

Postprint: Study on the Synergy between Urban Population Agglomeration and Land Ecological Resilience in the Yellow River Basin

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Abstract

Scientific assessment of the coordinated development level between urban population agglomeration and land ecological resilience in the Yellow River Basin is crucial for promoting ecological protection and high-quality development in the basin. Based on the three-dimensional framework of “resistance-adaptation-recovery,” a land ecological resilience evaluation system was constructed, and the spatio-temporal evolution patterns, spatial agglomeration characteristics, and influencing factors of the coordinated development level between urban population agglomeration and land ecological resilience in the Yellow River Basin from 2000 to 2023 were examined using the coupling coordination degree model, Moran’ s I, and the spatial Durbin panel Tobit model. The results show that: (1) Both urban population agglomeration level and land ecological resilience level exhibit a declining trend, with average annual decline rates of 0.98% and 0.26%, respectively; the urban population agglomeration level shows a stepped distribution pattern of “upstream > midstream > downstream” ; the land ecological resilience level shows a distribution pattern of “downstream > upstream > midstream” . (2) The coordinated development level between urban population agglomeration and land ecological resilience shows a declining trend, with a distribution pattern of “downstream > upstream > midstream” ; cities with high values mainly appear in downstream areas and provincial capitals, being in the primary coordination stage, while cities with low values are mostly resource-based cities, being in the near-disharmony stage. (3) The coordinated development level between urban population agglomeration and land ecological resilience exhibits positive spatial correlation. “High-high” agglomeration areas are mainly distributed in downstream regions and Sichuan Province; “low-low” agglomeration areas mainly appear in the Ningxia Yellow River urban agglomeration, Lanzhou-Xining urban agglomeration, and Hohhot-Baotou-Ordos-Yulin urban agglomeration. (4) Economic development level, industrialization level, scientific and technological innovation level, and government intervention are

important factors affecting the coordinated development of urban population agglomeration and land ecological resilience, and economic development level and industrialization level exhibit spatial spillover effects.

Full Text

Coordinated Study of Urban Population Agglomeration and Land Ecological Resilience in the Yellow River Basin

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Abstract

Scientifically evaluating the coordinated development level of urban population agglomeration and land ecological resilience in the Yellow River Basin is crucial for promoting ecological protection and high-quality development in the region. Based on a three-dimensional framework of “resistance-adaptability-resilience,” this study constructs a land ecological resilience evaluation system and employs the coupling coordination degree model, Moran’ s I, and spatial Durbin panel Tobit model to examine the spatiotemporal evolution, spatial agglomeration characteristics, and influencing factors of the coordinated development of urban population agglomeration and land ecological resilience in the Yellow River Basin from 2000 to 2023. The results indicate that: (1) Both urban population agglomeration and land ecological resilience levels exhibited declining trends, with average annual decrease rates of 0.98% and 0.26%, respectively. The spatial distribution of urban population agglomeration follows a stepped pattern of “upstream > middle reaches > downstream,” while land ecological resilience exhibits a “downstream > upstream > middle reaches” pattern. (2) The coordinated development level demonstrated a declining trend, shifting from primary coordination to barely coordinated, with a spatial distribution of “downstream > upstream > middle reaches.” High-value cities were mainly located in downstream areas and provincial capitals, remaining in the primary coordination stage, while low-value cities, predominantly resource-based, were on the verge of imbalance. (3) A significant spatial positive correlation exists in the coordinated development level. “High-high” agglomeration areas were mainly concentrated in downstream regions and Sichuan Province, whereas “low-low” agglomeration areas were primarily located in the Ningxia Yellow River city group, Lanzhou-Xining city group, and Hohhot-Baotou-Ordos-Yulin city group. (4) Economic development level, industrialization level, scientific and technological innovation level, and government intervention are important factors influencing the coordinated development, with economic development and industrialization levels exhibiting significant spatial spillover effects.

Key words: urban population agglomeration; land ecological resilience; coordinated development; influencing factors; Yellow River Basin

China's urbanization development has achieved remarkable success, with the urbanization rate increasing from 17.92% to 66.16%. Urbanization has promoted economic growth and social prosperity, but it has also intensified problems such as urban sprawl and ecological damage to land. In particular, the encroachment and damage to forests, grasslands, natural wetlands, and biological habitats by human activities have led to fragmentation of land ecological landscape patterns and decline of ecosystem service functions, seriously threatening land ecological security. Against the background of territorial spatial planning, the urgent priority is to rationally layout and enhance land ecological resilience—improving its capacity to resist and adapt to human activity disturbances and to recover quickly—so as to coordinate complex human-land relationships and systematically correct unsustainable human-land development patterns during the rapid urbanization period. In addition to emphasizing the impact of human activities on land ecological security, particular attention must be paid to how population distribution patterns shaped by urbanization development affect land ecological resilience. The Yellow River Basin, with its naturally fragile ecological environment, is especially critical for evaluating and analyzing the coordinated development level of urban population agglomeration and land ecological resilience and its influencing factors, thereby guiding the construction of harmonious human-land relationships in the basin from a spatial planning perspective.

Existing research on population agglomeration and land ecological resilience includes: First, studies on the interactive relationship between population agglomeration and land ecology. Current research primarily explores the impact of population agglomeration on land ecology. Scholars generally agree that urbanization is an endogenous driver of population agglomeration and economic growth. However, due to the lack of scientific planning and effective management, problems of low-quality and unbalanced urbanization have gradually emerged. In particular, the rapid development of spatial urbanization has led to uncontrolled urban sprawl, resulting in ecological problems such as damage to grasslands, forest areas, natural wetlands, and biological habitats. Other scholars have investigated the effects of population agglomeration on environmental pollution, vegetation restoration, and land use ecological efficiency, providing decision-making basis for coordinating human-land relationships and achieving sustainable development. Currently, literature on the impact of land ecology on population agglomeration is scarce, but the role of environmental factors in population migration has been widely discussed. Some scholars have examined the influence of environmental quality, air pollution, and climate risks on population migration behavior, finding that clean air, water quality, suitable climate, and healthy land ecology are key determinants of population migration. Second, ecological resilience research. Holling first proposed the concept of ecological resilience to define the capacity of ecosystems to withstand or absorb disturbances when facing risks and shocks. Subsequently, the concept has been gradually applied to urban and resource-environment fields. Due to its rich connotations,

scholars have quantified ecological resilience from different dimensions such as “resistance-resilience” and “sensitivity-adaptability,” analyzing factors like precipitation, high temperature, economic development, and environmental regulation. Other scholars believe that ecological governance and restoration significantly enhance land ecological resilience, thereby weakening the interference of population growth and economic development on land ecosystems. Taking large-scale forest restoration projects as an example, research indicates that such projects can improve land ecosystem resilience and enhance resistance to climate change.

Current academic discussions on the interactive relationship between population agglomeration and land ecology have matured, but research examining the coupling relationship between population agglomeration and land ecological resilience from a resilience perspective remains insufficient. The Yellow River Basin has long suffered from ecological problems such as soil erosion and land desertification, with particularly tense human-land relationships. Clarifying the human-land coupling relationship in the basin is crucial for resolving contradictions and achieving high-quality development. However, existing studies have paid insufficient attention to the Yellow River Basin and lack systematic analysis of all cities in the region. Therefore, this study takes 73 prefecture-level and above cities as research objects, explains the coordination mechanism between urban population agglomeration and land ecological resilience, and employs the coupling coordination degree model, Moran’s I , and spatial Durbin panel Tobit model to reveal the spatiotemporal evolution, spatial agglomeration characteristics, and influencing factors of the coordinated development level of the two systems, aiming to provide theoretical foundations and practical guidance for promoting harmonious human-land relationships in the Yellow River Basin. The marginal contributions of this study are: First, it reveals the coordination mechanism between urban population agglomeration and land ecological resilience, enriching the theoretical system of coordinated development research on the two systems. Second, it characterizes the spatiotemporal evolution features of the coordinated development level, broadening the research perspective on human-land relationships. Third, it identifies influencing factors of the coordinated development, providing policy recommendations for enhancing coordinated development and resolving human-land contradictions in the Yellow River Basin.

1 Theoretical Foundation

This study abstracts the coordination mechanism between urban population agglomeration and land ecological resilience as a process where subsystems and their internal elements interconnect and interact to promote overall system coordination. Land ecological resilience refers to the capacity of land ecosystems to resist, adapt, and recover from external pressures and internal stresses. Land ecological resilience affects population agglomeration through ecosystem services. Ecosystem service theory posits that ecosystem services are fundamental to human survival and development, providing natural resources such as food, water, and air to meet basic human needs, while also improving living

environments through climate regulation, water conservation, and soil greening. Land ecological resilience concerns the stability of land ecosystem structure and function, which subsequently affects the long-term performance of ecosystem services and is particularly critical for enhancing the population carrying and supporting capacity of ecosystems. Land ecological resilience can also reflect the rationality of human activities and the balance of ecological land spatial allocation through the frequency of natural disasters, thereby guiding population flow direction and quantity adjustment. Stronger land ecological resilience leads to lower frequency of natural disasters such as heat island effects, drought-flood disasters, and air pollution, creating a stronger “siphon effect” on the floating population.

Population agglomeration has dual impacts on land ecological resilience. First, population agglomeration positively affects land ecological resilience through agglomeration effects. New economic geography theory indicates that population agglomeration promotes economic growth through knowledge spillovers, technology diffusion, and labor market sharing. Economic growth brings higher fiscal revenue, providing more financial support for land ecological governance and restoration. Additionally, the agglomeration of high-quality labor promotes human capital accumulation, accelerates industrial structure optimization and upgrading, and drives technological innovation to improve resource utilization efficiency, reducing resource consumption and environmental pollution from economic growth, thereby weakening human activity interference on land ecological resilience. Second, continuous population expansion leads to high-intensity human activities that approach or exceed land ecosystem carrying capacity, negatively affecting ecological resilience. Landscape ecology theory emphasizes that human activities can directly affect ecological landscape patterns, forcing changes in ecosystem structure and function, which adversely impacts land ecological resilience. For example, population growth increases construction land use by encroaching on farmland and destroying wetlands, leading to ecological landscape fragmentation and vegetation diversity degradation. Population expansion also increases production and living energy consumption, causing over-exploitation and consumption of natural resources and exacerbating land ecological resilience attenuation. Furthermore, ecological metabolism theory points out that human activities can alter ecosystem energy flow and material cycling, thereby exerting stress on ecosystem metabolic efficiency and ecological resilience.

2 Methodology

2.1 Study Area Overview

The Yellow River Basin spans eastern, central, and western China, flowing through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong—nine provinces in total. Therefore, this study defines the research area as 73 prefecture-level cities (prefectures, leagues, municipalities) within these provinces. Due to severe data missing for autonomous prefectures,

leagues, and Haidong City, and because Jiyuan City is a province-administered county-level city, these were all excluded. During the study period, the administrative division of Laiwu City was adjusted. To ensure consistency of research objects across years, this study uniformly incorporated Laiwu City into Jinan City, resulting in 73 prefecture-level and above cities as research objects. Drawing on existing research, the Yellow River Basin is divided into upstream, middle reaches, and downstream areas to explore spatial differences in coordinated development.

[Figure 1: see original paper]

2.2 Models

2.2.1 Coupling Coordination Degree Model This study employs the coupling coordination degree model to explore the coordinated development level of urban population agglomeration and land ecological resilience. Calculation formulas and classification criteria are provided in reference [?]. Considering that urban population agglomeration and land ecological resilience are equally important, the 待定系数 (undetermined coefficients) α and β in the model are both set to 0.5.

2.2.2 Spatial Correlation Analysis This study uses global Moran's I and local Moran's I for spatial correlation analysis. Global Moran's I reflects the average degree of spatial association in the distribution of coordinated development levels, testing for spatial dependence. Local Moran's I reveals spatial clustering characteristics of coordinated development levels across different cities. Calculation formulas are provided in reference [?].

2.2.3 Spatial Durbin Panel Tobit Model Since the coordinated development level of urban population agglomeration and land ecological resilience ranges between 0 and 1, this study adopts the spatial Durbin panel Tobit model to analyze influencing factors. The model is specified as:

$$D_{it} = \alpha + \beta X_{it} + \rho W D_{it} + \theta W X_{it} + v_i + \gamma_t + \varepsilon_{it} \quad (1)$$

Where: D_{it} represents the coordinated development level of urban population agglomeration and land ecological resilience for city i in year t ; X_{it} denotes influencing factors; α and β are estimated coefficients; W is the Euclidean distance spatial weight matrix; ρ is the spatial autoregressive coefficient; v_i represents city fixed effects; γ_t represents time fixed effects; and ε_{it} is the random disturbance term.

Drawing on existing research [?], X_{it} includes: (1) Economic development level, measured by per capita GDP. Economic development provides financial support for land ecological governance and resilience restoration and is a key factor promoting coordinated development. (2) Industrialization level, measured by the

proportion of secondary industry value-added in GDP. Industrial production is a major source of energy consumption and environmental pollution, threatening land ecological resilience through resource extraction, construction land expansion, and pollutant emissions. (3) Scientific and technological innovation level, measured by the proportion of scientific and technological innovation expenditure in fiscal expenditure. Technological innovation can weaken the impact of human activities on the ecological environment, with green technology playing a particularly important role in coordinating urban population agglomeration and land ecological resilience. (4) Foreign investment level, measured by the proportion of actual utilized foreign investment in GDP. The “pollution haven hypothesis” suggests that developed countries tend to relocate polluting enterprises to developing countries with lower environmental regulation standards and pollution control costs, adversely affecting land ecology. (5) Government intervention, measured by the proportion of fiscal expenditure in GDP. Government-led land finance drives rapid urban spatial expansion through large-scale land development and urban infrastructure construction, severely constraining land ecological security.

2.3 Measurements

2.3.1 Urban Population Agglomeration Level Measurement This study uses the spatial Gini coefficient to characterize urban population agglomeration level. First, ArcGIS 10.5 software is used to extract all raster data within the study area and convert it to point data containing population distribution information. Then, point data is spatially matched with cities using latitude and longitude coordinates to identify the number of raster grids and population distribution within each city, enabling calculation of annual spatial Gini coefficients for population distribution across cities. Calculation formulas are provided in reference [?].

2.3.2 Land Ecological Resilience Evaluation System Construction

The urban land ecological resilience evaluation system is constructed across three dimensions: resistance, adaptability, and resilience. Resistance refers to the capacity of ecosystems to withstand external disturbances. Ecosystem services are crucial to resistance strength, with complex interactions among different service types effectively weakening human interference. Therefore, resistance is defined by ecosystem service value, with calculation processes provided in reference [?]. Adaptability refers to the capacity of ecosystems to self-adjust in response to external disturbances. Ecosystem stability, determined by landscape heterogeneity, connectivity, and shape, drives adaptability. Landscape heterogeneity enhances adaptability by enabling energy flow and material cycling and increasing flexibility in responding to human interference. Landscape connectivity supports biological community migration to safe areas when local environments deteriorate, thereby enhancing adaptability. Irregular landscape shapes may increase edge effects, altering spatial distribution and migration behavior of biological communities and affecting ecological landscape

structural stability. Therefore, adaptability is characterized by ecosystem stability, with indices calculated using Fragstats 4.2 software. Resilience refers to the capacity of ecosystems to recover to their original state or advance to a new stable state after disturbance. Research indicates that land use patterns significantly shape ecosystem resilience. Ecosystem resilience is calculated through area-weighted computation of urban land use types, with calculation formulas provided in reference [?]. The urban land ecological resilience evaluation system is shown in Table 1, with indicator weights determined using the entropy method [?].

2.4 Data Sources

Population distribution data were obtained from the LandScan global population distribution raster dataset developed by Oak Ridge National Laboratory. Land use type data were derived from the National Land Use Remote Sensing Monitoring Dataset released by the Chinese Academy of Sciences' Resource and Environmental Science Data Center. Grain yield data were sourced from provincial statistical yearbooks and the China Statistical Yearbook (2001-2023). Grain price data came from the China Agricultural Product Price Survey Yearbook (2001-2023). Socioeconomic data for 2000-2020 were obtained from the China City Statistical Yearbook, while data for 2021-2023 were collected from national economic and social development statistical bulletins of each city and provincial science and technology expenditure statistical bulletins. Missing data were supplemented by consulting city statistical yearbooks, statistical bulletins, or using interpolation methods.

3 Results and Analysis

3.1 Urban Population Agglomeration Level Analysis

As shown in Figure 2, the population agglomeration level in the Yellow River Basin exhibited a declining trend, with an average annual decrease rate of 0.98%. Referencing Zhou et al. [?], the urban land scale elasticity coefficient for the Yellow River Basin from 2000 to 2023 was calculated as [MATH_0], far exceeding the ideal value of 1.12, indicating that urban population growth lagged far behind urban land expansion, creating an imbalance that led to declining population agglomeration. The standard deviation and variation coefficient of population agglomeration increased from [MATH_1] to [MATH_2] and from [MATH_3] to [MATH_4], respectively, indicating widening inter-city disparities. The population agglomeration level displayed a stepped distribution pattern of "upstream > middle reaches > downstream." Upstream areas showed the highest population agglomeration at [MATH_5], attributable to limited economic development and fragile ecological systems constraining deep development and large-scale land use. Middle reaches followed at [MATH_6], while downstream areas showed the smallest variation amplitude at [MATH_7].

3.2 Urban Land Ecological Resilience Analysis

As shown in Figure 2, the land ecological resilience level in the Yellow River Basin was relatively low, averaging only [MATH_8], and demonstrated a 逐年下降趋势, decreasing from [MATH_9] in 2000 to [MATH_{10}] in 2023, with an average annual decrease of 0.26%, indicating increasing vulnerability of land ecosystems and severe threats to land ecological security. The standard deviation and variation coefficient increased from [MATH_{11}] to [MATH_{12}] and from [MATH_{13}] to [MATH_{14}], respectively, showing widening inter-city disparities. The land ecological resilience level exhibited a “downstream > upstream > middle reaches” distribution pattern. Downstream areas showed the highest resilience at [MATH_{15}]; upstream and middle reaches showed similar levels at [MATH_{16}] and [MATH_{17}], respectively, far below downstream levels. The ecological environment in upstream and middle reaches is naturally fragile, with plateau glaciers, grassland meadows, and the Three-River-Source region in upstream areas and the Loess Plateau in middle reaches being typical ecologically fragile zones highly susceptible to negative human impacts, making resilience enhancement particularly challenging.

3.3 Coordinated Development Level Analysis

3.3.1 Temporal Variation Characteristics The coordinated development level of the two systems in the Yellow River Basin roughly experienced a “decline-decline” process, showing an overall downward trend from [MATH_{18}] in 2000 to [MATH_{19}] in 2023. The coordination stage declined from primary coordination to barely coordinated, indicating increasingly tense human-land relationships in the basin (Figure 3). This results from the long-term implementation of an extensive development model that sacrifices ecological environment, causing severe resource bottlenecks and path dependency problems that constrain harmonious human-land development. The standard deviation and variation coefficient of coordinated development level increased from [MATH_{20}] to [MATH_{21}] and from [MATH_{22}] to [MATH_{23}], respectively, indicating that absolute inter-city disparities narrowed slightly while relative disparities widened. By region, all three areas showed declining trends, with downstream areas decreasing fastest from [MATH_{24}] to [MATH_{25}], at an average annual rate of 0.39%, related to rapid urbanization construction in downstream regions.

[Figure 3: see original paper]

3.3.2 Spatial Distribution Characteristics The coordinated development level exhibited an overall spatial distribution pattern of “downstream > upstream > middle reaches” (Figure 4). Downstream areas, with higher economic development levels and abundant resources (capital, labor), facilitate coordinated development. Middle reaches are rich in coal, oil, and natural gas resources, with industrial structures dominated by mineral resource development and related industries, featuring high proportions of pollution-intensive enter-

prises and frequent large-scale land exploitation activities that cause severe environmental problems such as soil erosion and desertification, resulting in insufficient land ecological resilience and low coordination levels. Due to unique natural landforms, environmental capacity, and water-soil resources, upstream areas face long-term contradictions between scarce construction land resources and growing economic development demands, exacerbating soil erosion in Qinghai, Gansu, and Ningxia and creating an ecological consumption-oriented industrial structure that poses severe challenges to land ecological protection. In terms of spatial pattern evolution, different cities showed declining coordination levels. In downstream areas, 12 cities including Zibo declined from primary to barely coordinated; in middle reaches, 8 cities including Jinzhong declined from barely coordinated to near-imbalance; Jiaozuo had the highest coordination level but experienced the most severe decline, dropping from intermediate to barely coordinated.

[Figure 4: see original paper]

3.4 Spatial Correlation Analysis

3.4.1 Spatial Autocorrelation Test The global Moran' s I for the coordinated development level of urban population agglomeration and land ecological resilience in the Yellow River Basin remained positive during 2000-2023 and passed significance tests at the 1% level (Table 2), indicating that the spatial distribution was not completely random. Instead, cities with similar coordination levels tended to cluster spatially, showing significant positive spatial correlation. Therefore, it is necessary to consider spatial effects when exploring influencing factors.

Based on the agglomeration distribution map (Figure 5), “high-high” clusters were mainly distributed in downstream areas and Sichuan Province in upstream areas, indicating relatively high overall coordination levels in these regions. “Low-high” clusters appeared in Hohhot, Xi' an, Xianyang, Weinan, Tianshui, and Yinchuan, showing these cities had better coordination than surrounding cities but their radiating effects were not yet significant. “Low-low” clusters were concentrated in the Ningxia Yellow River city group, Lanzhou-Xining city group, and Hohhot-Baotou-Ordos-Yulin city group, where economic development lags and resource-based cities dominate, with strong land demand for economic development making the naturally fragile land ecology face more severe challenges. Notably, by 2023, most cities in Sichuan Province shifted from non-significant clustering to “high-high” clustering, indicating Sichuan' s coordination level is relatively high and the gap with downstream areas is narrowing.

[Figure 5: see original paper]

3.4.2 Spatial Econometric Model Estimation Results As shown in Table 3, benchmark regression results indicate that economic development level and scientific and technological innovation level have significantly positive co-

efficients, showing they promote coordinated development. Cities with higher economic development gradually shift toward improving land use efficiency and allocate fiscal funds for land ecological governance, thereby promoting coordinated development. Land ecological restoration in the Yellow River Basin requires technological innovation support; the basin has continuously increased innovation investment and strengthened water-soil governance talent training to fundamentally solve land ecological problems through technological innovation. Industrialization level and government intervention have significantly negative coefficients, indicating they hinder coordinated development. The Yellow River Basin has a high industrial proportion with numerous polluting enterprises in coal, chemical, and smelting industries whose production activities constrain coordinated development. Government intervention manifests as over-reliance on land finance for economic development, leading to rapid urban spatial expansion and low land use efficiency, which is unfavorable for improving coordination.

Economic development and industrialization levels also exhibit spatial spillover effects. Economic development level has a significantly negative impact on surrounding cities' coordination. Population flowing from less developed to developed areas is a key urbanization characteristic; economically faster-growing cities attract labor from surrounding cities through "siphon effects," reducing population in surrounding cities and lowering their coordination levels. Industrialization level has a significantly positive impact on surrounding cities' coordination. With limited natural resources in the Yellow River Basin, increased industrial proportion promotes upstream and downstream industry agglomeration, increasing natural resource consumption and depriving surrounding cities of industrial development opportunities, which 反而 promotes coordinated development in surrounding cities.

Robustness tests were conducted using alternative spatial weight matrices and spatial econometric models. Regression results based on adjacency weight matrix and spatial Durbin model are shown as Model 1 and Model 2 in Table 3. In both models, the ρ values are significantly positive, consistent with benchmark results, and regression coefficients of influencing factors remain consistent with benchmark results, passing robustness tests.

4 Discussion

This study finds that the coordinated development level of urban population agglomeration and land ecological resilience in the Yellow River Basin shows a "downstream > upstream > middle reaches" distribution pattern, but the overall coordination level is low and declining. This indirectly confirms that extensive urbanization development models cause ecological disorder in the basin, severely constraining coordinated population agglomeration and ecological resilience development—problems also faced by the Pearl River Delta and Fenhe River Basin. Compared with previous studies, this research selects the Yellow River Basin with its fragile ecological foundation, lagging economic development, and particularly tense human-land relationships as the study area, exploring spatiotempo-

ral evolution characteristics and influencing factors of coordinated development. This enriches and supplements existing research. The findings help guide new urbanization development in the Yellow River Basin from a spatial planning perspective, alleviate human-land contradictions, and achieve ecological protection and high-quality development. Future research could be enhanced in several aspects: First, enrich and expand data indicators. As socioeconomic data gridding and refinement technologies advance, more accurate data definition and measurement of urban population agglomeration and land ecological resilience become possible. Second, conduct comparative analysis across different spatial scales. Combining provincial, municipal, and county-level analyses could clarify differences across scales, more accurately identify severely problematic areas, and propose more targeted policy recommendations. Third, use big data, cloud computing, and advanced modeling technologies to simulate and predict coordinated development trends.

5 Conclusions and Recommendations

5.1 Conclusions

- (1) Both urban population agglomeration and land ecological resilience showed fluctuating declining trends, with average annual decrease rates of 0.98% and 0.26%, respectively. Urban population agglomeration displayed a stepped distribution of “upstream > middle reaches > downstream,” while land ecological resilience showed a “downstream > upstream > middle reaches” pattern.
- (2) The coordinated development level exhibited a spatial positive correlation. “High-high” clusters were mainly distributed in downstream areas and Sichuan Province in upstream areas, while “low-low” clusters were primarily located in the Ningxia Yellow River city group, Lanzhou-Xining city group, and Hohhot-Baotou-Ordos-Yulin city group.
- (3) Economic development level, industrialization level, scientific and technological innovation level, and government intervention are important factors influencing coordinated development, with economic development and industrialization levels exhibiting spatial spillover effects.

5.2 Recommendations

Based on these conclusions, the following policy recommendations are proposed: First, coordinate population spatial distribution and land resource allocation to promote harmonious human-land relationships. The middle and upper reaches of the Yellow River Basin have naturally fragile ecological environments unsuitable for high-intensity human activities. Population should be actively guided to orderly relocate to plain and lowland areas with higher ecological carrying capacity, while restoring the ecological functions of vacated lands. Simultaneously, promote point-based development models centered on ecological protection, strictly manage land supply quantity and structure, establish and improve

incentive mechanisms for revitalizing construction land stock, and force improvements in land use efficiency. Downstream areas should improve national territorial space use supervision systems, demarcate three zones and three lines with high standards and strict requirements, and focus on resolving contradictions between farmland protection and urban development.

Second, fully consider the resource and environmental carrying capacity of the Yellow River Basin and rationally plan industrial layout. The middle and upper reaches are naturally fragile and key areas for ecological restoration. Strengthen enterprise environmental information disclosure and ecological environment monitoring systems, formulate and improve industrial landing standards for the Yellow River Basin, and effectively avoid cross-regional transfer of polluting industries. Meanwhile, downstream areas should leverage human capital advantages, focus on improving scientific and technological innovation capacity, accelerate the cultivation and development of strategic emerging industries, and support land ecological restoration in the Yellow River Basin.

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