Analysis of Habitat Quality Evolution and Response Based on Land Use Change in the Northern Shaanxi Coarse Sandy Region: Postprint

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Abstract

To address the insufficient research on habitat quality evolution under long-term land use changes in the coarse sandy area of northern Shaanxi, this study analyzes regional land use changes through land use type variations and transfer matrices for 2000, 2005, 2010, 2015, and 2020, and evaluates habitat quality and degradation degree across four annual cycles based on the InVEST model. The results indicate that: (1) Land use in the coarse sandy area of northern Shaanxi is primarily dominated by dryland, forestland, grassland, construction land, and bare land. (2) During 2000–2020, bare land experienced the largest transferred-out area, with a total decrease of 57.11%, mainly converted to grassland and cultivated land; construction land increased by 272.69% in total; the transferred-out and transferred-in areas of grassland were essentially balanced, primarily interconverted with cultivated land; the comprehensive land use dynamic degree declined from 1.32% to 0.61%. (3) The habitat quality index exhibited a trend of first increasing then decreasing, peaking at 0.43, which is generally low; cultivated land expansion threatens habitat restoration. Habitat quality is relatively high in the southwestern region, predominantly medium and relatively low grades in the central zone, and high grades appear in the Shenmu and Fugu mining areas in the north. The mean habitat degradation indices for 2000 and 2020 were 0.41 and 0.43, respectively, indicating a future deteriorating trend for habitats. Subsequent ecological management policies should primarily focus on preventing cultivated land and construction land expansion, and protecting forest and grassland categories. The research results can provide data references for ecological restoration in the coarse sandy area of northern Shaanxi.

Full Text

Preamble

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Evolution and Response Analysis of Habitat Quality in the More Sediments and Coarse Sediments Region of Northern Shaanxi Based on Land Use Change

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Abstract: Current research on long-term habitat quality evolution under land use change in the more sediments and coarse sediments region of northern Shaanxi remains insufficient. This study evaluates habitat quality and degradation over four annual cycles using the InVEST model, analyzing land use type changes and transfer matrices for 2000, 2005, 2010, 2015, and 2020. Results demonstrate that: (1) Land use is dominated by dry land, forested land, grassland, construction land, and bare land. (2) From 2000 to 2020, bare land exhibited the largest transfer-out area with a total decrease of 57.11%, primarily converting to grassland and cultivated land. Construction land increased by 272.69%, while grassland transfer-out and transfer-in areas remained essentially balanced, mainly interconverting with cultivated land. The comprehensive land use dynamic degree decreased from 1.32% to 0.61%. (3) The habitat quality index showed an initial increase followed by a decrease, peaking at 0.43 but remaining low overall. Cultivated land expansion threatens habitat restoration. Habitat quality is higher in the southwestern region, medium to low in central areas, and notably high in the northern Shenmu and Fugu mining districts. Average habitat degradation indices were 0.41 in 2000 and 0.43 in 2020, indicating a future deterioration trend. Subsequent ecological governance policies should focus on preventing cultivated land and construction land expansion while protecting forest and grassland ecosystems. These results provide data references for ecological restoration in the more sediments and coarse sediments region of northern Shaanxi.

Key words: land use; transfer matrix; InVEST model; habitat quality

Introduction

Land use and land cover change (LUCC) refers to the dynamic transformation process of land use patterns over time, representing a critical focus in global environmental change research [1-3]. Habitat quality, defined as the capacity of ecosystems to provide suitable conditions for the sustained survival and development of individuals and populations, serves as a vital indicator for assessing ecosystem services and reflects ecological health and regional biodiversity status [4-6]. As the foundation of ecosystems, land use changes directly influence key ecological processes including soil erosion, energy exchange, water cycling, and carbon cycling, thereby affecting ecosystem services [7-9].

The concept of ecosystem services, introduced by Ehrlich and Costanza, has evolved from theoretical frameworks to practical valuation methods [10-12]. With advances in geographic information systems, quantitative models such as SolVES, habitat suitability index models, and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model have become essential tools for fine-scale regional ecological assessment, with InVEST being the most widely applied [13-15]. Land use change, as the most direct manifestation of human activities, alters energy and material flows between habitat patches, ultimately transforming habitat quality and impacting regional biodiversity [16-18]. Previous studies have examined habitat quality response mechanisms, spatiotemporal evolution, urbanization coupling effects, and biodiversity correlations, providing valuable data support for regional ecological evaluation [19-22].

However, research in northwest China, an ecologically fragile region with harsh climate conditions, remains limited in scope and scale. Existing studies predominantly focus on urban areas and their surrounding environments [23-25], while large-scale ecological zone investigations often fail to capture localized ecological changes accurately [8,12-13]. The more sediments and coarse sediments region of northern Shaanxi, a primary source of Yellow River sediment, is characterized by deep loess deposits, sparse vegetation, and severe soil erosion [26]. Despite recent implementation of ecological restoration policies including the Grain for Green Program, aerial seeding afforestation, and high-standard farmland construction, concurrent intensive resource development as a key energy and chemical industry base has disrupted land use stability. This study employs land use remote sensing data from 2000, 2005, 2010, 2015, and 2020 to analyze land use changes, habitat quality evolution, and response patterns to land use transitions, aiming to provide scientific support for ecological restoration in this critical region.

[Figure 1: see original paper] Schematic diagram of more sediments and coarse sediments region in northern Shaanxi

1.1 Study Area

The more sediments and coarse sediments region of northern Shaanxi (35°19 –39°35 N, 107°15 –111°13 E) is located at the junction of Shanxi, Shaanxi, Inner Mongolia, Ningxia, and Gansu provinces in the middle and upper reaches of the Yellow River basin, covering a total area of 68,266 km^2. The terrain slopes from west to east with an average elevation of 1,200–1,500 m. The region experiences a semi-arid climate with average annual precipitation of 400–600 mm and evaporation of 1,200–1,500 mm. Rich in mineral resources that drive local industrial and economic development, the region' s GDP reached 654.365 billion yuan, with Yulin City contributing 223.193 billion yuan.

1.2.1 Land Use Dynamic Change

Land use data were obtained from the Aerospace Information Research Institute, Chinese Academy of Sciences (https://data.casearth.cn/) with a resolution of 30 m. Based on territorial spatial planning and the national "Land Use Status Classification" standard, combined with the actual ecosystem service conditions in the study area, land use data were reclassified into six categories as shown in . Using ArcGIS 10.2, land use maps from different periods were overlaid to analyze changes.

A land use transfer matrix represents the area transferred from land use type y to type x during a specific period, expressed as:

$C_{xy} =$

where C_{xy} is the transferred area from type y to type x (km^2), and x, y represent the land use types before and after conversion.

Land use dynamic degree intuitively describes the rate of land use transformation, comprising single dynamic degree and comprehensive dynamic degree. The single dynamic degree (K_i) for land use type i is calculated as:

$K_i = (U_a - U_b) / (U_i \times T) \times 100\%$

where U_a and U_b are the areas at the end and beginning of the study period (km^2), U_i is the initial area of type i (km^2), and T is the time interval (years).

The comprehensive dynamic degree (M) describes the overall transfer rate of all land use types in the study area, reflecting land change stability:

$M = \Sigma|\Delta U_{ij}| / (\Sigma U_i \times T) \times 100\%$

where ΔU_{ij} is the area converted from type i to j, and U_i is the initial area of type i.

1.2.2 InVEST Model Application

The InVEST model, developed jointly by Stanford University, The Nature Conservancy (TNC), and the World Wide Fund for Nature (WWF), is a comprehensive ecosystem service evaluation tool widely applied for assessing habitat quality degradation and animal/plant habitats [27-29]. The habitat quality module calculates habitat degradation degree D_{xj} for grid cell x in land use type j using:

$D_{xj} = \Sigma_r (w_r \times \Sigma_y (r_y \times i_{rxy} \times \beta x \times S\{jr\}))$

where R is the number of threat factors; w_r is the weight of threat factor r; Y_r is the number of grids containing threat factor r; r_y is the intensity of threat factor; *βx is the protection level of grid cell x; S*{jr} is the sensitivity of habitat type j to threat factor r; and i_{rxy} is the distance decay function.

The distance decay function i_{rxy} has two forms:

Linear decay: $i_{rxy} = 1 - (d_{xy} / d_r)$
Exponential decay: $i_{rxy} = \exp(-2.99 \times d_{xy} / d_r)$

where d_{xy} is the linear distance between grids x and y, and d_r is the maximum influence distance of threat factor r.

The final habitat quality Q_{xj} is calculated as:

$$Q_{xj} = H_j \times (1 - (D_{xj}^z / (D_{xj}^z + k^z)))$$

where H_j is habitat suitability; k is the half-saturation constant (typically half of the maximum degradation value); and z is a normalized constant (usually 2.5).

According to the InVEST model manual, threat factors and their weights, as well as sensitivity tables for different habitat types, must be defined. This study considered land use characteristics and anthropogenic impacts in the region, reviewing similar studies in northern Shaanxi, Lanzhou, and the Loess Plateau to establish dry land, construction land, and bare land as threat factors with corresponding weights, maximum influence distances, decay types, and sensitivities (and).

1.2.3 Habitat Contribution Rate Under Land Use Transfer

To explore the response of habitat evolution to land use change, ArcGIS zonal statistics were used to correlate major land use change grids with habitat quality change grids, extracting habitat change patterns under specific land use transitions. The habitat contribution rate (R_{ij}) calculates the ratio of habitat quality change when land use type i converts to type j [30]:

$$R_{ij} = (H_j - H_i) / H_i \times (S_i / S_{total}) \times 100\%$$

where R_{ij} is the habitat contribution rate when type i converts to j; H_i and H_j are habitat indices before and after conversion; S_i is the area of changed land use type i (km^2); and S_{total} is the total study area (km^2).

2.1.1 Land Use Area Change Analysis

The study area is dominated by dry land, forested land, grassland, construction land, and bare land, with average annual proportions of 16.52%, 8.43%, 69.52%, 0.39%, and 4.40%, respectively. The main changes during 2000–2020 are shown in [Figure 2: see original paper].

From 2000-2005, bare land and grassland showed the largest changes, with areas of -1,480.59 km^2 and +1,413.05 km^2, respectively. During 2005-2010, bare land and forested land changed most significantly (-379.90 km^2 and +295.38 km^2). From 2010-2015, bare land and dry land had the largest changes (-585.48 km^2 and +188.18 km^2). During 2015-2020, grassland and dry land showed the greatest changes (-519.14 km^2 and +450.50 km^2).

These changes reflect the implementation of ecological policies such as afforestation, grassland restoration, and grazing prohibition after 2000, which increased forest and grassland areas while reducing dry land and bare land. Additionally, construction land area increased continuously from 2000-2020, with annual increments of 52.75 km^2, 74.41 km^2, 82.08 km^2, and 117.84 km^2, corresponding to intensive resource extraction of coal and natural gas.

2.1.2 Land Use Transfer Analysis

Grassland and bare land showed substantial transfer changes (). During 2000-2005, grassland transfer-out and transfer-in areas were both 1,484.9 km^2, the largest among all land use types, indicating significant grassland circulation. From 2005-2010, grassland and bare land transfers were prominent, with outflow areas of 801.1 km^2 and 714.0 km^2, respectively. During 2010-2015, grassland and bare land had the largest outflow areas, while dry land showed the greatest inflow, likely due to high-standard farmland construction initiatives. From 2015-2020, construction land primarily converted from grassland (33.2 km^2, 47.8 km^2, 50.0 km^2, and 67.0 km^2), followed by bare land and dry land.

2.1.3 Land Use Dynamic Degree Analysis

Single dynamic degrees for the five major land use types (dry land, forested land, grassland, construction land, bare land) and comprehensive dynamic degrees were calculated to analyze change rates.

From 2000-2020, all single dynamic degrees except dry land showed decreasing trends, indicating reduced land circulation rates. Construction land dynamic degree decreased annually but peaked at 7.19% during 2015-2020, consistent with intensified resource exploitation and urban development. The comprehensive dynamic degree decreased from 1.32% to 0.61%, demonstrating that land use change rates slowed and the system gradually stabilized.

[Figure 3: see original paper] Linear fitting of land use dynamics

2.2 Habitat Quality Dynamic Changes

The InVEST habitat quality module calculated habitat quality from 2000-2020, classified into five levels (low, relatively low, medium, relatively high, high) using equal interval method. Spatial distribution patterns ([Figure 4: see original paper]) show:

Low-quality habitats are concentrated in northwestern Yulin counties (Hengshan District, northern Jingbian), located in the Mu Us Desert with extremely poor habitat conditions. High-quality habitats are distributed in Baota District and southwestern Yichuan County, within the eastern Ziwuling National Nature Reserve where forest and grassland account for 75.89% of land use and construction land accounting for only 0.18%.

From 2000–2020, high-quality habitat zones expanded northward to Zhidan County and eastward to Baota District. Relatively low-quality habitats were widespread before 2005 when bare land accounted for 6.88%, but construction land increased rapidly by 447.05 km^2 during 2000–2020, hindering habitat restoration.

The habitat quality index peaked at 0.43 in 2010 then declined to 0.41 in 2020, indicating overall low habitat quality. Low-grade areas decreased annually while relatively low-grade areas increased. Medium, relatively high, and high grades peaked in 2010 then declined but remained above 2000 levels, reflecting initial ecological restoration success followed by weakening effects from later development.

[Figure 5: see original paper] Changes of habitat quality area and habitat quality indices at different levels

2.3 Habitat Degradation Degree Dynamic Analysis

Habitat degradation degree reflects the impact of threat factors, with values ranging [0, 1] where higher values indicate greater degradation. Classified into weak, relatively weak, medium, relatively strong, and strong levels, spatial distribution ([Figure 6: see original paper]) shows a pattern of stronger degradation in central areas and weaker degradation in peripheral zones.

Central regions dominated by dry land (Mizhi, Zizhou counties) exhibit relatively strong degradation, while southwestern areas with extensive forest and grassland coverage (Zhidan, Yichuan) show weak degradation.

The habitat degradation index was lowest in 2000 at 0.41, increased subsequently, and reached 0.43 in 2020, indicating a rising probability of habitat deterioration. The 2010 high-standard farmland construction increased dry land area while reducing grassland, causing stronger degradation. Overall, areas with higher habitat quality grades generally show lower degradation (e.g., southwestern Baota District), while lower-quality areas exhibit higher degradation (e.g., central Suide County, southern Mizhi County).

Habitat degradation indices in more sediments and coarse sediments region of northern Shaanxi

2.4 Response Relationship Between Habitat Quality and Land Use Change

Habitat contribution rates of major land use changes () reveal close relationships between habitat quality variation and land use transfer:

Habitat increases primarily resulted from dry land converting to forest and grassland. During 2000-2005, dry land to forest and dry land to grassland transfers covered 156.35 km^2 and 1,192.47 km^2, increasing habitat quality by 0.3495% and 0.0693%, respectively. Bare land, as a threat factor, increased habitat quality when converted to dry land, forest, or grassland, with 1,329.65 km^2 of transfers increasing quality by 0.90%.

Habitat decreases mainly occurred when dry land converted to construction land or bare land, and when forest land converted to other types. During 2015-2020, dry land to construction land transfers of 81.63 km^2, 84.46 km^2, 3.10 km^2, and 18.58 km^2 decreased habitat quality by 0.0178%, 0.0018%, 0.0006%, and 0.0037%, respectively. Grassland conversion to dry land, construction land, and bare land also reduced habitat quality, particularly high-area transfers to bare land that weakened restoration efforts.

In summary, habitat quality is highly sensitive to land use transitions. While the Grain for Green policy effectively reduced bare land and improved habitat quality, resource exploitation has converted some forest and grassland to bare land and construction land, posing threats to habitat restoration.

3.1 Land Use Type Transfer Analysis

The study area is dominated by dry land, forested land, grassland, construction land, and bare land, which also constitute the main transfer categories. Dry land readily converts to grassland, bare land easily converts to dry land and grassland, and grassland frequently transitions between dry land and forested land, reflecting local production practices and long-term ecological policies [31-32].

Total dry land, forested land, and grassland area was only 755.5 km^2 in 2000, while construction land reached 33.2 km^2. By 2020, these became 298.2 km^2 and 740.7 km^2, respectively, with 67.0 km^2 of construction land. These findings align with Ji et al. [33], who reported large conversions from forest and grassland to dry land and surging construction land causing unbalanced regional development. Chen et al. [34] demonstrated that while farmland expansion may alleviate drought in oasis-desert ecotones, it encroaches on grassland and destabilizes grassland ecosystems. Therefore, coordinating land use development and optimizing land use patterns represent critical challenges for the region.

3.2 Habitat Quality and Degradation Degree Evolution Analysis

The southwestern region adjacent to Ziwuling National Nature Reserve exhibits the highest habitat quality. The Mu Us Desert area in Jingbian County improved from predominantly low-quality in 2000 to medium-quality by 2020, with scattered high-quality patches likely resulting from aerial seeding afforestation techniques that increased forest and grassland area.

From a degradation perspective, central regions with extensive dry land (Mizhi, Zizhou) show significantly higher degradation than peripheral zones, while southwestern forest-covered areas exhibit weak degradation. Habitat quality is sensitive to land use transitions: conversion to forest, grassland, wetland, and water bodies effectively improves quality, while construction land, bare land, and dry land hinder improvement, consistent with Hu et al.' s [35] findings in the Wei River Basin. Subsequent construction land development and farmland expansion warrant attention.

3.3 Subsequent Ecological Protection and Research Recommendations

Localized studies better reflect ecological quality and existing problems compared to large-scale assessments, enabling tailored conservation measures. To promote ecological restoration in the region, three approaches are recommended:

First, maintain current ecological policies, continuing Grain for Green, aerial seeding, and other measures to expand effective forest coverage. Second, moderate farmland and construction land expansion to prevent both outward transfer of farmland and encroachment on forest, grassland, and water bodies. Industrial and mining land expansion should follow "protect while developing" principles, with appropriate wetland and water body expansion. Third, future ecological assessments should delineate smaller regions based on ecological boundaries and production practices. Additionally, although InVEST is widely used and iteratively improved, its parameter settings primarily derive from expert scoring and literature references; subsequent research should optimize parameter calibration and comprehensively consider other factors affecting habitat quality.

4 Conclusion

1) The study area is dominated by dry land, forested land, grassland, construction land, and bare land. From 2000–2020, bare land, grassland, and dry land showed the largest changes, while wetland, other forested land, and water bodies had minimal changes. Bare land transfer-out area was largest with a total decrease of 57.11%, while construction land increased by 272.69%. The comprehensive land use dynamic degree decreased from 1.32% to 0.61%, indicating stabilizing land use.

2) The habitat quality index exhibited an increasing then decreasing trend, peaking at 0.43 in 2010 but remaining low overall. Farmland expansion encroached on green space, threatening habitat restoration. Degradation degree was higher in 2020 (index 0.43) than in 2000 (0.41), indicating a deteriorating trend.
3) Habitat quality was highest in the southwestern region, medium to low in central areas, and notably high in northern Shenmu and Fugu mining zones. Future ecological governance should focus on controlling farmland and construction land expansion while protecting forest and grassland.

The results provide data references for ecological restoration in the more sediments and coarse sediments region of northern Shaanxi.

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