

# Spatiotemporal Evolution of Land Use and Its Driving Mechanism in the Gansu Farming-Pastoral Ecotone Based on Geodetector: Post-print

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## Abstract

Based on RS, GIS, and the geographical detector, combined with socio-economic statistical data, this study analyzes the land use structure, dynamic degree, utilization degree, and land type transitions in the Gansu farming-pastoral ecotone from 2000 to 2020, and explores the driving factors of land use change in different periods. The results show that: (1) From 2000 to 2020, the Gansu farming-pastoral ecotone was dominated by cultivated land, forest land, and grassland, with the three accounting for more than 95% of the total area. The land use structure difference index was less than 0.01, indicating that the overall structure tended to be stable. The overall land use dynamic degree in the entire region showed a trend of first increasing and then slowing down; (2) The conversion among cultivated land, forest land, and grassland accounted for more than 96% of the total changed area in the study region, with active transitions among various land types. LUCC was relatively concentrated in the Loess Hilly Region of Central Gansu and the Gully Region of the Loess Plateau in Eastern Gansu; (3) Under the scenario of long-term land use change, the geographical detector demonstrates good applicability. The driving factors of land use change in the Gansu farming-pastoral ecotone vary across different periods. The changes are driven by the combined effects of socio-economic factors and natural geographical factors (with the former having stronger explanatory power for land use change). The interactions among various factors all exhibit two-factor enhancement or nonlinear enhancement effects, with two-factor interactions showing stronger explanatory power for land use change than single factors.

## Full Text

### Abstract

This study analyzed the land use structure, dynamics, intensity, and conversion patterns in the agro-pastoral transitional zone of Gansu Province from 2000 to 2020 using remote sensing (RS), geographic information systems (GIS), and Geodetector, combined with socioeconomic statistical data. The results indicate that: (1) From 2000 to 2020, cultivated land, forest land, and grassland were the dominant land use types in the study area, collectively accounting for over 95% of the total area. The structural difference index remained below 0.01, indicating overall stability in land use structure. The comprehensive land use dynamic degree initially increased before gradually slowing down. (2) Conversions among cultivated land, forest land, and grassland represented over 96% of the total conversion area in the region, with active mutual transformation among all land use types. Converted cultivated land was primarily transformed into forest and grassland, while other land types were converted to construction land. Land use changes were predominantly concentrated in the Loess Hills of Central Gansu and the Loess Plateau Gully Region of Eastern Gansu. (3) Geodetector demonstrated strong applicability for analyzing long-term land use change scenarios. The driving factors of land use change in Gansu's agro-pastoral transitional zone varied across different periods, with changes driven by the combined effects of socioeconomic and natural geographic factors. Socioeconomic factors exhibited stronger explanatory power for land use change than natural factors. All factor interactions demonstrated either two-factor enhancement or nonlinear enhancement effects, with two-factor interactions providing stronger explanatory power than single factors alone.

**Keywords:** agro-pastoral transitional zone; Geodetector; land use; spatio-temporal evolution; driving force; Gansu Province

### Introduction

Land is the most critical and non-renewable resource required for economic development and ecological cycles, serving as the foundation for all social activities. As economic globalization deepens and China's economy maintains long-term positive growth, the strategic importance of ecological civilization construction has become increasingly prominent, imposing more explicit requirements on land development, utilization, protection, and remediation. In 2017, the State Council issued the "National Land Planning Outline (2016-2030)," which aims to "comprehensively promote national land development, protection, and remediation, and accelerate the construction of a secure, harmonious, open, coordinated, competitive, and sustainable beautiful homeland."

The agro-pastoral transitional zone of Gansu Province holds a special ecological status, abundant natural resources, and significant development potential, playing a crucial role in maintaining national ecological security and improving local

livelihoods. As an important component of the northwestern ecological barrier, this region faces severe challenges including fragile ecological environments, mismatched water and soil resources, and prominent human-land conflicts due to natural conditions and human activities.

Research on the driving mechanisms of land use/cover change (LUCC) aims to reveal the causes, mechanisms, and future development directions of land use changes, attracting considerable attention from scholars worldwide. With advancements in remote sensing and geographic information systems, multi-source, high-precision data have provided greater technical support for land use change research. Geospatial information spectrum analysis also offers robust support for integrated studies on spatio-temporal evolution of land use changes across multiple temporal and spatial scales.

Scholars have conducted extensive research on LUCC and driving force analysis using various methods including multi-regional input-output models, cellular automata models, and support vector machines to explore driving mechanisms. Geodetector, developed by Wang Jinfeng et al., offers unique advantages as it can not only detect the driving mechanisms of impact factors on regional spatial patterns but also reflect the similarity of geographic phenomena within the same region and differences between different regions. Due to its immunity to multicollinearity among independent variables, Geodetector has been widely applied in natural and social sciences.

Some scholars have studied the agro-pastoral transitional zone of Gansu from perspectives such as ecosystem service value assessment and production potential, but research on land use change analysis and driving factors of various land types remains scarce. Located in the transitional zone between agricultural cultivation and pastoral grazing areas, Gansu's agro-pastoral transitional zone experiences frequent land use type changes due to natural conditions and human activities. Clarifying the spatio-temporal evolution and driving factors is crucial for ecosystem structure adjustment in the region.

Therefore, this study selected land use spatial data at 5-year intervals from 2000 to 2020, reclassifying it into six categories: cultivated land, forest land, grassland, water bodies, construction land, and unused land. Using Landsat imagery and socioeconomic statistical data, we analyzed county-level land use structure and change trends in Gansu's agro-pastoral transitional zone from 2000 to 2020. We selected 11 driving factors from natural geography and socioeconomic aspects to explore their influence on land use changes, aiming to provide scientific understanding and decision-making support for orderly land use structure regulation and sustainable development in the region.

### 1.1 Study Area Overview

The study area is the agro-pastoral transitional zone of Gansu Province (Figure 1), demarcated following Chen Quangong's designation. Located in the convergence zone of the Loess Plateau, Tibetan Plateau, and Inner Mongolia Plateau

in central and southern Gansu (34°00' ~37°27' N, 102°46' ~108°02' E), this region represents a core area of China's northern agro-pastoral transitional zone. The area features a dry climate with strong continental temperate monsoon characteristics, an average annual temperature of 10.4°C, and precipitation concentrated between June and September. Elevation decreases from west to east, ranging from 1002 to 4866 m. The total area of Gansu's agro-pastoral transitional zone is approximately  $9.93 \times 10^4$  km<sup>2</sup>, with terrain dominated by plateaus and mountains and complex geomorphology. The region encompasses 27 counties (districts) within Gansu Province.

## 1.2 Data Sources and Processing

The data used in this study primarily included Landsat remote sensing imagery, digital elevation models, annual precipitation data, road network data, and socioeconomic data for the agro-pastoral transitional zone of Gansu. Land use remote sensing monitoring datasets and administrative vector boundary data were obtained from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences. Digital elevation data (ASTER GDEM 30 m) were acquired from the Geospatial Data Cloud platform, from which elevation, slope, and aspect data were extracted.

Climate data (monthly precipitation data from 2000 to 2020) were sourced from the National Tibetan Plateau Scientific Data Center. After data extraction, annual precipitation was calculated at 1 km spatial resolution. Road construction data were obtained from Harvard University's Dataverse, with railway, highway, national road, and provincial road datasets selected for calculating road network density. Socioeconomic data were collected from the "China County Statistical Yearbook" and "Gansu Development Yearbook" for 2001-2021. All socioeconomic factors were rasterized, and change values during the study period were calculated using raster calculator tools.

### 1.3.1 Land Use Dynamics and Structural Differences

Land use change is primarily manifested in land use type changes, quantity changes, and resource-ecological background quality changes. Land use dynamic degree can characterize quantitative changes, including single land use dynamic degree (Ds) and comprehensive land use dynamic degree (Dc).

The formulas are given as:

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

$$D_c = \frac{\sum_{i=1}^n \sum_{j=1}^n |U_{ij}|}{2 \sum_{i=1}^n U_i} \times \frac{1}{T} \times 100\%$$

where  $U_a$  and  $U_b$  represent the initial and final quantities of a particular land use type,  $U_i$  is the quantity of land use type  $i$ ,  $U_{ij}$  is the absolute area converted from type  $i$  to type  $j$  ( $i \neq j$ ), and  $T$  is the study period length.

To quantitatively analyze spatio-temporal differentiation of land use, we employed the structural difference coefficient  $C_t$ , which measures differences between two time points based on Euclidean distance:

$$C_t = \sum_{i=1}^n |P_{bi} - P_{ai}|$$

where  $i$  represents land use type,  $t$  represents different research periods, and  $P_{ai}$  and  $P_{bi}$  represent the proportion of land use type  $i$  at the beginning and end of the study period, respectively. Following literature references,  $C_t$  is classified as minor difference ( $C_t \leq 0.25$ ), general difference ( $0.25 < C_t \leq 0.50$ ), and significant difference ( $C_t > 0.50$ ).

### 1.3.2 Land Use Degree Index

Based on the degree of human disturbance to land in its natural state, land use degree levels are classified. Considering the characteristics of the study area and previous research, this study divided land use types into four levels: unused land as level 1, forest land, grassland, and water bodies as level 2, cultivated land as level 3, and construction land as level 4. The land use degree index describes evolution trends among different level land types, with higher values indicating development toward land types with greater human interference.

The land use degree index is calculated as:

$$I = 100 \times \sum_{i=1}^n (A_i \times R_i)$$

where  $I$  is the land use degree index,  $A_i$  is the grade value of land use type  $i$ ,  $R_i$  is the proportion of land use type  $i$  area to total area, and  $n$  is the number of land use types.

### 1.3.3 Geodetector

Geodetector is a statistical method developed by Wang Jinfeng et al. for detecting spatial stratified heterogeneity and its underlying driving forces. Due to fewer constraints when processing mixed-type data, it has been widely applied in natural sciences and socioeconomic impact factor studies. The model consists of four components: factor detection, interaction detection, risk zone detection, and ecological detection. This study primarily applied factor detection, interaction detection, and ecological detection.

**Factor Detection:** This component detects the spatial differentiation of geographic factor  $y$  and whether factor  $x$  is a driving force behind this differentiation, measuring the explanatory power  $q$ :

$$q = 1 - \frac{\sum_{h=1}^L N_h \sigma_h^2}{N \sigma^2} = 1 - \frac{SSW}{SST}$$

where  $h = 1, \dots, L$  represents strata (classes, zones) of dependent variable  $y$  or factor  $x$ ;  $N_h$  and  $N$  are the numbers of units in stratum  $h$  and the entire region, respectively;  $\sigma_h^2$  and  $\sigma^2$  are variances of  $y$  values in stratum  $h$  and the entire region, respectively;  $SSW$  and  $SST$  are the within-stratum sum of squares and total sum of squares, respectively. The  $q$  value ranges from  $[0,1]$ , with larger values indicating stronger explanatory power of the driving factor on geographic phenomena.

**Interaction Detection:** This identifies interactions among different factors  $x_i$ , assessing whether the combined effect of factors  $x$  on dependent variable  $y$  is stronger or weaker than independent effects, and whether they are mutually independent. Interaction criteria are shown in Table 1.

**Ecological Detection:** This compares whether the impacts of two factors  $x$  on the spatial distribution of attribute  $y$  have significant differences.

### 1.3.4 Driver Factor Selection and Discretization

The spatial pattern and evolution of land use result from the combined effects of natural geographic location and socioeconomic policies. The natural factors in Gansu's agro-pastoral transitional zone exhibit significant regional differentiation, and urbanization development shows non-equilibrium differences. Based on existing empirical analyses and data availability, this study selected 11 influencing factors from natural geography and socioeconomic elements.

Using ArcGIS 10.8, we created a 10 km  $\times$  10 km regular fishnet grid, applied the fastest interpolation method—nearest neighbor assignment—to resample each grid center point, generating 1,023 valid sampling points. Geodetector requires numerical variables to be discretized into categorical variables, so we used the natural breaks method to classify socioeconomic and natural geographic factors into 5-7 categories.

### 2.1.1 Land Use Structure Changes

During the study period, the land use structure in Gansu's agro-pastoral transitional zone (Figure 2) was dominated by cultivated land, forest land, and grassland, with the three categories accounting for over 95% of the total area. The structural difference coefficients for the four periods were 0.006, 0.009, 0.007, and 0.008, respectively, all representing minor differences and indicating that the land use structure remained generally stable.

From the perspective of land use dynamic changes (Figure 3), the comprehensive land use dynamic degree ( $D_c$ ) for the entire region showed an overall trend of initial increase followed by deceleration, with values of 0.15%, 0.28%, 0.11%, and 0.34% for the four periods. The change characteristics varied across periods, primarily manifested as cultivated land reduction and increases in other land types.

Grassland was the largest and most widely distributed land use type, accounting for over 55% of the area and showing fluctuating growth trends. This land type remained relatively stable with minimal overall impact. Cultivated land ranked second in area but showed consecutive annual reductions, decreasing from 25.12% to 23.54%, primarily due to reduced agricultural labor and implementation of the Grain for Green policy. Forest land area fluctuated and increased from 15.75% to 16.30% and then decreased to 16.34%. Construction land showed the most significant growth, increasing from 0.76% to 2.06%, with the fastest change rate of 1.52% during 2010-2015, reflecting effective urbanization construction driven by population growth and economic development.

### 2.1.2 Land Use Type Changes

The land use transfer Sankey diagram (Figure 4) illustrates the sources and destinations of land use changes. The increases and decreases in cultivated land, forest land, and grassland constituted the main types of land change, with frequent mutual conversions among all land types. The primary change type ratios are shown in Table 3.

During 2000-2005, land use type changes were relatively limited in frequency and quantity. Cultivated land had the largest transfer-out area, with 70.58% converted to grassland and 15.75% to construction land. Grassland had the largest transfer-in area, with 85.12% converted from cultivated land. Construction land transfer-out primarily involved cultivated land and grassland, accounting for 79.29% and 15.75%, respectively.

During 2005-2010, land use type changes became more frequent and numerous. Cultivated land transferred out 1283.20 km<sup>2</sup>, with 58.42% converted to grassland and 20.16% to construction land. Grassland transfer-out area was 115.86 km<sup>2</sup>, with 57.89% converted to cultivated land and 25.61% to forest land. Grassland had the largest transfer-in area, with 78.60% converted from cultivated land. Construction land transfer-out area was 58.39 km<sup>2</sup>, with 77.26% converted to cultivated land, while transfer-in area was 100.20 km<sup>2</sup>, with 84.48% converted from cultivated land and 78.80% from grassland.

During 2010-2015, land use type changes slightly decreased in frequency and quantity, with cultivated land and grassland conversion being particularly significant. The “cultivated land → grassland” change (code 3-2, ratio 0.55%) was most prominent, primarily occurring in Min County (79.40 km<sup>2</sup>) and Zhang County (38.74 km<sup>2</sup>) in the Loess Hills of Central Gansu, with another 97.73 km<sup>2</sup> occurring in Huan County (62.24%) and Huachi County (23.96%) in the

Loess Plateau Gully Region. The “grassland → cultivated land” change (code 2-3, ratio 0.64%) was more spatially dispersed, with 55.46% occurring in Min County and 27.34% in Zhang County.

During 2015-2020, land use type changes slightly decreased in quantity and became more fragmented spatially. The main change types remained similar to the previous period, dominated by “cultivated land → grassland” (code 3-2, ratio 0.29%) and “grassland → cultivated land” (code 2-3, ratio 0.24%). Cultivated land converted to grassland mainly in Huan County (51.69 km<sup>2</sup>), Jingyuan County (24.37 km<sup>2</sup>), and Huachi County (23.16 km<sup>2</sup>), while grassland converted to cultivated land primarily in Huan County (44.54 km<sup>2</sup>) and Huachi County (21.05 km<sup>2</sup>).

### 2.1.3 Land Use Spatial Changes

Based on similarities and consistency in geographic location, climate, and terrain characteristics, and considering administrative integrity and previous research, Gansu’s agro-pastoral transitional zone was divided into four subregions: the Loess Plateau Gully Region of Eastern Gansu, the Loess Hills of Central Gansu, the Tibetan Plateau-Loess Plateau Transition Zone, and the Eastern Tibetan Plateau Alpine Region. Image interpretation results showed that cultivated land and grassland were widely distributed, forest land was mainly distributed in the northwest corner and southern areas, water bodies were scattered, construction land was concentrated in strip patterns in the central-northern region, and unused land was distributed along the northern edge and southern areas.

During 2000-2005, land use changes were limited and spatially dispersed. The most significant change was “cultivated land → grassland” (code 3-2, ratio 0.76%), concentrated in Min County (115.86 km<sup>2</sup>) and Zhang County (73.29 km<sup>2</sup>) of the Loess Hills of Central Gansu.

During 2005-2010, land use changes increased slightly, with cultivated land and grassland conversion being particularly significant. The “cultivated land → grassland” change (code 3-2, ratio 0.55%) remained prominent, primarily occurring in Min County (79.40 km<sup>2</sup>) and Zhang County (38.74 km<sup>2</sup>) of the Loess Hills of Central Gansu, with another 97.73 km<sup>2</sup> in Huan County and Huachi County of the Loess Plateau Gully Region. The “grassland → cultivated land” change (code 2-3, ratio 0.64%) was more spatially dispersed.

During 2010-2015, land use changes slightly decreased and became more fragmented. The main change types were “cultivated land → grassland” (code 3-2, ratio 0.29%) and “grassland → forest land” (code 2-1, ratio 0.24%). Grassland converted to forest land was concentrated in Huan County (51.69 km<sup>2</sup>) and Huachi County (21.05 km<sup>2</sup>) of the Loess Plateau Gully Region.

During 2015-2020, land use changes surged. The “cultivated land → grassland” change (code 3-2, ratio 0.70%) was most significant, with cultivated land conversion to grassland primarily occurring in Huan County (108.49 km<sup>2</sup>), Hui Ning

County (72.93 km<sup>2</sup>), and Yongjing County (57.29 km<sup>2</sup>). The “grassland → cultivated land” change (code 2-3, ratio 0.50%) was also notable, with grassland conversion to cultivated land mainly in Hui Ning County (41.09 km<sup>2</sup>), Yongdeng County (46.29 km<sup>2</sup>), and Jingtai County (53.51 km<sup>2</sup>).

From 2000 to 2020, the population in Gansu’s agro-pastoral transitional zone increased from  $9.71 \times 10^6$  to  $10.55 \times 10^6$ , *urbanization rate rose from  $27.67 \times 10^6$*  to  $4.55 \times 10^6$  tons, and regional GDP grew from  $1.98 \times 10^{10}$  to  $3.68 \times 10^{10}$  yuan. Population growth, urbanization, and rapid economic development were the primary drivers for conversion of other land types to construction land.

## 2.2 Land Use Degree Analysis

The land use degree index in Gansu’s agro-pastoral transitional zone showed a trend of initial decline followed by increase during 2000-2020. Specifically, the index decreased by 0.34 from 2000-2005, indicating evolution toward land types with lower human disturbance, closely related to local ecological restoration initiatives such as Grain for Green. From 2005-2010, the index increased by 0.52, indicating evolution toward land types with higher human disturbance, primarily due to rapid urbanization and construction land expansion.

Taking 2020 as an example (Figure 6), land use degree in Gansu’s agro-pastoral transitional zone gradually decreased from centers in Lanzhou City and Linxia City toward the periphery. The highest index value occurred in Anning District (289.52), while the lowest was in Luqu County (215.78).

### 2.3.1 Single-Factor Detection Analysis

Based on formula (3), the explanatory power  $q$  of each factor on the comprehensive land use dynamic degree ( $D_c$ ) in Gansu’s agro-pastoral transitional zone was calculated (Table 5). At the 95% confidence level, slope aspect ( $x_2$ ) and population density ( $x_7$ ) showed no significant effect on land use dynamic degree during the study period ( $P > 0.05$ ), while other factors passed the significance test.

Overall, socioeconomic factors were the dominant drivers of land use change in the region. Fixed asset investment ranked first among influencing factors in the first three periods, with its explanatory power reaching 36.3% during 2000-2005. Regional GDP’s explanatory power surged to first place in the last period, indicating that land use change primarily depended on economic development. Road network density ranked third in influence during the first three periods, demonstrating that road construction’s impact on land use change cannot be ignored, as accelerated urbanization drives continuous construction land expansion. The influence of population density and urban population proportion gradually weakened, suggesting demographic factors had relatively minor impacts. Among natural geographic factors, elevation and precipitation were

also important drivers, showing clear spatial differentiation (Figure 7). Slope' s driving effect was weak, with explanatory power consistently below 10%.

### 2.3.2 Interaction Detection Analysis

The interaction detection results for driving factors of comprehensive land use dynamic degree in Gansu' s agro-pastoral transitional zone are shown in Figure 8. For all four periods, the interactive effects of factors on land use change were stronger than single-factor effects, showing either nonlinear enhancement or two-factor enhancement. This indicates that land use change in the study area resulted from multi-factor collaboration.

During 2000-2005, the interaction between urban population proportion ( $x_8$ ) and road network density ( $x_9$ ) had the largest interactive explanatory power of 42.7%. The interaction between urban population proportion and fixed asset investment ( $x_{10}$ ) ranked second at 40.1%, indicating that land use change during this period was jointly driven by population structure, economic investment, and road construction factors.

During 2005-2010, the interactive explanatory power between urban population proportion ( $x_8$ ) and fixed asset investment ( $x_{10}$ ) and regional GDP ( $x_{11}$ ) reached 45.8% and 44.6%, respectively, with strong explanatory power. This suggests that socioeconomic factors remained the primary drivers of land use change during this period, except for the population density factor.

During 2010-2015, economic development became an important factor driving land use change. The interaction between regional GDP ( $x_{11}$ ) and fixed asset investment ( $x_{10}$ ) had the largest interactive explanatory power of 48.3%. Additionally, climate condition interactions strengthened compared to previous periods, with interactions between precipitation ( $x_4$ ) and fixed asset investment, regional GDP, and urban population proportion reaching 41.6%, 40.8%, and 39.7%, respectively.

During 2015-2020, with accelerated modern urbanization, interactions between urban population proportion ( $x_8$ ) and other factors became more significant, primarily showing nonlinear enhancement effects. The interactions with fixed asset investment ( $x_{10}$ ), regional GDP ( $x_{11}$ ), and road network density ( $x_9$ ) reached  $q$  values of 49.2%, 48.7%, and 46.8%, respectively. This indicates that population structure, economic development level, and road construction jointly became the strongest factors driving land use change.

Overall, the two-factor interactive effects driving land use change in Gansu' s agro-pastoral transitional zone varied across periods, but interactions involving urban population proportion, fixed asset investment, and other factors consistently showed strong explanatory power. Synergistic effects among factors were stronger than single-factor effects. Interactions between population distribution and climate conditions also strengthened over time. While single-factor driving effects were relatively balanced without dominant factors, two-factor

interaction results showed that land use change during the study period was influenced by interactive factors including economic development, population distribution, road construction, and climate conditions. Socioeconomic factor interactions were stronger than natural geographic factors, but their combined influence increased substantially.

### 2.3.3 Ecological Detection Analysis

The ecological detection results for land use change driving factors in Gansu' s agro-pastoral transitional zone are shown in Figure 8. At the 95% confidence level, elevation and slope, slope and aspect, precipitation and urban population proportion, fixed asset investment and road network density showed no significant differences in their impacts on the spatial distribution of comprehensive land use dynamic degree across all four periods (test value = 0), indicating these factors had similar driving mechanisms and spatial distribution patterns that did not change significantly over time.

At the 95% confidence level, slope and aspect with precipitation, urban population proportion, regional GDP, fixed asset investment, and road network density showed significant differences across all four periods (test value = 1), indicating these factors were significantly affected by temporal changes and had distinct impacts on land use change spatial patterns. Taking mean annual precipitation as an example, the difference between maximum (1118.77 mm in Xiahe County in 2005) and minimum (883.06 mm in Huachi County in 2020) values showed spatial pattern differences over time, specifically declining from southwest to northeast. At the county scale, the precipitation difference was largest in Xiahe County (2101.00 mm in 2000) and smallest in Luqu County (1084.87 mm in 2020).

From 2000 to 2020, the region' s population increased by 8.4%, fixed asset investment net increased by  $9.71 \times 10^{11}$  yuan, road network density increased 1.06 times, and regional GDP grew 3.77 times. Economic development, urbanization, and road construction drove continuous construction land expansion, while rural population decline and labor shortages led to cultivated land abandonment and grassland degradation in mountainous and alpine regions. The development model centered on Lanzhou City and Linxia City attracted substantial population and shifted from the initial stage, with the proportion of secondary and tertiary industry value-added to regional GDP increasing from 87.09% to 91.72%.

## 3 Discussion

This study analyzed spatio-temporal characteristics of land use changes in Gansu' s agro-pastoral transitional zone from 2000 to 2020 through land use structure, dynamic degree, degree index, and land type transfer. In terms of land use structure, cultivated land decreased by 1566.44 km<sup>2</sup>, while forest land, grassland, water bodies, construction land, and unused land increased by

544.55 km<sup>2</sup>, 85.86 km<sup>2</sup>, 58.39 km<sup>2</sup>, 797.73 km<sup>2</sup>, and 79.91 km<sup>2</sup>, respectively. Regarding land use dynamic degree, cultivated land's dynamic degree remained negative, while water bodies and construction land maintained positive values, with construction land peaking in 2010-2015. Forest land's dynamic degree was positive in 2005-2010 and negative in other periods, while grassland's dynamic degree was negative in 2000-2005 and positive in other periods.

Land use degree showed an overall trend of initial decline followed by increase, with land types gradually evolving toward those with higher human interference, decreasing from centers in Anning District and Linxia City toward the periphery. Regarding land type transfer, cultivated land, forest land, and grassland transfers were the main change types, with construction land primarily converted from forest land and cultivated land. Land type transfers were particularly frequent in the Loess Hills of Central Gansu and the Loess Plateau Gully Region of Eastern Gansu.

During 2000-2020, the ecosystem service function and water retention capacity of Gansu's agro-pastoral transitional zone enhanced. Cultivated land reduction indicates increasingly prominent human-land relationship issues, while construction land increase demonstrates significant urbanization progress and scale expansion. This study employed Geodetector's factor detection, interaction detection, and ecological detection to analyze driving factors from natural geography and socioeconomic perspectives. The detection results indicate that land use change in the study area resulted from multi-factor collaboration, with two-factor effects stronger than single-factor effects and anthropogenic factors showing stronger driving forces, consistent with previous research findings.

This primarily stems from the complex natural environment, special human-land relationships, and geographic location constraints on regional economic development in Gansu's agro-pastoral transitional zone. The characteristics of vast land with sparse population in the southern region determined that population density, economic development, and road network density had relatively weak impacts on land use change.

Since 2000, Gansu Province has implemented ecological projects such as Grain for Green and slope-to-terrace conversion to improve regional ecological environments and soil erosion, causing significant land use structure changes. As an important grain production area and livestock origin in China, Gansu's agro-pastoral transitional zone has enhanced regional productivity and competitiveness through modern agricultural and pastoral cluster development under the rural revitalization strategy, driving land use structure changes while strengthening endogenous development capacity.

This study analyzed land use changes in Gansu's agro-pastoral transitional zone and examined driving factors affecting spatio-temporal differentiation of land use change degree based on Geodetector. Geodetector enabled quantitative analysis of each driving factor's influence mechanism and provided insights into driving forces under two-factor interactions, addressing limitations of con-

ventional methods in analyzing factor interaction mechanisms and differences. However, due to data collection limitations, this study lacked consideration of policy implementation and grazing factors when selecting factors, which should be improved in future research. Additionally, the discretization process used direct county-level assignment for some factors, which may affect analysis precision to some extent. These issues require further resolution, and future research should also explore optimal land use allocation in the study area.

## 4 Conclusions

Based on multi-source data including remote sensing monitoring and socioeconomic statistics, this study analyzed spatio-temporal change characteristics and driving mechanisms of land use in Gansu's agro-pastoral transitional zone from 2000 to 2020 using land use dynamic degree, geospatial information spectrum, and Geodetector models. The main conclusions are:

- 1) From 2000 to 2020, cultivated land, forest land, and grassland were the dominant land use types in Gansu's agro-pastoral transitional zone. The structural difference degree was minor, indicating generally stable land use structure. The comprehensive land use dynamic degree showed an overall trend of initial increase followed by deceleration. Land change characteristics were primarily manifested as increases in forest land, grassland, water bodies, construction land, and unused land, along with cultivated land reduction.
- 2) During the study period, the increase and decrease of cultivated land, forest land, and grassland were the main land change types in the region, with frequent mutual conversions among all land types. Converted cultivated land was primarily transformed to forest land and grassland, while other land types were converted to construction land. Therefore, improving the utilization efficiency of existing construction land, strengthening ecological civilization construction, and promoting integrated development of cultivation, breeding, and marketing chains are recommended. Land use type changes were mainly concentrated in the Loess Hills of Central Gansu and the Loess Plateau Gully Region of Eastern Gansu.
- 3) Geodetector demonstrated good applicability in long-term (2000-2020) land use change scenarios. Driving factors for land use change in Gansu's agro-pastoral transitional zone varied across periods. Fixed asset investment remained the primary driving factor throughout, while regional GDP's influence strengthened in later periods. Elevation, precipitation, and road network density were also important driving forces. Interaction detection results showed that land use change was driven by the combined effects of socioeconomic and natural geographic factors, with socioeconomic factors generally showing stronger explanatory power. All factor interactions exhibited two-factor enhancement or nonlinear enhancement effects, with two-factor interactions providing stronger explanatory power

than single factors. Ecological detection results showed that at the 95% confidence level, five factor pairs (slope and aspect with precipitation, urban population proportion, regional GDP, fixed asset investment, and road network density) consistently showed significant differences in their impacts on the spatial distribution of comprehensive land use dynamic degree across all four periods.

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

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