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Agriculture–Space Coupling and Planning Response in Central Gansu Arid Loess Region Under Climate Resilience

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Abstract

Climate change poses persistent risks to agriculture and rural livelihoods in arid and semi-arid regions. Focusing on 235 townships in the arid Loess Region of Central Gansu, this study links the assessment of potential agricultural resilience with the interpretation of spatial matching and planning responses. A pressure–carrier–mechanism–response framework organizes historical climate constraints, agricultural and spatial conditions, coordination diagnosis, and proposed interventions within a common analytical sequence. Entropy-weight evaluation, a coupling coordination model, and type-based spatial projection are applied to 50 representative townships and extended to the wider study area. The existing results show stronger performance in irrigated river-valley areas and weaker performance in loess hilly and rain-fed areas. Water–soil mismatch is the principal diagnosed constraint in 74% of the cases of obstacles in representative townships. The framework's contribution lies in connecting the diagnosis of agricultural and spatial conditions to differentiated planning responses. It provides a basis for discussing water–land management, agricultural service organization, and county-to-township planning coordination under locally specific resource constraints.

Keywords: climate resilience; agricultural resilience; agriculture—space coupling; coupling coordination; obstacle identification; spatial planning; arid Loess Region of Central Gansu

1. Introduction

1.1. Background and Research Gaps

Climate change threatens agricultural production and rural livelihoods in arid and semi-arid regions [1]. The arid Loess Region of Central Gansu is characterized by limited precipitation, intense evaporation, recurrent drought, and contrasting irrigation conditions. Rain-fed agriculture, dispersed settlements, and weak infrastructure further constrain agricultural adaptation [2–4]. These challenges concern both agricultural capacities and the spatial arrangement of water, land, settlements, and production services [5]. An agriculture–space coupling perspective is therefore needed to identify whether agricultural capacities correspond to their spatial supports and how planning can address potential mismatches [6,7].

Agricultural resilience research increasingly adopts a systems perspective, considering the capacities to withstand disturbances, adapt, and transform [8,9]. Related rural resilience studies have expanded the understanding of environmental, social, and economic conditions supporting these capacities [10]. However, identifying resilience attributes or constructing composite indices does not automatically specify which spatial relationships

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require intervention. Research on community and rural resilience also provides insights into local adaptation and planning [11,12], but connecting these insights to township-level decisions requires explicit consideration of resource conditions and spatial configurations.

The remaining challenge is to connect agricultural resilience assessment with spatial diagnosis and planning implementation. Agricultural activities depend on spatial carriers, yet their joint evaluation requires more than a description of individual system characteristics [13]. Coupling coordination scores can summarize agricultural and spatial conditions, but their planning value depends on explaining which water–land–settlement relationships require attention and which interventions are appropriate. Building on research on land management and spatial resilience planning [14], this study focuses on translating township-scale matching diagnosis into differentiated planning responses [15].

1.2. Research Objectives and Analytical Framework

This study examines 235 townships in the arid Loess Region of Central Gansu through a pressure–carrier–mechanism–response framework. Historical climate pressures establish the context, agricultural and spatial conditions constitute the carriers, coordination diagnosis identifies potential matching constraints, and the response layer organizes planning measures. The mechanism layer supports interpretation rather than causal identification.

Using entropy-weight evaluation, coupling coordination analysis, and representative-township spatial projection, the study assesses potential agricultural resilience and spatial conditions, interprets their principal matching constraints, and develops differentiated planning responses. Its contribution lies in connecting resilience assessment with spatially actionable diagnosis. By linking township diagnosis, county-level coordination, and local implementation, the framework translates broad climate-adaptation objectives into proposed planning responses suited to local conditions [14].

2. Theoretical Framework

2.1. Core Concepts

Agricultural climate resilience refers to the capacity of agricultural systems to sustain essential functions, adapt to changing conditions, and undergo transformation when confronted with climate disturbances [16]. It encompasses resistance, adaptability, and transformability [17]. In this study, the assessment focuses on potential resilience represented by structural conditions supporting these capacities rather than directly observed recovery following climatic shocks.

Agriculture–space coupling describes the relationships between agricultural activities and their spatial supports, including water resources, land, and settlements [6]. The analysis examines whether agricultural capacities correspond to these spatial conditions, providing a basis for interpreting potential constraints and identifying planning responses.

2.2. Four-Dimensional Framework Construction

This study develops a pressure–carrier–mechanism–response framework to connect climate-related constraints, agricultural and spatial conditions, coordination diagnosis, and planning responses (Figure 1). The four layers organize successive stages of analysis rather than constituting four independently calculated components of the evaluation model.

The pressure layer establishes the regional context through historical climate and disaster patterns, particularly drought and water scarcity. It guides the interpretation of climate-related agricultural constraints. Historical hazard measures are used for contextual diagnosis rather than directly incorporated into the agricultural resilience and spatial composite indices.

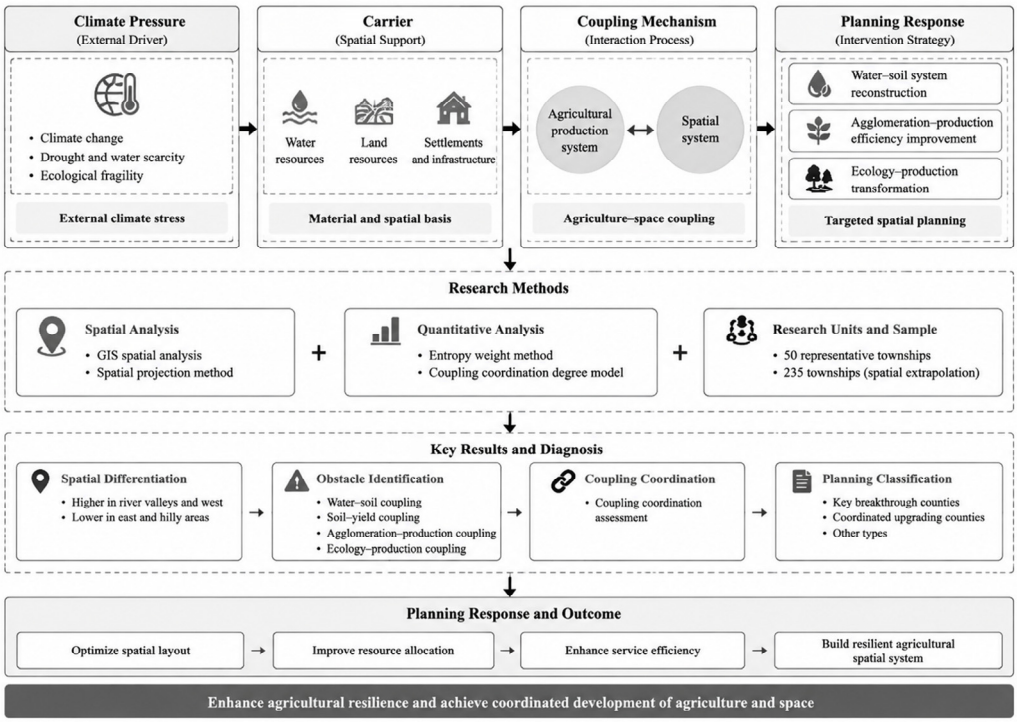


Figure 1. Four-dimensional analysis framework.

The carrier layer evaluates agricultural capacities and their spatial supports. Potential agricultural resilience is assessed through indicators of resistance, adaptability, and transformability, while the spatial evaluation covers water-related conditions, land, and settlements. Climate relevance is reflected in the interpretation of these indicators as structural conditions associated with coping with climatic pressures; they do not directly measure the effects of specific climate events.

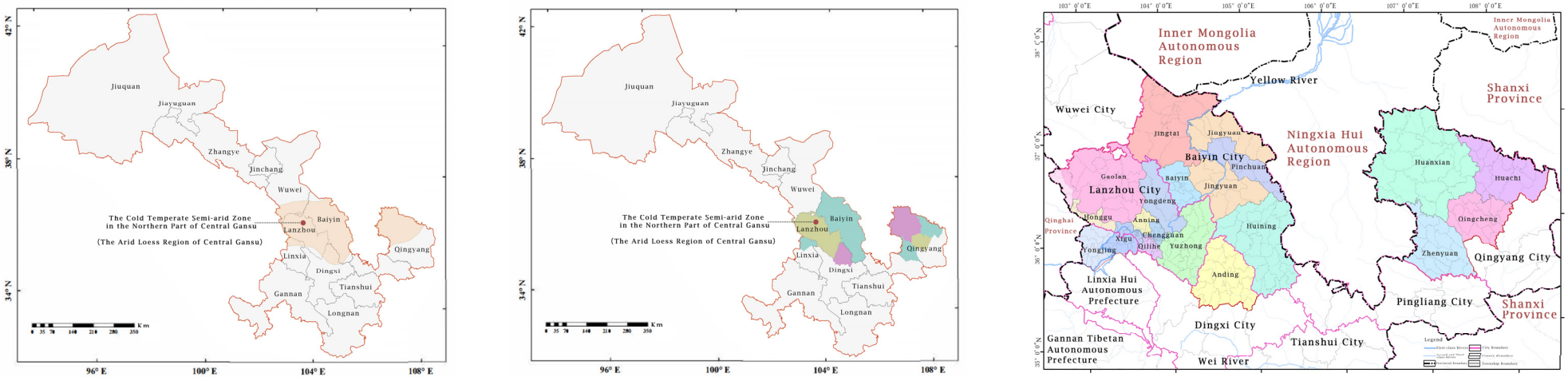
The mechanism layer examines the correspondence between the agricultural and spatial indices through coupling coordination analysis and pairwise diagnosis. It identifies differences in matching conditions and supports the interpretation of potential constraints rather than establishing causal mechanisms. The response layer organizes differentiated planning measures addressing water–soil, settlement–production, and ecology-related concerns [10].

The analytical sequence therefore proceeds from historical pressure diagnosis to agricultural and spatial evaluation, identification of matching differences, territorial classification, and formulation of planning responses. Spatial planning provides the proposed means of adjusting resource allocation and the organization of agricultural activities [16]. The framework thus connects diagnosis with planning intervention, while the effectiveness of the proposed measures remains to be evaluated through implementation [18].

3. Materials and Methods

3.1. Overview of the Study Area

The cold temperate semi-arid area in the northern part of the arid Loess Region of Central Gansu (IIC3) is the arid area of the Loess in Central Gansu (Figure 1), which includes the whole area of Lanzhou and Baiyin, Yongjing County of Linxia Prefecture, Anding District of Dingxi City, Huanxian County of Qingyang City, and Huachi, Qingcheng and Zhenyuan; the total number of towns in the study area shown in Figure 2.



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

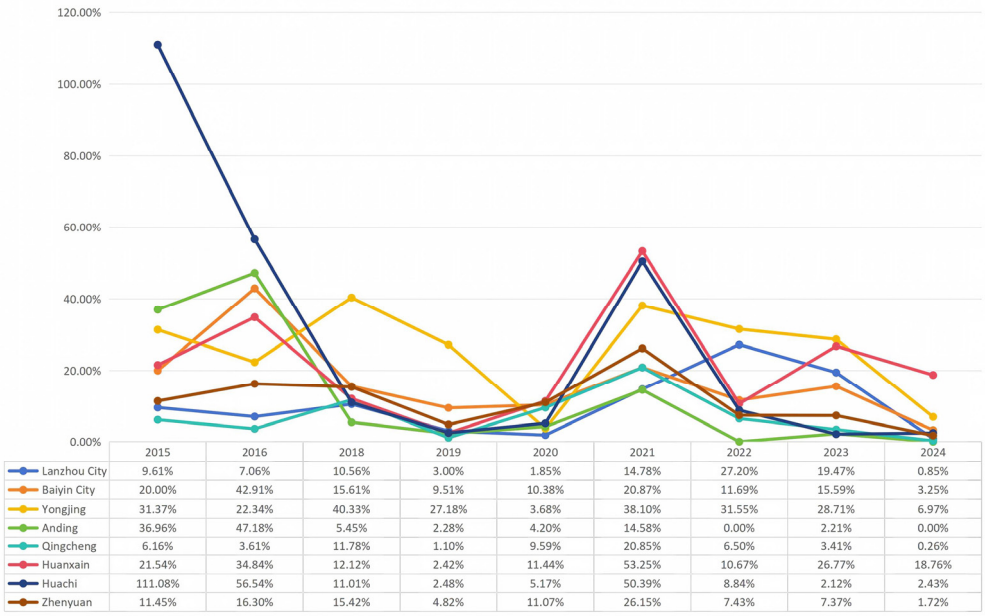
Figure 2. Map of location and administrative divisions. (**a**) Climatic regionalization of Gansu Province. (**b**) Administrative divisions of the arid Loess Region of Central Gansu. (**c**) Scope of study area. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

This region was selected because recurrent drought and water scarcity coexist with contrasting agricultural and spatial conditions, including irrigated river valleys, rain-fed farming areas, loess hills, and dispersed settlements. These contrasts provide a relevant setting for examining how potential agricultural resilience corresponds to water, land, and settlement configurations under climatic constraints. The region therefore offers insights into differentiated planning needs within a shared dryland context.

The findings may inform other arid and semi-arid agricultural regions facing similar resource and spatial constraints. However, their transferability primarily concerns the analytical framework and diagnosis-to-planning approach. Specific assessment results and proposed measures remain dependent on local environmental conditions, agricultural practices, irrigation systems, and planning institutions.

3.1.1. Agricultural Climatic Degree Differentiation

Based on the relevant data in the rural yearbooks of Gansu Province in various regions from 2015 to 2024 (except 2017), as shown in Figure 3, statistics and analysis are carried out to obtain relevant content such as natural disasters.

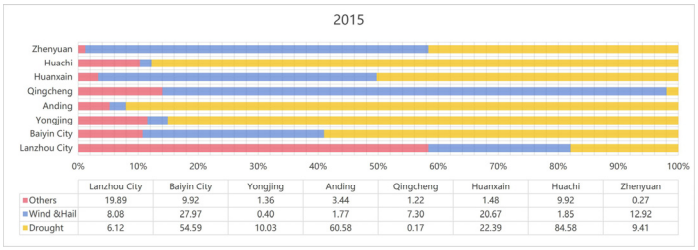


	2015	2016	2018	2019	2020	2021	2022	2023	2024
Lanzhou City	9.61%	7.06%	10.56%	3.00%	1.85%	14.78%	27.20%	19.47%	0.85%
Baiyin City	20.00%	42.91%	15.61%	9.51%	10.38%	20.87%	11.69%	15.59%	3.25%
Yongjing	31.37%	22.34%	40.33%	27.18%	3.68%	38.10%	31.55%	28.71%	6.97%
Anding	36.96%	47.18%	5.45%	2.28%	4.20%	14.58%	0.00%	2.21%	0.00%
Qingcheng	6.16%	3.61%	11.78%	1.10%	9.59%	20.85%	6.50%	3.41%	0.26%
Huanxain	21.54%	34.84%	12.12%	2.42%	11.44%	53.25%	10.67%	26.77%	18.76%
Huachi	111.08%	56.54%	11.01%	2.48%	5.17%	50.39%	8.84%	2.12%	2.43%
Zhenyuan	11.45%	16.30%	15.42%	4.82%	11.07%	26.15%	7.43%	7.37%	1.72%

Figure 3. Ratio of natural disaster area to sown area of crops.

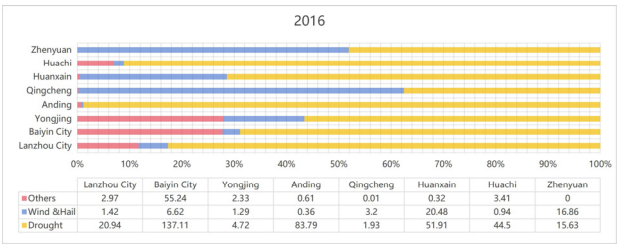
Based on the analysis in Figure 4, combined with the disaster composition data from 2015 to 2024 (except 2017), the degree of climate disasters in each agricultural region is divided into four categories. Data is missing for 2017 because the 2018 statistical yearbook was not found in publicly available sources; the trend shown in the figure was inferred based on the data from the preceding and following years and, thus, may have some issues.

Based on the analysis in Table 1, it can be found that the proportion of drought in Huanxian County exceeds 70% all year round, reaching as high as 98%. The types of disasters in Baiyin City are the most diverse and can be categorized as compound disasters. The proportion of disasters in Lanzhou City has dropped to 11–19%, showing the strongest resilience.



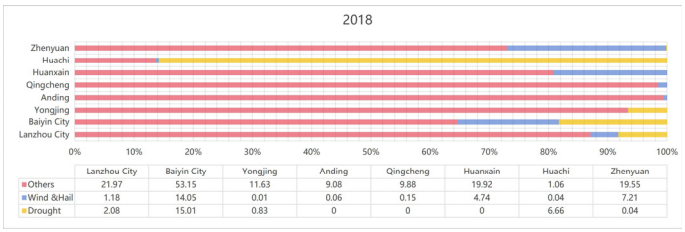
	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	19.89	9.92	1.36	3.44	1.22	1.48	9.92	0.27
Wind &Hail	8.08	27.97	0.40	1.77	7.30	20.67	1.85	12.92
Drought	6.12	54.59	10.03	60.58	0.17	22.39	84.58	9.41

(**a**)



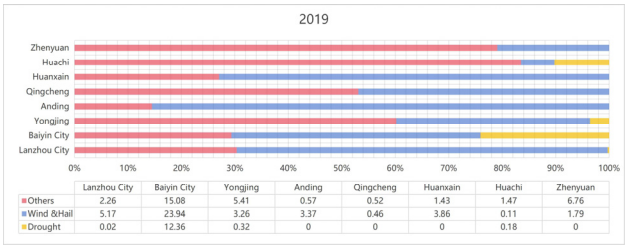
	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	2.97	55.24	2.33	0.61	0.01	0.32	3.41	0
Wind &Hail	1.42	6.62	1.29	0.36	3.2	20.48	0.94	16.86
Drought	20.94	137.11	4.72	83.79	1.93	51.91	44.5	15.63

(**b**)



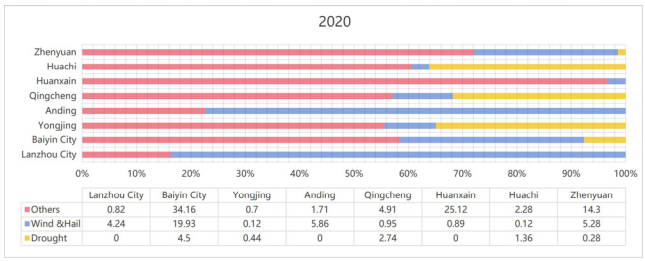
	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	21.97	53.15	11.63	9.08	9.88	19.92	1.06	19.55
Wind &Hail	1.18	14.05	0.01	0.06	0.15	4.74	0.04	7.21
Drought	2.08	15.01	0.83	0	0	0	6.66	0.04

(**c**)



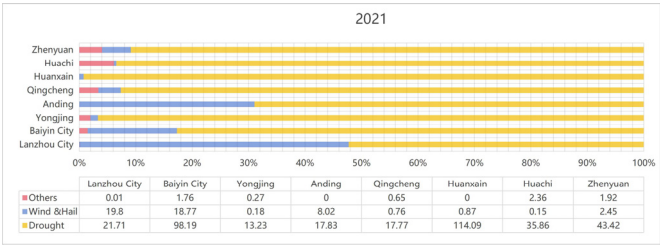
	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	2.26	15.08	5.41	0.57	0.52	1.43	1.47	6.76
Wind &Hail	5.17	23.94	3.26	3.37	0.46	3.86	0.11	1.79
Drought	0.02	12.36	0.32	0	0	0	0.18	0

(**d**)



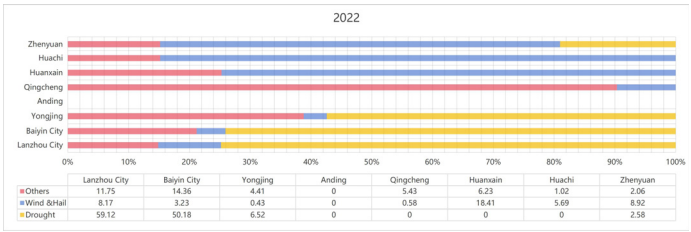
	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	0.82	34.16	0.7	1.71	4.91	25.12	2.28	14.3
Wind &Hail	4.24	19.93	0.12	5.86	0.95	0.89	0.12	5.28
Drought	0	4.5	0.44	0	2.74	0	1.36	0.28

(**e**)



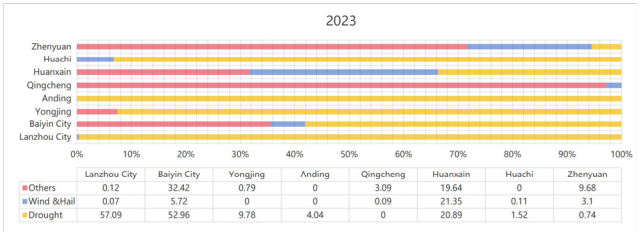
	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	0.01	1.76	0.27	0	0.65	0	2.36	1.92
Wind &Hail	19.8	18.77	0.18	8.02	0.76	0.87	0.15	2.45
Drought	21.71	98.19	13.23	17.83	17.77	114.09	35.86	43.42

(**f**)



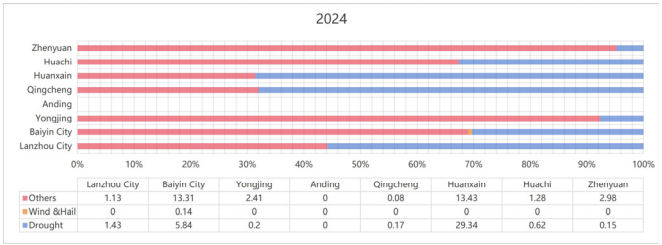
	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	11.75	14.36	4.41	0	5.43	6.23	1.02	2.06
Wind &Hail	8.17	3.23	0.43	0	0.58	18.41	5.69	8.92
Drought	59.12	50.18	6.52	0	0	0	0	2.58

(**g**)



	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	0.12	32.42	0.79	0	3.09	19.64	0	9.68
Wind &Hail	0.07	5.72	0	0	0.09	21.35	0.11	3.1
Drought	57.09	52.96	9.78	4.04	0	20.89	1.52	0.74

(**h**)



	Lanzhou City	Baiyin City	Yongjing	Anding	Qingcheng	Huanxain	Huachi	Zhenyuan
Others	1.13	13.31	2.41	0	0.08	13.43	1.28	2.98
Wind &Hail	0	0.14	0	0	0	0	0	0
Drought	1.43	5.84	0.2	0	0.17	29.34	0.62	0.15

(**i**)

Figure 4. Change of the proportion of disasters year by year. (**a**) Distribution map of disaster proportions in 2015. (**b**) Distribution map of disaster proportions in 2016. (**c**) Distribution map of disaster proportions in 2018. (**d**) Distribution map of disaster proportions in 2019. (**e**) Distribution map of disaster proportions in 2020. (**f**) Distribution map of disaster proportions in 2021. (**g**) Distribution map of disaster proportions in 2022. (**h**) Distribution map of disaster proportions in 2023. (**i**) Distribution map of disaster proportions in 2024.

Table 1. Types and Causes of Climate Disasters.

Type	Study Area	Major Disasters	Leading Agriculture	Genesis
Drought type	Huan Xian, Anding, Zhenyuan, Huachi	Drought (65–98%)	Potato, corn, grass and livestock, small miscellaneous grains	High precipitation dependence and lack of irrigation in dry-farming areas
Wind–hail type	Baiyin City, Qingcheng	Wind and hail (5–27%)	Plateau summer vegetables, apples, wolfberry	Fruits, stems and leaves of cash crops are vulnerable to damage
Compound type	Baiyin City, Yongjing	Alternate drought, wind, flood and low temperature	Multivariate planting and breeding	Multiple disasters are superimposed, and risk sources are complex
Low type	Lanzhou City	Other disasters mainly	Plateau summer vegetables and urban agriculture	Sufficient water conservancy guarantee in irrigation areas along the Yellow River

3.1.2. Regional Comparison of Agricultural Disaster Impacts

Based on the analysis in Table 2, it can be found that the proportion of drought in Huanxian is low, but the total area affected is low; this disaster is of the "high-frequency and low loss" type. Yongjing accounted for more than 30% of the disaster, which belongs to the "continuous exposure" type; Lanzhou City is the only area showing a downward trend.

Table 2. Dominant types and risk characteristics of climate disasters.

Study Area	Reported Disaster Profile	Disaster-Type Share of Total Affected Crop Area	Affected Crop Area/Sown Area	Descriptive Interpretation
Lanzhou City	Other disasters	Other disasters: 50–81%	47% → 11% (decrease)	Decrease in the relative extent of affected crops
Baiyin city	Mixed disaster profile	Drought, 14–55%; wind, 5–28%	Stable, 20–30%	Multiple disaster types represented
Yongjing	Relatively dispersed disaster composition	Individual reported categories: 10–40%	Stable, 30–42%	Comparatively high affected-area ratio
Anding	Drought-related profile	Drought: 9–84%	Stable, 15–17%	Wide variation in drought share
Qingcheng	Wind/hail/drought	Wind and hail, 3–21%; drought, 0–20%	Stable, 9.5–12%	Wind, hail, and drought represented
Huanxian	Drought-dominated profile	Drought: 52–98%	Stable, 9.5–12%	Drought constituted the majority of recorded affected area
Huachi	Drought/wind/hail	Drought, 36–85%; wind, and hail 1–7%	Stable, 10–12%	Substantial variation in drought share
Zhenyuan	Drought-related profile	Drought: 43–66%	Stable, 9.5–11%	Substantial drought contribution to recorded affected area

Note: Disaster-type shares describe the composition of recorded disaster-affected crop area, whereas affected-area ratios describe affected crop area relative to sown area. Ranges summarize reported values during 2015–2024. These indicators do not directly measure disaster frequency, economic loss, or agricultural resilience. The decrease reported for Lanzhou is descriptive and does not imply statistical significance.

Regional comparison method. Two indicators were used to distinguish disaster composition from the relative extent of agricultural impacts. The disaster-type share was calculated as the crop area affected by a specific disaster divided by the total recorded disaster-affected crop area. The affected-area ratio was calculated as the total disaster-affected crop area divided by the total sown area:

$$P_{kit} = \frac{A_{kit}}{A_{it}} \times 100\%$$

$$R_{it} = \frac{A_{it}}{S_{it}} \times 100\%$$

Here, A_{kit} represents the crop area affected by disaster type k in region i and year t, A_{it} denotes the total recorded disaster-affected crop area, and S_{it} denotes the total sown area. Absolute affected area is a separate indicator expressed in hectares and is not presented in Tables 2 and 3. Neither percentage directly represents disaster frequency or economic loss.

Table 3. Climate resilience zoning.

Contrast Dimension	Lanzhou	Baiyin, Yongjing, and Qingcheng	Anding, Huanxian, Zhenyuan, and Huach
Irrigation conditions	Yellow River irrigation areas	Mixed irrigation conditions, including Yellow River diversion projects and partially irrigated areas	Predominantly rain-fed agriculture
Disaster composition	"Other disasters" accounted for 50–81% of recorded affected crop area	Mixed disaster profiles, with differences among regions	Substantial drought shares, with variation among regions
Affected-area ratio	Decreased from 47% to 11%	Baiyin: 20–30%; Yongjing: 30–42%; Qingcheng: 9.5–12%	Anding: 15–17%; Huanxian: 9.5–12%; Zhenyuan: 9.5–11%; Huachi: 10–12%
Relevance to subsequent analysis	Examine agricultural capacities alongside irrigated spatial conditions	Examine differences in agricultural–spatial matching under mixed irrigation conditions	Examine water-related constraints and agricultural–spatial matching in predominantly rain-fed settings

Note: The columns provide descriptive regional groupings rather than resilience classes. Irrigation conditions are contextual characteristics; their causal effects on disaster impacts are not established by this comparison.

The regional comparison summarizes the reported ranges and descriptive changes during 2015–2024. Indicators were compared in their original units without normalization or aggregation into a composite score. The regional profiles summarize disaster composition, relative affected extent, and irrigation conditions; they do not constitute a quantitative classification of resilience. Disaster frequency, interannual stability, and statistically significant trends were not inferred from these percentage ranges.

Regional comparison results: Table 2 shows that disaster composition and affected-area ratios varied across regions. Drought shares ranged from 52% to 98% in Huanxian, 43% to 66% in Zhenyuan, and 36% to 85% in Huachi, while their affected-area ratios were approximately 9.5–12%, 9.5–11%, and 10–12%, respectively. Thus, a comparatively low affected-area ratio could coexist with a substantial drought share. In Anding, the drought share ranged from 9% to 84%, indicating considerable variation in disaster composition.

Yongjing had an affected-area ratio of approximately 30–42%, compared with 20–30% in Baiyin and 9.5–12% in Qingcheng. Lanzhou's reported affected-area ratio decreased from 47% to 11%. This decrease describes the recorded agricultural impacts and does not, by itself, demonstrate improved climate resilience.

Table 3 summarizes these disaster profiles alongside irrigation conditions. The regional differences provide a historical context for examining the correspondence between agricultural capacities and water, land, and settlement conditions. However, the comparison does not establish irrigation as the principal cause of these differences or directly rank regional agricultural resilience.

3.2. Data Source

The data sources of this study are shown in Table 4, including spatial data, statistical data and field survey data.

Table 4. Data source.

Data Type	Source	Temporal Coverage/Reference Year	Spatial Resolution/Scale	Temporal Resolution	Purpose
Land-use data	ESA CCI	2010, 2020	10 m	Two reference years	Extraction of arable land, woodland and grassland
DEM	SRTM	The latest data	30 m	Static terrain dataset	Slope calculation, terrain analysis
Township boundary vector	Natural resources sector	Boundary reference year	Township level	Single reference version	Spatial statistics and mapping
Meteorological data	China Meteorological Data Service Centre	Site data, 2020–2025 (4–9)	Meteorological stations	Daily/monthly/annual	Calculation of growing-season precipitation and the dry-farming potential index
Agricultural population, total population	*Gansu Statistical Yearbook*	[2016–2025] Excluding 2018	County level	Annual/single reference year	Calculation of agricultural population density and population agglomeration
Cultivated land area, irrigation ratio, etc.	*Gansu Statistical Yearbook*	[2016–2025] Excluding 2018	Township level	Annual/single reference year	Calculation of relevant evaluation indicators
Field survey data	Field surveys	10.2025/05.2026	Township/village level	Survey campaigns	Crops actually grown, crop selling prices, climate-related measures, agricultural income, and other relevant information

Spatial data were harmonized to WGS 1984. Township-level population and irrigation data refer to 2024 and were obtained from the 2025 *Gansu Statistical Yearbook*. The dry-farming potential index used mean April–September precipitation for 2020–2025, with townships within the same city/county assigned the same precipitation value.

3.3. Research Methodology

3.3.1. Evaluation Model of Agricultural Climate Resilience

The evaluation draws on an established farming-system resilience framework that distinguishes robustness, adaptability, and transformability [18]. These capacities provide a conceptual reference for the resistance, adaptability, and transformation dimensions adopted here. Table 5 retains three dimensions, seven elements, and nine indicators, which represent structural conditions potentially supporting resilience rather than observed responses to climatic shocks.

Table 5. Indicators and interpretive assumptions for evaluating potential agricultural climate resilience.

Criterion Layer	Feature Layer	Indicator	Rationale for Dimension Assignment and Interpretation
Resistance	Water resources guarantee	Irrigation rate of cultivated land +	Represents irrigation provision that may buffer rainfall shortages; its contribution depends on the reliability and sustainability of water supply.
	Water and soil	Potential terrace coverage +	Represents the potential for terracing to support soil and water conservation; it does not measure actual terrace construction or performance [19].
		Sloping farmland Conversion rate +	Represents a land-management response that may reduce cultivation on erosion-prone slopes; benefits depend on the conversion type and subsequent management [20].
	Economic buffers	Agricultural population density +	Represents agricultural labour availability that may support production and collective action. Higher density may also increase water and land pressures; the positive direction reflects the labour-support assumption [21].
Adaptability	Dry farming technology	Dry-farming potential index +	Represents environmental production potential relevant to adaptation in rain-fed agriculture; it does not directly measure farmers' adoption of adaptive technologies [22].
	Agricultural organization	Population agglomeration +	Represents spatial conditions that may facilitate coordination and access to services; agglomeration alone does not demonstrate effective agricultural organization.
Transformation power	Agricultural diversification	Non-agriculturalization index +	Represents potential livelihood diversification and reduced dependence on agriculture; benefits depend on employment opportunities and do not directly demonstrate agricultural transformation [23].
	Ecological value	Rate of returning farmland to forests +	Represents ecological restructuring through land-use conversion; its contribution depends on vegetation suitability, water availability, and livelihood trade-offs.
		Forest and grass coverage +	Represents an ecological condition potentially supporting land-use restructuring; coverage alone does not establish transformation capacity or its effectiveness [24].

Note: "+" denotes the positive direction adopted in the existing index calculation. Indicator assignments describe hypothesized contributions to potential resilience and are not exclusive to individual dimensions. Positive directions do not imply universally beneficial effects. The index measures structural conditions rather than observed performance following climate shocks.

Resistance includes irrigation provision, potential terrace coverage, sloping farmland conversion, and agricultural population density, interpreted as proxies for water supply, land management, and agricultural labor resources. Adaptability includes dry-farming potential and population agglomeration, representing environmental production potential and possible conditions for coordination and service access. Transformation includes non-agriculturalization, farmland-to-forest conversion, and forest and grass coverage, interpreted as proxies for livelihood diversification and ecological restructuring.

These assignments are analytical interpretations rather than exclusive or empirically validated relationships. Agricultural population density, for example, may support labor

availability and collective action while increasing pressure on limited water and land resources. Its positive direction represents the labor-support interpretation adopted in this study. Likewise, ecological restoration and non-agriculturalization may involve trade-offs rather than uniformly beneficial effects.

The entropy weight method determines indicator weights from variation within the dataset, and a weighted composite index is used to calculate the scores [19–22]. Although this procedure reduces reliance on discretionary weighting, it does not establish causal importance or validate indicator directions. Because the assessment does not include observed losses, yield stability, recovery time, income variability, or insurance access, the resulting index is interpreted as potential agricultural climate resilience rather than demonstrated resistance, recovery, or transformation following climate shocks.

(1) Data normalization, min-max normalization for nine indicators.

positive indicator:

$$Z_{ij} = \frac{X_{ij} - X_{min}}{X_{\max} - X_{\min}}$$

Negative indicator:

$$Z_{ij} = \frac{X_{\max} - X_{ij}}{X_{\max} - X_{\min}}$$

(2) The entropy weight method is used to calculate the weight.

The entropy value of the index of item j can be calculated as follows:

$$E_j = -\frac{1}{\ln(n)} \times \sum \left(p_{ij} \times \ln p_{ij} \right)$$

Of which:

$$p_{ij} = \frac{Z_{ij}}{\sum Z_{ij}}$$

weight:

$$w_j = \frac{1 - E_j}{\sum (1 - E_j)}$$

For the entropy-weight calculation, i denotes one of the 50 representative townships n = 50 and ***j*** denotes an indicator. The number of indicators is m = 9 for potential agricultural climate resilience and m = 6 for the spatial subsystem. Entropy weights were calculated separately for the two indicator systems using the 50 representative townships.

(3) Calculation of composite index.

Toughness index:

$$S_i = \sum \left(w_j \times Z_{ij} \right)$$

3.3.2. Spatial Subsystem Evaluation Model

The spatial subsystem evaluation adopts the same comprehensive index method as agricultural resilience, covering three dimensions of water resource space, land space and settlement space. A total of six indicators are shown in Table 6, and the weights of each indicator are also determined by the entropy weight method [25,26].

Spatial composite index:

$$I_i = \sum (w_k \times Z_{ik})$$

Table 6. Evaluation index system of spatial subsystem.

Feature Layer	Indicator	Unit	Direction	Regional Characteristics
Water resources space	Proportion of cultivated land in the Yellow River Valley	%	+	Agriculture in Lanzhou and Baiyin River Valley
	Gully density	km/km^2	−	Fragmentation of loess hilly
Land space	Proportion of cultivated land with flat topography	%	+	Yuanmian agriculture (Dong Zhiyuan)
	Proportion of cultivated land on the edge of forest land	%	+	Forest margin agriculture (Ziwuling)
	Contiguous degree of cultivated land	%	+	Mechanization potential
Settlement space	Average distance between settlement and cultivated land	km	−	Facilitation of production

Note: "+" denotes the positive direction adopted in the existing index calculation, and "−" indicates the negative direction adopted.

3.3.3. Coupling Coordination Model

The coupled coordination degree model is the core analysis method of this study, which adopts a two-layer structure.

(1) Total coupling: coupling coordination degree between agricultural resilience index S and spatial composite index I.

Coupling degree:

$$C = \frac{2 \times \sqrt{S \times I}}{S + I}$$

Aggregate coordination index:

$$T = \alpha \times S + \beta \times I$$

Coupling coordination degree:

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

Here, S denotes the potential agricultural climate resilience index, and I denotes the spatial subsystem evaluation index. Both are dimensionless composite scores calculated from normalized indicators. C is the coupling degree, describing the relative balance between the two subsystem scores, whereas T represents their combined development level. The coefficients α and β specify the relative contributions of S and I, respectively, with $\alpha + \beta = 1$. In this study, $\alpha = \beta = 0.5$, assigning equal importance to the two subsystems. D is the coupling coordination degree, integrating their relative balance and combined level. Higher D values indicate greater coordination within this evaluation framework rather than a demonstrated causal relationship or observed resilience performance.

(2) Four pairs of coupling: calculate the coupling coordination degree of the four pairs of indicators, respectively.

To sum up the above Table 7, the criteria for the classification of coordination levels are as follows: D value of 0.90–1.00 is high-quality coordination, 0.80–0.89 is good coordination, 0.70–0.79 is intermediate coordination, 0.60–0.69 is primary coordination, 0.50–0.59 is barely coordination, 0.40–0.49 is on the verge of imbalance, 0.30–0.39 is mild imbalance, 0.20–0.29 is moderate imbalance, and 0.10–0.19 is serious imbalance [22].

Table 7. Coupling pair analysis.

Coupling Pair	System A	System B	Meaning
Water–soil coupling	Irrigation rate of cultivated land	Potential coverage of terraced fields	Synergy of water resources and soil and water
Soil–yield coupling	Proportion of cultivated land with flat topography	Dry-farming potential index	Matching of land condition and dryland production
Polymerization-production coupling	Average distance between settlement and cultivated land (positive)	Non-agriculturalization index	Settlement distribution and agricultural transformation
Ecology-production coupling	Forest and grass coverage	Rate of returning farmland to forest	Ecological restoration and agricultural coordination

3.4. Representative-Township Selection

3.4.1. Selection Basis and Classification Criteria

This study adopted a stratified purposive approach to select representative townships, combining rural statistical data from the 2025 *Gansu Statistical Yearbook*, existing topographic maps, empirical thresholds, and agricultural production characteristics [26–29]. The selection procedure distinguished data-based classification from judgment-based case selection. Statistical records and maps provided the information used to characterize townships, empirical thresholds established operational classification boundaries [30], and regional knowledge supported the identification of representative agricultural cases and adjustments to their geographical distribution. The yearbook edition identifies the statistical source, while the reference years of the underlying data are specified in Table 4 [31].

All 235 townships were classified according to geomorphology, water conservancy conditions, and settlement location.

Geomorphology: existing topographic maps, DEM data, and regional geomorphological characteristics were used to distinguish five types: Yellow River Valley (A), Loess Plateau (B), loess hilly area (C), windy and sandy area (D), and forest margin area (E).

Water conservancy conditions: cultivated-land irrigation ratios were considered together with river distribution and water conservancy projects. Using the adopted 30% irrigation-ratio threshold and the irrigation supply context, townships were classified into Yellow River Irrigation Area (1), high-lift irrigation area (2), Yintao Irrigation Area (3), and dry-farming area (4).

Settlement location: commuting distances, farming radii, and spatial autocorrelation information were considered using empirical distance boundaries. Townships were classified as suburban (a, <15 km), outer suburban (b, 15–30 km), and remote (c, >30 km).

The classification thresholds were adopted as practical rules informed by regional experience and existing geographical information. They were not estimated through statistical optimization or treated as universally applicable boundaries.

3.4.2. Selection Procedure

The selection proceeded in four stages.

First, each township was assigned a combination code representing geomorphology × water conservancy conditions × settlement location (Figure 5).

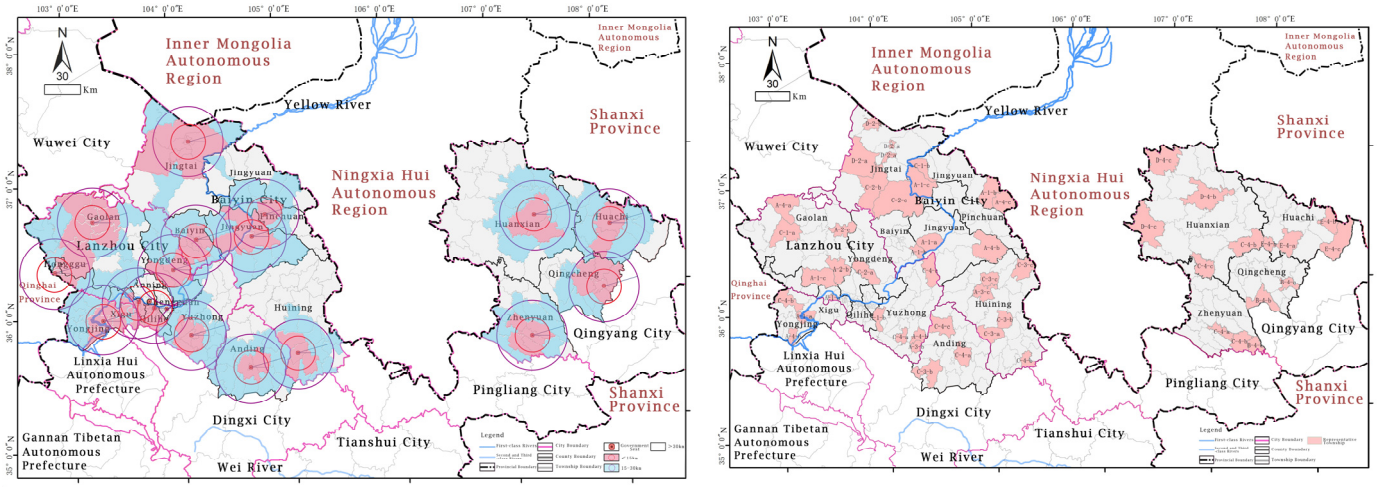


Figure 5. Selection of representatives from townships. (**a**) Represents the analysis of township circles. (**b**) Represents a summary of township codes. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

Second, the number of townships belonging to each observed code was counted to establish the distribution of classification combinations across the study area.

Third, the principal crop-production activities associated with each combination were identified. Because the study focuses on rural agriculture, candidate townships were considered in relation to both their classification characteristics and their representative planting industries. Sample allocation followed the existing rules: three townships were selected from combinations containing at least ten townships, two from combinations containing five to nine, one or two from combinations containing two to four, and the township itself from singleton combinations. Selection within these groups was purposive rather than random.

Fourth, the candidate list was reviewed across counties and districts. Adjustments were made to avoid excessive concentration within individual administrative units while considering the classification codes and agricultural characteristics of the candidates. This procedure resulted in the selection of 50 representative townships from the full set of 235.

The sample was designed to capture variation in geographical conditions, irrigation provision, settlement location, and representative crop-production activities. Its representativeness therefore rests on structured coverage of these characteristics rather than random selection or sample proportion alone. The procedure does not establish statistical equivalence between the selected townships and the full population, and differences within individual classification combinations may remain.

3.4.3. Representative-Township Selection Results and Assumptions Underlying Spatial Projection

The extension of representative-township results to the wider study area assumes that similarities in classification characteristics and agricultural production provide a reasonable basis for transferring information between townships. These similarities support regional interpretation but do not imply identical resilience conditions.

Local differences in crop composition, infrastructure, management, and service access may remain within the same classification combination. Consequently, projected results are interpreted as estimates of regional patterns rather than independently observed values

for every township. Their use in planning should account for the uncertainty associated with purposive selection and within-group variation.

The final sample comprises 50 representative townships covering 10 geographical combination types (Figure 5), accounting for 21.28% of the 235 townships. Its representativeness rests on structured coverage of geographical conditions and agricultural characteristics rather than demonstrated statistical equivalence with the full study area.

4. Results

4.1. Spatial Pattern of Agricultural Resilience

4.1.1. Comprehensive Evaluation Index System for Resilience

Table 8 presents nine indicators covering resistance, adaptability, and transformation. Indicators were selected for their theoretical relevance to potential agricultural climate resilience, availability at the township scale, and limited conceptual overlap. Their weights were calculated using the entropy weight method, which reflects variation within the dataset rather than causal importance.

Table 8. Rural agriculture resilience evaluation weights.

Dimension	Indicator	Unit	Directional	Weight
Resistance	Irrigation rate of cultivated land	%	+	0.180
Resistance	Potential coverage of terraced fields	%	+	0.355
Resistance	Slope farmland conversion rate	%	+	0.182
Resistance	Agricultural population density	Person/km ^{2}	+	0.014
Adaptability	Dry-farming potential index	—	+	0.065
Adaptability	Population agglomeration	Person/km ^{2}	+	0.009
Transformation power	Non-agriculturalization index	%	+	0.084
Transformation power	Rate of returning farmland to forest	%	+	0.022
Transformation power	Forest and grass coverage	%	+	0.089

From the perspective of weight distribution, the potential coverage rate of terraced fields (0.355), the rate of conversion of sloping farmland to other types of land (0.182), and the irrigation rate of cultivated land (0.180) have higher weights than other indicators, indicating that these water- and soil-related indicators contribute more strongly to the differentiation of the composite agricultural resilience index rather than demonstrating causal importance. This pattern is consistent with the natural geographical background of the study area, which is located in the arid and semi-arid transition zone and where precipitation is a primary limiting factor for agricultural production. Forest and grassland coverage (0.089) and the non-agriculturalization index (0.084) have the next highest weights, reflecting their relative contributions to the composite index rather than demonstrated effects on resilience enhancement.

4.1.2. Comprehensive Score of Representative-Township Resilience

Based on the weights calculated using the entropy weight method and the standardized index values, the comprehensive agricultural resilience index ($\boldsymbol{S}$) for 50 representative townships was calculated. The results were used to classify the resilience level into five levels: high, medium-high, medium, medium-low, and low, according to the natural discontinuity method, as shown in Figure 6.

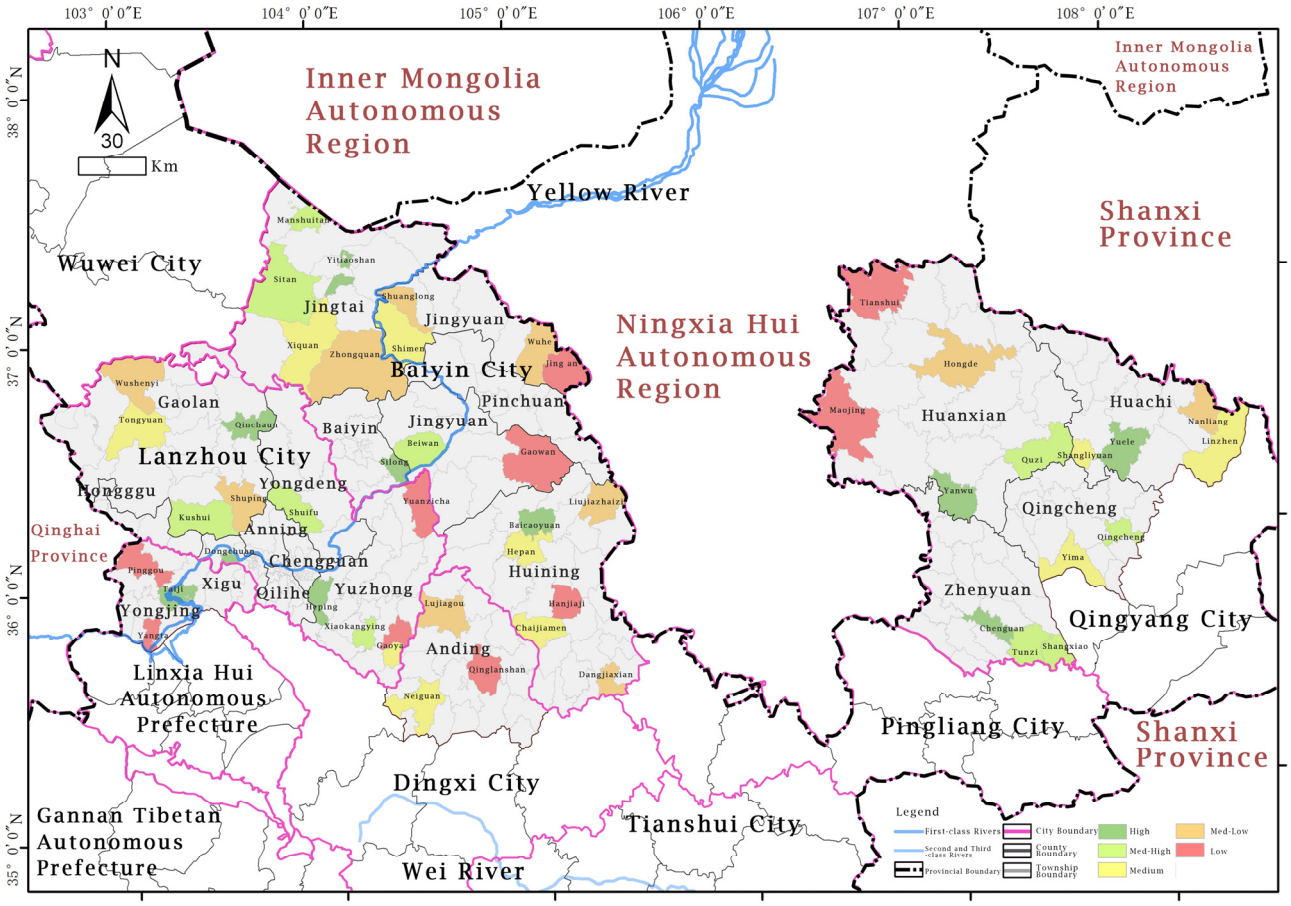


Figure 6. Comprehensive evaluation of the resilience of rural industries in representative towns and villages. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

Sample towns with low and medium resilience are basically distributed in every county in the study area and are more concentrated in the northern part of the four counties of Qingyang, outside Yongjing County, Anding of Yuzhong, and Huining. The sample towns with medium resilience are basically located in the forest edge area of Qingyang City and around the areas of medium-high resilience, forming a resilience transition circle. Most of the medium-high and high-resilience sample towns are distributed in river valleys and water diversion areas, and the rest are scattered throughout the entire region, as shown in Table 9.

Table 9. Represents the classification of township agriculture resilience levels.

Type Combination	Number of Samples	Mean Toughness	Toughness Grade
A-1/A-2/C-3/C-4/D-2/E-4	10	0.364	High toughness
A-1/B-4/C-2/C-4/D-2	10	0.239	Medium-high
A-3/B-4/C-1/C-2/C-3/E-4	10	0.204	Medium
A-1/A-4/C-1/C-2/C-3/C-4/D-4/E-4	10	0.179	Medium-low
A-4/C-3/C-4/D-4	10	0.129	Low

4.1.3. Spatial Projection of Toughness Evaluation Results

The potential agricultural climate resilience scores of the 50 representative townships were projected to all 235 townships using classification-combination means. Each combi-

nation was defined by geomorphology—Yellow River Valley (A), Loess Plateau (B), loess hilly area (C), windy and sandy area (D), and forest margin area (E)—water conservancy conditions—Yellow River Irrigation Area (1), high-lift irrigation area (2), Yintao Irrigation Area (3), and dry-farming area (4)—and settlement location—suburban (a), outer suburban (b), and remote (c). For each combination, the arithmetic mean of the scores of all selected representative townships was calculated and assigned to every township within that combination. Where only one representative township was selected, its score constituted the combination mean. Grades were determined from the assigned scores using the same grading criteria. The township-level results were subsequently summarized at the county level to describe regional spatial patterns. This projection assumes relevant structural similarities within each combination and does not capture all within-combination variation.

Based on the projection results in Figure 7, the spatial pattern of agricultural resilience in the study area was drawn. From the perspective of spatial distribution, the agricultural resilience in the study area shows an overall pattern of "high in the northwest and low in the southeast in the western area, low in the northwest and middle in the south in the eastern area; high along the river and low in the hills", which is highly consistent with the spatial coupling relationship between water conservancy conditions and landform types.

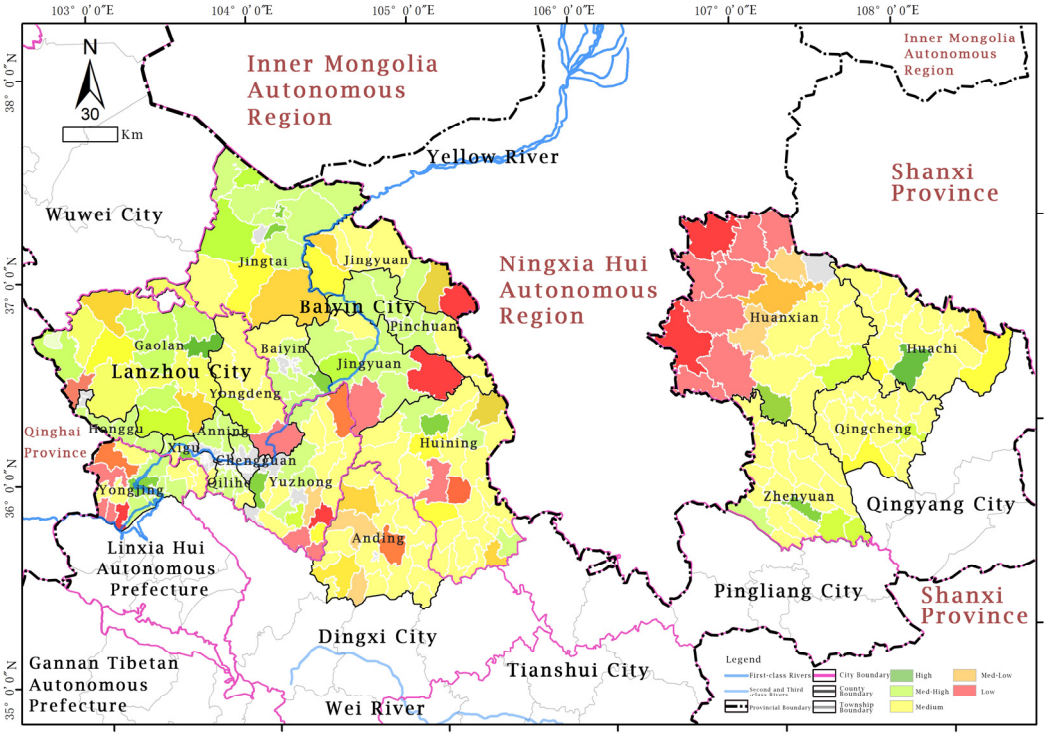


Figure 7. Comprehensive evaluation of the resilience of industries in townships and villages across the region. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

County areas and distribution of high and medium resilience: townships a with resilience index are concentrated in the Yellow River Diversion Irrigation Area along the main stream of the Yellow River. On the county scale, Gaolan, Baiyin, Pingchuan and Jingyuan are the core, extending north to the Yellow River Diversion Irrigation Area in Jingtai and south to the Yellow River Diversion Area in Yongjing. The above-mentioned counties are located in the Yellow River Valley. Relying on the advantages of the Yellow River water resources, the irrigation rate of cultivated land is generally higher than 45%.

The suburban or suburban location further enhances the ability to gather factors and forms a relatively stable agricultural production system, with an average resilience value of over 0.22.

Counties and distribution of medium resilience: townships with a medium resilience index are mainly distributed in loess hills, loess plateaus, forest edge areas, and edge areas of river valleys and rivers. In the county area, they are mainly plateau areas such as Yongdeng, Huining, Anding, and Dongzhiyuan in four counties of Qingyang. This type of county has certain basic agricultural conditions but is restricted by unstable water supply or the accessibility of suburban locations. The resilience level ranges from 0.19 to 0.22, with large spatial differences within it.

Counties with medium-low and low resilience and their distribution: the towns with the lowest resilience index are concentrated and contiguously distributed in the loess hilly and ravine areas. At the county level, the entire Huanxian, Huining, and central and southern part of Anding District are the most typical. The above-mentioned counties are located in loess hilly areas, with dry-farming areas as the main water conservancy type. The irrigation rate of cultivated land is generally lower than 30%. The proportion of sloping farmland is high, and the forest and grass coverage rate is low. In addition, the service radiation in exurban or remote areas is insufficient. Multiple constraints superimpose to form a "low-resilience trap". The average resilience value is less than 0.16. This area is key, and it is a difficult study area in which to improve agricultural resilience.

4.2. Comprehensive Evaluation of Space Subsystems

4.2.1. Space Evaluation Index System

The spatial subsystem evaluation comprises six indicators across water resources space, land space, and settlement space. In the water resources spatial dimension, the proportion of cultivated land in the Yellow River Valley describes the geographical concentration of farmland in a river-valley setting. It is used as an indirect locational proxy rather than a direct measure of water availability or irrigation access. Gully density represents terrain dissection and potential erosion susceptibility; its negative direction reflects the constraints associated with more dissected terrain rather than erosion-control capacity.

The land spatial dimension includes the proportion of cultivated land on flat terrain, the proportion at forest margins, and cultivated-land contiguity, describing terrain conditions, forest–farmland configuration, and spatial continuity, respectively. The settlement spatial dimension uses the average distance between settlements and cultivated land to represent spatial separation rather than directly measured production efficiency. All indicators are quantified at the township level. Their directions represent the interpretive assumptions adopted in the evaluation, while the limitations of these spatial proxies are acknowledged.

Table 10 presents the entropy weights of the six spatial indicators. The proportion of cultivated land in the Yellow River Valley has the highest weight (0.537), followed by the average distance between settlements and cultivated land (0.193) and the proportion of cultivated land at forest margins (0.137). These indicators carry greater relative weight in differentiating the composite spatial index rather than demonstrating causal importance. The remaining weights are 0.084 for flat-terrain cultivated land, 0.026 for gully density, and 0.023 for cultivated-land contiguity. The high weight of the river-valley indicator should be interpreted as the prominence of farmland location within the index, not as evidence of greater actual water availability.

Table 10. Spatial system evaluation weight.

Feature Layer	Indicator	Unit	Direction	Weight
Water resources space	Proportion of cultivated land in the Yellow River Valley	%	+	0.537
	Gully density	km/km^2	−	0.026
Land space	Proportion of cultivated land with flat topography	%	+	0.084
	Proportion of cultivated land on the edge of forest land	%	+	0.137
	Contiguous degree of cultivated land	%	+	0.023
Settlement space	Average distance between settlement and cultivated land	km	−	0.193

Note: "+" denotes the positive direction adopted in the existing index calculation, and "−" indicates the negative direction adopted.

4.2.2. Representative-Township Spatial Evaluation Results

Based on the entropy weight method to determine the weight of six indicators, the spatial composite index (I) of 50 representative townships is calculated. The spatial composite index reflects the comprehensive level of various types of combinations in terms of spatial resource endowment and spatial allocation efficiency.

The townships with high spatial comprehensive index are concentrated in the Yellow River valley and forest edge areas, such as Yangta Township and Taiji Town in Yongjing, Silong Town in Baiyin, etc. The towns with a low spatial comprehensive index are concentrated in the dense areas of loess hills and gullies, such as Huining, Anding, Huanxian, etc., as shown in Figure 8.

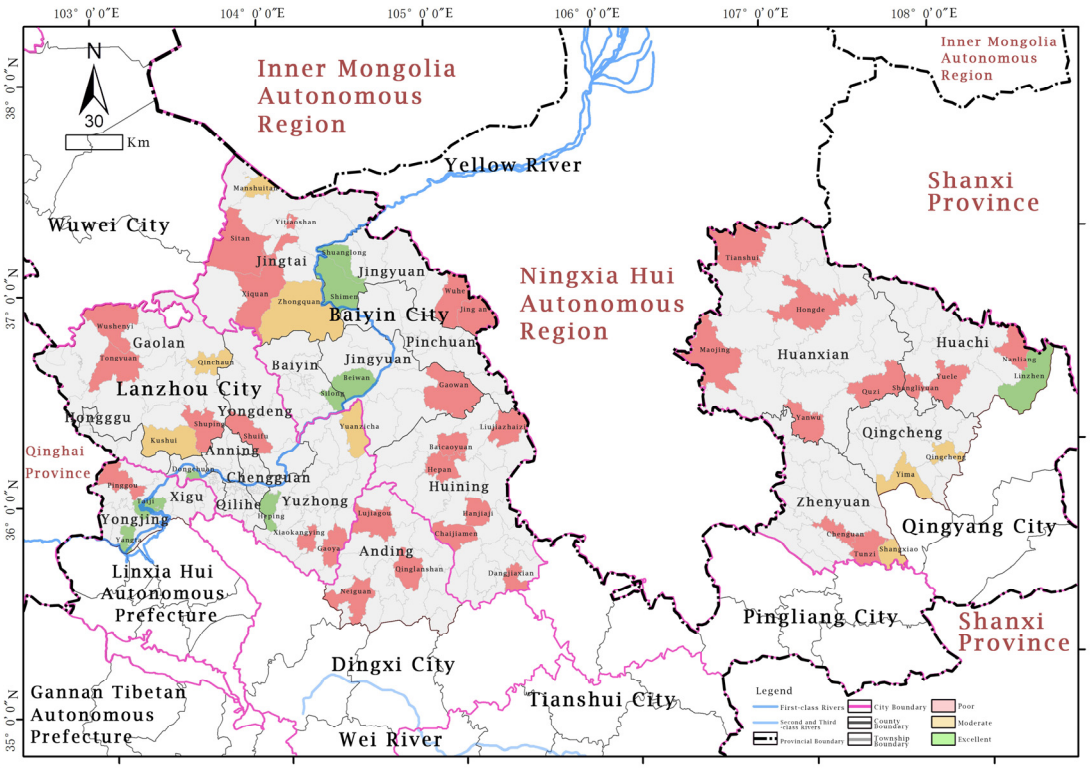


Figure 8. Comprehensive evaluation of rural space on behalf of villages and towns. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

According to the type combination statistics (Table 11), the spatial comprehensive index of the plateau agriculture × Yellow River irrigation × suburb type (0.58) and of the loess hilly × rain-fed dry-farming × remote type (0.29) are the lowest, which is basically consistent with the type combination order of the resilience index, indicating that there is a significant positive correlation between spatial resource endowment and the level of agricultural resilience.

Table 11. Represents the classification of township spatial evaluation grades.

Type Combination	Number of Samples	Spatial Composite Score Mean	Evaluation Grade
A-1/A-4/C-1/E-4	9	0.518	Excellent
A-1/A-2/B-4/C-2/C-4/D-2	8	0.190	Medium
A-3/A-4/C-2/C-3/C-4/D-2/D-4/E-4	33	0.103	Inferior

4.2.3. Global Characteristic Analysis of Spatial Subsystem

Using the same type of projection method, the evaluation results of the spatial subsystem are applied to 235 townships in the whole region, as shown in Figure 9, and the spatial differentiation laws of the three dimensions are analyzed, respectively.

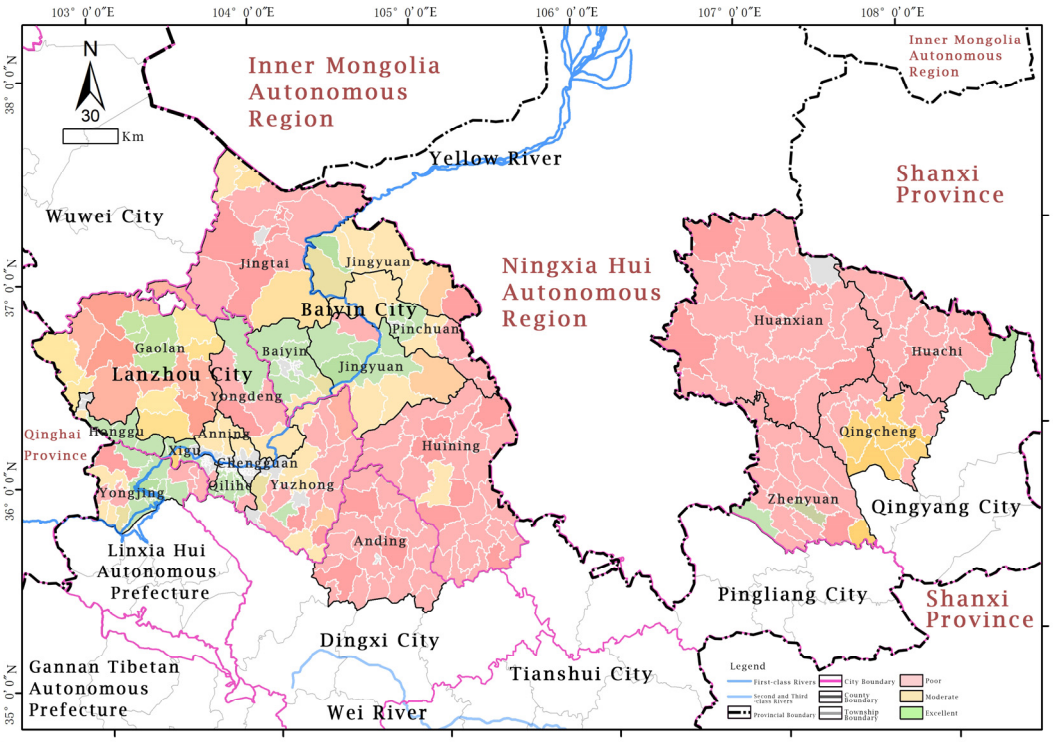


Figure 9. Comprehensive evaluation of rural space in the whole area. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

The distribution pattern of spatial comprehensive score is highly consistent with the trend of the main stream of the Yellow River, the distribution of the Loess Plateau and the topography and geomorphology conditions, showing the overall trend of "the western area is moderately good in the central and northern areas, and the southern area is poor; the eastern area is generally poor".

The excellent areas are concentrated in the diversion and irrigation areas along the Yellow River (Baiyin, Jingtai, Yongjing, northern Jingyuan and Pingchuan) and scattered in

the forest edge areas (southeast of Huachi) and southwest of Zhenyuan. With the triple advantages of water resources, land resources and settlement space superimposed on each other, the comprehensive score of this area ranks among the highest in the whole region.

The middle area is distributed around the fine area in a band shape, mainly involving Yongjing, Gaolan, Yuzhong, Jingyuan and Jingtai. In addition, it is distributed in the forest margin area of Qingyang City (central and southern Qingcheng). The conditions of each dimension in this part of the area are balanced, but there are no obvious outstanding advantages.

Poor areas are contiguously concentrated in loess hilly and gully areas (Huining, Anding, Huanxian, Huachi, Zhenyuan), which are far away from the main stream of the Yellow River and have high gully density and scattered settlements. The superposition of triple disadvantages makes the comprehensive score significantly low.

To sum up, the combination relationship between water resources and topography is the core factor that determines the spatial comprehensive score. Irrigation areas along the Yellow River and agricultural areas on the plateau are the areas with the best foundation in the whole region, while loess hilly and gully areas are the areas with the weakest comprehensive conditions.

4.3. Coupled Agriculture Coordination Diagnosis

4.3.1. Space System Coupling Coordination

The potential agricultural climate resilience index and the spatial subsystem evaluation index were used to calculate the coupling coordination degree of the 50 representative townships. The results were subsequently projected to all townships in the study area, followed by county-level correlation analysis.

The coupling coordination degree (D) was classified using the ten-grade classification attributed to Liao Chongbin [22], with the original thresholds retained. The calculated values fell within six of these ten grades: moderate imbalance, mild imbalance, near imbalance, barely coordinated, primary coordination, and intermediate coordination. Only these observed grades are presented in the results. No categories were merged, and no thresholds were adjusted according to the sample distribution.

4.3.2. Evaluation of Coupling Coordination Degree of Representative Townships

Using the original ten-grade classification described in Section 4.3.1, the coupling coordination degrees of the 50 representative townships were summarized and mapped (Figure 10). The calculated values occupied six categories, with most townships concentrated in mild imbalance, near imbalance, and barely coordinated categories. No representative township reached good or high-quality coordination, indicating substantial scope for improving agriculture–space coordination.

Townships in the primary and intermediate coordination categories are mainly distributed in irrigation areas along the Yellow River, particularly Yongjing and northern Jingyuan. These townships exhibit relatively favorable coordination within the sample, but their intermediate grades still indicate potential for improvement. Townships in the near-imbalance and barely coordinated categories are widely distributed around higher-value areas, including Yongjing, Gaolan, Yuzhong, northern Jingyuan, southern Jingtai, and southeastern Qingyang. Their scores indicate incomplete coordination between potential agricultural resilience and spatial support conditions. Moderate and mild imbalance categories are concentrated in Yuzhong, Huining, Anding, and northern Huanxian. These areas exhibit low coordination scores; where both subsystem indices are also low, the results indicate the coexistence of low potential agricultural resilience and limited spatial support.

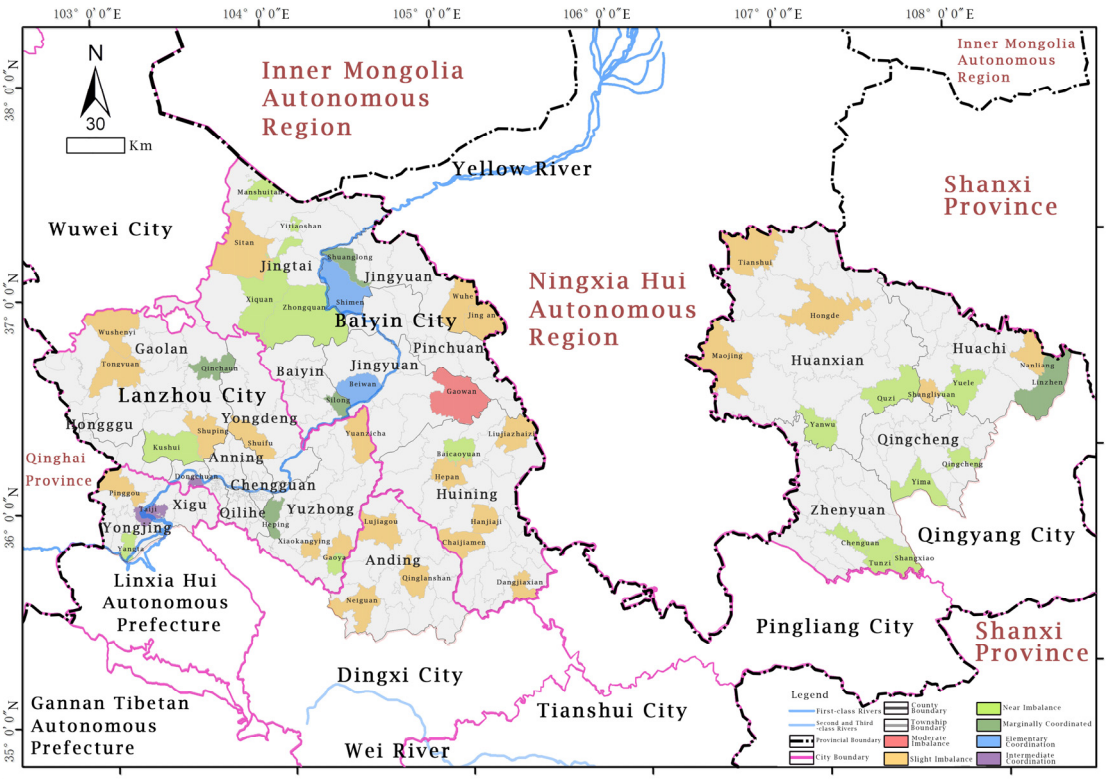


Figure 10. Evaluation of coupling coordination degree of representative villages and towns. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

4.3.3. Analysis of Coupling Relationship Characteristics of Townships in the Whole Region

Following the projection procedure described in the Section 3, D values from the 50 representative townships were extended to all 235 townships across 10 classification combinations (Figure 11). Each township received the mean D value of the selected representative townships within its combination. The supplementary classification table provides the number of townships, representative cases, and assigned D value for each combination. The resulting map describes spatial differences in combination-level estimates rather than independently calculated values for every township. Overall, higher values occur along the Yellow River in the central part of the western study area, with lower values towards its northern and southern margins; the eastern study area generally exhibits lower coordination.

Higher projected values are concentrated in Yellow River diversion irrigation areas, including Yongjing, Xigu, Qilihe, Baiyin, Pingchuan, and northern Jingyuan. These areas fall within the primary and intermediate coordination categories. Their distribution corresponds broadly to favorable irrigation and land conditions, although these associations do not establish causal effects.

Intermediate projected values form transitional belts around the higher-value areas. In the western study area, these include southern Gaolan, much of Jingtai, southern Yuzhong, southern Huining, central and southern Anding, and parts of Jingyuan and northern Pingchuan. In the eastern study area, they include central and southern Qingcheng and Zhenyuan, central and western Huachi, and eastern Huanxian. These areas mainly fall within the near-imbalance and barely coordinated categories. Agricultural or spatial lag is identified from the relative subsystem scores rather than from D alone.

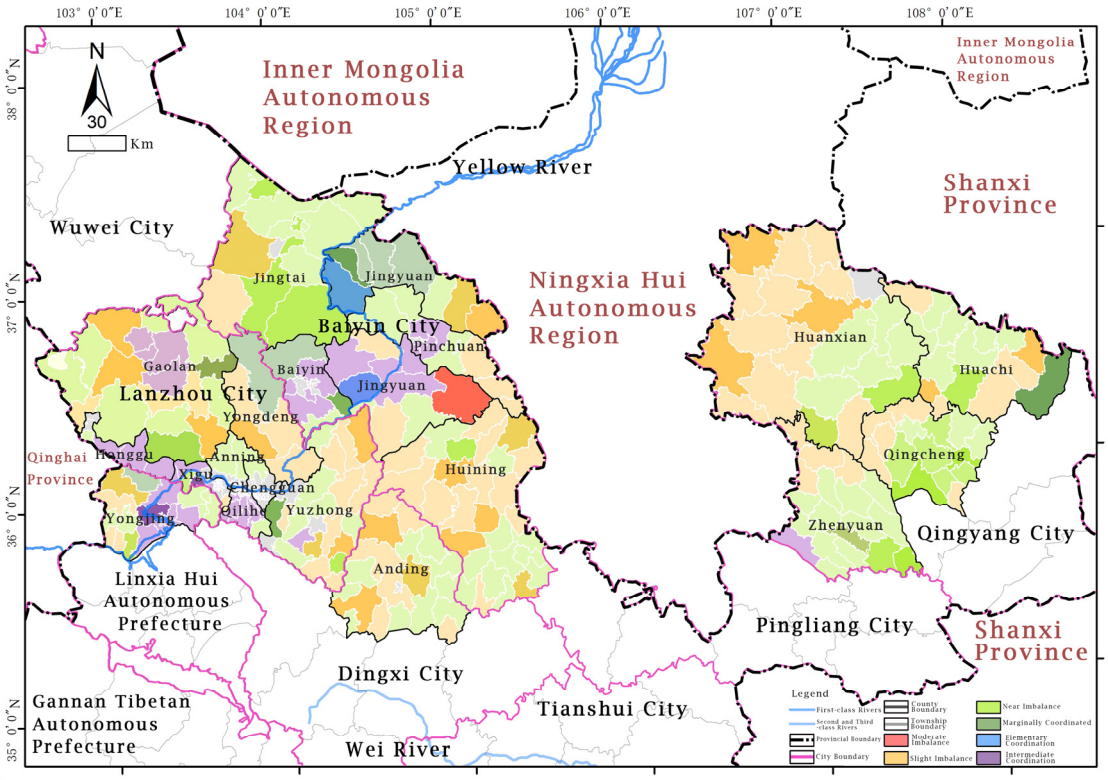


Figure 11. Evaluation of the coordination degree of township coupling in the whole region. This map was prepared using the standard map provided by the Ministry of Natural Resources of China (map approval no. GS(2024)0650). The boundaries of the base map have not been modified.

Lower projected values are concentrated in northern Huanxian, peripheral Huachi, northern Qingcheng and Zhenyuan, and central and northern Anding and Huining. These areas generally fall within the moderate- and mild-imbalance categories and are associated with loess hilly and gully terrain, dispersed settlements, and distance from the Yellow River main stream. These characteristics provide a context for interpreting low coordination scores but do not independently demonstrate barriers to resilience improvement or a low-level equilibrium trap.

Overall, the projected pattern consists of higher-value concentrations along the Yellow River, transitional surrounding areas, and contiguous lower-value areas in the loess hills and gullies. Water-related spatial conditions and terrain provide relevant interpretive context; their causal importance is not established by this descriptive analysis.

4.4. Mechanism Verification and Obstacle Identification

4.4.1. Distribution of Core Disorder Types

In order to identify obstacle factors, this study selects four pairs of core coupling relationships, calculates the coordination degree of each coupling pair based on 50 representative towns, and then deduces the diagnosis results to 235 towns in the whole region through the spatial mapping method, as shown in Table 7.

As can be seen from the results, among the 50 representative townships, water–soil coupling imbalance is the most common core obstacle (37, accounting for 74%), much higher than poly–production coupling (seven, accounting for 14%) and ecology–production coupling (two, accounting for 4%). The remaining four townships (8%) have compound barriers.

The obstacle diagnosis results of 50 representative townships (Figure 12) are applied to all townships in the whole region through the same type of spatial mapping method. The results show that the obstacle type structure of representative towns is representative

in the whole region: water–soil coupling imbalance is the main obstacle type, which is concentrated and contiguously distributed in loess hilly and gully areas and rain-fed and dry-farming areas. Poly–production coupling disorder followed, scattered in river valleys and suburbs. Ecology–production coupling imbalance is mainly located in the forest margin and ecologically fragile zone. Compound barriers are widely scattered in multi-type ecotones, and these are the areas where it is most difficult to improve resilience and where priority intervention is most needed.

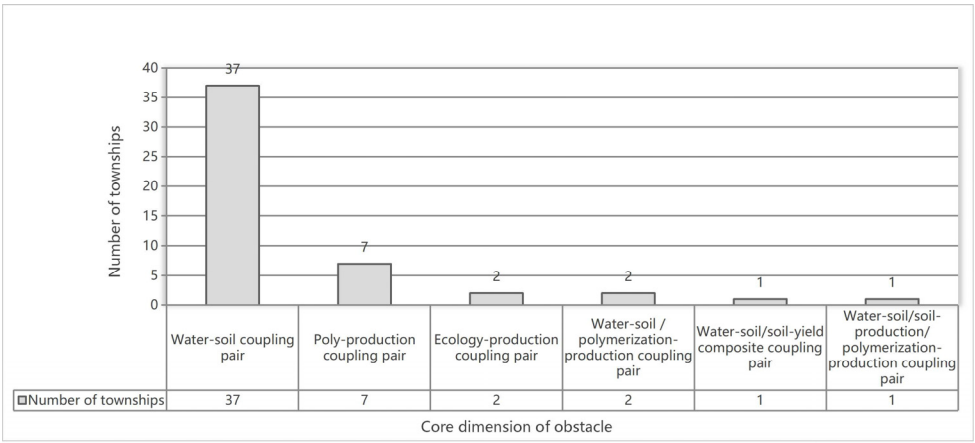


Figure 12. Represents the core dimension statistics of obstacles in townships.

To sum up, the agriculture–space coupling imbalance in the research area is dominated by water–soil, and the differences between types of areas are secondary. Most towns are subject to the dual constraints of drought, water shortage and water and soil shortage.

4.4.2. Attribution of Obstacles

The observed agriculture–space coupling constraints can be interpreted through three complementary perspectives. These interpretations suggest possible mechanisms rather than establish causal relationships.

Physical geography: the study area lies in the arid and semi-arid transition zone of the Loess Plateau, where limited precipitation, high evaporation, and dissected terrain provide a context for water–soil mismatches [32]. Water–soil coupling was identified as the principal constraint in 37 of the 50 representative townships (74%). This finding supports prioritizing the joint assessment of irrigation reliability and soil–water conservation needs in these townships. It does not imply that irrigation expansion is universally appropriate; interventions should consider local water availability and ecological limits.

Spatial structure: settlement dispersion and separation from farmland may increase travel and transport costs and reduce access to agricultural services [33]. In suburban areas, expansion of built-up land may fragment farmland and intensify competition between agricultural and other land uses [34]. These pathways offer possible explanations for settlement–production mismatches, but transport costs, service accessibility, and land-use competition were not directly tested in this study.

Agricultural and ecological transition. Differences in crop-production patterns, livelihood diversification, and ecological restoration may also affect the correspondence between agricultural activities and spatial conditions. Ecology–production mismatches may arise where restoration measures and agricultural or livelihood adjustments are insufficiently coordinated. However, the indicators used here do not establish the timing or causal direction of these processes.

Alternative explanations include irrigation access, household income, transport connectivity, employment structure, depopulation, government support, and market distance. These factors were not jointly controlled, so the attribution remains preliminary. The diagnosis therefore informs planning priorities and further investigation rather than demonstrating the causes of the observed constraints.

5. Planning the Response

5.1. Planning Response Framework

The China Adaptation to Climate Change Progress Report 2025 provides the policy context for integrating climate adaptation into territorial spatial planning. The proposed framework draws on hierarchical and categorical planning principles [35], county-level planning under security and resilience objectives [36], and coupling-informed rural industrial planning [37]. Research on rural industrial integration land and urban–rural coupling assessment further informs the consideration of land-use conditions and the connection between assessment and planning [38–41].

Building on these foundations, this study proposes a diagnosis–classification–implementation framework. Its specific contribution is to connect the diagnosis of 50 representative townships with geomorphology × irrigation × location combinations, county-level coordination, and township-level implementation. Diagnostic information flows upward to inform differentiated strategies, while planning priorities and implementation requirements are transmitted downward. A proposed monitoring feedback loop supports subsequent diagnosis and strategy adjustment, as shown in Figure 13. This integrated pathway is the authors' synthesis; its implementation effectiveness has not been evaluated in this study.

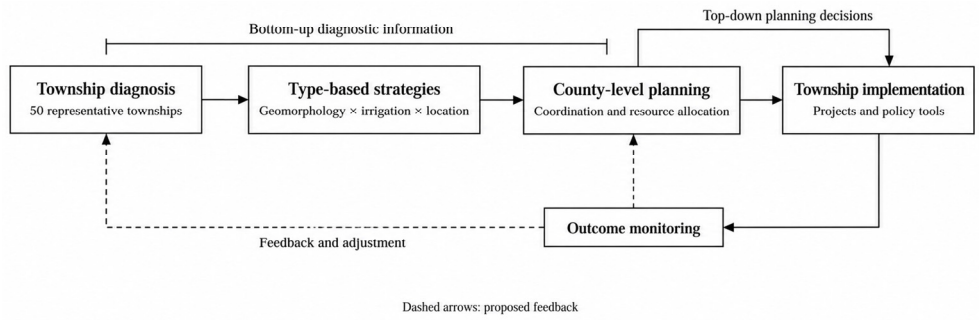


Figure 13. Diagnosis-to-planning response framework.

5.2. Classification and Implementation Based on Obstacle Type

Planning responses are organized around the four coupling pairs defined in Section 4.4. The diagnosis identifies potential matching constraints rather than demonstrating their causes. Accordingly, the following measures are proposed options requiring local verification rather than interventions whose effectiveness has been established. Compound constraints are addressed through coordinated combinations of these measures.

(1) Water–soil coupling constraints

Where irrigation provision and potential terrace coverage indicate matching constraints, priorities include assessing irrigation reliability, improving existing irrigation facilities, and implementing locally suitable terracing and soil–water conservation measures [28,42]. Additional irrigation should be considered only where sustainable water supply is demonstrated. These measures can be incorporated into county-level agricultural infrastructure and cultivated-land protection programs [29].

(2) Land–production coupling constraints

This pair links the proportion of cultivated land on gentle terrain with the dry-farming potential index. Where mismatches are identified, planning should assess whether crop-production arrangements are compatible with terrain and growing-season precipitation. Potential responses include adapting crop composition and cultivation practices and improving suitable farmland while avoiding expansion onto erosion-prone slopes. These measures can be incorporated into agricultural development and cultivated-land improvement programmes.

(3) Settlement–production coupling constraints

This pair links settlement–farmland distance with the non-agriculturalization index. Where mismatches are identified, priorities include examining access between settlements, farmland, agricultural services, and employment opportunities. Potential measures include improving agricultural service networks and coordinating settlement development with farmland protection [27]. County-level programs for village layouts and service facilities can support implementation [26]. Settlement relocation should not be inferred as necessary from this diagnosis alone.

(4) Ecology–production coupling constraints

This pair links forest and grass coverage with farmland-to-forest conversion. The diagnosis should prompt assessment of restoration suitability and compatibility with agricultural livelihoods rather than an automatic increase in vegetation coverage. Potential responses include erosion prevention, restoration using locally suitable vegetation, land-use restrictions in ecologically sensitive areas, and adaptation of production arrangements where restoration affects farmland. Implementation should coordinate ecological restoration with agricultural and livelihood support.

(5) Combined implementation for compound constraints

Where multiple coupling constraints are identified, the relevant measures should be combined through county-level comprehensive land improvement and ecological restoration programs. Priorities should follow the diagnosed combinations and local feasibility rather than applying the same package to every township. Implementation monitoring should distinguish changes in the original diagnostic indicators from additional measures of environmental and livelihood outcomes.

5.3. County Planning Transmission and Spatial Landing

5.3.1. County-Level Priorities Under Resource Constraints

The representative-township diagnosis informs three county-level planning orientations. These orientations summarize the conditions of the sampled townships and should not be interpreted as uniform classifications of every township within a county.

Priority improvement areas, including Huining, Anding, Huachi, and Huanxian, are characterized by low potential agricultural resilience and prominent water–soil constraints. Planning should prioritize the maintenance of existing irrigation facilities, locally suitable terracing, rainwater harvesting, and soil–water conservation. Where water availability is limited, improving existing systems and adapting rain-fed production should take precedence over expanding irrigation.

Coordinated upgrading areas, including Jingtai, Jingyuan, Yongdeng, Yuzhong, Zhenyuan, and Qingcheng, face combinations of water–soil, settlement–production, and ecology–production constraints. Measures should follow the locally diagnosed pair: irrigation reliability and land management for water–soil constraints; agricultural service access and settlement–farmland connections for settlement–production constraints; and suitable restoration coordinated with production adjustments for ecology–production constraints.

Land–production mismatches should additionally inform crop and cultivation choices according to terrain and growing-season precipitation.

Transformation and optimization areas, including Baiyin District, Lanzhou New District, Xigu, Gaolan, and Yongjing, require coordination between agricultural production and urban or suburban development. Priorities include protecting productive farmland, managing settlement expansion, and improving agricultural services and facilities. In townships where water–soil constraints remain prominent, particularly in Yongjing, these needs should be addressed alongside suburban spatial optimization rather than replaced by a uniform transformation strategy.

Under limited finance, infrastructure, or water supply, intervention priorities should consider the diagnosed constraint, the population and farmland served, implementation feasibility, maintenance requirements, and ecological limits. Low-cost improvements to existing facilities and service networks should generally precede major new construction. Expensive projects should be phased and subject to feasibility assessment. The prevalence of water–soil constraints supports early attention to this issue but does not justify allocating resources solely according to obstacle frequency or expanding irrigation without a sustainable water source. These are proposed decision principles rather than the results of a formal investment-ranking analysis.

5.3.2. Phased Implementation and Planning Transmission

In the near term (2026–2035), implementation should prioritize urgent and feasible improvements to existing systems. Water–soil-constrained townships should focus on irrigation maintenance, suitable terrace rehabilitation, and erosion prevention. Settlement–production-constrained townships should improve agricultural service access and settlement–farmland connections. Land–production and ecology–production diagnoses should guide locally appropriate cultivation adjustments and restoration measures. Under limited funding and water availability, maintenance and low-cost improvements should precede major infrastructure expansion. Baseline monitoring should be established to assess implementation outcomes.

In the medium term (2035–2050), county governments should coordinate infrastructure, agricultural services, and land improvement across townships. Priorities include optimizing settlement–production relationships, adapting production to terrain and precipitation conditions, and integrating ecological restoration with livelihood support. Larger projects should be phased according to financial capacity, sustainable water availability, and ecological limits, with priorities adjusted using monitoring results.

Beyond 2050, planning should emphasize the continued adaptation of agricultural and spatial systems to changing climatic and socioeconomic conditions. Long-term priorities include infrastructure renewal, sustained ecosystem management, and periodic revision of production and settlement strategies. Monitoring should support adjustments to county objectives and local implementation. Essential maintenance and ecological protection should continue throughout all phases.

6. Conclusions and Discussion

6.1. Conclusions

(1) Agricultural resilience presents the overall pattern of "the western area is high in the northwest and low in the southeast, and the eastern area is low in the northwest, middle and south, high along the river and low in the hills", which is highly consistent with the spatial coupling relationship between water conservancy conditions and landform types.

(2) The differentiation pattern of spatial comprehensive evaluation is highly consistent with the trend of the main stream of the Yellow River, the distribution of the Loess Plateau

surface, and the topography and geomorphology conditions, showing the overall trend of "the western area is moderately good in the central and northern regions, and the southern area is poor; the eastern area is generally poor".

(3) The degree of agriculture–space coupling coordination is the overall characteristic of "the western area is higher along the Yellow River in the central part, the northern and southern areas are moderately low; the eastern area is generally moderately low".

(4) Agriculture–space coupling imbalance: water–soil is the dominant feature, and regional differences in type are the secondary characteristics. Most towns are subject to the dual constraints of drought, water shortage and water and soil shortage.

(5) Planning response should be classified and implemented by county as a unit, and 19 districts and counties are divided into three categories according to type combination and obstacle characteristics. Key breakthrough type: water–soil coupling obstacles are prominent, focusing on irrigation and terrace construction. Coordinated promotion type: the types of obstacles are diverse, policies are implemented in different regions, and delivery is classified. Transformation and optimization type: prominent imbalance between agglomeration and production; modern agriculture in the suburbs. The three types are all implemented through the county-level general plan–township planning–village planning system.

6.2. Discussion

The proposed framework may inform other arid and semi-arid agricultural regions where water scarcity, terrain constraints, and settlement patterns jointly shape agricultural conditions. Its transferable contribution is the connection between potential resilience assessment, spatial diagnosis, and differentiated planning responses. Application elsewhere would require locally appropriate indicators, classification thresholds, crop calendars, and planning instruments. The Yellow River irrigation categories and regional thresholds used here should not be transferred directly, and the representative-township approach would require reassessment against local heterogeneity and data availability.

The analysis also has limitations. First, representative-township selection and type-based projection enable regional coverage but do not capture all within-type variation. Second, entropy weights reflect indicator variability rather than causal importance. Third, coupling coordination describes system matching rather than causal effects, and the index measures potential resilience rather than observed responses to climate shocks. Finally, historical climate information provides context, while future scenarios and dynamic adaptation are not explicitly modeled. Future research should combine locally validated indicators, longitudinal observations, climate scenarios, and evaluation of planning outcomes.

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