

## Spatial Migration Characteristics and Ecological Impacts of Ecological Migration in Arid Regions: A Case Study of Gulang County, Gansu Province (Postprint)

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### Abstract

Ecological migration is one of the effective approaches for rural revitalization in western China and regional ecological protection and restoration. Investigating the spatial migration characteristics and ecological impacts of ecological migration contributes to regional poverty alleviation and ecological civilization construction. Taking a typical ecological migration area in the arid northwest as an example, and from the county spatial perspective, this study systematically analyzes the spatiotemporal variation characteristics of spatial migration and vegetation restoration in Gulang County from 2010 to 2018 by calculating the land use transfer matrix and dynamic degree, and utilizing the Normalized Difference Vegetation Index (NDVI) and Vegetation Restoration Degree (VRD). The results show that: (1) From 2010 to 2018, the spatial migration characteristics of ecological migration manifested as terrain changing from high to low, slope from steep to gentle, traffic-oriented and spatial aggregation, with a total of  $6.24 \times 10^4$  migrants, accounting for 20.20% of the county's permanent population. (2) From 2010 to 2018, the NDVI in the study area spatiotemporally exhibited a continuously increasing trend in the southern emigration area and a "V"-shaped trend of first decreasing then increasing in the northern immigration area. The minimum NDVI in the overall migration area increased from 0.10 to 0.15, an increase of 50.00%; the maximum NDVI increased from 0.52 to 0.72, an increase of 38.46%; the minimum NDVI in the resettlement area decreased from 0.10 to 0.09, a decrease of 10.00%; the maximum NDVI increased from 0.66 to 0.72, an increase of 9.09%. (3) The average NDVI and VRD in the study area showed a continuous and rapid upward trend, and the ecological migration had significant effects on ecological environment protection. Among them, the protection effect was most obvious in the southern overall migration area, where the average NDVI increased from 0.19 to 0.42, an increase

of 121.05%, and the VRD increased from 0.26 to 0.75, an increase of 188.46%.

## Full Text

### Spatial Migration Characteristics and Ecological Impacts of Ecological Migrants in Arid Regions: A Case Study of Gulang County, Gansu Province

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**Abstract:** Ecological migration represents one of the effective pathways for rural revitalization and regional ecological protection and restoration in western China. Investigating the spatial migration characteristics and ecological impacts of ecological migrants can contribute significantly to regional poverty alleviation and ecological civilization construction. This study selects Gulang County in Gansu Province—a region characterized by sensitive ecological conditions in arid areas, distinctive resettlement sites, and a large migrant population. From a county-level spatial perspective, we innovatively employ indicators intrinsically linked to ecological migration, including the Normalized Difference Vegetation Index (NDVI) and Vegetation Restoration Degree (VRD). By integrating statistical yearbooks, land use data, ecological migration information, and MODIS remote sensing data obtained through field investigations, we systematically analyze the spatiotemporal characteristics of ecological migration and vegetation restoration policies in Gulang County from 2010 to 2018 through calculations of land use transfer matrices, dynamic degrees, NDVI, and VRD. The results reveal: (1) From 2010 to 2018, ecological migration exhibited spatial characteristics of moving from high to low terrain, from steep to gentle slopes, traffic orientation, and spatial aggregation, totaling  $6.24 \times 10^4$  migrants and accounting for 20.20% of the county's permanent population. (2) During 2010–2018, NDVI in the study area showed a continuous increase in southern migrant-sending regions and a “decrease-first-then-increase” pattern in northern resettlement areas. The minimum NDVI value in the overall migration area increased from 0.10 to 0.15, while the maximum increased from 0.52 to 0.72. In the resettlement area, the minimum NDVI value decreased from 0.10 to 0.09, while the maximum increased from 0.66 to 0.72. (3) Both mean NDVI and VRD in the study area demonstrated continuous and rapid upward trends, indicating that ecological migration has produced significant ecological protection effects. The most pronounced protection effects occurred in the southern overall migration area, where mean NDVI increased from 0.19 to 0.42 and mean VRD increased from 0.26 to 0.75. Ecological migration in arid regions consti-

tutes an effective approach to improving regional ecological environments while alleviating population pressure in mountainous areas. Moreover, by combining resettlement with low-quality land resources such as wastelands and deserts, it effectively reduces damage to sensitive and fragile ecosystems caused by human activities. Therefore, determining how to better leverage ecological migration to improve ecological environments in sensitive and fragile areas, achieve rural revitalization, and promote sustainable rural development represents a critical contemporary issue in balancing ecological protection with rural revitalization.

**Keywords:** ecological migration; population migration; rural revitalization; ecological restoration; arid region

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## 1 Introduction

Ecological civilization construction and rural revitalization constitute millennial strategies vital to the development of the Chinese nation, with ecological migration in arid regions representing a crucial component of China's ecological protection and poverty alleviation consolidation efforts. The spatial migration and ecological environmental impacts of ecological migration stimulate the livelihood vitality and sustainable development of migrants—key factors in China's successful poverty alleviation era. Ecological migration not only reduces continuous environmental degradation from human activities but also facilitates ecosystem recovery and reconstruction in migrant-sending areas, holding significant importance for regional ecological improvement.

The United Nations Environment Programme defined ecological migrants in 1985 as people who must relocate due to environmental collapse that severely affects their quality of life or even threatens their survival. Domestic scholars view ecological migration as both an effective measure to adjust spatial mismatches between ecosystem service supply and demand and a critical initiative for China's poverty reduction and mitigation of human-environment conflicts. Existing research has employed diverse analytical methods and perspectives to investigate ecological migration across different regions, focusing on the Three Gorges Reservoir area, Sanjiangyuan Nature Reserve, and Ningxia's Hongsibu District. Research perspectives have examined migrant households, spatial structure adjustments, and human-land coupling to comprehensively evaluate the ecological impacts of migration policies and resettlement. Studies have also adopted “cultural turn” paradigms to predict development trends in migration geography, utilizing participatory semi-structured interviews, qualitative aggregation methods, partial correlation analysis, field surveys, and questionnaires. Combined with land use transfer matrices and geographical detectors, researchers have constructed multiple regression model frameworks to analyze migrants' willingness, livelihood capital, and stability, thereby verifying the comprehensive impacts of ecological migration policies. Foreign scholars have focused more on the socio-economic and environmental impacts of immigrants on destination areas,

psychological changes before and after migration, and subsequent development predictions, though research on ecological impacts formed during the migration process remains limited.

Reviewing existing literature reveals that early research concentrated on resettlement, livelihood capital, and policy responses, while later studies shifted toward predicting ecological impacts and sustainable development of migrants. However, research on spatial migration characteristics of ecological migrants and environmental impacts in arid regions using NDVI and VRD combined with spatial analysis methods remains scarce. Therefore, this study selects Gulang County, Gansu Province—a region with sensitive ecological characteristics in arid areas, special resettlement sites, and a large migrant population—to explore the spatiotemporal migration characteristics and ecological impacts from 2010 to 2018. By combining NDVI and other indicators with ecological migration data, statistical yearbooks, land use data, and remote sensing data, this research aims to provide scientific evidence for policy formulation in arid region rural revitalization and ecological protection.

## 2 Study Area and Data

### 2.1 Study Area Overview

Gulang County is located in the eastern section of the Hexi Corridor, central Gansu Province, between 102°38'~103°54' E and 37°09'~37°54' N. The county encompasses the Qilian Mountains National Ecological Park along its border, representing a critical component of China's western ecological security barrier. The terrain slopes from high in the south to low in the north, with elevations ranging from 1583 to 3703 m and annual precipitation of approximately 300 mm, classifying it as a typical northwest arid region. As of 2018, the county's total land area was 5046 km<sup>2</sup>.

Based on geographical location and Gulang County's Ecological Migration Plan, we classify ecological migration zones into three types: overall migration area (entire township population relocated), core migration area (partial township population relocated), and resettlement area (township population receiving migrants). The overall migration area includes Hengliang Township, Gancheng Township, and Xinbao Township; the core migration area includes Shibalipu Township, Huangyangchuan Town, Heisongyi Town, Dingning Town, Peijiaying Town, Minquan Town, Gufeng Town, and Dajing Town; the resettlement area includes Huanghuatan Town and Xijing Town.

### 2.2 Data Collection and Processing

**Remote sensing data** were obtained from the MODIS NDVI composite product for China, provided by the Chinese Academy of Sciences Computer Network Information Center (<http://www.gscloud.cn>), with a spatial resolution of 250 m and temporal resolution of 16 days. Based on the vegetation phenology of the

study area, June to September represents the growing season and thus better reflects actual vegetation conditions. We calculated monthly NDVI values using integrated procedures and computed the annual growing season mean NDVI from the monthly composites to represent vegetation coverage. All remote sensing image processing was conducted in ENVI 5.3, with data accuracy meeting research requirements.

**Land use data** were sourced from the Chinese Academy of Sciences Resource and Environmental Science Data Center (<http://www.resdc.cn>), using the 2010–2018 land use/cover change classification standard. Data from three periods were reclassified into six land use types (cropland, forestland, grassland, water bodies, construction land, and unused land) based on Gulang County's characteristics using ArcGIS 10.5, with field survey sampling for correction. Google Earth was used for visual verification of classification results, with Kappa coefficients for all periods exceeding 0.84, meeting research requirements.

**Socioeconomic data** were obtained from Gulang County Statistical Bureau's statistical yearbooks (2010–2018), poverty alleviation relocation project data, and ecological migration materials, including permanent population by township, ecological migration numbers, and resettlement site information. These data were visualized in ArcGIS to map migration routes and environmental changes, with Origin 2021 used for statistical analysis.

## 2.3 Methods

**2.3.1 Land Use Transfer Matrix** The land use transfer matrix comprehensively and concretely reflects regional land use change structure while indicating change directions caused by human activities. Originating from quantitative descriptions of system state transitions in systems analysis, it reveals spatiotemporal land use pattern changes by quantifying transitions from time  $T_1$  to  $T_2$ . The mathematical expression is:

$$S_{ij} = \begin{pmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{pmatrix}$$

where  $S$  represents area ( $\text{km}^2$ ),  $n$  is the number of land use types, and  $i, j$  represent initial and final land use types, respectively.

**2.3.2 Land Use Dynamic Degree** Land use change responses to human activities manifest through change speed, transfer direction, and degree. The dynamic degree of a single land use type reflects its quantitative change rate, calculated as:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$$

where  $K$  is the dynamic degree of a land use type during the study period,  $U_a$  and  $U_b$  are the initial and final areas ( $\text{km}^2$ ), and  $T$  is the study period duration.

**2.3.3 Normalized Difference Vegetation Index (NDVI)** NDVI, the normalized ratio of red and near-infrared band differences in remote sensing imagery, is a crucial parameter reflecting vegetation status, growth condition, and spatial distribution density, linearly correlated with vegetation density. Healthy, dense vegetation reflects more near-infrared radiation than sparse vegetation, with the healthiest woodlands showing the highest NDVI values. The formula is:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where  $NIR$  is the near-infrared band value and  $R$  is the red band value from MODIS imagery.

**2.3.4 Vegetation Restoration Degree (VRD)** Vegetation index serves as an effective indicator for ecological restoration, with vegetation recovery representing the key component and step in ecological restoration. VRD measures vegetation recovery degree over a specific period, where higher values indicate better restoration, calculated using NDVI averages from different time periods:

$$VRD = \frac{NDVI_{T_2} - NDVI_{T_1}}{NDVI_{T_1}}$$

where  $VRD$  is vegetation restoration degree,  $NDVI_{T_2}$  is the NDVI in period  $T_2$ , and  $NDVI_{T_1}$  is the initial NDVI in period  $T_1$ .

## 3 Results

### 3.1 Spatial Migration Characteristics of Ecological Migrants

From 2010 to 2018, ecological migration numbers showed a trend of rapid increase followed by gradual growth temporally, and spatially exhibited characteristics of high-to-low terrain, steep-to-gentle slope, traffic orientation, and spatial aggregation (Fig. 2). In 2010, the county implemented a “government-guided, voluntary registration” policy, relocating  $3.47 \times 10^4$  people from the southern overall and core migration areas with slopes exceeding  $25^\circ$  to the northern resettlement areas with gentler slopes. In 2015, the government implemented the “Two No Worries, Three Guarantees” poverty alleviation policy, relocating  $2.77 \times 10^4$  people from the southern mountainous areas with harsh natural conditions and backward production facilities to the northern resettlement areas with flat terrain and convenient transportation, minimizing threats from natural geological disasters. Simultaneously, populations shifted from relatively

dispersed villages to concentrated resettlement sites, facilitating comprehensive and concentrated land resource utilization.

From 2010 to 2018, the total number of ecological migrants across all townships reached  $6.24 \times 10^4$ , accounting for  $20.20 \times 10^4$  migrants (71.63% of total relocations), including  $4.12 \times 10^4$  impoverished people (76.40% of the town's total migrants). Xijing Town received  $1.77 \times 10^4$  migrants (28.37% of total relocations), including  $0.65 \times 10^4$  impoverished people (36.72% of the town's total migrants). The ecological migration project protected the ecological environment in southern sending areas and along the Qilian Mountains National Park, improved the original environment in northern resettlement areas, substantially reduced poverty rates in southern mountainous regions, and forged a new path out of poverty following the development direction of "scaled, regional, diversified, and high-efficiency" industries, offering valuable lessons for national rural revitalization and ecological protection projects.

### 3.2 Ecological Impacts of Ecological Migration

**3.2.1 Impacts on Land Use Area Change** During the study period, ecological migration significantly affected land use area and dynamic degree changes in Gulang County (Table 1). In the overall migration area, cropland and water areas showed an initial increase followed by decrease, while grassland and unused land exhibited a "decrease-first-then-increase" pattern, and forestland area continuously decreased. The dynamic degree of forestland change was most significant, decreasing from  $2.44 \text{ km}^2$  to  $1.85 \text{ km}^2$  with a dynamic degree of -24.10%, likely due to the lack of maintenance and natural drought affecting lower-quality forestland, thereby impacting local ecological environments.

In the core migration area, cropland and forestland showed a "decrease-first-then-increase" trend, while water bodies, construction land, and unused land initially increased then decreased. Unused land change was most pronounced from 2015–2018, increasing from  $0.09 \text{ km}^2$  to  $4.99 \text{ km}^2$  with a dynamic degree of 1050.30%, resulting from continuous outward migration reducing human activities. In the resettlement area, cropland, water bodies, and construction land continuously increased, while forestland and unused land initially increased then decreased, and grassland continuously decreased. From 2010–2015, construction land, cropland, and water body dynamic degrees were most significant at 289.63%, 66.74%, and 84.08%, respectively, due to increasing migrant numbers requiring housing and food security, necessitating conversion of grassland, low-quality forestland, and unused land to cropland, while water areas increased to meet agricultural irrigation and domestic needs.

**3.2.2 Impacts on Land Use Transfer** Ecological migration impacts manifested not only in land use type area changes but also in mutual conversions between types (Table 2, Fig. 4). During 2010–2015, land use transfers showed: cropland 转入量  $15.47 \text{ km}^2$ , grassland 转入量  $11.29 \text{ km}^2$ , water bodies 转入量  $8.32 \text{ km}^2$ ; 转出量: grassland  $18.45 \text{ km}^2$ , unused land  $9.21 \text{ km}^2$ , water bodies  $3.12 \text{ km}^2$ .

The largest conversion area was between grassland and cropland at 12.36 km<sup>2</sup>. This period marked the initial to rapid development phase of ecological migration, focusing on housing construction and cropland reclamation in northern resettlement areas and returning cropland to forest/grassland in southern areas, with southern cropland mainly converting to grassland and northern grassland and unused land mainly converting to cropland and construction land.

During 2015–2018, land transfers showed: cropland 转入量 18.45 km<sup>2</sup>, grassland 转入量 12.36 km<sup>2</sup>, water bodies 转入量 9.21 km<sup>2</sup>; 转出量: grassland 15.47 km<sup>2</sup>, unused land 11.29 km<sup>2</sup>, water bodies 3.12 km<sup>2</sup>. The largest conversion was grassland to cropland at 326.61 km<sup>2</sup>, with significant unused land to grassland (20.88 km<sup>2</sup>) and cropland (98.17 km<sup>2</sup>). This period represented the 攻坚 and stabilization phase, focusing on southern migration and original homestead reclamation, with northern resettlement areas meeting livelihood needs and implementing national ecological protection policies. Consequently, cropland 转入量 mainly came from grassland, unused land, and construction land, while grassland 转入量 mainly came from cropland and unused land.

**3.2.3 Impacts on NDVI Change** Ecological migration significantly influenced NDVI values, which continuously increased temporally and showed the greatest increases in southern overall and core migration areas spatially (Table 3). The minimum NDVI in the overall migration area increased from 0.10 to 0.15, while the maximum increased from 0.52 to 0.72. In the core migration area, the minimum increased from 0.11 to 0.15 and the maximum from 0.57 to 0.84. In the resettlement area, the minimum decreased from 0.10 to 0.09 while the maximum increased from 0.66 to 0.72, indicating short-term ecological disruption from large-scale migration but subsequent improvement through urban greening and village beautification policies.

Mean NDVI values in all zones showed upward trends, with the core migration area showing the most significant growth from 0.19 to 0.42 (Table 4). This resulted from outward migration reducing human socioeconomic activities' impact on natural vegetation, coupled with diversified rural incomes, improved living standards, and industrial restructuring reducing dependence on traditional agricultural resources like cropland, thereby alleviating ecosystem pressure.

**3.2.4 Impacts on VRD Change** VRD in the study area showed continuous temporal increase and rapid vegetation recovery in southern overall and core migration areas (Table 4). Mean VRD in the overall migration area increased from 0.26 to 0.75, in the core migration area from 0.31 to 0.88, and in the resettlement area from 0.20 to 0.71. The most pronounced vegetation restoration occurred in southern areas (Fig. 5), with northern resettlement areas also showing overall upward trends, demonstrating that poverty alleviation relocation and ecological migration projects effectively protected both sending and receiving area environments.

These improvements stemmed from several factors: improved electricity infras-

structure reduced dependence on traditional timber, decreasing tree felling; rapid southern-to-northern population migration combined with strict national environmental protection policies; and implementation of the “Two Mountains Theory” and ecological civilization construction, all contributing to effective vegetation and environmental protection.

## 4 Conclusions

Using MODIS remote sensing imagery combined with land use transfer matrices and dynamic degree calculations, this study systematically analyzed land use, NDVI, and VRD changes to examine the spatiotemporal migration characteristics and ecological impacts of ecological migration in Gulang County from 2010 to 2018. The main conclusions are:

- (1) Ecological migration in the study area exhibited spatial characteristics of high-to-low terrain, steep-to-gentle slope, traffic orientation, and spatial aggregation. The total of  $6.24 \times 10^4$  migrants accounted for 20.20% of the permanent population, with impoverished individuals comprising 92.17% of migrants.
- (2) Cropland and grassland areas showed dynamic mutual conversion, with cropland in northern resettlement areas continuously increasing while grassland and forestland showed a “decrease-first-then-increase” pattern. This resulted from continuous migrant influx in resettlement areas requiring conversion of low-quality grassland, forestland, and unused land to cropland to meet basic livelihood needs.
- (3) Mean NDVI and VRD showed continuous upward trends, with the most significant increases in southern overall and core migration areas. Mean NDVI increased from 0.19 to 0.42 and mean VRD from 0.26 to 0.75, indicating that ecological migration significantly improved vegetation coverage and ecological environment quality.

Achieving regional green, inclusive, and sustainable development requires rational implementation of ecological migration, rural revitalization, and ecological restoration measures. Ecological migration in arid regions directly improves regional ecological environments by reducing population pressure in mountainous areas and combining resettlement with low-quality land resources like wastelands and deserts, thereby minimizing damage to sensitive and fragile ecosystems. How to better leverage ecological migration to improve environments in sensitive areas, achieve rural revitalization, and promote sustainable rural development represents a key contemporary challenge in balancing ecological protection with rural revitalization.

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