

Spatiotemporal Variation of Cultivated Land Resources and Its Influencing Factors in Gansu Province over the Past 25 Years: Postprint

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Date: 2022-06-02T00:00:00+00:00

Abstract

Investigating the spatiotemporal dynamics of cultivated land resources and their driving factors holds significant practical importance for enhancing regional food security, strictly adhering to the red line of cultivated land protection, and formulating cultivated land conservation policies and measures. Based on four-phase land use datasets for Gansu Province from 1995, 2005, 2015, and 2020, and with the support of technologies such as ArcGIS and Geo Da, this study comprehensively analyzed the spatiotemporal variation characteristics of cultivated land in Gansu Province over the past 25 years at raster, grid, and county scales, and employed the geographical detector method to identify the primary driving factors underlying cultivated land changes. The results indicate: (1) From 1995 to 2020, cultivated land in Gansu Province decreased by 1.6%, with an increase from 1995-2005 followed by a decline from 2005-2020. Cultivated land primarily transitioned to grassland, forestland, and construction land, while unused land mainly converted to cultivated land and grassland. (2) The spatial distribution of cultivated land demonstrates a typical pattern of “more in the southeast, less in the northwest.” This distribution is jointly influenced by natural and socioeconomic factors, wherein the interaction between population and land development intensity constituted the primary cause of spatial distribution disparities in Gansu Province in 1995, 2005, and 2015, whereas the interaction between temperature and precipitation emerged as the dominant factor influencing cultivated land in 2020. The findings can provide a scientific basis for cultivated land protection and management in Gansu Province.

Full Text

Spatio-temporal Changes and Influencing Factors of Cultivated Land Resources in Gansu Province in the Past 25 Years

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Abstract

Studying the spatio-temporal changes and driving factors of cultivated land resources is of great practical significance for improving regional food security, strictly adhering to cultivated land protection red lines, and formulating cultivated land protection policies and measures. Based on land use data from Gansu Province for four time points (1995, 2005, 2015, and 2020), this study comprehensively analyzed the spatio-temporal evolution characteristics of cultivated land in Gansu over the past 25 years at grid, reseau, and county scales using ArcGIS and GeoDa. Geographic detectors were employed to identify the main driving factors behind cultivated land changes. The results show that: (1) From 1995 to 2020, cultivated land area decreased by 1.6%, with an increase from 1995 to 2005 followed by a decrease from 2005 to 2020. Cultivated land primarily converted to grassland, forest, and construction land, while unused land mainly converted to cultivated land and grassland. (2) The spatial distribution of cultivated land exhibited typical characteristics of “more in the southeast and less in the northwest.” (3) The spatial distribution of cultivated land was influenced by the combined effects of natural and socio-economic factors. The interaction between population and land development intensity was the main reason for the spatial distribution differences of cultivated land in Gansu during 1995, 2005, and 2015, while the interaction between temperature and precipitation became the dominant factor affecting cultivated land in 2020. These findings can provide a scientific basis for the protection and management of cultivated land resources in Gansu Province.

Keywords: land use; cultivated land; spatio-temporal evolution; driving factors; Gansu Province

Introduction

Cultivated land is a crucial material resource for human survival and development, bearing the heavy responsibility of providing food for humanity and relating to national food security and high-quality economic development. With the acceleration of socio-economic development and urbanization in China, the contradiction between limited cultivated land resources and the expansion of urban construction land and ecological land has become increasingly prominent, leading to frequent problems such as reduced quantity, degraded quality, fragmented space, and ecological environmental issues in cultivated land. The continuous reduction of reserve cultivated land resources has further increased the pressure on rational utilization, protection, and balance of cultivated land occupation and compensation. Additionally, the COVID-19 pandemic has severely impacted global food supply chains, posing serious hidden dangers to food security worldwide. Therefore, exploring the spatio-temporal evolution characteristics of cultivated land and clarifying its driving factors are of important guiding significance for regional sustainable utilization of cultivated land, food security protection, and optimization of territorial spatial layout.

Given the close relationship between cultivated land changes and regional environmental changes and socio-economic development, research on the spatio-temporal change characteristics and driving factors of cultivated land has always been a hot topic among scholars both domestically and internationally. Previous studies have analyzed the spatio-temporal change characteristics of cultivated land resources at global and local scales using methods such as multiple cropping index, standard deviation of area change, standard deviational ellipse, and exploratory spatial data analysis. In terms of driving mechanisms, researchers have employed spatial econometric models and artificial neural networks to explore the driving forces of cultivated land use changes, finding that cultivated land changes result from the combined effects of natural and socio-economic factors. Population and industrial transformation play decisive roles in cultivated land changes in the Huang-Huai-Hai Plain, while socio-economic factors dominate cultivated land loss in eastern coastal areas. Geographical detectors have been widely applied in driving factor detection due to their advantages of being user-friendly, requiring few assumptions for categorical variables, and establishing more reliable relationships between dependent and independent variables than classical regression. Studies using geographical detectors in karst mountainous areas and Central Asian countries have found that socio-economic factors exert greater influence than natural factors.

However, current quantitative research on the combined effects of natural and socio-economic factors remains insufficient, with most studies focusing on central and eastern China, while research on spatio-temporal evolution analysis and driving factors of cultivated land in northwestern regions is scarce. As a typical mountainous plateau region in northwestern China, Gansu Province features complex terrain, poor cultivated land conditions, diverse soil types, relatively insufficient per capita cultivated land, and scarce reserve resources for

development and utilization, with the contradiction between large population and limited land becoming increasingly prominent. Therefore, in-depth analysis of cultivated land resources and their influencing factors in Gansu is of great significance for better protecting cultivated land resources and strengthening land management. Previous studies on cultivated land changes in Gansu have focused on either specific local areas or certain time periods, leaving the spatio-temporal change characteristics of the entire province in recent years unclear and lacking quantitative detection of driving factors over long time series. This study employs dynamic raster data and uses ArcGIS and other technologies to comprehensively analyze the spatio-temporal change characteristics of cultivated land in Gansu over the past 25 years from grid, county, and county scales using land use transfer matrix, kernel density analysis, cultivated land change dynamic degree, and spatial distribution correlation analysis. Geographic detectors are used to identify the main driving factors of cultivated land changes, aiming to provide references for rational planning and utilization of cultivated land resources in Gansu.

1.1 Study Area Overview

Gansu Province is located in northwestern China between $32^{\circ}11' \sim 42^{\circ}57' N$ and $92^{\circ}13' \sim 108^{\circ}46' E$, with a long and narrow terrain stretching 1,659 km from east to west and 530 km from north to south. Situated at the intersection of the Loess Plateau, Qinghai-Tibet Plateau, and Inner Mongolia Plateau, it borders Ningxia, Shaanxi, Sichuan, Qinghai, Xinjiang, and Inner Mongolia, with its northwestern end bordering Mongolia. The terrain slopes from southwest to northeast, with elevations ranging from 565 to 5,789 m. The complex terrain features crisscrossing mountains, creating a typical mountainous plateau landscape. Gansu has a complex climate system with an average annual temperature of $0\text{--}15^{\circ}C$. Most areas are dry, with arid and semi-arid zones accounting for 73.11% of the total area. Annual precipitation ranges from 36.6 to 734.9 mm, generally decreasing from southeast to northwest, resulting in a fragile ecological environment. The province has a forest area of $5.38 \times 10^4 \text{ km}^2$, with a forest coverage rate of 11.33%. The total land area is $42.58 \times 10^4 \text{ km}^2$, and the permanent population is 25.0198 million.

[Figure 1: see original paper]

1.2 Data Sources and Preprocessing

Land use data and administrative division data were obtained from the Resources and Environmental Science Data Center of the Chinese Academy of Sciences (<http://www.resdc.cn>). Based on existing land classification standards and research needs, land use types were reclassified into six categories: cultivated land, forest, grassland, water, construction land, and unused land, with a spatial resolution of $1 \text{ km} \times 1 \text{ km}$. The average classification accuracy for cultivated land and construction land reached 85%, while other land use types

achieved an average accuracy of over 75%, meeting research requirements. Precipitation and temperature data were sourced from the National Earth System Science Data Center (<http://www.geodata.cn>). DEM data were obtained from the Geospatial Data Cloud (<http://www.gscloud.cn>), with a spatial resolution of $1 \text{ km} \times 1 \text{ km}$. Socio-economic data were collected from the *Gansu Statistical Yearbook*.

1.3 Methods

1.3.1 Land Use Transfer Matrix

The land use transfer matrix describes the transfer between land use types over a period, analyzing the quantity and direction of dynamic changes in regional land use types. The mathematical model is:

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

where S represents land area, n is the number of land use types, i is the initial land use type, and j is the final land use type.

1.3.2 Land Development Intensity

Land development intensity (LDI) refers to the proportion of construction land area to the total regional land area, calculated as:

$$LDI = \frac{C}{S} \times 100\%$$

where S is the total regional land area and C is the construction land area. A higher LDI value indicates greater land development intensity.

1.3.3 Kernel Density Analysis

Kernel density analysis is a non-parametric method for estimating data distribution density functions. It calculates the distance from point or line features to reference locations to establish peaks and create smooth continuous surfaces. Since cultivated land distribution is spatially discrete and cannot intuitively represent its overall spatial continuity, this study uses kernel density analysis to characterize spatial location differences and continuity of cultivated land in the study area.

1.3.4 Cultivated Land Change Dynamic Degree

Cultivated land change dynamic degree characterizes the quantity distribution and change speed of cultivated land in a study area during a certain period, quantitatively evaluating the degree of cultivated land change. The mathematical formula is:

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

where K is the dynamic degree of cultivated land change during the study period, U_a is the initial cultivated land area (km^2), U_b is the final cultivated land area (km^2), and T is the time interval (years). In this study, T is measured in years, so K represents the annual change rate of cultivated land in Gansu.

1.3.5 Spatial Distribution Correlation Analysis

Spatial autocorrelation analysis is a spatial statistical method that tests whether a variable is associated with its neighboring spatial points and reflects the spatial clustering of a variable or geographic phenomenon in a region or adjacent areas. The commonly used correlation indicator is Moran's I index. Using GeoDa software, LISA cluster maps of cultivated land area were created to classify four regional spatial difference types: high-high clustering (both the region and its neighbors have large cultivated land areas with small spatial differences), high-low clustering (the region has large cultivated land area while neighbors have small areas with large spatial differences), low-high clustering (the region has small cultivated land area while neighbors have large areas with large spatial differences), and low-low clustering (both the region and its neighbors have small cultivated land areas with small spatial differences).

1.3.6 Geographical Detector

Factors influencing cultivated land changes are complex and can be divided into natural and socio-economic factors. Geographical detector is a statistical method for exploring spatial differentiation and revealing underlying driving forces, including risk detector, factor detector, ecological detector, and interaction detector. This study mainly uses factor detector and interaction detector to analyze influencing factors of cultivated land spatial distribution and identify the explanatory power of pairwise factor interactions. The influence degree of factors is measured by the q -value:

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

where q represents the influence degree of factors on cultivated land spatial distribution, ranging from $[0,1]$. A larger q value indicates stronger explanatory

power of the factor. SSW and SST represent the sum of within-layer variance and total variance, respectively; N is the total number of units; σ^2 is the variance of Y values in the entire region; L is the stratification of variable Y or influencing factor X ; N_h is the number of units in layer h ; and σ_h^2 is the variance of Y values in layer h .

2.1 Current Cultivated Land Use and Transfer Characteristics

To study land use transfer in Gansu Province from 1995 to 2020, this study spatially overlaid and statistically analyzed land use types at different time nodes using ArcGIS 10.2 Intersect and Excel tools to obtain land use transfer matrices for three periods (Table 1 and Table 2). Overall, Gansu's land use structure was dominated by grassland and cultivated land (excluding unused land), accounting for approximately 39.6% and 15.0% of the total area, respectively. The land use structure changed significantly from 1995 to 2020. Cultivated land area decreased from 65,043.75 km² to 63,983.50 km², a reduction of 1,060.25 km² (1.6%). Unused land area also decreased from 171,689.50 km² to 169,213.25 km², a reduction of 2,476.25 km², mainly converting to cultivated land and grassland. Other land types showed varying degrees of increase, particularly forest and construction land, which increased by 2,114.50 km² (2.15%) and 808.75 km² (61.70%), respectively. Conversion characteristics among land types varied across different time periods.

The 1995–2005 land use transfer matrix (Table 1) shows that unused land experienced the largest area change, followed by forest, cultivated land, and construction land, while water and grassland changed minimally. Cultivated land and forest had annual net increases of 39.25 km² and 61.45 km², respectively, while unused land had an annual net decrease of 108.43 km². The 2005–2020 transfer matrix (Table 2) differs, with construction land showing the largest conversion area, followed by cultivated land, unused land, and grassland. Both cultivated land and unused land decreased, with annual net reductions of 96.85 km² and 119.10 km², respectively. Cultivated land mainly flowed to forest and grassland, while unused land mainly converted to cultivated land and grassland, closely related to policies such as the Grain for Green Program, Western Development, and unused land development. Construction land showed an increasing trend in annual net growth, from 32.80 km² to 119.10 km², reflecting rapid urbanization and economic development.

2.3 Spatial Distribution Correlation Analysis of Cultivated Land

Spatial autocorrelation analysis of cultivated land area in 1995, 2005, 2015, and 2020 using GeoDa showed significant positive correlation, with Moran's I values of 0.52, 0.51, 0.51, and 0.52, respectively, and Z -values all significant at $p = 0.001$. This indicates that the spatial distribution pattern of cultivated land

in Gansu has significant positive spatial autocorrelation, with adjacent regional units sharing similar attribute values.

Local spatial autocorrelation results (Figure 4) show that, except for non-significant areas, low-low clusters of cultivated land were most numerous, followed by high-high clusters, while high-low and low-high clusters were rare. Low-low clusters were mainly distributed in the Hexi region of northwestern Gansu and Gannan Tibetan Autonomous Prefecture, where land use types are primarily unused land and grassland in ecologically fragile and sensitive areas with small cultivated land areas and low density. High-high clusters were mainly distributed in southeastern Gansu, including Dingxi, Tianshui, Pingliang, Qingyang, Linxia Hui Autonomous Prefecture, Longnan, and parts of Baiyin, such as Li County, Xihe County, Cheng County, Huining County, and Jingyuan County. These regions have similar natural conditions to their neighbors and high cultivated land areas.

Kernel density analysis with natural breaks classification shows that areas with higher cultivated land density were concentrated in central and eastern Gansu, including Dingxi, Tianshui, Pingliang, Qingyang, Lanzhou, and parts of Baiyin and Linxia Hui Autonomous Prefecture. Specifically, Tongwei County in Dingxi, Qin' an County, Qingshui County, and Zhangjiachuan Hui Autonomous County in Tianshui, Zhuanglang County and Jingning County in Pingliang had the highest cultivated land density. The total cultivated land area was 65,043.75 km² in 1995, 64,992.75 km² in 2005, 65,436.25 km² in 2015, and 63,983.50 km² in 2020. The spatial distribution consistently showed the typical pattern of "more in the southeast and less in the northwest," with little change in spatial distribution patterns across years (Figure 2 and Figure 3). Differences in natural conditions, economic development levels, and population growth rates created obvious spatial variations in cultivated land distribution.

[Figure 2: see original paper]

[Figure 3: see original paper]

[Figure 4: see original paper]

2.4.1 Dynamic Degree of Cultivated Land Change

Using counties as the minimum unit for spatial analysis of cultivated land change dynamic degree, this study analyzed differences among counties in Gansu. Figure 5 shows that spatial differences in dynamic degree were significant across counties and time periods. From 1995 to 2005, dynamic degrees were high in most counties, particularly in the Hexi region, likely due to flat terrain, abundant resources, leading per capita cultivated land, and intense human activities. From 2005 to 2020, dynamic degrees decreased in most counties, though counties in Jiuquan City showed a pattern of increase then decrease. The dynamic degree shifted from widespread changes to localized changes, then to frequent changes across counties, mainly due to significant adjustments in land use struc-

ture and agricultural structure, along with large-scale development of unused land into cultivated land.

From a temporal perspective, cultivated land decreased more than it increased in all three periods (Figure 7). After 2005, cultivated land decreased more due to the Grain for Green Program, rapid urbanization, and shelterbelt construction. Rural population migration to urban areas also reduced cultivated land area. However, later policy implementations led some labor to return to rural areas, resulting in more cultivated land increase during 2005-2015. In the 2015-2020 period, cultivated land decreased again, though the reduction was smaller than in 2005-2015.

[Figure 5: see original paper]

[Figure 6: see original paper]

2.4.2 Spatial Distribution of Cultivated Land Change Types

To better reveal the spatial increase and decrease of cultivated land, this study used a $10 \text{ km} \times 10 \text{ km}$ grid as the statistical unit to classify changes in each period as increase or decrease types, obtaining spatial distribution patterns (Figure 7). Spatially, the distribution of cultivated land change types was relatively balanced across Gansu, with small differences between periods. Temporally, from 1995 to 2005, 26,505 grids showed increase and 26,068 showed decrease. From 2005 to 2015, decrease dominated, with 30,243 decrease grids and 22,330 increase grids scattered among them. From 2015 to 2020, decrease grids decreased to 28,599, while increase grids rose to 23,974, but the change magnitude was small.

[Figure 7: see original paper]

2.5 Analysis of Driving Factors of Cultivated Land Spatio-temporal Evolution

This study selected three natural driving factors (precipitation, temperature, and slope) and three socio-economic driving factors (population, GDP, and land development intensity), totaling six factors. The study area was divided into 4,260 units using $10 \text{ km} \times 10 \text{ km}$ grids, with each factor classified into five levels. Geographical detector calculations showed the contribution rates of each factor to cultivated land spatial distribution (Table 3). The contribution rate rankings were similar across different periods, with dominant factors showing certain similarities.

From 1995 to 2015, socio-economic factors had greater influence than natural factors. Population (X_2) and land development intensity (X_6) had the greatest impact on cultivated land spatial distribution in Gansu, with their interaction being the main cause of spatial distribution differences. Temperature (X_3) and slope (X_1) had q-statistic values between 0.01-0.14, indicating limited influence

on cultivated land spatial distribution. By 2020, the influence of socio-economic factors weakened while natural factors strengthened. Although population (X_2) and land development intensity (X_6) still had greater contribution rates than precipitation (X_1) and temperature (X_3), their influence decreased significantly. The interaction between temperature and precipitation had the strongest explanatory power for cultivated land spatial distribution. Precipitation's interaction with other factors had greater impact on cultivated land spatial differentiation than temperature and slope interactions, suggesting precipitation may be the main natural factor affecting cultivated land spatial differentiation in Gansu.

To detect interactions between driving factors, pairwise interaction detection was performed (Table 4). In 1995, the maximum interaction values were $X_2 X_6$ (0.53) and $X_1 X_2$ (0.52). In 2005, $X_2 X_6$ had the maximum interaction value (0.54). In 2015, $X_2 X_6$ also had the maximum interaction value (0.53). In 2020, $X_1 X_3$ had the maximum interaction value (0.52), followed by $X_1 X_2$ (0.48). All interactions were either bivariate enhancement or non-linear enhancement, meaning two factors together increased explanatory power for cultivated land spatial distribution. Even the weakest factor (slope) enhanced its influence when interacting with other factors.

Overall, the spatial differentiation of cultivated land in Gansu results from the interaction of multiple factors rather than a single factor. From 1995 to 2015, accelerated population growth and rapid urbanization increased human impacts on cultivated land, with continuous construction land expansion making population and land development intensity the main factors affecting cultivated land spatio-temporal differentiation. However, driven by food security pressure, cultivated land loss has been controlled to some extent, and the continuous promotion of high-standard basic farmland construction projects has stabilized the spatial distribution pattern of cultivated land in Gansu. With precipitation mainly concentrated in July–September and showing an upward trend, increased precipitation provides favorable conditions for crop growth. Consequently, the impact of economic development level on cultivated land has gradually weakened, and the interaction between precipitation and temperature has become stronger than that between population and land development intensity ($0.52 > 0.48$), becoming the dominant factor affecting cultivated land.

3 Conclusions

Based on land use data from four time points in Gansu Province and using ArcGIS, GeoDa, spatial distribution correlation analysis, and geographical detectors, this study analyzed land use transfer, revealed spatio-temporal change characteristics of cultivated land, and identified main driving factors of spatial differentiation. The main conclusions are:

- (1) Gansu's land use structure changed significantly from 1995 to 2020. Cultivated land decreased by 1.6%, with an increase from 1995 to 2005 followed

by a decrease from 2005 to 2020. According to land use transfer matrices, cultivated land mainly flowed to grassland, forest, and construction land, while unused land mainly converted to cultivated land and grassland. Conversion characteristics among land types showed obvious differences across study periods.

- (2) The spatial distribution of cultivated land in Gansu showed typical characteristics of “more in the southeast and less in the northwest.” Low-low clusters were most numerous, mainly distributed in the Hexi region of northwestern Gansu and Gannan Tibetan Autonomous Prefecture—ecologically fragile and sensitive areas with small cultivated land areas and low density.
- (3) The spatial distribution of cultivated land in Gansu is influenced by the combined effects of natural and socio-economic factors. The contribution rate rankings of factors were similar across periods from 1995 to 2020, with dominant factors showing certain similarities. The interaction between population and land development intensity was the main reason for spatial distribution differences of cultivated land in Gansu during 1995, 2005, and 2015. However, by 2020, the interaction between temperature and precipitation became the dominant factor affecting cultivated land.

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

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