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Identification and Optimization of Attractive Territorial Spaces in Gansu Province Based on the Supply-Demand Ratio of Ecosystem Services

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KEYWORDS

Attractive Territorial Spaces, Ecosystem Service Supply-Demand Ratio, Geographic Detector, Landscape Pattern Analysis, Strategy Matrix for Attractive Territorial Spaces

ABSTRACT

High-quality Attractive Territorial Spaces (ATS) are key to enhancing national territorial space quality. This study proposes a systematic framework for identifying and optimizing ATS, integrating ecosystem service (ES) supply-demand analysis, driving factor detection, ATS identification, landscape pattern analysis, and optimization strategies. Key findings include: (1) Significant spatial imbalances in ES supply-demand in Gansu Province, with the west as a vital water source and carbon sink and the east excelling in cultural services. (2) NDVI and population are primary factors driving ES spatial differences, influencing carbon sequestration, recreation, and aesthetic landscapes. (3) Urban and ecological spaces exhibit fragmentation, while agricultural spaces lack diversity and connectivity. The Attractiveness Territorial Index (ATI) aligns with Gansu's spatial planning, providing targeted strategies to improve territorial space value and quality while protecting attractiveness elements.

1. Introduction

As the concept of ecological civilization development becomes deeply rooted in people's hearts, the notion of well-being associated with a good life is also quietly transforming. The pursuit of a good life has transcended the basic satisfaction of material needs (Costanza, et al., 2017), shifting towards a desire for healthy soil, fresh air, clean water, beautiful environments, pleasant climates, and cultural landscapes. The integration of culture and tourism is becoming a new engine for economic growth (Irfan, et al.,2023). In January 2020, the Ministry of Natural Resources issued the "Technical Guidelines for the Preparation of Provincial Territorial Space Planning (Trial)" which mentioned "using the means of territorial space planning, in conjunction with all-for-one tourism, to strengthen the overall protection and shaping of culture and landscapes, and to create high-quality ATS" (Ministry Of Natural Resources,2020). This development trend poses new challenges to regional ecosystems, and the symbiosis and prosperity of culture and ecology have become the core competitiveness of future regional development(Tao, et al.,2022). The identification of ATS integrates multidimensional val-

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ues of ecology, culture, and socio-economics. Although existing methods such as ecosystem service assessment, cultural value assessment, and GIS spatial analysis provide a rich set of analytical tools, there is a lack of a comprehensive evaluation system.

The supply-demand ratio of ES is a key indicator for assessing regional ecological welfare and sustainable development(Gong, et al.,2022). Since the concept of ES was proposed in the 1970s(Hardaker, et al.,2022), its status in academia and policy-making has become increasingly prominent(Dietze, et al.,2019). Existing studies have made significant achievements in the quantification methods of ecosystem service supply and demand relationships(Liu, et al.,2023), spatial flows(Liu, et al.,2024), and policy formulation(Ninan, et al.,2013), but there is still a lack of integration with territorial space planning applications(Tang, et al.,2020). Research has often focused on single types of services(Castro, et al.,2014), and spatial heterogeneity analysis is often limited(Clements, et al.,2017), failing to fully capture the interactions of regional service flows and their impact on the supply-demand ratio(Sun, et al.,2022; Jia, et al.,2023). Additionally, studies on the impact of socio-economic factors on the supply-demand ratio of ES are also insufficient(Castro, et al.,2014; Pistón, et al.,2022), failing to fully reflect the influence of economic development and population structure on the supply-demand ratio(Zhang, et al.,2022). Moreover, much of the existing research is concentrated on theoretical exploration and methodological construction(Chen, et al.,2023), with relatively few empirical studies on specific regions, especially in the western regions of China. As an important province in western China, Gansu Province's research on the supply-demand ratio of ES has significant regional representativeness and practical significance(Nolan, et al.,2008).

Therefore, this paper applies the supply-demand ratio of ES to the identification of ATS, offering a new perspective and methodology for territorial space planning(Chen, et al.,2022). Utilizing cutting-edge optimal parameter geographic detectors(OPGD) (He, et al.,2023), this study explores the driving factors affecting the supply-demand ratio of ES(Zhao, et al.,2024) and the connections between various services(Wang, et al.,2022). Additionally, landscape pattern analysis is conducted using Fragstats (Bhattacharya, et al.,2024). By integrating the natural geography and cultural characteristics of Gansu Province, this study proposes locally adaptive optimization strategies for territorial space (Figure 1). This research constructs an integrated assessment framework that not only considers the supply and demand of ES but also takes into account cultural, social, and economic factors, providing a new tool for comprehensive assessment and planning of ATS.

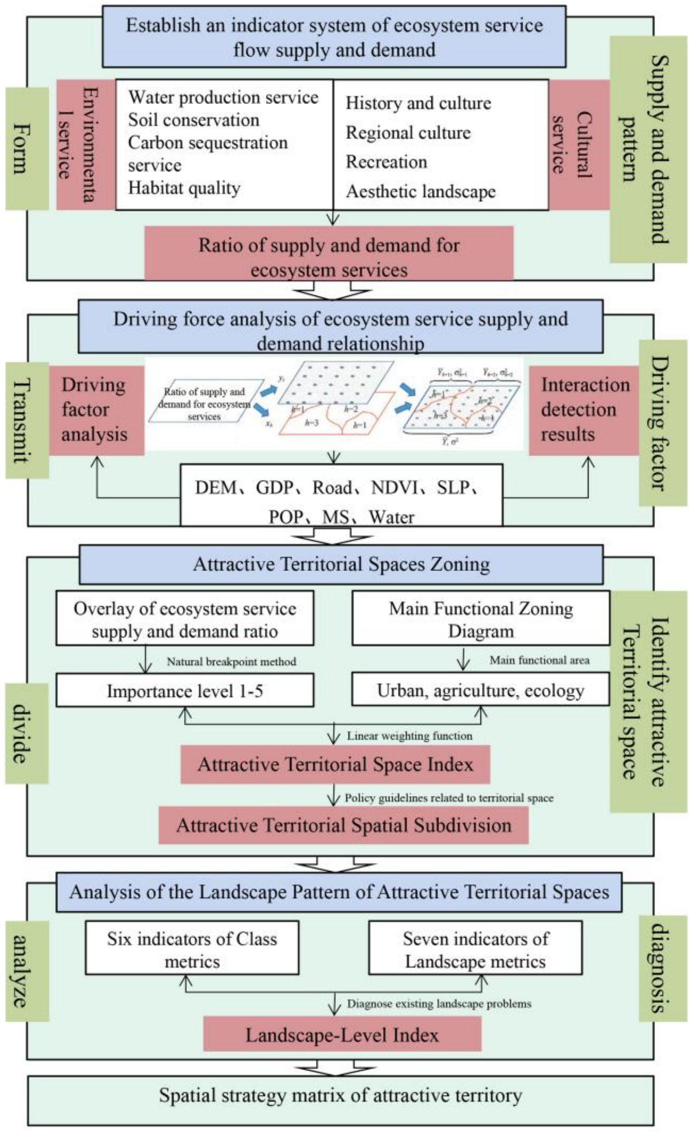

Figure 1 I The workflow of this study

2. Research Methods and Data Sources

2.1. Overview of the Study Area

Gansu Province (32°11′—42°57′N, 92°13′—108°46′E) is located in the northwest of China and boasts a rich diversity of terrain and climate. It is an important province in Western China, with 14 prefecture-level administrative divisions, including 12 cities and 2 autonomous prefectures, comprising a total of 86 counties. Gansu Province covers an area of ap-

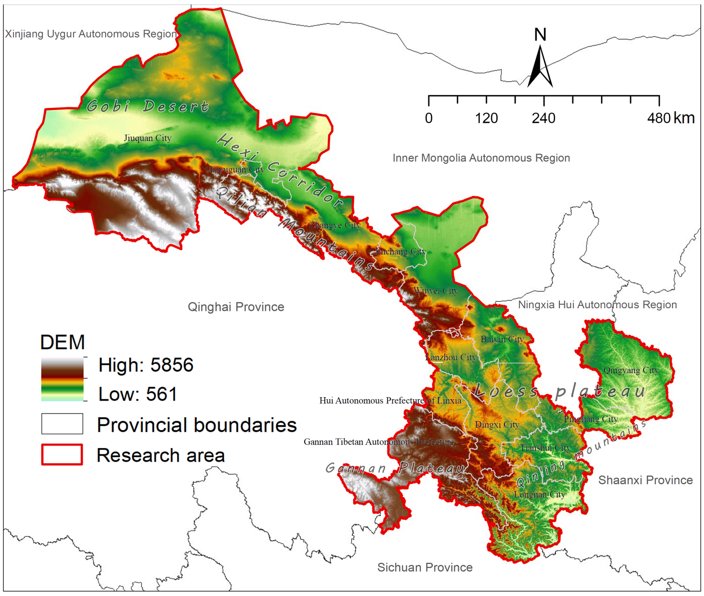

Figure 2 I Gansu Province Administrative Divisions Topographic Map

proximately 425,800 square kilometers and includes a variety of terrains such as the Qilian Mountains, the Loess Plateau, the Hexi Corridor, the Gannan Plateau, the Gobi Desert, and the Qinling Mountains.(Song, et al.,2023)(Figure 2), with a temperate continental climate characterized by decreasing precipitation from southeast to northwest. Gansu is not only a significant node of the Yellow River civilization and the Silk Road but also a testament to the integration of multi-ethnic cultures and the history of red culture and religious culture. Its cultural landscapes range from the Mogao Caves in Dunhuang to the Tibetan customs in Gannan(Yu, et al.,2022), showcasing the fusion of history and modernity. However, the province faces ecological pressures, and there is a contradiction between economic development and environmental protection(Li, et al.,2019), especially in ecologically fragile areas where resource development impacts the supply of ES(Lv, et al.,2019).Therefore, this article will conduct identification and optimization research of ATS in Gansu Province, based on its topographical features and zoning.

2.2. Data Sources

All data selected for this study were based on the time point of 2020, with spatial resolution for gridded data set at 30m×30m. The coordinate system was uniformly corrected to the WGS_1984_Albers projection coordinate system (Table 1).

2.3. Research Methods

2.3.1. Assessment of Ecosystem Service Supply and Demand

This study, taking into account literature references and data availability, selects four environmental service indicators including water yield(WY), SC, CS, and habitat quality(HQ)(Wei, et al.,2023), as well as four cultural service indicators such as historical culture(HC), regional culture(RC), RE, and AL(Ghasemi, et al.,2023), to form the ecosystem service supply index system (Table 2). For the assessment of ecosystem service supply, this study employs a physical quantity evaluation method, particularly the InVEST and MaxEnt models, to objectively reflect the structure and function of ecosystems. Through spatial mapping of these models(Regamey, et al.,2015), this

Table 1 I Data sources

Data	Source
Precipitation data and potential evapotranspiration data	National Tibetan Plateau Scientific Data Center（http://data.tpde.ac.cn）
Spatial distribution data of soil types	Geographic data platform, School of Urban and Environmental Sciences, Peking University(http://geodata.pku.edu.cn)
Digital Elevation Model (DEM), NDVI, land use, administrative boundaries, road network, POP and Gross Domestic Product (GDP) grid data	Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences（https://www.resdc.cn/）
Historical and cultural sites, intangible cultural heritage, service points, green parks POI (Point of Interest) data	Peking University open research data platform（https://doi.org/10.18170/DVN/WSXCNM）

study quantifies the supply of ES in Gansu Province and constructs an integrated supply pattern of ES by normalization and weighted overlay.

Ecosystem service demand reflects the dependence and requirements of humans on ecological services. In this study, a method combining the land use intensity index with socio-economic indicators is employed to construct an ecosystem service demand index (Yan, et al.,2023). This index quantifies the demand for ES by human activities, reveals the dependency on ecological services in different regions, and comprehensively considers socio-economic development and population distribution, providing a new analytical tool for ecological protection and sustainable development strategies. The formula is as follows:

$$ESD = LDI \times ln(POP + 1) \times ln(GDP + 1) \quad (1)$$

$$LDI = 100 \times \left(\sum_{i=1}^{n} P_i \times Q_i \right) \quad (2)$$

Table 2 | Assessment of ES supply

ES	Principle and method	Calculation process	Used data
WY	InVEST model Annual WY module	$WY = P - (Q + E + S + GW)$ In the equation, WY represents the quantitative result of water conservation function, P represents rainfall, Q represents surface runoff, E represents evapotranspiration, S represents the change of soil water content, and GW represents the groundwater recharge.	Precipitation data, land use data
SC	InVEST model Sediment Delivery Ratio module	$SD = RKLS - ULSE$, $RKLS = R \times K \times LS$, $USLE = R \times K \times LS \times C \times P$ In the formula, R represents the factor of rainfall erosivity; K represents the factor of soil erodibility; LS represents the factor of slope length; C corresponds to the factor of vegetation cover; and P indicates the factor of SC measures.	Soil type spatial distribution data, land use data
CS	InVEST model Carbon Storage and Sequestration module	$C_{total} = C_{above} + C_{below} + C_{soil} + C_{dead}$ Where: C_{above} is the amount of carbon stored on the ground; C_{below}x is the underground carbon storage; C_{soil}x is soil carbon storage; C_{dead}x is dead organic carbon storage.	NDVI data, land use data
HQ	InVEST model HQ module	$quality = \sum (sensitivity * threat\ distance)/(1 + protection)$ Where: quality represents the quality of the habitat, sensitivity represents the sensitivity of each habitat type to each threat, threat distance represents the distance between the grid cell and the threat, and protection represents the level of legal protection the cell receives.	DEM, slope and aspect data, land use data
HC	MaxEnt model	$H(P) = -\sum_{x \in X} P(x) \ln P(x)$ Where: H (P) represents the entropy of random variable X; P (x) is the probability that the random variable X is X;X is the set of all possible values of the random variable X;log represents the natural logarithm (the logarithm base e).	Environmental variable data: DEM, NDVI, land use, administrative boundary, road network, POP and GDP grid data, microblog evaluation POI data Model data: historical and cultural sites, intangible cultural heritage, service points, green park POI data
RC	MaxEnt model		
RE	MaxEnt model		
AL	MaxEnt model		

Where: ESD serves the needs of the ecosystem; POP and GDP are POP density and per capita GDP respectively. LDI is the comprehensive land use intensity index. P_i is the grade i land use intensity (i=1,2,3,4); Q_i is the percentage of area occupied by Class i land use type; n is the classification number of land use intensity.

2.3.2. Ecosystem Service Supply-Demand Ratio

To analyze the relationship between the supply and demand of ecological and cultural services in Gansu, the supply-demand ratio of ES is used to represent the proportional relationship between the services provided by ecosystems and the demand for these services by human society (Li, et al.,2016). The formula is as follows:

$$ESDR = \frac{S - D}{\left(S_{max} + D_{max}\right)/2} \tag{3}$$

Where, ESDR is the supply and demand ratio of ES, S is the supply amount of ES, D is the demand for ES, S_{max} is the maximum supply amount of ES, and D_{max} is the maximum demand for ES. When ESDR >0, supply is greater than demand. When ESDR =0, supply equals demand. When ESDR <0, supply is less than demand.

2.3.3. Geographic Detector

The geographic detector is a tool based on the theory of spatial distribution consistency, developed by Wang Jinfeng and colleagues (Wang, et al.,2010), which is used to detect the spatial heterogeneity of geographical phenomena and to explain the underlying driving forces. It includes four types of detectors: risk detector, factor detector, ecological detector, and interaction detector. Prior to applying this method, continuous data must be discretized. Song Y and colleagues (Song, et al.,2020) proposed an OPGD that optimizes the discretization process of spatial data and the spatial scale of spatial analysis, determining the best parameter combination for the geographic detector model. This study employs "natural," "quantile," and "geometric" three discretization methods to discretize continuous driving factors, The reasons for selecting these three classification methods are rooted in their unique strengths and complementary nature in data processing. The natural breakpoint classification emphasizes the natural grouping of data, the quantile classification ensures balanced sample sizes, and the geometric classification maintains consistent interval widths. By employing these three methods in combination, we are able to analyze the influence of driving factors on the spatial heterogeneity of ecosystem service supply and demand ratios from multiple angles, thereby furnishing the Geographic Detector model with more comprehensive and precise input data.

2.3.3.1. Factor Detection.

Used to test the spatial heterogeneity of ecological environment quality Y , and to detect the driving factor X that explains the spatial heterogeneity of ecological environment quality Y . The degree of explanation is measured by the q value, with the formula as follows:

$$q = 1 - \frac{\sum_{i=1}^{K} S_i \sigma_i^2}{S\sigma^2} \tag{4}$$

Where, i=1, …, K represents the number of categories for the driving factor X_n; S_i is the number of samples in the i category; S is the total number of samples; σ_i^2 is the variance of the i category; σ^2 is the variance of the ecosystem service supply-to-demand ratio Y. $q \in [0,1]$, the larger the q value corresponding to the driving factor X_n, the stronger its explanatory power for the ecosystem service supply-to-demand ratioY.

2.3.3.2. Interaction Detection

It is used to identify the types of interactions between different driving factors X_n and to determine whether the explanatory power of two driving factors acting together on the ecosystem service supply-demand ratio Y is mutually enhancing, mutually diminishing, or independent. The main types of interaction include non-linear enhancement, independence, dual-factor enhancement, single-factor non-linear reduction, and non-linear reduction.

2.3.4. Identification of ATS

Drawing from the established methods for dividing ATS within the context of territorial spatial planning as referenced in existing literature (Zhang, et al., 2012; Wang, et al., 2021; Zheng, et al., 2017; Li, et al., 2020), this study proposes an Attraction Territorial Index (ATI) from the perspective of the supply-to-demand ratio of ES. The index utilizes the supply-to-demand ratios of various ES as indicators and employs a weighted sum overlay method in ArcGIS.The index uses the supply and demand ratio of various ecosystem services as the index, adopts the weighted sum superposition of ArcGIS, and uses the analytic Hierarchy Process (AHP) to scientifically determine the weight of each index. Specifically, the weights of the indicators were assigned as follows: WY 20%, SC 15%, CS 15%, HQ 10%, HC10%, RC10%, RE10%, and AL10%. In view of the drought conditions and soil erosion problems in Gansu Province, water production services, soil conservation, and carbon sequestration services were assigned higher weights to reflect their relative importance under specific regional conditions in Gansu Province.

The natural breaks method is used to categorize the supply-to-demand ratio map of ES into five classes:Supply<<Demand,Supply<Demand,Supply=Demand,Supply>Demand,Supply>>Demand.Subsequently, the primary functional areas of Gansu Province's territorial spatial planning (Li, et al., 2022) are weighted and overlaid, with the weights oriented towards ecological priority, specifically for urban development areas, main agricultural product areas, and key ecological function areas. The linear weighted function is utilized to calculate the Attraction Territorial Index. Finally, the division of ATS is determined according to the relevant policy guidelines for territorial spatial planning.

2.3.4.1.Matrix of Ecosystem Service Supply-To-Demand Ratio Overlay With Primary Functional Areas

The division of ATS categorizes urban development areas as follows: areas where Supply<<Demand are designated as Urban Charm Potential Zones, areas where Supply< Demand are recognized as Ecological Charm Nurturing Zones, and areas where Supply≥Demand are identified as Urban Charm Development Zones. This method of division accommodates the future urban development in China, which is anticipated to devolve to county-level economies. It provides flexibility for the future trajectory of urban growth.

In the primary agricultural product areas, areas where Supply < Demand are defined as Agricultural Charm Potential Zones, areas where Supply=Demand are Agricultural Charm Nurturing Zones, and areas where Supply>Demand are Agricultural Charm Development Zones. This division implements the primary functional zoning and the permanent agricultural red line within the territorial spatial planning of Gansu Province, ensuring food security.

For key ecological function areas, areas where Supply<Demand are classified as Ecological Charm Potential Zones, areas where Supply=Demand and Supply>Demand are considered Ecological Charm Nurturing Zones, and areas where Supply>>Demand are Ecological Charm Development Zones. This method prioritizes ecology, focusing on the protection and nurturing of the diverse and fragile ecological environment of Gansu Province. The southern region,

Table 3 I Matrix Overlaying the Ratio of Ecosystem Service Supply to Demand with Primary Functional Zones

	Supply << Demand (1)	Supply < Demand (2)	Supply = Demand (3)	Supply > Demand (4)	Supply >> Demand (5)
Urban Development Area 1	Urban Attractive Potential Area (UA_1)	Urban Attractive Nurturing Area (UA_2)	Urban Attractive Development Area (UA_3)	Urban Attractive Development Area (UA_4)	Urban Attractive Development Area (UA_5)
Main Agricultural Product Area 2	Agricultural Attractive Potential Area (AA_2)	Agricultural Attractive Potential Area (AA_3)	Agricultural Attractive Nurturing Area (AA_4)	Agricultural Attractive Development Area (AA_5)	Agricultural Attractive Development Area (AA_6)
Key Ecological Function Area 3	Ecological Attractive Potential Area (EA_3)	Ecological Attractive Potential Area (EA_4)	Ecological Attractive Nurturing Area (EA_5)	Ecological Attractive Nurturing Area (EA_6)	Ecological Attractive Development Area (EA_7)

with its stable and superior ecological conditions, is positioned for development.

2.3.4.2.Index of ATS

$$\mathrm{ATI} = \sum_{i=1}^{n} \left(X_i \times \mathrm{T}_j \right) \quad (5)$$

Where, ATI represents the Ecological Problem Index, $\mathrm{X_i}$ denotes the standardized ecosystem service supply-to-demand ratio,n is the number of ecosystem service supply-to-demand ratio indicators, and $\mathrm{T_j}$ signifies the weights of the various ecosystem service supply-to-demand ratio indicators. A higher ATI value indicates a higher Index of ATS, and vice versa.

2.3.5..Landscape Pattern Indices

Landscape indices refer to quantitative measures that encapsulate detailed information about landscape patterns, categorized into class-level indices, patch-level indices, and landscape-level indices. In this study, Fragstats software is utilized to analyze the landscape pattern indices of the partitioned ATS, to diagnose existing landscape issues within these spaces, and to inform strategic proposals. Drawing from relevant research (Hu, et al.,2023; Wu, et al.,2024), this paper selects six Class metrics including Number of Patches (NP), Patch Density (PD), Landscape Division Index (DIVISION), Aggregation Index (AI), Landscape Shape Index (LSI), and Patch Cohesion Index (COHESION) (Shen, et al.,2015), as well as seven Landscape metrics comprising NP, PD, DIVISION, AI, LSI, COHESION, and Shannon's Diversity Index (SHDI).

2.3.6.Strategy Matrix For ATS

Based on the landscape pattern analysis from the previous sections that identified landscape issues within the existing ATS, a strategy matrix for ATS is proposed, focusing on three types of spaces: ecological, agricultural, and urban. This matrix serves as a model for pattern optimization and the formulation of planning strategies. The horizontal axis of the matrix represents the divided ATS, while the vertical axis represents the three aforementioned types of spaces. The development of strategies aims to leverage the flow and connectivity of the supply and demand relationships of ES. Integrated with the high-quality attractive spatial structure diagram of Gansu Province's territorial spatial planning, the matrix ensures that the three types of spaces prioritize ecology, sustainable development, and comprehensive enhancement. This constitutes the planning strategy.

3. Research Results

3.1. Supply Pattern of ES

The pattern of ecosystem service provision in Gansu Province is significantly uneven and influenced by topographical characteristics, with notable differences between the eastern and western regions (Figure 3). In the western region, taking the Qilian Mountains as an example, the high altitude and abundant precipitation lead to limited water production services, weak soil retention capacity, but rich CS and cultural services. In the eastern region, represented by the Loess Plateau and valley landforms, the lower terrain and poor soil permeability result in low water production service provision, and the soil retention service faces challenges. However, the region is rich in historical and cultural landscapes, with prominent cultural service provision.

Specifically, the plateau area is the main provider of water production services, while the valley and Loess Plateau areas are deficient in water production service provision. The Loess Plateau and the middle and lower reaches of the Yellow River have lower soil retention service provision, while the Qilian Mountains and the forest areas of the Loess Plateau have strong CS capabilities. Ecologically sensitive areas such as the Qilian Mountain National Park provide good HQ. In terms of historical and cultural services, heritage sites such as the Mogao Caves in Dunhuang and the Maijishan Grottoes make significant contributions, and ethnic minority areas such as Gannan Tibetan Autonomous Prefecture have an important impact on the provision of regional cultural services. For leisure and entertainment resources, natural and cultural attractions such as the Zhangye Danxia landform, the Fuximiao Temple in Tianshui, as well as natural beauty and cultural landscapes like the Qilian Snow Mountain and the Yellow River Gorge, provide people with rich aesthetic and recreational enjoyment.

3.2. ES Demand Pattern

The distribution of ecosystem service demand in Gansu Province is significantly influenced by per capita GDP, POP density, and the intensity of land use (Figure 4). The area surrounding Lanzhou City,

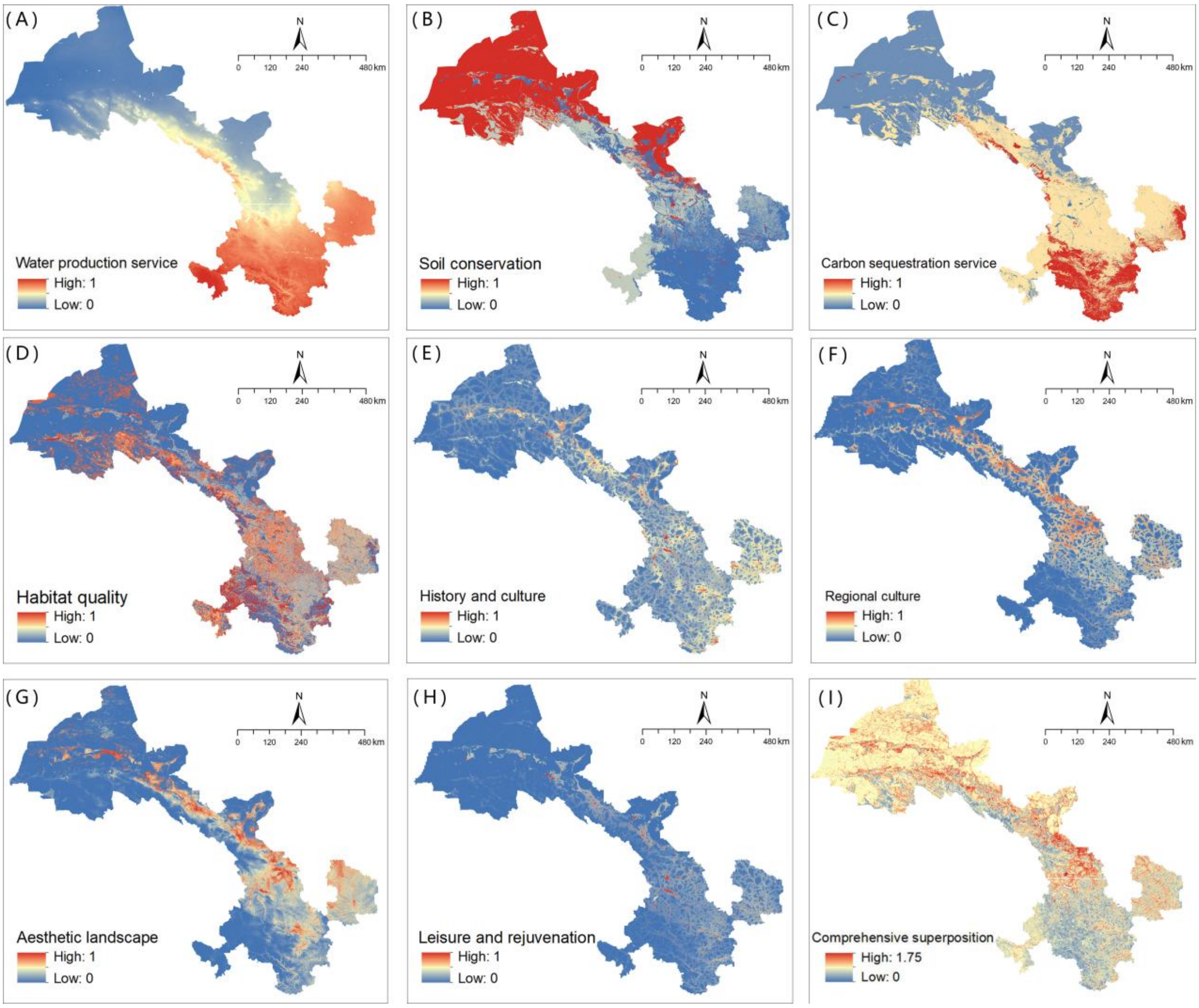

Figure 3 | Supply pattern of ES in Gansu Province

due to its high per capita GDP, advanced economic development, high POP density, and level of urbanization, exhibits an urgent demand for ES. Metropolitan areas such as Lanzhou and Tianshui, along with their surrounding regions, have a high POP density, and residents have a substantial demand for water resources, green space for RE, and biodiversity conservation. POP growth also exacerbates the pressure on the supply of ES. With the advancement of urbanization and industrialization, especially in the eastern region and Lanzhou City, the intensity of land use has increased, leading to a reduction in ecosystem service provision, such as the decrease in green spaces and the destruction of habitats, directly affecting the demand pattern, particularly in terms of land management and environmental quality improvement.

The demand for ES in Gansu Province shows regional differences. The economically developed and densely populated areas surrounding Lanzhou City have a significant demand for water resources and environmental improvement. Other relatively economically developed medium and small cities, such as Tianshui and Zhangye, also face similar demands and need to balance economic development with resource protection. The demand in nature reserves and sensitive areas is concentrated on biodiversity and water source conservation. Tourism-rich areas like Dunhuang require historical and cultural protection as well as the improvement of the tourism environment. Agricultural areas such as the Hexi Corridor need soil retention and water resource supply. Overall, the demand for ES in Gansu Province is mainly concentrated in cities with rapid economic development, ecologically sensitive areas, regions rich in tourism resources, and agricultural concentration areas, reflecting the province's urgent need to seek a balance between economic and cultural development and ecological protection.

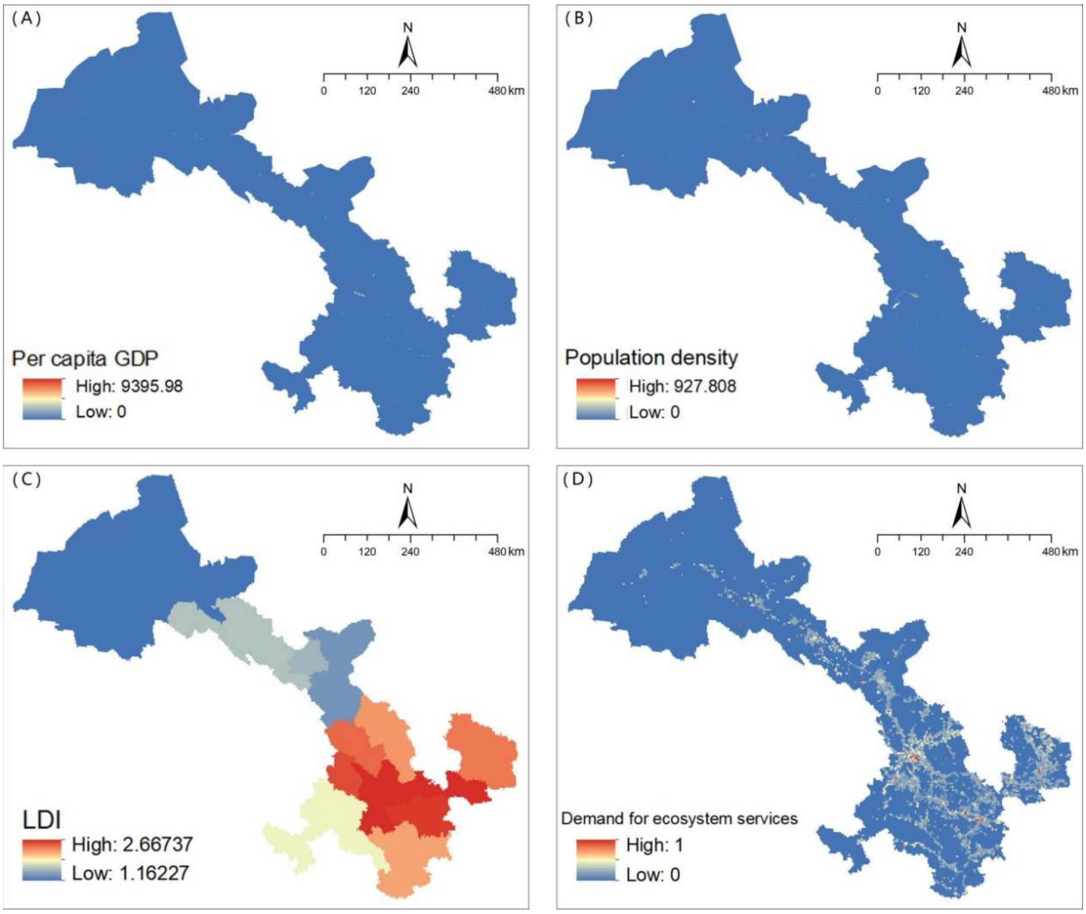

Figure 4 | Demand pattern of ES in Gansu

3.3. Analysis of the Supply and Demand Relationship of ES

The analysis of the supply-demand ratio of ecosystem services in Gansu Province, as revealed by the ArcGIS-generated supply-demand ratio map (Figure 4), is categorized based on the six major terrains that dominate the province's landscape (Figure 2).

Qilian Mountains: Located in the northwest of Gansu Province, the Qilian Mountains, with their steep peaks and vast glaciers, provide abundant WY services. This results in a supply-demand ratio represented by lighter red or orange colors, indicating a surplus of supply. The region's rich vegetation cover and minimal human disturbance contribute to higher supplies of SC and CS services compared to demand, with supply exceeding demand. The richness of biodiversity ensures a high supply of HQ, with the supply-demand ratio indicating a surplus, represented by red. The supply of HC and RC services is moderate. However, due to the region's remoteness and poor transportation, demand is low, resulting in a lighter red or orange supply-demand ratio. The supply of AL and RE services is moderate, limited by the level of economic development and infrastructure. Consequently, demand has not yet been fully developed, resulting in a red or orange supply-demand ratio.

Loess Plateau:Mainly distributed in the eastern and central parts of Gansu Province, covering about 24.9% of the province's land area, the Loess Plateau is divided into the eastern and central sections, each exhibiting different supply-demand relationships.Eastern Loess Plateau: Located in the eastern part of Gansu Province, including cities like Qingyang and Pingliang, the climate is mild with slightly higher precipitation, leading to WY supply greater than demand. However, due to severe loess erosion, the supply of SC services is insufficient, with the supply-demand ratio also showing a light blue color. The supply of CS and HQ is relatively good. The supply of cultural services is rich, with moderate demand, resulting in a red supply-demand ratio.Central Loess Plateau: Located in the central part of Gansu Province, including parts of Dingxi, Lanzhou, Baiyin, and Tianshui, the climate is more arid, making WY supply limited, with the supply-demand ratio slightly showing an imbalance. Complex terrain exacerbates soil and water loss, making the supply-demand shortage of SC services more acute. CS and HQ have been improving in recent years due to environmental attention, with the supply and demand being in balance. The supply of historical and cultural services is rich, but due to the more central location, the demand for cultural tourism development is higher, resulting in a red to light yellow supply-demand ratio, indicating opportunities for sustainable use of cultural resources.

Gannan Plateau:Located in the southwestern part of Gansu Province, the Gannan Plateau benefits from precipitation and snowmelt, providing a high supply of WY services. With a sparse population, the demand is relatively low, and the supply-demand ratio shows an adequate supply. The high-altitude meadows and wetlands offer strong SC and CS capabilities, with the supply-demand ratio also indicating an adequate supply. The richness of biodiversity ensures a high supply of HQ, with the supply-demand ratio showing an adequate supply. Tibetan culture provides moderate supplies of HC and RC services, but due to insufficient tourism development, demand is low, resulting in a gray-green supply-demand ratio. The supply of AL and RE services is gray-green, indicating potential for economic development and infrastructure construction in the region.

Hexi Corridor:Located on the eastern side of the Qilian Mountains, stretching about 1000 km from east to west, the Hexi Corridor is a natural geographical corridor and an important agricultural and population concentration area in Gansu Province. Relying on the meltwater from the Qilian Mountains, the WY service supply is sufficient, but the arid climate and agricultural irrigation demands result in a supply-demand ratio slightly favoring demand. SC and CS services are influenced by vegetation cover and land use changes, and with increased ecological protection awareness, the supply-demand ratio is relatively balanced. HQ is positively affected by nature reserves, with the supply-demand ratio indicating an adequate supply. As a crucial part of the ancient Silk Road, the Hexi Corridor has rich natural and cultural services. With the development of cultural tourism and the economy, the demand is increasing, and the supply-demand ratio shows an adequate supply with development potential.

Gobi Desert:Located in the northwest of Gansu Province, including areas around Dunhuang in the Jiuquan region, northern Zhangye, surrounding Jiayuguan and Wuwei, and areas around Jinchang, the Gobi Desert faces tight WY service supplies, with the supply-demand ratio tending to lower levels. Due to the extremely arid climate and rich mineral resources, the supply of SC services is adequate. However, low vegetation cover leads to insufficient CS and HQ supplies, and with sparse population and lower economic development, demand is also low, resulting in a supply-demand ratio tending to lower levels. The unique landscapes of the Gobi Desert provide certain AL values, with moderate supply but low demand due to underdevelopment, resulting in a supply-demand ratio that is low except for key scenic areas like Dunhuang and Jiuquan, which have adequate supplies.

Qinling Mountains:Located in the southeast of Gansu Province, including the southeastern part of Tianshui, the northern and eastern parts of Longnan, and the southeastern counties of Pingliang like Zhuanglang and Huating, the Qinling Mountains have abundant precipitation and dense forests, providing a solid basis for WY services. With moderate population and economic demands, the supply-demand ratio shows an adequate supply. The rich vegetation cover and mountainous terrain ensure a high supply of SC services, matching moderate demands from agricultural activities and urbanization, resulting in a balanced supply-demand ratio. The diversity of vegetation contributes significantly to CS and HQ, with the supply-demand ratio indicating an adequate supply. The supply of HC and RC services is moderate, aligning with the growing demand from cultural tourism development. The supply of AL and RE services is high due to unique natural landscapes, matching the increasing demand from eco-tourism, indicating potential for development.

3.4. Analysis of the Driving Forces of Ecosystem Service Supply and Demand Relationship

3.4.1. Selection of Driving Factors

The factor detection using the Geographic Detector can determine to what extent the driving factors explain the spatial differentiation of the supply and demand ratio of various ES. The selection of driving factors takes into account the impact of natural factors and human activities on ES. Preliminary selection included 8 representative driving factors: DEM, GDP, Distance to Roads (DR), NDVI, Slope (SLP), POP, Mountain Shadow (MS), and Water Distance (WD). Ecological detection indicated that all 8 driving factors significantly affect the supply and demand ratio of ES, thus proceeding with the following analysis.

3.4.2 Analysis of Driving Factors

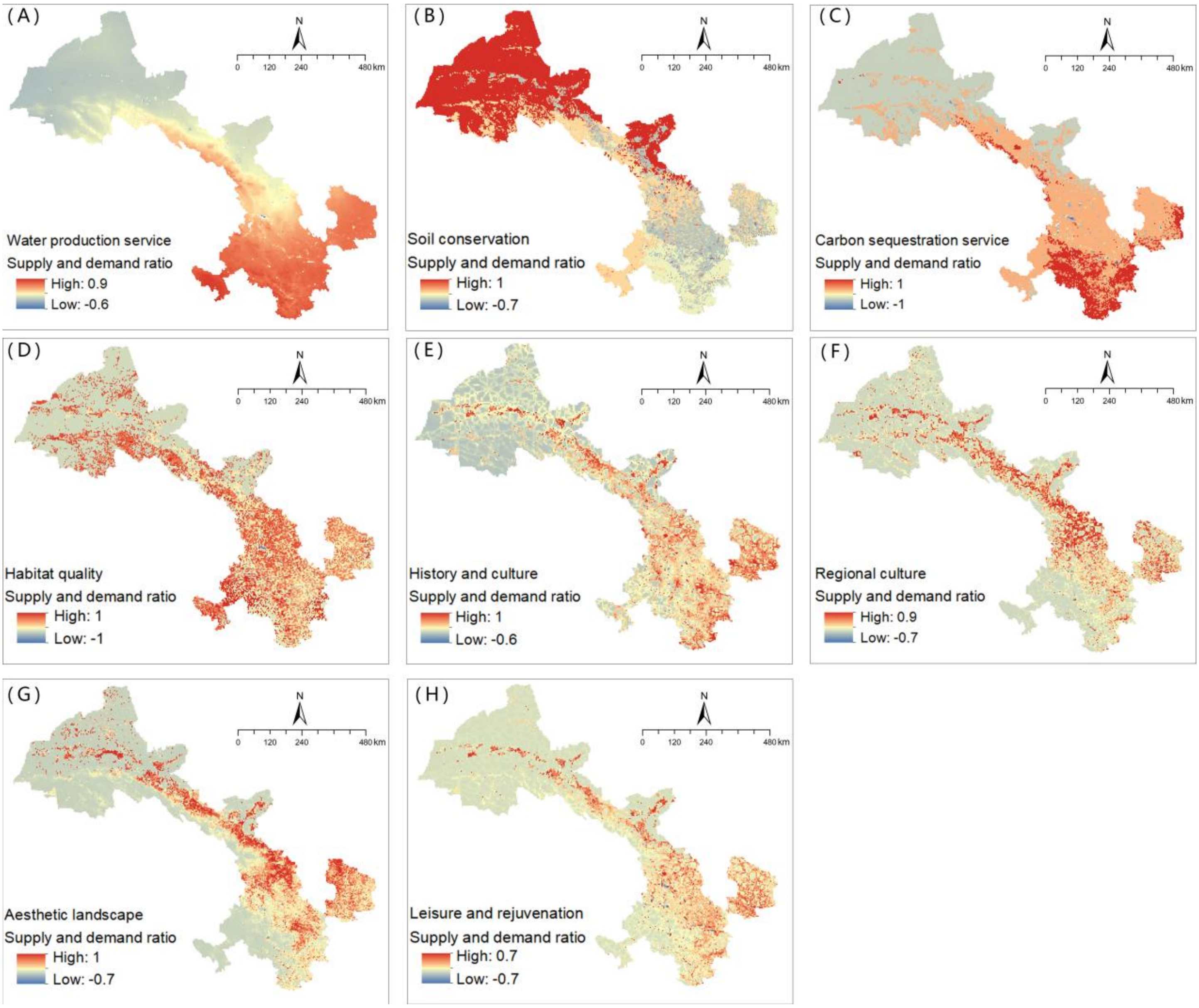

Figure 5 l Distribution of ES supply and demand in Gansu Province

Based on the OPGD, the correlation analysis between the ecosystem service supply and demand ratio (Y) and multiple geographical environmental and socio-economic driving factors (X) revealed the contribution of each driving factor to the spatial heterogeneity of ES, as shown in Table 4 and Figure 6:NDVI has an extremely high explanatory power for CS, with a correlation coefficient as high as 0.6509, highlighting the fundamental role of vegetation cover in the carbon cycle process of ecosystems;POP's explanatory power for RE and AL is also significant, with correlation coefficients of 0.2630 and 0.1998, respectively, indicating that the density of POP distribution significantly affects the social demand and utilization patterns of these services;GDP, as an indicator of regional economic development level, has a correlation coefficient with RC and HC of 0.1046 and 0.1010, respectively, reflecting the indirect role of economic development on the spatial heterogeneity of supply and demand for cultural ES;the positive correlation between DR and HQ, with a correlation coefficient of 0.0839, reveals the positive link between accessibility to biodiversity conservation areas and HQ maintenance by transportation infrastructure;the correlation coefficients of DEM with RE and AL are 0.0673 and 0.0439, respectively, reflecting the potential role of topography on the supply of these services.The correlation coefficient between SLP and HC is 0.0127, showing the role of topographical factors in the protection of historical and cultural heritage.However, the correlation between WD and WY is extremely low, with a coefficient of 0.0008, indicating that WD has a

Table 4. Driver factor detection results table

variable	WY	SC	CS	HQ	HC	RC	RE	AL
DEM	0.0439	0.0541	0.0055	0.0554	0.0563	0.0673	0.0439	0.1312
GDP	0.1010	0.1391	0.1992	0.0122	0.0656	0.1046	0.1010	0.1152
DR	0.0316	0.0588	0.0020	0.0170	0.0460	0.0839	0.0316	0.0305
NDVI	0.1185	0.6509	0.0155	0.1921	0.1233	0.1693	0.1185	0.1870
SLP	0.0059	0.1566	0.0008	0.0508	0.0054	0.0127	0.0059	0.0056
POP	0.1998	0.4929	0.2424	0.0902	0.1401	0.2630	0.1998	0.2425
MS	0.0022	0.0898	0.0005	0.0261	0.0028	0.0065	0.0022	0.0015
WD	0.0089	0.0287	0.0004	0.0141	0.0116	0.0008	0.0089	0.0024

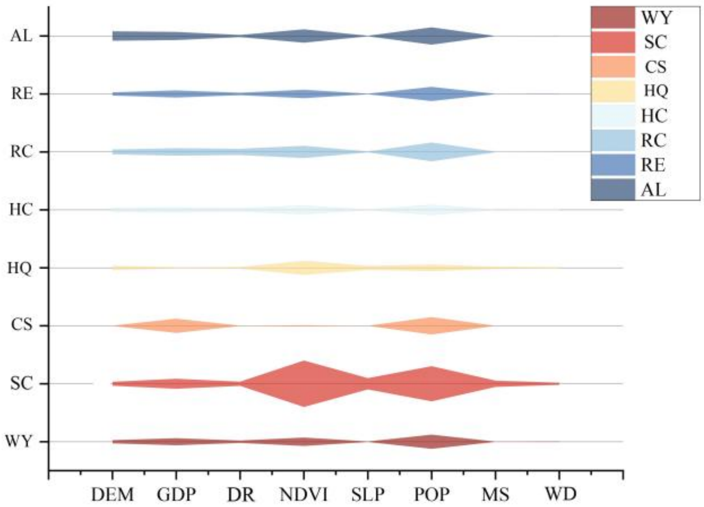

Figure 6 I Gansu Ecosystem Service Supply-Demand Ratio and Driving Factor Association Map

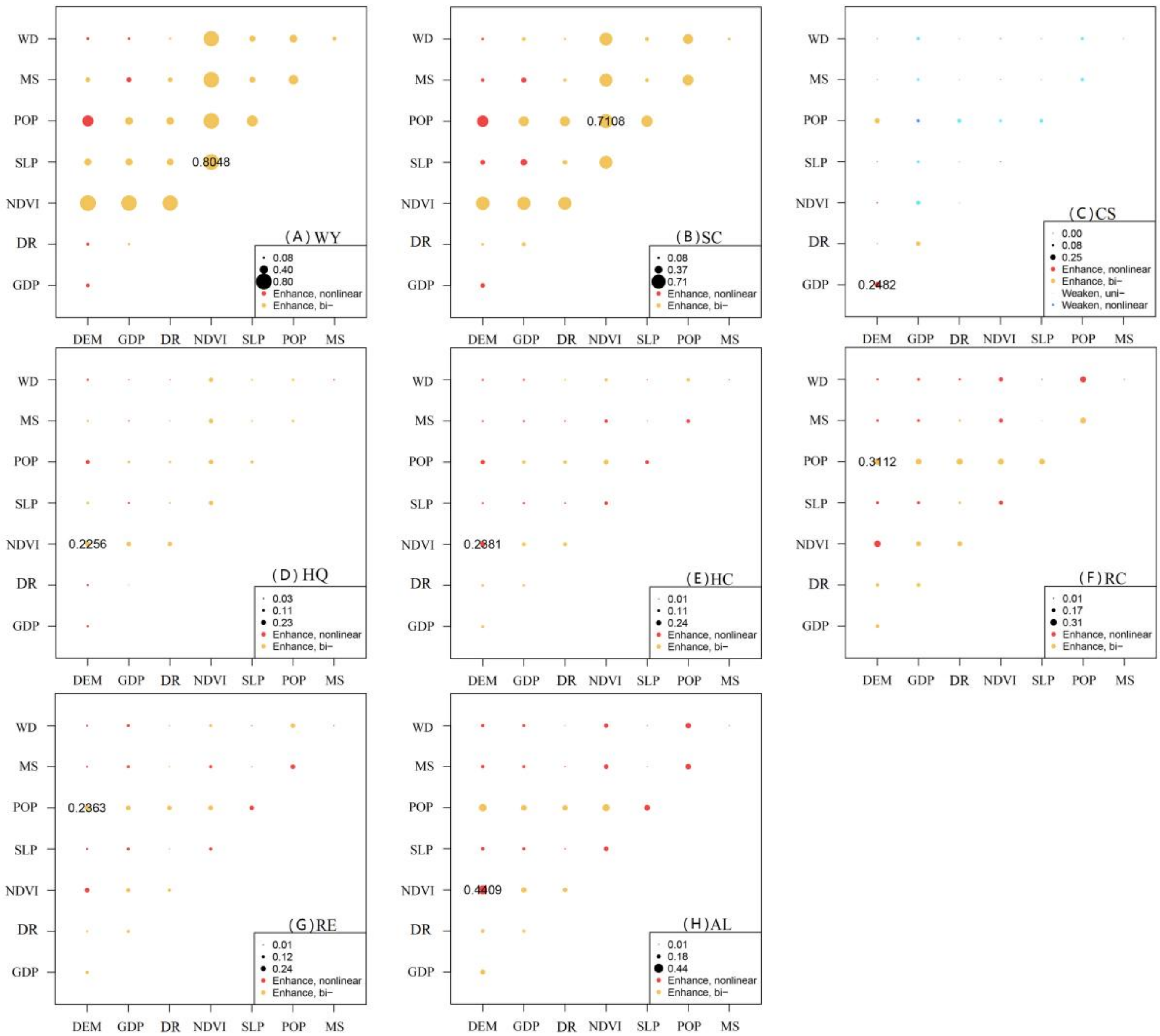

Figure 7 I Interaction Detection Map

limited impact on the spatial heterogeneity of water production services.

In conclusion, the NDVI and POP are identified as the two most influential driving factors impacting the spatial heterogeneity of ES, exerting a decisive influence on CS , RE and AL, respectively.Other factors, including GDP, DR, DEM, SLP, and MS, also contribute to the spatial heterogeneity of ES to different extents, albeit with lesser impact.WD has negligible influence on the spatial heterogeneity of WY.

3.4.2. Results of Interaction Detection

Based on the results of the driving factor detection, the interaction detector overlays two driving factors spatially, calculates the relative importance of the two driving factors, and then explains the interaction and combined driving force of these two variables by comparing the driving forces of the supply and demand ratio of various ES.

The results (Figure 7) indicate that the supply and demand ratio of ES is significantly influenced by various driving factors across different service types.There is a nonlinear enhancing relationship between WY and GDP, suggesting a complex dynamic link between economic development and the supply of water resources, and a dual-factor enhancing relationship with DR, indicating a positive synergistic effect between the construction of road networks and water production services.SC also shows dual-factor enhancing interactions with other driving factors, involving synergistic effects of multiple factors such as land use patterns, vegetation conditions, and terrain. CS are subject to nonlinear enhancing influences from multiple factors including DEM, GDP, DR, NDVI, SLP, POP, and MS, reflecting the complexity of CS's spatial distribution.The nonlinear enhancing and dual-factor enhancing interactions between HQ and DR and GDP reveal the potential importance of traffic accessibility and the level of economic development for biodiversity conservation areas.The nonlinear enhancing relationship of HC and RC services with DR highlights the role of transportation infrastructure in the supply of cultural services.The nonlinear enhancing relationship between RE and AL with GDP indicates that as the economy grows, the demand for these services also increases accordingly.

3.5. ATS Zoning

By employing a linear weighted function to overlay the ecosystem service supply-demand ratio map (Figure 8A) with the main functional area map of Gansu Province's territorial spaces planning (Figure 8B),ATI is calculated (Figure 8C).The results show that areas with a high ATI are where the ecosystem service supply is equal to or greater than demand, and the main functional areas are key ecological function zones.These regions are primarily distributed in ecologically crucial areas such as the Qilian Mountains, the Gannan Plateau, and agriculturally rich regions like the Hexi Corridor, Tao River Basin, Longnan area, and Qingyang area.Areas with a moderate Attractive Index are mainly concentrated in large and medium-sized cities such as Lanzhou, Dingxi, and Tianshui, as well as ecologically fragile areas like Subei, where environmental ES are in deficit but cultural services are relatively good.Areas with a general Attractive Index include the northern parts of Jiuquan and Wuwei, where the main functional areas are agricultural and urban areas that consume more ES, and the land types are mostly gobi and grasslands, making the ecological environment fragile;places like Jinchang and Baiyin Pingchuan areas are resource-exhausted cities with insufficient ecosystem service supply and significant environmental issues;areas like Yongdeng County and Yuzhong County in Lanzhou, and the northern part of Dingxi have more industrial industries, which also have a higher demand for ES.

By using the Attractive Territorial Spaces Index, urban, agricultural, and ecological patches are classified.According to the zoning method of ATS areas proposed in the previous text, the ATS areas are divided into three major categories: Development Area, Conservation Area, and Protection Area.Each of the three major categories is further divided into three subcategories, urban, agricultural, and ecological, resulting in a total of nine subcategories of ATS areas (Figure 8D), facilitating subsequent landscape pattern analysis.

3.6. Analysis of the Landscape Pattern of ATS

Pearson correlation analysis (Figure 9D) reveals a positive correlation between NP and PD with a coefficient of 0.97, indicating that an increase in the number of patches is often accompanied by an increase in patch density.A negative correlation exists between LPI and LSI with a coefficient of -0.11, suggesting that the presence of larger patches may reduce the irregularity of patch shapes.The positive correlation between CONTAG and COHESION (0.98) indicates that when patches are more adjacent to each other,

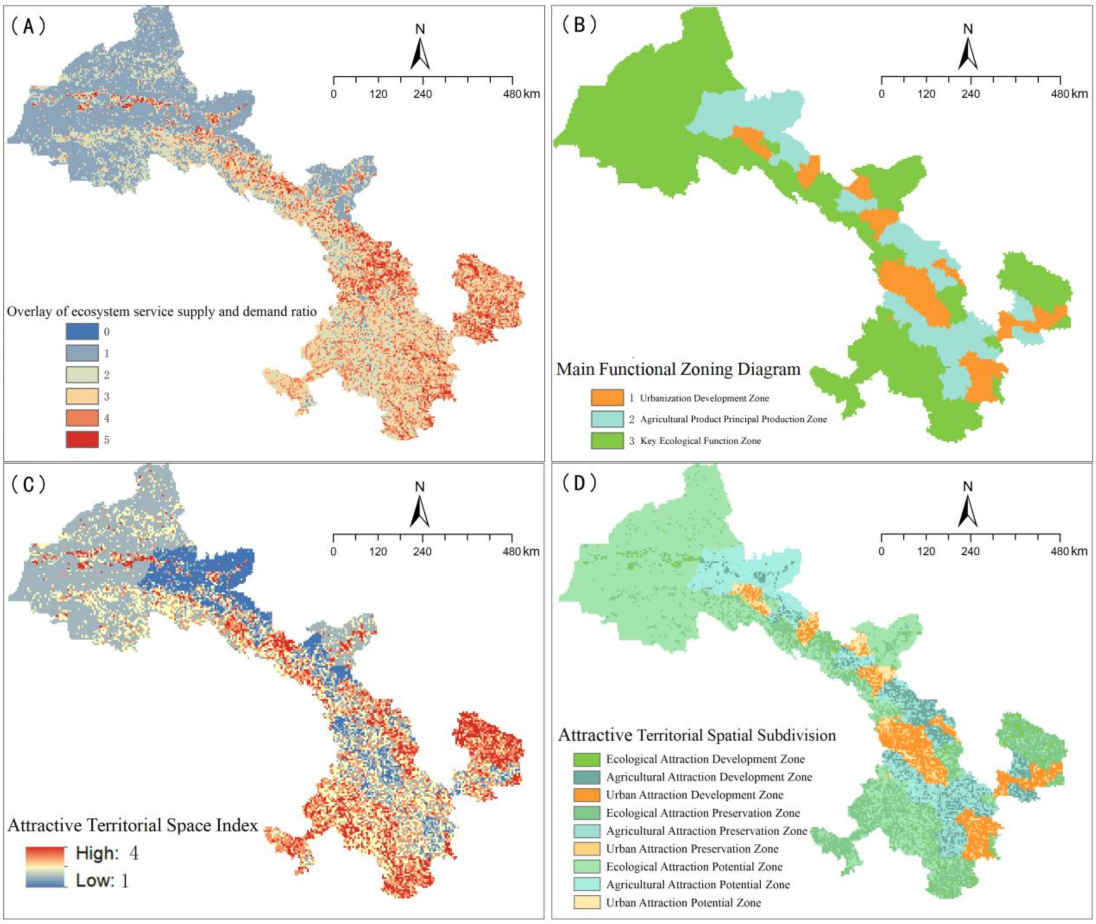

Figure 8 I ATS Zoning Map

their spatial clustering tendency is enhanced.The negative correlation between DIVISION and COHESION as well as AI with a coefficient of -0.99 points out that highly fragmented landscape areas tend to have a lower degree of spatial aggregation.Additionally, the negative correlation between SHDI and DIVISION (-0.08) indicates a trade-off relationship between landscape diversity and the degree of spatial fragmentation.

In order to propose targeted strategies, the ecosystem service supply-demand ratio is overlaid with the main functional area matrix (Table 3), and landscape pattern analysis is conducted for the three types of ATS: urban, agricultural, and ecological.-Combining the aforementioned correlation analysis, we obtain:

Urban Spaces (Figure 9A): The conservation areas (UA_1), such as Jiuquan, Jinchang, and Baiyin cities, which are resource-exhausted cities, exhibit a high degree of spatial continuity and uniformity. While the urban conservation areas (UA_2) do not have an advantage in terms of the number and density of patches, they also demonstrate a high degree of aggregation.Urban development areas (UA_3, UA_4, UA_5), especially UA_3, show a high level of fragmentation, irregular patch shapes, and clear separation between patches, which may weaken the continuity of urban functions and ecological connectivity.

Agricultural Spaces (Figure 9B): The conservation areas (AA_2, AA_3) are concentrated in the Hexi Corridor, and although they have a high AI, the landscape shows significant fragmentation.The agricultural conservation areas (AA_4) are located in the Yellow River Basin, with a high COHESION value, making them suitable for agricultural maintenance and cultivation.The agricultural development areas (AA_5, AA_6), on the other hand, show clear separation between patches.

Ecological Spaces (Figure 9C): The conservation areas (EA_3, EA_4), such as Subei, Minqin County, and the Qilian Mountains, Gannan region, have concentrated ecological patches, but the high patch density and irregular shapes in area EA_4 suggest issues with the fragmentation of ecological spaces. The ecological conservation areas (EA_5, EA_6) are mainly in the Longnan and Qingyang regions, with high DIVISION values, indicating poor connectivity.The ecological development area (EA_7), located

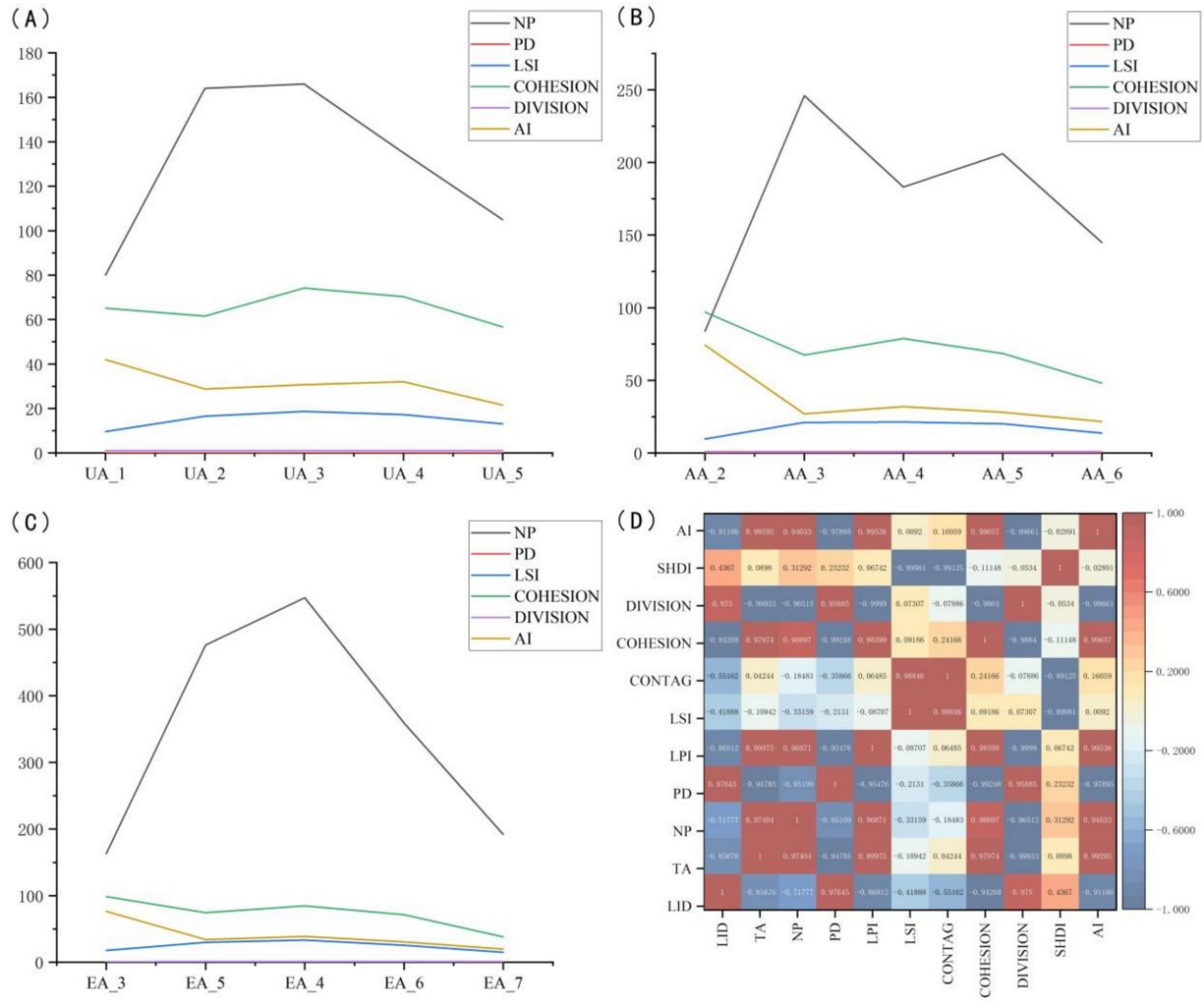

Figure 9 | Analysis of the Landscape Pattern of ATS

in southeastern Gansu, has a low COHESION value and a high DIVISION value, reflecting a low degree of spatial aggregation and a high degree of separation of ecological patches.

Overall (Table 5), urban spaces (UA_land) exhibit high NP and PD values, indicating the presence of relatively concentrated large patches.However, the DIVISION value reaches 1.529, suggesting a certain degree of fragmentation in urban areas.Agricultural spaces (AA_land) have high NP, PD, and LPI values, indicating larger areas of agricultural concentration.However, the low SHDI and DIVISION values indicate a lack of landscape diversity and connectivity.Ecological spaces (EA_land) have a lower PD value and a higher LPI value, suggesting the existence of large core areas within ecological patches.However, the low COHESION and DIVISION values demonstrate weak patch connectivity and a higher degree of fragmentation.Therefore, targeted planning and management measures are needed to promote sustainable development in the region.

Table 5 | Landscape-Level Index

LID	TA	NP	PD	LPI	LSI	CONTAG	COHESION	DIVISION	SHDI	AI
UA_land	5266256	650	0.012	3.188	19.924	7.640	68.329	0.993	1.529	30.753
AA_land	9019347	864	0.010	26.794	21.398	12.936	84.637	0.925	1.530	42.324
EA_land	25964586	1737	0.007	36.269	28.931	23.443	93.494	0.865	1.365	52.749

4. Discussion

4.1. ATS Strategy Matrix

The strategy matrix for the ATS is optimized and refined based on the landscape pattern analysis presented earlier, which identified issues such as fragmentation and poor connectivity within the current ATS.By integrating the impacts of driving factors such as NDVI and POP on the ATS, these areas are categorized into Development Zones, Conservation Zones, and Protection Zones (Figure 10), with respective optimization measures proposed (Table 5).In the Development Zones, the primary emphasis lies in fostering a harmonious co-development between economic expansion and ecological conservation. This is achieved by executing green infrastructure initiatives and endorsing sustainable land management policies, thereby attenuating the adverse effects of anthropogenic activities on ecosystem services.The Conservation Zones are dedicated to preserving and augmenting the natural capital of ecosystems. This objective is pursued by engaging local communities and implementing ecological education programs, which serve to elevate the environmental stewardship and involvement of residents in conservation efforts. Lastly, the Protection Zones implement the most stringent conservation protocols to safeguard biodiversity and vital ecological processes. Within these zones, there is a steadfast commitment to ensuring that the livelihoods and welfare of indigenous communities are comprehensively addressed and maintained.Some planning strategies already have a complete technical route within the territorial spatial planning.The following discussion will focus on the innovative aspects that are either incomplete or unaddressed in the territorial spatial planning.

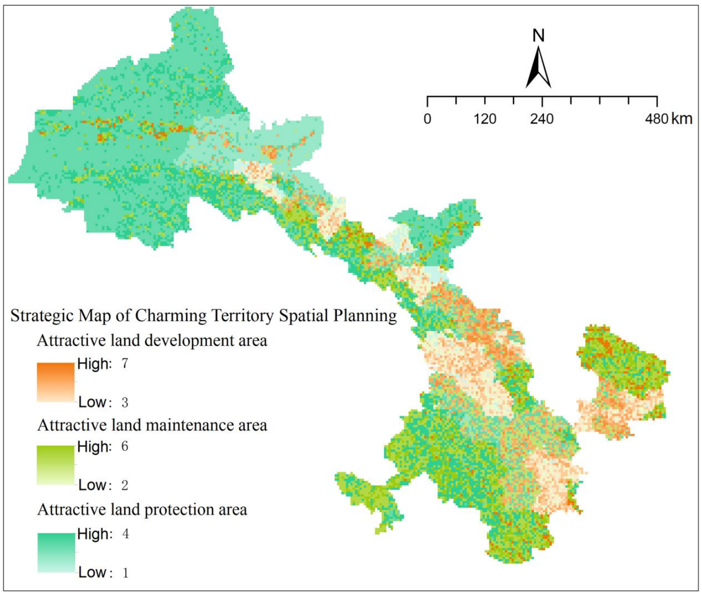

Figure 10 I ATS Planning Strategy Map

4.2. Urban Spatial Strategy Matrix

Analysis of the urban spatial landscape pattern (Figure 9A) reveals a certain degree of fragmentation

Table 5 I Spatial strategy matrix of attractive territory

	Attractive land development area	Attractive land maintenance area	Attractive land protection area
Urban space	Macro-level guidance: Resource strategic integration	Middle-level optimization: Structural and functional enhancement	Micro-level management: Precision efficiency optimization
	• Strengthening regional comprehensive transportation level	• Intensive land use for existing development	• Prioritizing ecological control in building land use
	• Promoting digital transformation of industries	• Smart contraction of underdeveloped counties and districts	• Establishing a sound mechanism for grassroots social governance in cities
	• Enhance the accessibility and effectiveness of public services	• Optimizing the layout of green infrastructure	• Public participation in shaping the city's charismatic landscape
Agricultural space	Enhancing agricultural development efficiency	Green and efficient agricultural practices	Ecological agricultural land reclamation
	• Improving the quality of agricultural production space	• Reducing non-point source pollution from agriculture	• Retiring cropland for afforestation, grass planting, and moisture retention
	• Diversified integration development of rural industries	• Implementing smart water-saving agriculture	• Adjusting agricultural production methods
	•Building Charismatic Villages and Preserving Cultural Heritage	• Agricultural Technological Innovation	• Ecological Compensation Mechanism in Ecologically Vulnerable Areas
Ecological space	Shaping Charismatic land: Ecological Development Leading the Way	Nurturing Ecological Charisma: Cultural Integration with Landscape	Ecological Protection Core: Restoration and Control Taken Together
	• Developing a System of Ecological Protection Areas	• Ecological Restoration: Cultural Landscape Integration	• Ecological Restoration: Prioritizing Natural Recovery
	• Shaping and Maintaining Charismatic Landscape Areas	• Landscape Optimization: Equal Emphasis on Ecological and Cultural Aspects	• Ecological Control: Strengthening Red Line Protection
	• Ecological Protection and Value Enhancement Go Hand in Hand	• Ecological Control: Integrating Cultural Heritage Preservation	• Construction of ecological security pattern

Table 6 | Urban spatial strategy matrix

Starting Point	Strategic Framework		Target Entities	Implementation Directions
Macro-level Guidance: Strategic Integration of Resources	Enhance the Level of Regional Integrated Transportation	Elevate the Infrastructure of Integrated Transport Hubs	Airports/Aviation Ports	√
			High-Speed Rail/Intercity Rail	
		Strengthen Inter-County Traffic Connectivity	Conventional Railways/Freight Railways	√
			Highways	
	Promote the Digital Transformation of Industries		Commercial and Trade Services	√
			Cultural, Sports, and Tourism	
			High-Tech Industries/Strategic Emerging Industries	
			High-End Equipment Manufacturing	
	Enhance the Accessibility and Efficiency of Public Services		Urban Town System	√
			Urban-Rural Public Service System	
			Community Living Circle	Coordinate the Relationship Between Infrastructure and Population Density
Meso-level Optimization: Enhancement of Structural Functionality	Intensify Land Use for Sustainable Development		Land for Construction	√
			Existing Land for Construction	√
			Infrastructure Layout	Drive the Synergy Effects of Urban-Rural Integration and Ecological Protection
Micro-level Management: Precision Optimization of Efficiency	Prioritize Ecological Management in Land Allocation for Construction		Fundamental Spaces for Ecological	√
			Key Ecological Functional Areas	
			Optimized Ecological Spaces	
	Strengthen the Mechanisms of Grassroots Social Governance in Cities		Community Organizations	√
			Social Organizations	
			Government Departments	
	Public Participation in Shaping the City's Charming Landscape		Urban Residents	Create Channels Facilitating Resident Participation, Such as Community Meetings and Workshops
			Urban Planners and Designers	Establish a Bridge for Communication Between the Government and the Public
			NGOs	Integrate Social Resources and Implement Supervision and Evaluation

Note: √ indicates content that has been addressed in the planning

and low spatial aggregation in the urban areas of Gansu Province.Enhancing the level of integrated transportation in the region is crucial for strengthening the connectivity of the urban landscape (Lee, et al., 2017) (Table 6).From an economic perspective, enhancing transportation infrastructure not only promotes economic growth but also improves connectivity between regions, thereby enhancing the mobility and accessibility of ecosystem services.Further analysis of the driving factors of the ecosystem service supply-demand ratio (Figure 7) reveals the significant synergistic effects of GDP on ES such as WY, HQ, and CS. The digital transformation of industries and the intensive use of existing land for development are important initiatives for promoting green economic growth (Yang, et al., 2023).However, a comprehensive assessment of the ecosystem supply-demand ratio (Figure 5) indicates that many cities in Gansu Province suffer from a deficiency in the supply of cultural services such as RE and AL.To address this challenge, improving the accessibility and efficiency of public services is particularly urgent. In addition, strengthening the grassroots social governance mechanism in cities and encouraging public participation in shaping the charming urban landscape can not only meet the spiritual needs of citizens but also enhance the transparency of planning (Eilola, et al., 2023).

4.3. Agricultural Spatial Strategy Matrix

The agricultural spatial strategy (Table 7) is formulated around the regulation and guidance of agriculture and rural areas.The agricultural regions in Gansu Province are relatively concentrated, with a high degree of landscape aggregation, and most are adjacent to river basins.Optimizing the layout of agricultural spaces has become the core of the strategy.Through a comprehensive assessment of the supply-demand ratio of ES (Figure 5), especially in the Hexi Corridor and Tao River Basin, it has been found that the supply of key services such as WY and SC has failed to meet the demand.To address these challenges, we have proposed a series of strategies that integrate multi-disciplinary insights from ecology, sociology, and economics. Initially, from an ecological standpoint, it is recommended to establish ecological compensation mechanisms in ecologically vulnerable areas. This includes implementing measures such as converting farmland back to forests and grasslands and soil conservation initiatives to restore and enhance the productivity and biodiversity of agricultural ecosystems (Zhong, et al., 2020).These measures not only improve the agricultural ecological environment but also enhance the supply capacity of ecosystem services.

From a sociological perspective, enhancing farmers' environmental awareness and participation can more effectively promote sustainable agricultural development while ensuring that local communities benefit from ecological improvements. Furthermore, advancing rural industry diversification and agricultural technological innovation not only increases the efficiency and yield of agricultural production but also strengthens the resilience of the rural economy and contributes to the improvement of social well-being.

Additionally, the construction of attractive rural communities and the promotion of cultural heritage have been proposed to enhance the appeal and connectivity of agricultural spaces. By protecting and promoting traditional agricultural cultures, we can not only boost the appeal of rural tourism but also facilitate the conservation and transmission of cultural diversity, further enhancing the social and cultural value of agricultural spaces.

In summary, through a cross-disciplinary approach and comprehensive strategies, this study provides scientific basis and practical guidance for the sustainable development of agricultural spaces in Gansu Province. It ensures the coordinated development of ecological protection and agricultural production, laying a solid foundation for harmonious coexistence between humans and nature.

4.4. Ecological Spatial Strategy Matrix

The implementation of ecological spatial strategies (Table 8) in Gansu Province focuses not only on constructing an ecological security pattern and utilizing the "dual evaluation" system for the identification and assessment of key ecological spaces but also on ecological restoration and management to address the urgent ecological challenges faced by the province.Through a comprehensive assessment of the ecosystem supply-demand ratio (Figure 5), signif-

Table 7 | Ecological spatial strategy matrix

Starting Point	Strategic Framework		Target Entities	Implementation Directions
Enhancing Agricultural Development Efficiency	Enhancement of Agricultural Production Space Quality		High-Standard Farmland	√
			High-Quality Farmland	Coordinating the Compatibility of Fertile Land Protection with Urban Expansion
			Famous, Special, and High-Quality Agricultural Product Area	√
	Integrated and Diversified Development of Rural Industries	Integration of the Three Rural Industries	Agriculture, Industry, and Service Industries	√
		Promoting the Development of Industry by Integrating Agriculture and Tourism	Agricultural Areas with Tourism and Leisure Value	√
	Construction of Charming Rural Areas and Cultural Heritage	Enhancing Rural Public Services and Infrastructure	Rural Settlements	√
		Advancing Rural Residential Environment Rectification		
Practices of Green and Efficient Agriculture	Reduction of Agricultural Non-point Source Pollution		Areas with Excessive Use of Fertilizers, Pesticides, and Solid Waste	Harmonizing the Interrelationships between Agricultural and Ecological Zones
	Development of Smart Water-saving Agriculture		Irrigated Agricultural Regions	√
	Innovation in Agricultural Science and Technology	Agricultural Intelligence Driven by Big Data and AI Technology	Agricultural Research Institutions	Achieving Precision Management in Agricultural Production
		Germplasm Innovation		Breeding Technology for Cultivating High-Yield, High-Quality Crop Varieties
Ecological Agricultural Land Consolidation	Reforestation, Restoration of Grasslands, and Moisture Conservation through Land Retirement		Areas Facing Severe Ecological Challenges and Soil Degradation	Optimizing the Symbiotic Relationship between Agricultural and Ecological Spaces
	Adjustment of Agricultural Production Methods	Terraced Field Conversion from Sloping Cultivated Land	Agricultural Land in Areas with Severe Soil Erosion	√
		Fallow and Crop Rotation	Areas with Severe Non-point Source Pollution	√
	Establishment of Ecological Compensation Mechanisms in Ecologically Fragile Areas		Ecological Benefit Areas	Achieving Balanced Interests and Shared Benefits among Regions

Note: √ indicates content that has been addressed in the planning icant differences have been found in the southeast and northwest of Gansu Province in terms of WY, SC and CS, making the restoration of soil and water ecological sources particularly critical.From an ecological perspective, implementing ecological restoration projects on mountains and river channels can effectively enhance the spatial aggregation and connectivity of ecological patches, thereby facilitating the construction of ecological landscape corridors. This process not only contributes to enhancing the overall functioning of ecosystems but also strengthens their adaptability to climate change and human activities.

The nonlinear enhancing and dual-factor enhancing interaction between HQ and DR and GDP reveals the potential importance of traffic accessibility and the level of economic development for biodiversity conservation areas.From an economic analysis perspective, improving transportation infrastructure and promoting economic development not only enhance the integration and biodiversity of ecological patches but also foster the sustainable development of ecological industries and landscapes (Zhang, et al., 2021).This integrated approach paves a new path for Gansu Province's provincial development with distinct characteristics, ensuring the coordinated integration of ecological protection and economic growth.

4.5. Limitations and Prospects

This study proposes a systematic method for identifying and optimizing ATS by integrating the supply-demand ratio of ES. However, it has limitations, including imperfect dynamic monitoring and forecasting mechanisms, insufficient refinement of local adaptive strategies, and a need for more in-depth analysis of driving factors. Future research should focus on establishing a more precise dynamic monitoring system (Qi, et al., 2023). By establishing a long-term, periodic data collection and updating system, we can more accurately track changes in ecosystem service indicators, thereby capturing the dynamic characteristics of ecosystems. Additionally, this study was unable to fully predict the future trends and potential impacts of ATS changes. Future research can adopt scenario analysis methods to explore possible changes in ATS under different development paths. By setting multiple scenarios, such as sustainable development, economic development priority, and environmental protection priority, etc., the long-term impacts of these

Table 8 | Ecological spatial strategy matrix

Starting Point	Strategic Framework		Target Entities	Implementation Directions
Shaping a Charming National Territory: Prioritizing Ecological Development	Developing a System of Ecological Protection Areas		National Park	√
			Nature Reserve	√
			Natural Park	Achieving Mutually Beneficial Win-Win between Ecological Conservation and Cultural Heritage
	Shaping and Preserving Charming Landscape Areas		Natural Landscape Attraction Area	Enhancing the Complementarity between Ecological and Recreational Functions
			Agricultural Landscape Attraction Area	Balancing the Dual Benefits of Agricultural Cultivation and Tourism
			Cultural Landscape Attraction Area	√
	Synchronizing Ecological Conservation with Value Enhancement		Characteristic Arboreal/Wild Medicinal Herbs	Coordinating the Mutual Promotion Mechanism between Ecological Balance and Economic Growth
Nurturing Ecological Charm: Integrating Culture into the Landscape	Ecological Restoration: Integration of Cultural Landscapes		Damaged Ecosystem	√
	Landscape Optimization: Balancing Ecological and Cultural Considerations		Urban Green Space Park	√
	Ecological Management: Emphasizing Cultural Heritage		Areas of High Density Distribution of Key Flora and Fauna	√
Core of Ecological Protection: Restoration and Management Go Hand in Hand	Ecological Restoration: Prioritizing Natural Recovery	Terrestrial Ecological Source Restoration	Soil Erosion Area	Restoring Ecological Functions and Enhancing Land Use Value
			Mountain Degradation Area	√
		Aquatic Ecological Source Restoration	Disrupted River	Enhancing Riverine Service Functions
			River Channels with Weakened Flood Discharge Function	√
	Ecological Management: Strengthening Redline Protection		Ecological Protection Redline Area	√
	Constructing an Ecological Security Framework		Corridor	√
			Matrix	√
			Patch	√

Note: √ indicates content that has been addressed in the planning scenarios on the supply-demand ratio of ecosystem services can be assessed.Deepening the prediction of long-term trends in ecosystem services, refining local adaptive strategies to meet the specific needs of different regions, and enhancing the analysis of interactions among driving factors and their long-term impacts (Yuan, et al., 2024), will promote the coordinated development of the economy and environment. This will improve the quality of national territorial space planning and management, providing a solid scientific foundation for the formation of sustainable development models with local characteristics.

5. Conclusion

(1) Ecosystem Service Supply and Demand Pattern: The supply pattern of ES in Gansu Province exhibits significant imbalances, with the western Qilian Mountains serving as key water sources and carbon sinks, while the eastern Loess Plateau and valley regions, despite water scarcity, are rich in cultural resources.The demand pattern for ES is influenced by factors such as GDP per unit area, POP density, and intensity of land use.The city of Lanzhou and its surrounding areas, due to their economic development and dense POP, have a significant demand for ES.-Analysis of the supply-demand ratio reveals imbalances in key services such as water resources and SC, with urgent demand in densely populated and rapidly developing areas.

(2) Driving Factor Detection: Analysis using the Geographic Detector indicates that NDVI and POP are the two strongest driving factors affecting the spatial heterogeneity of ES.NDVI has a very high explanatory power for the spatial heterogeneity of CS, while POP density significantly impacts the demand for RE and AL.

(3) Landscape Pattern Analysis: Landscape index analysis shows that urban spaces (UA_land) exhibit relatively concentrated large patches but have a certain degree of fragmentation;agricultural spaces (AA_land) have large concentrated areas but lack landscape diversity and connectivity;ecological spaces (EA_land) have large core areas but weak patch connectivity and a higher degree of fragmentation.

(4) Strategy Matrix Proposed: For urban spaces, measures such as improving comprehensive transportation levels and promoting the digital transformation of industries are proposed; strategies for agricultural spaces focus on optimizing the layout of agricultural spaces and establishing ecological compensation mechanisms;ecological space strategies emphasize ecological restoration and management to address ecological challenges.

CRediT Authorship Contribution Statement

Yaqi Wang: Conceptualization, methodology,Writing - manuscript, software, visualization, investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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