Spatiotemporal Variation and Prediction of Land Use and Habitat Quality in the Wei River Basin Based on PLUS and InVEST Models (Postprint)

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Abstract

Habitat quality constitutes a crucial foundation for human well-being and sustainable development, holding significant implications for regional ecological conservation and sustainable land resource utilization. This study examines the Wei River Basin, employing land use data from 2000, 2010, and 2020, and applies the Patch-generating Land Use Simulation (PLUS) model and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model to project and assess the spatiotemporal dynamics of land use and habitat quality. The results reveal: (1) During 2000–2020, construction land and grassland areas in the Wei River Basin increased annually, forest land area showed slight growth, while cultivated land area continued to decrease. During 2020–2050, land use change trends remain largely consistent with those of 2000–2020, though the intensity decreases significantly; construction land expansion slows down, cultivated land reduction decreases, and grassland proportion surpasses that of cultivated land, becoming the primary land use type within the basin. (2) From 2000–2020, a clear polarization trend in habitat quality emerged across the basin, with expanded areas of both low and high habitat quality zones and contracted medium-quality areas, while the overall habitat quality level showed an upward trend. From 2020–2050, habitat quality continues to increase annually but at a decelerating rate; the intensity of habitat quality change decreases, low-quality habitat areas gradually diminish, medium-quality areas stabilize, and high-quality areas increase. These findings provide a scientific basis and decision-making reference for sustainable land resource utilization and high-quality development in the Wei River Basin.

Full Text

Spatial and Temporal Changes in Land Use and Habitat Quality in the Weihe River Basin Based on the PLUS and InVEST Models and Predictions

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Abstract: Habitat quality is a critical foundation for human well-being and sustainable development, holding significant importance for regional ecological conservation and sustainable land resource utilization. This study examines the Weihe River Basin as its research area, analyzing land use data from 2000 to 2020 and employing the Patch-Generating Land Use Simulation (PLUS) model and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model to predict and evaluate spatial-temporal changes in land use and habitat quality. The results indicate that from 2000 to 2020, construction land and grassland areas in the Weihe River Basin increased annually, forest land area grew slightly, while cultivated land area continued to decline. Predictions for 2020–2050 suggest that land use changes will follow similar trends but with significantly reduced intensity, as construction land expansion slows, cultivated land loss decreases, and grassland area surpasses cultivated land to become the dominant land type in the basin. Habitat quality analysis reveals a clear polarization trend from 2000 to 2020, with increased areas of both low and high habitat quality and decreased areas of moderate habitat quality, though the overall habitat quality level showed an upward trend. From 2020 to 2050, habitat quality is projected to continue improving annually, albeit at a slower pace, with decreasing change intensity. Low habitat quality areas will gradually shrink, moderate habitat quality areas will remain stable, and high habitat quality areas will increase. These findings provide scientific evidence and decision-making references for sustainable land resource utilization and high-quality development in the Weihe River Basin.

Keywords: land use; habitat quality; PLUS model; InVEST model; Weihe River Basin

1 Introduction

Land use change serves as a crucial link between human socioeconomic activities and natural environmental evolution, directly reflecting human modification of terrestrial systems and representing a core component of global environmental change research. Traditional models such as the Cellular Automata (CA) model, Logistic regression model, and CLUE-S model have been widely applied in ecological redline delineation, geomorphological evolution analysis, and territorial spatial optimization. However, these models demonstrate limitations in large-scale and multi-category comprehensive simulations. The Patch-Generating Land Use Simulation (PLUS) model effectively addresses these shortcomings by introducing a land expansion analysis strategy and a multi-type random patch seed generation mechanism, offering advantages in high simulation accuracy and rapid data processing that enable effective simulation of complex multi-category land use evolution processes.

Habitat quality refers to the capacity of an ecosystem to provide resources necessary for individual and population survival and reproduction within specific spatiotemporal conditions, representing a vital factor for maintaining biodiversity and regional sustainable development. Land use conditions typically reflect habitat quality levels, with close relationships between the two. Analyzing spatial-temporal characteristics of land use change can further reveal habitat quality change patterns and underlying causes. With rapid development in dynamic modeling technologies for land use change, numerous scholars have integrated geography and ecology theories to predict land use changes and evaluate future habitat quality. For instance, studies have coupled the CA-Markov and InVEST models to analyze spatiotemporal evolution and predictions of urban landscape patterns and habitat quality, while others have employed the FLUS model to simulate ecosystem service value under multiple scenarios. These studies demonstrate the strong applicability of such coupled models.

Land use change affects the cycling of material and information flows among habitat patches, thereby influencing regional habitat quality levels. Research on habitat quality changes can directly reflect the status and trends of regional ecosystem service functions, holding great significance for ecological conservation and sustainable development. Current models for assessing regional habitat quality include InVEST, Artificial Intelligence for Ecosystem Services (ARIES), and Social Values for Ecosystem Services (SolVES). Among these, the InVEST model is widely applied due to its operational convenience, strong visualization capabilities, and relatively complete theoretical framework. Previous research has effectively demonstrated the scientific validity and applicability of the InVEST model across various scales.

Both the PLUS and InVEST models are widely used and effective, yet few studies have coupled these models to predict future land use spatial patterns and explore regional habitat quality development trends. Therefore, this study integrates the PLUS and InVEST models to analyze the evolution of land use and habitat quality in the Weihe River Basin from 2000 to 2020 and predict future habitat quality spatial patterns. The research aims to explore the evolution mechanisms of land use and habitat quality in the Weihe River Basin, providing effective scientific references for watershed ecological environment management, conservation, and promotion of high-quality regional development.

1.1 Study Area Overview

The Weihe River Basin (104°00 -110°20 E, 33°50 -37°18 N) is the largest sub-basin of the Yellow River Basin, located in northwest China with a total area of 1.34$×10^{5}$ km^2, spanning Shaanxi, Gansu, and Ningxia provinces. The region lies in an arid and semi-arid zone with concurrent rainfall and heat, featuring an average annual precipitation of 683.6 mm and average annual temperature of 7.8-13.5°C. The topography is complex, with higher elevations in the west and lower in the east, and diverse soil and vegetation types. Natural conditions vary significantly across the basin: the western and northern regions have harsh natural conditions, fragile ecological environments, and lower economic development levels, including the Liupan Mountain concentrated poverty area. While regional economic development and ecological conditions have steadily improved through poverty alleviation and ecological governance initiatives, ecological stability requires further enhancement. The central region comprises flat plains with superior location advantages, concentrated population, and rapid economic development, where human-land conflicts are prominent. The southern region features the Qinling Mountains with high vegetation coverage and favorable ecological conditions.

1.2 Data Sources and Processing

Considering model accuracy and realism, this study comprehensively incorporates natural and socioeconomic factors affecting land use. Based on principles of driver factor accessibility, timeliness, and significance, we selected elevation, population, GDP, distance to rivers, roads, railways, highways, county centers, city centers, and urban built-up areas as driving factors influencing land use change. The primary data sources include administrative boundaries, land use data, socioeconomic statistics, and spatial data for land use driving factors (Table 1). To ensure spatial consistency, ArcGIS 10.2 software was used to process all driving factors and land use data through clipping and resampling, uniformly converting them into raster files with 90 m × 90 m resolution.

Table 1 Data source information table

Data Category	Specific Data	Source
Administrative boundaries	Provincial and municipal boundaries of Shaanxi, Gansu, and Ningxia	Government work reports
Land use data	Land use data for 2000, 2010, and 2020	Chinese Academy of Sciences Resource and Environment Data Center (http://www.resdc.cn)

Data Category	Specific Data	Source
Socioeconomic statistics	Regional GDP and population data for 2000–2020	Statistical yearbooks
Natural environmental conditions	Elevation, average annual precipitation, average annual temperature, soil erosion degree	Chinese Academy of Sciences Resource and Environment Data Center (http://www.resdc.cn)
Socioeconomic conditions	Distance to nearest river, railway, road (provincial, national, county), highway, county center, city center, urban built-up area	Geographic National Condition Moni-toring Platform (http://www.dsac.cn/)

2 Methods

2.1 PLUS Model

The PLUS model is a cellular automata-based model for simulating land use change. By analyzing the spatial characteristics of land use expansion and driving factors between two periods, the model employs a random forest algorithm to sample and calculate land use expansion, obtaining development probabilities for each land use type. It then uses a roulette wheel-based adaptive inertia competition mechanism to obtain comprehensive land use change probabilities, and finally combines random patch generation, transition matrices, and threshold decrement mechanisms to optimize and determine final land use patterns.

2.1.1 Suitability Probability Calculation Under the PLUS model' s land expansion analysis strategy module, a random sampling mechanism reduces computational load while the random forest algorithm, capable of handling high-dimensional data and resolving driver factor collinearity, mines land use transition rules to obtain development probabilities for each land use type. The formula is:

$$P_{d,k}(X) = \frac{1}{M}\sum_{n=1}^{M} I[h_n(X) = d]$$

where X is a vector composed of driving factors; $h_n(X)$ is the land use prediction type calculated when the decision tree is n; $I[\cdot]$ is the indicator function of the decision tree; M is the number of decision trees; d takes values of 0 or 1, where 1 indicates transformation from other land use types to land use type k, and 0 indicates no transformation to type k; and $P_{d,k}(X)$ is the probability of growth of land use type k at spatial unit i under condition d.

2.1.2 Neighborhood Weight Setting Neighborhood weights primarily reflect the difficulty of conversion between different land use types. Based on existing research and the actual conditions of the Weihe River Basin, we set neighborhood weight parameters (Table 2).

Table 2 Neighborhood weight parameters

Land Use Type	Weight
Cultivated land	0.5
Forest land	0.8
Grassland	0.6
Water area	0.4
Construction land	1.0
Unused land	0.3

2.1.3 Adaptive Inertia Coefficient Calculation Adaptive inertia can be adaptively adjusted during the iteration process based on differences between expected land quantity demand and actual conditions, directing land use quantity toward expected targets and thereby simulating spatial land use type changes. The formula is:

$$D_k^t = \begin{cases} D_k^{t-1} & \text{if } G_k^{t-1} \times D_k^{t-1} \leq G_k^{t-1} \\ \frac{G_k^{t-1} - G_k^{t-2}}{D_k^{t-1} \times G_k^{t-2}} & \text{if } G_k^{t-1} \times D_k^{t-1} > G_k^{t-1} \text{ and } G_k^{t-2} > 0 \\ D_k^{t-1} \times 2 & \text{if } G_k^{t-1} > G_k^{t-2} > 0 \end{cases}$$

where D_k^t and D_k^{t-1} are the inertia coefficients of land use type k at times t and $t-1$; G_k^{t-1} and G_k^{t-2} are the differences between land demand and actual quantity at times $t-1$ and $t-2$.

2.1.4 Random Patch Generation Parameter Setting The random patch generation mechanism better simulates natural growth of various land use types during actual land use change processes. To control the generation of multi-type land use patches, the model employs a threshold decrement rule in the competition process to limit spontaneous growth of each land use type. The formula is:

$$P_{d,k}^{t+1} = P_{d,k}^t \times \Omega_{i,k}^t \times D_k^t \times (1 + r)$$

where $P_{d,k}^t$ is the suitability probability of land use type k developing from type d at spatial unit i; $\Omega_{i,k}^t$ is the neighborhood weight of land use type k at spatial unit i at time t; D_k^t is the adaptive inertia coefficient; r is a random value between 0 and 1; and μ_k is the threshold for new land use patch generation.

2.1.5 Transition Matrix and Final Land Use Development Probability Calculation The transition matrix defines whether conversions between land use types are permitted, effectively constraining unreasonable transformations. A patch generation threshold decay coefficient is also set to constrain spontaneous growth processes of land use types and determine final land use patterns. The formulas are:

$$\tau_{k,l} = \tau_{k,0} \times \delta^l$$

$$TM_{c,k} = \begin{cases} 1 & \text{if conversion from type } c \text{ to } k \text{ is allowed} \\ 0 & \text{if conversion from type } c \text{ to } k \text{ is restricted} \end{cases}$$

where N is the total number of land use types; *step* is the number of steps needed to meet land use demand; l is the threshold decay step number; $\tau_{k,l}$ is the land use growth threshold; δ is the decay coefficient; $TM_{c,k}$ is the transition matrix defining whether land use type c can convert to k. Based on land use change characteristics and ecological environment policies in the Weihe River Basin, we established the transition matrix (Table 3).

Table 3 Transition matrix

Land Use Type	Cultivated Land	Forest Land	Grassland	Water Area	Construction Land	Unused Land
Cultivated Land	1	1	1	1	1	1
Forest Land	1	1	1	0	0	1
Grassland	1	1	1	0	0	1
Water Area	0	0	0	1	0	0
Construction Land	0	0	0	0	1	0
Unused Land	1	1	1	1	1	1

2.2 Habitat Quality Model

We employed the Habitat Quality module of the InVEST model to assess habitat quality. Habitat quality reflects the capacity of the environment to provide resources and conditions required for individual and population survival and development. When habitat quality is favorable, resource needs are met and biodiversity development is ensured. This module incorporates human activity interference into habitat quality evaluation, as habitat quality levels significantly decline with increased human activity intensity. The principle involves calculating habitat quality scores by combining external threat factors and their intensity with the sensitivity of each land use type to these threats. The formula is:

$$Q_{ik} = H_k \times \left(1 - \frac{M_{ik}^z}{M_{ik}^z + K^z}\right)$$

$$M_{ik} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) \times r_y \times i_{rxy} \times \beta_x \times S_{kr}$$

where Q_{ik} is the habitat quality of land use type k at spatial unit i, ranging between 0 and 1 (higher values indicate better quality); H_k is the habitat suitability of land use type k; M_{ik} is the habitat degradation degree at spatial unit i; z is a model default parameter with value 2.5; K is the half-saturation coefficient, typically set to 0.5 times the maximum habitat degradation value; R is the number of threat factors; Y_r is the number of cells of threat factor r in the land use layer; w_r is the weight of threat factor r; r_y is the intensity of threat factor r; i_{rxy} is the threat level of threat factor r to habitat; β_x is the legal protection level; and S_{kr} is the sensitivity of land use type k to threat factor r.

In addition to land use data, these formulas require setting threat factors, land use type habitat suitability, and sensitivity to threats based on regional conditions and existing research. Referencing previous studies and software documentation, we identified cultivated land, construction land, and unused land as threat factors, setting their weights, maximum influence distances, and degradation types (Table 4). We further established habitat suitability and relative sensitivity to threats for each land use type (Table 5).

Table 4 Maximum influence distance and weight of threat factors

Threat Factor	Maximum Distance (km)	Weight	Spatial Decay Type
Cultivated land	3	0.5	Exponential
Construction land	8	1.0	Linear
Unused land	2	0.3	Exponential

Table 5 Sensitivity of land use types to habitat threat factors

Land Use Type	Habitat Suitability	Cultivated Land	Construction Land	Unused Land
Cultivated land	0.5	0.3	0.6	0.2
Forest land	1.0	0.8	0.9	0.4
Grassland	0.7	0.5	0.7	0.3
Water area	0.9	0.6	0.8	0.5
Construction land	0.0	0.0	0.0	0.0
Unused land	0.2	0.3	0.4	0.1

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3 Results

3.1 Land Use Change

Land use in the Weihe River Basin is dominated by cultivated land, grassland, and forest land. From 2000 to 2020, significant land use changes occurred, with fragmented cultivated land in the western and northern parts of the basin gradually converting to grassland. Forest land area in the Ziwuling and Liupan Mountain areas increased slightly, while construction land expansion was prominent in the Guanzhong Plain, with modest growth in the Jinghe Valley.

Cultivated land, though having the highest area proportion, continuously decreased from 5.89$\times10^{4}$ km^2 to 5.44$\times10^{4}$ km^2, representing a serious cultivated land protection challenge. Forest land area first increased then decreased, but overall showed an upward trend with a net increase of 43.78 km^2. Grassland, construction land, water area, and unused land all showed continuous growth, with area increases of 1682.68 km^2, 1729.62 km^2, 49.01 km^2, and 11.89 km^2 respectively. Construction land showed the highest growth rate, nearly doubling in area. Overall, land use changes in the basin exhibited a "one decrease, multiple increases" pattern, with cultivated land decreasing while other land use types increased (Figures 2-3).

Figure 2 [Figure 2: see original paper] Spatial distributions of land use in Weihe River Basin from 2000 to 2020

Figure 3 [Figure 3: see original paper] Land use area of various types in Weihe River Basin from 2000 to 2020

3.2 Land Use Prediction

To validate model accuracy, we compared the PLUS model' s predicted 2020 land use data with actual conditions, calculating overall accuracy and Kappa coefficient. The results showed an overall accuracy of 87.6% and Kappa coefficient of 0.84, indicating high spatial consistency and good model applicability for this study.

Using 2020 land use data as a baseline, we predicted land use patterns for 2030, 2040, and 2050. Analysis of the predicted spatial patterns (Figure 4) reveals that future land use will continue existing trends, reflecting two major themes: ecological restoration and economic development. In western and northern regions, cultivated land will continue converting to grassland, while forest land, water area, and unused land remain relatively stable. Construction land in the Guanzhong Plain will show concentrated expansion. Over time, ecological stability in vulnerable areas will improve, and the development pattern centered on the Xi' an metropolitan area will become more prominent.

From 2020 to 2050, cultivated land will continue decreasing, though at a slower rate, indicating that cultivated land protection remains challenging. Forest land area will decline slightly, while grassland growth will slow and its area will stabilize, surpassing cultivated land to become the largest land use type in the basin. This highlights the need for enhanced grassland ecological protection to fully leverage ecosystem self-recovery. Water area will show stable growth—a positive trend. Construction land will continue expanding but at a reduced rate. Unused land will be fully developed and utilized, with its area continuously decreasing. Overall, land use changes from 2020 to 2050 will be consistent with 2000–2020 trends but with significantly reduced intensity, indicating stabilization of land use structure (Figure 5).

Figure 4 [Figure 4: see original paper] Spatial distribution prediction of land use in Weihe River Basin from 2030 to 2050

Figure 5 [Figure 5: see original paper] Area changes of land use types in Weihe River Basin from 2000 to 2050

3.3 Habitat Quality Change

Based on overall habitat quality conditions in the Weihe River Basin, we used the natural breaks method to classify habitat quality into five levels: low (0.0–0.3), relatively low (0.3–0.5), moderate (0.5–0.7), relatively high (0.7–0.9), and high (0.9–1.0). Analysis of area proportion changes shows significant variation among different habitat quality levels, with a clear polarization trend. Low habitat quality areas, having the highest proportion, continuously increased by 1799.71 km^2. Relatively low habitat quality areas showed dramatic changes, decreasing by 4688.63 km^2 (a 3.49% drop). Moderate habitat quality areas slightly increased by 38.01 km^2. Relatively high habitat quality areas increased by 1785.41 km^2 (a 37.94% rise). High habitat quality areas overall increased by 1051.76 km^2 (a 0.78% improvement). The average habitat quality scores for the Weihe River Basin in 2000, 2010, and 2020 were 0.52, 0.54, and 0.56 respectively, indicating moderately high overall habitat quality with a continuously improving trend, demonstrating significant ecological management achievements.

Spatially (Figure 6), high habitat quality areas are concentrated in mountainous regions such as the northern Qinling foothills, Liupan Mountains, and Ziwuling areas, dominated by forest land with stable natural ecological environments and minimal human disturbance. Relatively high habitat quality areas are mainly distributed in hilly and gully regions of the eastern and northern Loess Plateau, as well as in buffer zones at mountain foothills. Moderate habitat quality areas are primarily located in the northern part of the basin and around river channels within the Guanzhong Plain, dominated by grassland and water areas. Relatively low habitat quality areas show high fragmentation and are concentrated in the western and northwestern regions. Low habitat quality areas are highly concentrated within the Guanzhong Plain, dominated by cultivated land and construction land. Overall, the basin is characterized by distinct regional differences, with high habitat quality in areas unsuitable for human production due to natural conditions, and lower habitat quality in areas with favorable natural and location conditions where human activities are intensive.

To further analyze spatial habitat quality changes, we overlaid habitat quality maps and identified change patterns (Figure 7). Changes were classified as: significantly improved (>0.2), slightly improved (0.0-0.2), stable (0.0), slightly decreased (−0.2-0.0), and severely degraded (<−0.2). The results show that from 2000 to 2020, habitat quality improvement dominated, with stable areas accounting for over 40%, mainly in the northern Qinling foothills, Ziwuling areas, and Guanzhong Plain where land use types were stable. Slightly improved areas covered 31,081.59 km^2, concentrated in the eastern and northern Loess Plateau hilly regions. Significantly improved areas (3,814.37 km^2) were scattered but highly consistent with ecological restoration zones. Slightly decreased areas (24,096.28 km^2) were mainly concentrated around urban built-up areas. Severely degraded areas (2,823.54 km^2) were directly impacted by construction land expansion and require urgent effective measures.

Figure 6 [Figure 6: see original paper] Spatial distributions of habitat quality in Weihe River Basin from 2000 to 2020

Figure 7 [Figure 7: see original paper] Spatial variation of habitat quality in Weihe River Basin from 2000 to 2020

Table 6 Area and proportion of habitat quality grades in Weihe River Basin from 2000 to 2020

Table 7 Change area and proportion of habitat quality in Weihe River Basin from 2000-2020

3.4 Habitat Quality Simulation

Based on land use prediction results, we used the InVEST model to simulate habitat quality grade distribution for 2030-2050 (Figure 8). The results show that the spatial pattern of habitat quality will remain relatively stable, with overall quality continuously improving but at a gradually slowing pace. Low habitat quality areas will continue decreasing but at a reduced rate, dropping to 915.99 km^2 (40.98% of the basin). Relatively low habitat quality areas will first increase then decrease, with a net reduction of 1026.97 km^2. Moderate habitat quality areas will continue slight growth, increasing by 10.27 km^2. Relatively high habitat quality areas will increase by 38.01 km^2, though the growth rate will slow. High habitat quality areas will show minimal change.

From 2020 to 2050, the average habitat quality scores are projected to be 0.57, 0.58, and 0.59, representing improvements of 0.01, 0.02, and 0.03 respectively compared to 2020. The intensity of habitat quality changes will decrease, and spatial pattern changes will be minimal. Low habitat quality areas will gradually shrink, moderate areas will remain stable, and high-quality areas will increase (Figure 9).

Figure 8 [Figure 8: see original paper] Spatial distribution prediction of habitat quality in Weihe River Basin from 2030 to 2050

Figure 9 [Figure 9: see original paper] Habitat quality area of Weihe River Basin from 2030 to 2050

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4 Discussion

4.1 Causes of Land Use Change

Land use change in the Weihe River Basin results from multiple factors. Cultivated land area continuously decreased due to China' s policy of returning farmland to forest and grassland, combined with rapid socioeconomic development in various cities that increased demand for construction land, leading to substantial occupation of suburban cultivated land—particularly prominent in plains with favorable natural and location conditions. Notably, active land policies during the poverty alleviation period expanded channels for cultivated land supplementation, slowing the reduction trend. Forest land and grassland, as important ecological land types, play crucial roles in controlling soil erosion and desertification in ecologically vulnerable areas. While implementing policies for returning farmland to forest and grassland, the government established nature reserves and forest parks and promoted ecological economies, driving rational development and protection of forest and grassland resources. With enhanced awareness of intensive and economical construction land use, rigid spatial planning constraints, and local government promotion of secondary development of abandoned and idle construction land, construction land expansion has been effectively controlled. Water areas are vital for maintaining regional aquatic ecological balance, and measures such as river and beach management and the river chief system have established various water wetlands represented by the Weihe Wetland Corridor and Jinghe Wetland Park, effectively protecting water areas.

4.2 Causes of Habitat Quality Change

Habitat quality in the Weihe River Basin is closely related to land use patterns. Continuous improvement in habitat quality levels benefits from high forest coverage in the Qinling and Liupan Mountain areas and significant ecological restoration measures including farmland conversion, mountain closure for afforestation, and grass planting for sand fixation. The Qinling region at the southern end of the basin serves as an important ecological security barrier with high and stable habitat quality. The Loess Plateau hilly and gully areas in the western and northern parts of the basin, as key targets for ecological management and restoration, have seen improving ecological conditions and gradually increasing habitat quality. In contrast, the central plain areas with lower elevation and superior location advantages host the Guanzhong-Tianshui Economic Zone, featuring numerous cities with rapid economic development and intense human disturbance, resulting in poorer habitat quality. This spatial pattern of high habitat quality on both sides and lower quality in the middle, and higher quality in the west than east, is the primary reason for the observed distribution.

Socioeconomic development and urban expansion in the central plain areas drive land use conversion, with construction land development leading to increased low habitat quality areas. However, overall, ecological compensation strategies and governance measures have promoted conversion of western and northern cultivated land to ecologically suitable grassland and forest land, gradually improving ecological conditions and driving the upward trend in overall habitat quality.

4.3 Recommendations and Outlook

As a strategic node in China' s western development, the Weihe River Basin holds significant importance for coordinating socioeconomic development and ecological environment construction. Our analysis of land use and habitat quality changes reveals several issues requiring attention. Regarding land use, construction land expansion occupying high-quality cultivated land and unbalanced urban development are prominent problems. We recommend further promoting intensive and economical land use policies, tapping existing construction land potential, clarifying urban positioning and division of labor, and scientifically guiding urban expansion and coordinated regional development. Regarding habitat quality, plain areas with higher economic development and concentrated populations show poor habitat quality and severe degradation trends, requiring heightened attention through measures such as constructing ecological landscape corridors and increasing urban green space.

Prediction results indicate stable land use change trends and continuously improving habitat quality levels from 2020 to 2050. Aligning with policies such as the "Yellow River Basin Ecological Protection and High-Quality Development Plan" and the "Shaanxi Province Qinling Ecological Environment Protection Regulations," ecological governance and protection remain the contemporary theme for sustainable development in the Weihe River Basin. Continuing to advance ecological management and protection in the Loess Plateau hilly and gully areas, southern Qinling foothills, and Ziwuling areas will build a solid ecological foundation and enhance ecological barrier quality and efficiency, providing good ecological security for building a new pattern of western development, the Belt and Road Economic Belt, and rural revitalization.

This study provides evidence for the improving ecological environment in the Weihe River Basin, with habitat quality in ecologically fragile areas and Qinling water conservation zones showing positive trends, consistent with previous research conclusions. However, land use change is influenced by multiple factors, and some impact factors were not included due to data acquisition difficulties and quantification challenges. Future research should deepen investigations to improve PLUS model prediction accuracy. Additionally, the InVEST model lacks a scientifically accurate and unified parameter setting system for habitat quality assessment; future work should focus on optimizing parameter settings.

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5 Conclusions

This study analyzed land use and habitat quality changes in the Weihe River Basin from 2000 to 2020 and predicted future patterns using the PLUS and InVEST models. The main conclusions are:

1. From 2000 to 2020, construction land and grassland areas increased annually, forest land area grew slightly, and cultivated land area continuously decreased. Construction land developed rapidly, with its area nearly doubling. Cultivated land loss was severe, primarily converting to grassland and construction land. Forest land area first increased then decreased but showed an overall upward trend, with reductions mainly converting to grassland.

2. PLUS model predictions indicate that land use changes from 2020 to 2050 will follow similar trends as 2000–2020 but with significantly reduced intensity. Construction land expansion will slow, cultivated land loss will decrease, and grassland area will continue growing to surpass cultivated land as the dominant land type.

3. InVEST model results show a clear polarization trend in habitat quality from 2000 to 2020, with increased areas of low and high habitat quality and decreased moderate habitat quality areas. However, the overall habitat quality level increased. Spatially, habitat quality improvement areas are concentrated in the western and northern Loess Plateau hilly and gully regions, while degradation areas cluster around the Xi' an metropolitan area.

4. From 2020 to 2050, overall habitat quality will continue improving annually but at a slowing pace, with decreasing change intensity. Low habitat

quality areas will gradually shrink, moderate areas will remain stable, and high-quality areas will increase, indicating a stable and improving trend in the basin’ s ecological environment.

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Note: Figure translations are in progress. See original paper for figures.