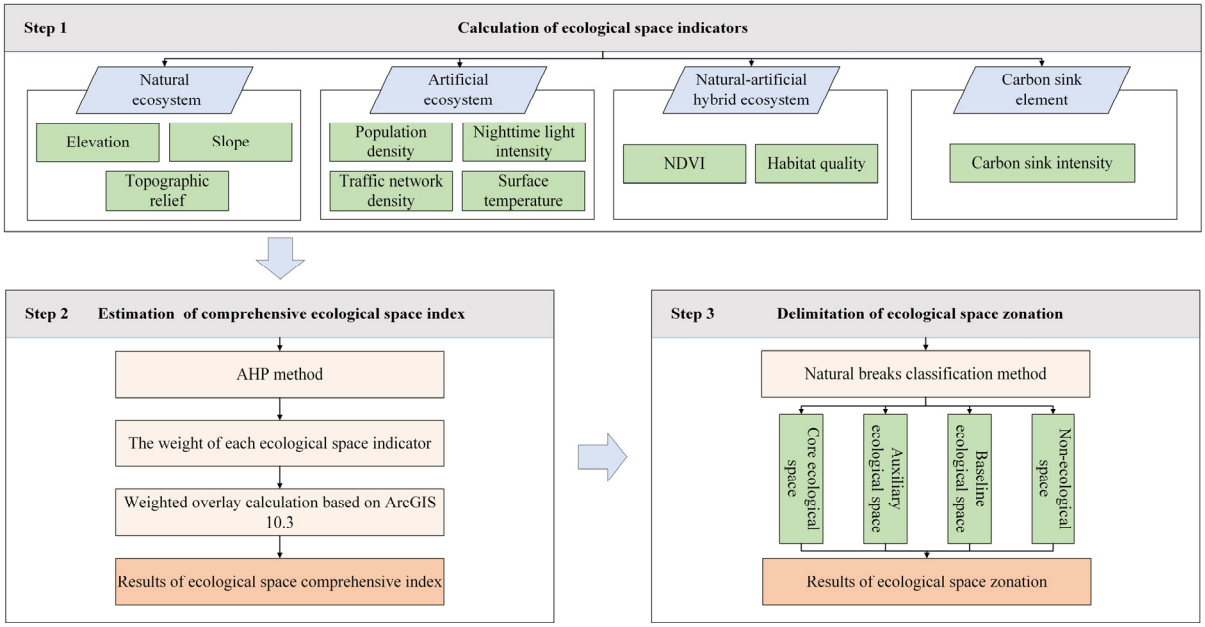


Figure 2. Multivariate comprehensive identification model of ecological space under the dual carbon targets.

3.3. Computational Method for the Identification Indicators of Ecological Space

Table 2 outlines the methods for calculating ecological space recognition indicators. Elevation, slope, relief degree, population density, and NDVI were processed using the Google Earth Engine (GEE) [43]. The GEE enables batch data visualization and cloud processing, significantly enhancing the efficiency of indicator calculations [44]. It is worth noting that, following the completion of each indicator calculation, the raster resampling tool in ArcGIS 10.3 software was employed to resample the resolution to 100 m.

Table 2. Computational method for the identification indicators of ecological space.

Type	Indicator	Method
Natural ecosystem	Elevation	The SRTM DEM data was obtained from the GEE (ID: USGS/SRTMGL1_003), and then, the elevation data was generated based on administrative boundary data and the clipping function.
	Slope	Utilizing the DEM data of the study region, the slope was computed through the slope function on the GEE.
	Relief degree	The expression of relief degree is as follows: $RDLS = \frac{ALT}{1000} + \left\{ (H_{max} - H_{min}) * \left[1 - \frac{P(A)}{A} \right] \right\} / 500$ (2) The relief degree is denoted by $RDLS$, and ALT signifies the mean elevation in the area. H_{max} and H_{min} respectively represent the maximum and minimum elevations of the designated area. $P(A)$ is the flat terrain within the specific region, A represents the overall area of the designated zone, and 500 is the base elevation of China. Based on expression (2) and the DEM data of the study area, the relief degree was calculated using the Zonal Statistics and Raster Calculator tools in ArcGIS 10.3.

Table 2. *Cont.*

Type	Indicator	Method
Artificial ecosystem	Population density	Population density information was derived for the study area by accessing the WorldPop dataset through the GEE platform (ID: WorldPop/GP/100 m/pop) and applying the dataset to the defined administrative boundaries utilizing the image clipping functionality.
	Nighttime light intensity	Using NPP-VIIRS-like NTL data, the nighttime light intensity for the study area was acquired by employing the Extract by Mask tool in ArcGIS 10.3 software. The nighttime light intensity within the study region was extracted utilizing the NPP-VIIRS-like NTL dataset, achieved through the application of the 'Extract by Mask' functionality embedded in ArcGIS 10.3 software.
	Traffic network density	The traffic network density was calculated by employing the 'Line Density' feature in ArcGIS 10.3, making use of the OpenStreetMap dataset that covers the region.
	Surface temperature	The annual mean temperature was calculated for the study area by utilizing the 'Raster Calculator' tool integrated within ArcGIS 10.3 software, working with the 1-km monthly mean temperature dataset for China.
Natural–artificial interaction ecosystem	NDVI	After obtaining the MOD13Q1 data for the study area from the GEE platform (ID: MODIS/006/MOD13Q1), the monthly average NDVI was calculated using the mean function.
	Habitat quality	Utilizing the GlobeLand30 dataset of the study area, habitat quality was assessed using the 'Habitat Quality' component of the InVEST modeling framework.
Carbon sink element	Carbon sink intensity	Combining the carbon sink coefficient method with GlobeLand30 dataset of the study area, the total carbon sink for a unit land area (100 m × 100 m) was ascertained using the Zonal Statistics and Raster Calculator tools in ArcGIS 10.3 software.

3.4. Implementation of the AHP Method

The AHP method, proposed by American operations researcher Thomas L. Saaty, is a systematic multi-criteria decision-making tool [45]. Its primary aim is to decompose complex issues into a manageable hierarchical structure and use a quantitative paired comparison method to quantify the importance of elements at each level, thereby facilitating scientifically reasonable decision-making. This study selected 10 indicators from four aspects to construct an ecological space recognition system (Figure 2). Initially, by comparing each indicator in pairs and constructing judgment matrices using the 1–9 scale method, the weights of factors at each level were analyzed. Subsequently, the comprehensive ecological space index was computed using the following formula:

$$A = \sum_{i=1}^{m} \omega_i D_i \quad (3)$$

where A represents the comprehensive index of ecological space for a certain area, m is the number of indicators, ω_i is the weight value of indicator i, and D_i is the normalized value of the indicator.

4. Results

4.1. Distribution Characteristics of Land Use in Counties with Different Landform Types

Figure 3 illustrates the spatial distribution of land use patterns in Jingbian, Fuping, and Chenggu counties for the year 2020. The figure distinctly displays substantial variations in the spatial distribution characteristics of land use across counties with different landform types. In Jingbian County, grassland was predominant, covering 60.07% of the total area, indicative of this region's typical plateau meadow landscape. Cultivated land, accounting

for 34.04%, was primarily located in flat areas between gullies, forming terraced agricultural landscapes. Forestland and construction land areas constituted a minimal fraction, neither exceeding 2% of the total area.

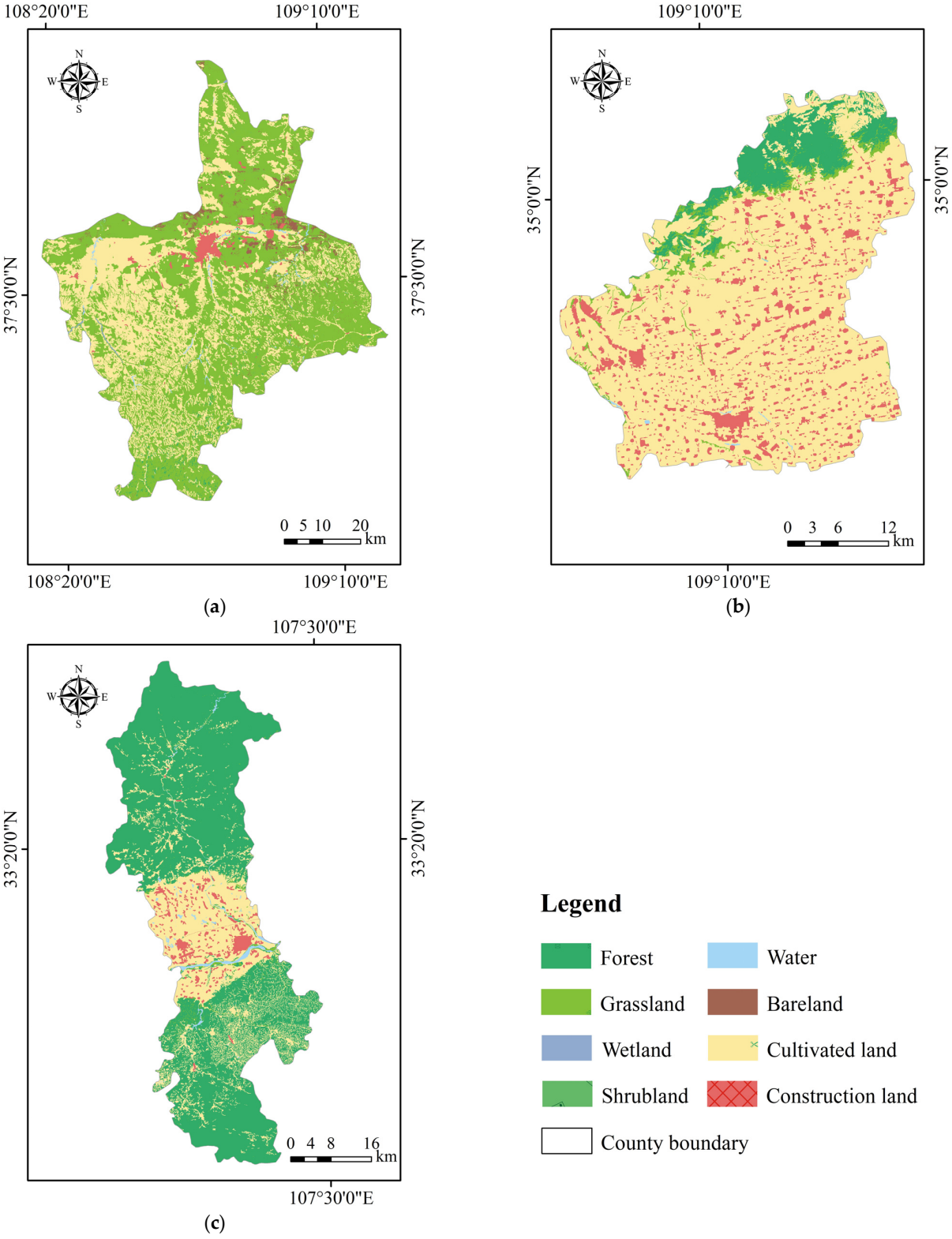


Figure 3. The distribution pattern of land use. (**a**) Jingbian County. (**b**) Fuping County. (**c**) Chenggu County.

In Fuping County, cultivated land was the dominant land use, constituting 76.14% of the total land area, leading to large, contiguous expanses of cropland. Benefiting from fertile soils and superior irrigation conditions, Fuping County emerged as a major commodity grain-producing region. The proportion of construction land areas was relatively high at 11.08%, signifying that those plains in the region primarily served agricultural production and urban expansion. Meanwhile, forestland covered 8.97% of the overall land expanse, concentrated in hilly and mountainous regions in the northern part of the county.

Conversely, Chenggu County was primarily characterized by forestland, occupying 68.98% of the total land area, mainly located in the southern Qinling Mountains and northern Bashan Mountains, featuring predominantly natural forests with crucial ecological protection functions. Cultivated land accounted for 25.36% of the total land area in the county, mainly situated in flat central regions such as valleys and basins. Other land types, including grassland, shrubland, and wetland, had relatively smaller areas. Construction land was limited in the county due to topographical conditions, constituting only 3.15% of the total land area.

4.2. Analysis of Carbon Sink Discrepancies in Counties with Different Landform Types

Table 3 presents the proportions and total amounts of carbon sinks attributed to different land uses in these counties. As observed in the table, there are significant differences in the total carbon sink quantities and structures across counties with varying landform types. Jingbian County, situated on the vast Loess Plateau, features a unique semi-arid continental monsoon climate, leading to a grassland-dominated ecological environment. In 2020, the total carbon sink capacity of Jingbian County was 4.75×10^4 tons, with grassland contributing 86.36% to this total. This substantial contribution highlights the county's reliance on grassland ecosystems for carbon sinks. Forestland played a secondary role, accounting for 7.20% of the carbon sink, while shrubland and water constituted 1.35% and 4.32%, respectively. Wetland and bareland made up a minimal portion of the overall carbon sink.

Table 3. Carbon sink proportions and total carbon sinks across different land uses.

County Name	Carbon Sink Proportion (%)						Total Carbon Sink ($\times 10^4$ t)
	Forest	Grassland	Shrubland	Wetland	Water	Bareland	
Jingbian County	7.20	86.36	1.35	0.76	4.32	0.01	4.75
Fuping County	92.92	6.06	0.00	0.00	1.02	0.00	1.05
Chenggu County	98.45	0.29	0.04	0.00	1.22	0.00	13.52

Fuping County, located on the Guanzhong Plain, presents a stark ecological contrast to the rugged terrain of Jingbian. Fuping County had the smallest total carbon sink amount among the three counties, amounting to 1.05×10^4 tons. Its carbon sink was primarily driven by forestland, which accounted for 92.92% of the total carbon sink, highlighting the dominance of forest in flat plain areas. Contributions from grassland and water were smaller, at 6.06% and 1.02%, respectively. Other land uses contributed minimally to the carbon sink.

Chenggu County, nestled amidst the majestic Qinba Mountains, had the highest total carbon sink capacity among the three counties, reaching 13.52×10^4 tons. The county's carbon sink was almost entirely dependent on forestland, reaching a proportion of 98.45%, underscoring the unique ecological advantage of mountainous regions. This finding confirms the extreme importance of mountain forests as natural carbon reservoirs, emphasizing the critical role of protecting these ecosystems within regional and national dual carbon strategies (Table 3).

Based on the above analysis, it is evident that distinct types of land use demonstrate noteworthy variations in their contributions to carbon sink, which are closely tied to the geomorphic traits and land use configurations within each county. Specifically, in Jingbian County, situated on the Loess Plateau, the prevalence of grassland results in these areas being the foremost contributors to the overall carbon sink capacity. In Fuping County, located in the Guanzhong Plain, where cultivated land, construction land, and forestland constitute the primary land use types, given the carbon-rich nature of cultivated land and construction land, forests emerge as the most significant contributors to carbon sink. Chenggu County, situated in the Qinling Mountains in southern Shaanxi, has a substantial amount of mountainous forestland, resulting in forests contributing the most to the total carbon sink.

4.3. Distribution Characteristics of Ecological Spaces in Counties with Different Landform Types

In this study, the proposed model was utilized to identify ecological space divisions in Jingbian, Fuping, and Chenggu counties. The model allocated weights to various indicators as follows: elevation (0.0104), slope (0.0233), relief degree (0.0711), population density (0.0410), nighttime light intensity (0.0944), traffic network density (0.0225), surface temperature (0.0158), NDVI (0.2013), habitat quality (0.0577), and carbon sink intensity (0.4625). Figures 4 and 5 illustrate the proportions and distribution patterns of ecological spatial zones in counties with varying landform types, respectively.

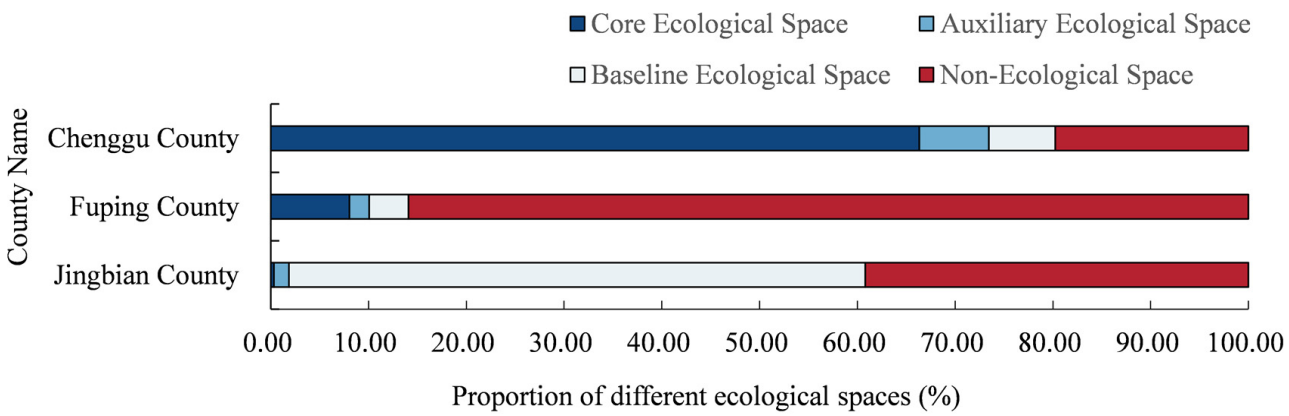


Figure 4. Distribution proportions of ecological spaces in counties with different landform types.

The presented figures demonstrate significant disparities in the distribution characteristics of ecological spaces across counties with varying landform types, revealing unique patterns closely tied to their respective geographical environments. Jingbian County was predominantly characterized by baseline ecological spaces, which exhibited the widest distribution, encompassing 58.96% of the total area. Situated in the loess plateau of northern Shaanxi, Jingbian County faced severe soil erosion and had low vegetation coverage, indicative of a fragile ecosystem. The county showcased intricate erosion patterns and densely distributed gullies, signifying robust regional protection features and relatively minimal human intervention. The proportion of non-ecological spaces was 39.20%, primarily concentrated in densely populated areas and economically vibrant regions, particularly in the central urban core. However, the percentage of core ecological spaces was a mere 0.33%, primarily embedded within the baseline ecological spaces (Figure 4).

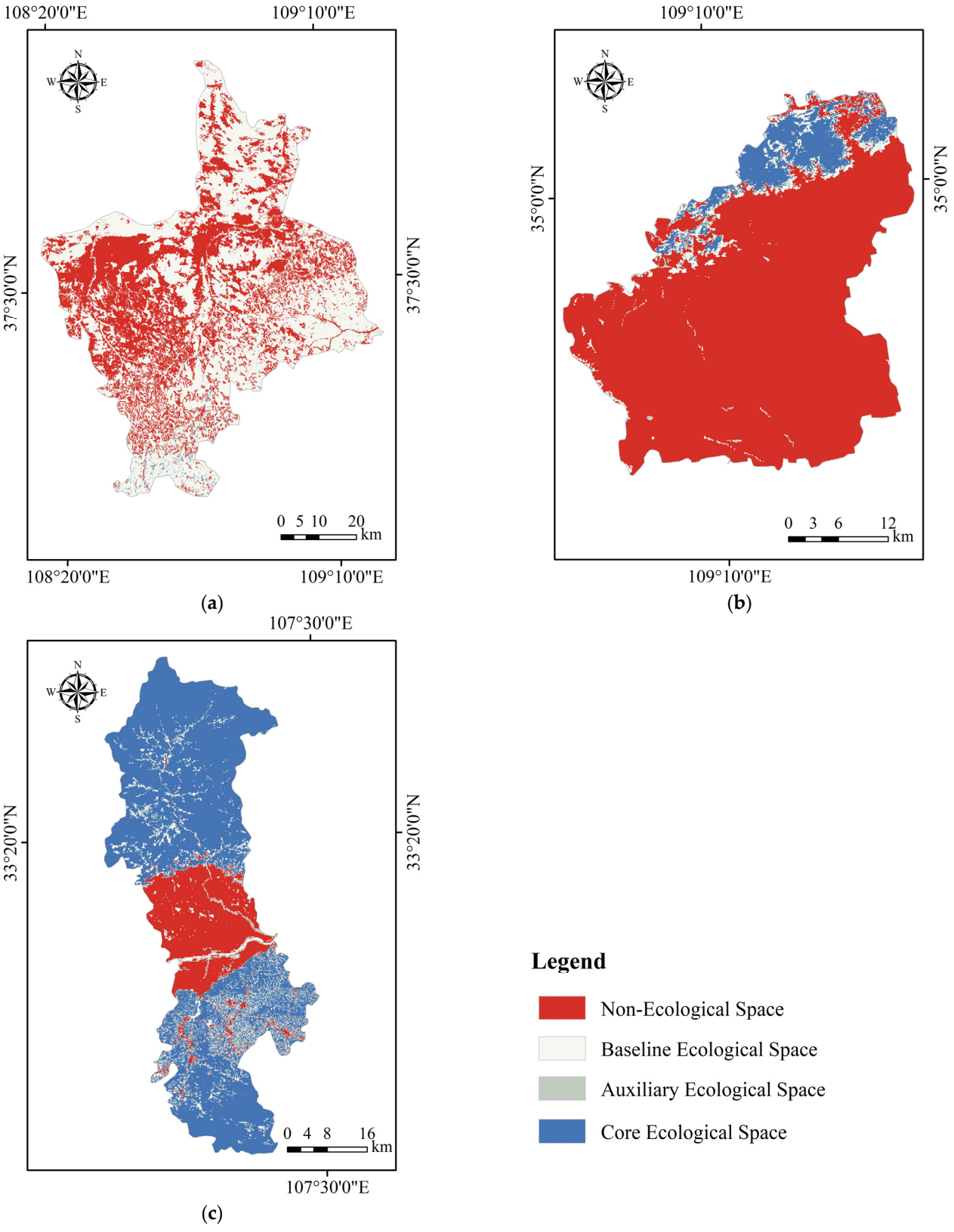


Figure 5. Distribution patterns of ecological spaces in counties with different landform types. (**a**) Jingbian County. (**b**) Fuping County. (**c**) Chenggu County.

In contrast, Fuping County was characterized by the dominance of non-ecological spaces, constituting up to 85.93% of the area, illustrating a county with high population density and intensive land use. Situated in the Guanzhong Plain, the county is characterized by flat terrain, convenient transportation, and frequent socio-economic activities, thereby experiencing significant human impacts. Despite having a modest proportion of core ecological spaces (8.03%) and a limited quantity of auxiliary and baseline ecological spaces (2.02% and 4.02%, respectively), the overall pressure on ecological conservation was substantial. This necessitates heightened attention to regional protection and restoration efforts in future ecological planning and management, aiming to strike a balance between human activities and ecological conservation (Figure 5).

However, Chenggu County, located in the Qinba Mountains, predominantly consists of core ecological spaces, occupying 66.34% of the total area. It also had relatively high proportions of auxiliary (7.10%) and baseline (6.79%) ecological spaces. These ecological spaces were concentrated in the southern Qinling Mountains and the northern Bashan Mountains, underscoring the county's complex mountainous ecosystem with rich biodiversity. Comparatively, non-ecological spaces constituted only 19.77% of the area, mainly concentrated in the Han River Plains at the center of the county. A comparative analysis of these three counties reveals that different landform types directly impact the distribution of ecological spaces, implying the need for region-specific development strategies and optimization measures to achieve dual carbon goals and societal transformation.

5. Discussion

5.1. Carbon Sink Enhancement Strategies of Ecological Spaces in Counties with Different Landform Types

Under the prevailing circumstances of worldwide climate alteration, ecological spaces, integral components of Earth's ecosystems, play a decisive role in achieving dual carbon targets through effective management and optimization [7,46,47]. At the county scale, ecological spaces harbor critical processes in regional carbon cycles, including carbon sequestration, oxygen release, and biodiversity preservation [46,48]. Counties with diverse landform types face unique ecological challenges and conservation pressures due to natural variations and human interventions [8,49,50]. The existing literature often considers ecological spaces within a generic context [51]. This study, however, examines the specific impacts of landform diversity on carbon sinks in land use and integrates carbon sink potential into the framework for identifying ecological spaces. While existing strategies for optimizing ecological spaces have been discussed from multiple perspectives, including natural entity elements, ecosystem services, and ecological security patterns [52–54], they overlook the unique characteristics and conservation opportunities presented by diverse landforms. The potential for carbon sinking varies significantly among counties with different landform types. This variability necessitates a more nuanced and terrain-specific approach to enhancing carbon sinks. Jingbian, Fuping, and Chenggu counties, as representatives of different landform types, each exhibit distinct characteristics in their ecological spaces. Developing and implementing context-specific strategies for optimizing ecological spaces according to unique landform features would be more conducive to sustainable resource utilization and serve as an indispensable means for advancing regional development.

Jingbian County, situated in the Loess Plateau, was predominantly dominated by baseline ecological spaces, signifying a relatively fragile ecosystem. Consequently, strategies aimed at enhancing the carbon sink in Jingbian County should prioritize the protection and restoration of these ecosystems, with particular attention on augmenting grassland

vegetation cover and mitigating soil erosion. Recommended measures for enhancing carbon sink include strengthening grassland management, adjusting agricultural planting patterns, establishing ecological corridors, transitioning cultivated land to forestland and grassland, and developing green energy (Table 4).

Table 4. Carbon sink enhancement strategies of ecological spaces in counties with different landform types.

County Name	Dominant Ecological Space	Optimization Strategies
Jingbian County (Loess Plateau)	Baseline ecological space	(1) Strengthen grassland management: Given that grasslands are the county's primary carbon sink, enhancing their protection and restoration could effectively prevent degradation and desertification, thereby enhancing carbon sink capabilities. (2) Adjust agricultural planting structures: Promote water-saving agriculture and efficient farming techniques, minimize the application of fertilizers and pesticides, and thus increase the carbon storage capacity of cultivated land. (3) Establish ecological corridors: Encourage the creation of new ecological corridors to connect existing ecological spaces, restoring and maintaining the integrity of the ecological network. (4) Convert cultivated land to forestland and grassland: Transform steeply sloped cultivated land and low-yield fields that are unsuitable for cultivation into forestland or grassland to restore vegetation cover, thereby increasing soil fertility and carbon storage. (5) Develop green energy sources: Considering the importance of the energy industry in the area, encourage enterprises to research and adopt green energy, establishing a low-carbon and efficient energy supply system.
Fuping County (Guanzhong Plain)	Non-ecological space	(1) Restrict the sprawl of construction land: Strictly enforce urban development boundaries, improve the efficiency of construction land use, and revitalize existing construction land resources. (2) Expand urban greening and landscape gardening: Strengthen the construction of urban green spaces and build multi-level and multi-type green space systems to enhance the carbon sink capability of urban ecological spaces. (3) Construct high-standard farmland: Considering the high proportion of cultivated land, the stability of the farmland ecosystem can be enhanced through the construction of high-standard farmland, reducing carbon emissions during farmland management. (4) Plan green infrastructure: Integrate green infrastructure concepts into urban and rural planning, scientifically and rationally arrange construction land, and alleviate the encroachment of urban expansion on ecological spaces. (5) Enhance science popularization and publicity: Encourage and educate farmers to participate in low-carbon agriculture and forestry carbon sink practices.

Table 4. *Cont.*

County Name	Dominant Ecological Space	Optimization Strategies
Chenggu County (Qinba Mountains)	Core ecological space	(1) Protect core ecological areas: Give priority to the protection of ecologically sensitive and key areas, such as the Qinba Mountains, to avoid excessive human disturbance. (2) Restore and rebuild ecosystems: Optimize land management systems to improve ecosystem service capabilities, consolidating and enhancing the carbon sink capacities of current carbon sink lands. (3) Adhere strictly to ecological protection red lines: Clearly define the scope of ecological protection red lines, limit the expansion of non-ecological spaces, and rationally plan population distribution and economic activities. (4) Establish carbon sink trading mechanisms: Utilize market forces to incentivize the optimization of land use structure, and support and develop carbon sink industries. (5) Develop ecological tourism: Leveraging the rich forest resources to develop eco-tourism, increase local economic revenue, and promote the protection of ecosystems through sustainable means.

Fuping County, located in the Guanzhong Plain, has been governed by non-ecological spaces and has encountered considerable ecological conservation challenges. Consequently, the carbon sink enhancement strategy for Fuping County should prioritize the optimization of land use structures, curbing carbon emissions from construction land and enhancing the carbon sink potential of cultivated land. It is recommended that Fuping County implement strategies to enhance its carbon sink capacity, such as restricting the sprawl of construction land, expanding urban greening and landscaping, constructing high-standard farmland, planning green infrastructure, and enhancing science education and awareness (Table 4).

Chenggu County, situated in the Qinba Mountains, was dominated by core ecological spaces with relatively intact ecosystems. Thus, strategies for enhancing the carbon sink for Chenggu County should prioritize the protection and augmentation of these existing ecosystems' carbon sink capacity, emphasizing the management of land use types that contribute to carbon sinks. It is recommended that Chenggu County adopt carbon sink enhancement strategies, such as protecting core ecological areas, restoring and rebuilding ecosystems, strictly maintaining ecological protection boundaries, establishing carbon sink trading mechanisms, and developing ecological tourism (Table 4).

Each recommended strategy is devised to align with the specific ecological and geomorphological characteristics of the counties, highlighting a nuanced approach that considers the unique opportunities and conservation challenges presented by their diverse landforms. This tailored strategy development enables a more effective and sustainable enhancement of carbon sinks across diverse territories.

5.2. Advantages and Limitations of Research

This study breaks through the limitations of traditional land use consolidation methods [55] and indicator system calculation approaches [56], thoroughly considering the inherent connections between the multidimensional characteristics of ecological spaces and carbon sink functions, thereby integrating carbon sink elements into the framework for identifying ecological spaces. Expanding upon this groundwork, the research took a unique perspective from the standpoint of landform types, systematically and comprehensively elucidating the varied characteristics in land use structure, carbon sink potential, and ecological space arrangements across different counties. Furthermore, it proposes targeted strategies for enhancing carbon sink tailored to the specific geomorphological

attributes of each county, thus enriching and broadening the research perspective for the optimization of ecological space. Despite its focus on three representative counties within Shaanxi Province, the findings of this study carry potential international reference value. Globally, numerous countries and regions encounter similar challenges in managing and optimizing carbon emissions [57,58]. In pursuit of the carbon reduction goal, the flexible formulation and implementation of carbon sink augmentation strategies based on local conditions emerge as particularly crucial [2,5]. The theoretical framework developed in this study can provide guidance for regions sharing analogous geomorphological features, facilitating their scientific and rational classification of ecological space types and design of adaptive pathways for enhancing carbon sinks. However, the study also has certain limitations, such as the lack of in-depth exploration of the specific challenges that may be encountered in the implementation process of various strategies and their corresponding solutions. Future research should strengthen considerations of the economic and social dimensions, coupled with policy implementation, which will enable a more comprehensively analysis of the adaptability and effectiveness of various carbon sink strategies across varying development stages and environmental conditions.

6. Conclusions

This study extensively explored the zoning of ecological spaces and carbon sink enhancement strategies in counties with different landform types under dual carbon targets. The results show that landform types significantly influence the land use structure, the potential of carbon sink, and the arrangement of ecological spaces within counties. Specifically, Jingbian County in the Loess Plateau primarily relied on extensive grassland ecosystems for carbon sink, with baseline ecological spaces playing a dominant role. In contrast, in Fuping County, a plains region, non-ecological spaces accounted for 85.93% of the area, with the main land use types being carbon-emitting cultivated land and construction land. Chenggu County, however, had a total carbon sink reaching 13.52×10^4 tons, almost entirely relying on mountainous forest land, with core ecological spaces taking precedence. It is advised to adopt suitable and differentiated ecological space carbon sink strategies tailored to the ecological characteristics of counties with different landform types to achieve regional emission reduction and carbon sink enhancement. This study offers practical and feasible solutions and strategies for enhancing carbon sinks across counties with varying landform types, thereby facilitating the achievement of broader ecological conservation and sustainable development goals. Future research should build on the current findings and conduct more detailed analyses of the interactions between different ecological systems within the context of carbon sink optimization.

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Data Availability Statement: All data sources supporting the results of this study are listed in Table 1.

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