# Spatiotemporal Variation and Evaluation of Cultivated Land Quality Grades in Arid Regions: A Case Study of Xining City (Postprint)

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## Abstract

This study takes Xining City, Qinghai Province as the research object. Based on the "Farmland Quality Grade" (GB/T33469-2016) standard, an evaluation index system for farmland quality in Xining City was constructed using the Delphi method, Analytic Hierarchy Process (AHP), fuzzy mathematics, and other methods. Combined with Geographic Information System (GIS) software technology, farmland quality in Xining City was evaluated for 2015 and 2018, and the spatiotemporal distribution of farmland quality and soil nutrient characteristics were analyzed to investigate the current status of farmland quality in Xining City. The results indicate: (1) The average farmland quality grades were 6.74 and 6.33 in 2015 and 2018, respectively, representing an improvement of 0.41 over the 4-year period. The overall improvement in farmland quality grades primarily originated from grades III, IV, V, and VII, with the proportion of high and medium-grade farmland area to total farmland area increasing by 1.49% in 2018 compared to 2015. (2) Farmland quality grades exhibited substantial spatial distribution differences during the 4-year period. High and medium-grade farmland was mainly concentrated in Huangzhong District in the central region and Datong Hui and Tu Autonomous County (hereinafter referred to as Datong County) in the north, while low-grade farmland was predominantly distributed in marginal mountainous areas and higher altitude regions. Farmland exhibiting quality improvement was primarily located in Datong County, Huangyuan County, and Huangzhong District. (3) Compared with 2015, soil organic matter, available phosphorus, and readily available potassium contents all increased in 2018, with the evaluation grade of available phosphorus content showing improvement. The research results provide a comprehensive evaluation of farmland quality across the entire Xining City area, effectively reflecting the current farmland quality status of the region and offering guiding significance for agricultural production.

# Full Text

## Spatiotemporal Variation and Evaluation of Cultivated Land Quality Grade in Arid Areas: A Case Study of Xining City

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**Abstract:** Taking Xining City in Qinghai Province as the research object and following the *Quality Grade of Cultivated Land* (GB/T33469-2016), this study constructed an evaluation index system for cultivated land quality in Xining City using the Delphi method, analytic hierarchy process, and fuzzy mathematics. Combined with geographic information system (GIS) technology, we evaluated the quality of cultivated land in Xining City for 2015 and 2018, analyzed the spatiotemporal distribution patterns and soil nutrient characteristics, and explored the current status of cultivated land quality. The results showed that: (1) The average cultivated land quality grades were 6.74 in 2015 and 6.33 in 2018, representing an improvement of 0.41 grades over the four-year period. The overall improvement in cultivated land quality grades primarily originated from grades three, four, five, and seven, with the combined area of high- and medium-grade land increasing by 1.49% of the total cultivated land area in 2018 compared to 2015. (2) The spatial distribution of cultivated land quality grades showed significant variation during this period, with high- and medium-grade land concentrated mainly in the central Huangzhong District and northern Datong Hui and Tu Autonomous County (hereafter referred to as Datong County), while low-grade land was distributed primarily in mountainous peripheral areas and higher-altitude regions. The improvement in cultivated land quality mainly occurred in Datong County, Huangyuan County, and Huangzhong District. (3) Compared with 2015, soil organic matter, available phosphorus, and readily available potassium contents all increased in 2018, with the evaluation grade for available phosphorus content rising. This study provides a comprehensive evaluation of cultivated land quality across the entire Xining region, with results that accurately reflect the current cultivated land quality status and offer valuable guidance for agricultural production.

**Keywords:** cultivated land quality; grade change; spatial distribution; geographic information system (GIS); Xining City

## 1 Introduction

Cultivated land forms the foundation for ensuring agricultural production and food supply. With rapid economic development and industrialization, China's cultivated land has experienced varying degrees of degradation, affecting crop safety and the nation's overall agricultural production strategy. Concurrently, consumer demand for agricultural products has shifted from quantity alone to safety, green production, and high quality. Consequently, protecting and improving cultivated land quality has become an urgent priority. Understanding the current status of cultivated land resources is crucial for China's ecological, economic, and social development, and cultivated land quality evaluation serves as a vital tool for investigating and clarifying existing cultivated land conditions.

To ensure food security, China has established a 120 million hectare cultivated land red line and implemented policies for strengthened protection and compensation balance. In 2016, the Ministry of Agriculture and Rural Affairs issued *Quality Grade of Cultivated Land* (GB/T33469-2016) (hereafter referred to as the "Standard"), which standardized and unified evaluation methods and procedures for cultivated land quality assessment nationwide. This standard provides scientific and technical guidance for conducting contemporary cultivated land quality evaluations and lays the foundation for assessing protection status, promoting synchronized quality improvement and conservation efforts, transforming agricultural production structures, and fostering sustainable development.

Current cultivated land quality evaluation research primarily focuses on three aspects: quality grade assessment, spatiotemporal variation analysis, and identification of major influencing factors. For instance, Yao et al. evaluated cultivated land quality in a typical black soil region of Northeast China from 1985 to 2015, finding that the quality grade improved by 1.2 grades over this 30-year period. Kang assessed the quality grades and spatial variation of soil nutrients in the Loess Plateau region—one of China's nine major agricultural zones—between 2000 and 2015, providing preliminary insights into soil nutrient status and cultivated land quality while analyzing the main factors influencing spatial differences. Dai et al. conducted evaluations of cultivated land quality and productivity at the county level in Wuchuan County. Although cultivated land quality evaluation has been gradually implemented across China, several challenges remain. Existing evaluation results often lack unified standards and may not accurately reflect actual conditions, necessitating timely updates and supplementary data. Additionally, China's complex topography and climate hinder large-scale, uniform cultivated land surveys.

Regarding the current research landscape, studies on cultivated land quality improvement and soil fertility enhancement are more prevalent in economically developed eastern coastal regions, with most research frameworks based on large regions or provincial scales. Conversely, research on spatiotemporal variation of cultivated land quality in western regions and smaller municipal or county scales remains limited. Xining City, the capital of Qinghai Province with a population exceeding one million on the Qinghai-Tibet Plateau, is also an important central city in Northwest China approved by the State Council. Since the promulgation of the national “Standard” and administrative reorganization, no comprehensive evaluation of cultivated land quality across Xining’s entire jurisdiction has been reported. Given that Qinghai Province has limited cultivated land resources, primarily concentrated in Xining and Haidong regions, with generally low quality and severe soil erosion, accurately understanding the spatiotemporal variation and nutrient change characteristics of cultivated land quality in this region is particularly important for agricultural development in Qinghai Province.

This study takes Xining City in Qinghai Province as the research object, using the city’s cultivated land quality monitoring points as coordinates and following the “Standard.” By integrating GIS technology to construct a cultivated land quality evaluation index system, we conducted a scientific and reasonable assessment of cultivated land quality grades, providing technical support for further agricultural structure adjustment and quality improvement in the region.

## 2 Study Area Overview

Xining City (36°13 –37°28 N, 101°52 –101°54 E) comprises Chengdong, Chengxi, Chengzhong, Chengbei Districts, Huangzhong District, Huangyuan County, and Datong Hui and Tu Autonomous County (hereafter referred to as Datong County). Located in eastern Qinghai Province on the northeastern Qinghai-Tibet Plateau, the city features higher terrain in the southwest and lower terrain in the northeast, with a strip-like distribution from east to west, making it one of the key cities in China’s western development initiative. The region has a continental plateau semi-arid and alpine cold temperate climate, with an average annual sunshine duration of 2,510.1 hours, maximum temperature of 34.6°C, minimum temperature of -18.9°C, and average annual precipitation of 493.4 mm. The total area of Xining City is 76.60$\times10^{4}$ hm$^{2}$, with a cultivated land area of 14.47$\times10^{4}$ hm$^{2}$ (including 11.75$\times10^{4}$ hm$^{2}$ of irrigated land and 2.72$\times10^{4}$ hm$^{2}$ of dry land). The total population is 238.71$\times10^{4}$, with 64.81$\times10^{4}$ rural residents accounting for 27.15% of the total population.

## 3 Materials and Methods

### 3.1 Data Sources and Processing

This study established 118 investigation sampling points (Figure 1). Data sources primarily included current land use raster maps, soil type maps, and administrative division vector data for Xining City, along with soil sample collection and analysis data from 2015 and 2018. Soil physicochemical indicators were measured following methods specified in *Soil Agrochemical Analysis* and the “Standard,” and a cultivated land quality grade evaluation database was established. Soil type raster data, administrative division vector data, and current land use raster data were overlaid to form evaluation unit maps, attribute values were assigned to evaluation units, and a cultivated land resource management information system was established.

[Figure 1: see original paper] Distribution of sampling points

### 3.2 Evaluation Unit Determination

The evaluation unit serves as the smallest unit for assessing cultivated land quality, and its rationality directly affects the accuracy and validity of evaluation results. Therefore, evaluation units should have essentially consistent basic conditions and attributes while maintaining certain differences. This study employed the overlay method and parcel method, superimposing soil type raster data, administrative division vector data, and current land use raster data to create a base map of patches. Following relevant technical standards, the base map was processed to generate 2,157 evaluation units, with each processed patch having unique attributes.

### 3.3 Evaluation Index System and Weight Determination

The selection of evaluation indices directly impacts the accuracy and practicality of results. Chosen indices should reflect regional characteristics, exhibit significant variation within the region, remain relatively stable over time series, and be easily obtainable. Cultivated land quality is influenced by many factors, with natural factors being the most important. As shown in Table 1, this study established the Xining City cultivated land quality grade evaluation index system based on the "Standard's" specified "topography, soil physical and chemical properties, soil profile configuration, cultivated land management, and ecological environment" index system structure, combined with the study area's natural conditions and field conditions. The system includes target layer, criterion layer, and index layer structures. The Delphi method was used to construct judgment matrices for each index, after which index weights were calculated. The combined weights were obtained by summing individual index weights according to the criterion layer classification standards.

### 3.4 Determination of Evaluation Index Membership Degree

Based on fuzzy mathematics principles and considering the numerical characteristics of some evaluation indices in the Xining City cultivated land quality evaluation process, three membership functions (peak type, 戒上型, and 戒下型) were fitted, while conceptual functions were assigned membership degrees directly using the Delphi method. The results are shown in Table 2.

**Table 1** Cultivated land quality evaluation indices and weights in Xining City

**Table 2** Membership functions of cultivated land quality evaluation indices in Xining City

*Note: y represents factor membership degree; u represents measured sample* *value; a represents index coefficient; c represents standard index; U1 represents index lower limit value; U2 represents index upper limit value.*

**Table 3** Attribute and membership degree of cultivated land quality evaluation indices in Xining City

### 3.5 Cultivated Land Quality Grade Classification and Comprehensive Index Calculation

According to the "Standard," the comprehensive index for each evaluation unit was calculated using the cumulative addition method with the formula:

$$IFI = \sum (C_i \times F_i)$$

where $IFI$ is the comprehensive cultivated land quality index, $C_i$ is the combined weight of the $i$th evaluation index, and $F_i$ is the membership degree of the $i$th evaluation index.

Following the "Standard's" provisions, cultivated land quality grades were divided into ten equal intervals. Higher $IFI$ values indicate better cultivated land quality, with Xining's comprehensive index ranging between grades two and ten. To ensure evaluation results matched actual conditions and could guide local agricultural production structure adjustment, field verification and expert validation were conducted. The final classification standards are shown in Table 4.

**Table 4** Classification standard for comprehensive index of cultivated land quality in Xining City

The average cultivated land quality grade was calculated using the area-weighted average method:

$$\overline{A} = \sum (I \times A) / \sum A$$

where $\overline{A}$ is the average cultivated land quality grade, $I$ is the cultivated land quality grade, and $A$ is the area occupied by each grade ($hm^2$).

## 4 Results and Analysis

### 4.1 Changes in Cultivated Land Quality Grade Area

**Table 5** Area change of cultivated land quality grades in Xining City

As shown in Table 5, Xining's total cultivated land area was 144,707.79 $hm^2$ in 2015, with high-, medium-, and low-grade land accounting for 6,237.12 $hm^2$ (4.31%), 51,460.56 $hm^2$ (35.56%), and 87,010.11 $hm^2$ (60.13%), respectively. In 2018, the areas from low to high grades were 10,418.15 $hm^2$, 49,428.85 $hm^2$, and 84,860.79 $hm^2$, representing 7.20%, 34.16%, and 58.64% of the total, respectively. Compared with 2015, high-grade land area increased by 58.64% in 2018, while medium- and low-grade land areas decreased by 1.40% and 1.49%, respectively. Among high-grade land, grade three showed the most significant increase at 43.33% and 35.72% in 2015 and 2018, respectively. For medium-grade land, grades four and five accounted for 28.66% and 52.03% in 2015, and 12.25% and 44.70% in 2018, respectively, with grade four area decreasing by 28.02% and grade five area increasing by 2.01%. Grade six area decreased by 10.08%. Among low-grade land, grade seven accounted for 45.22% and 54.16% in 2015 and 2018, respectively, with grade seven area increasing by 7.96%, while grades eight and nine decreased by 2.36% and 5.46%, respectively. Grades one, two, and ten each accounted for less than 5.78% and showed minimal impact.

The average cultivated land quality grades for Xining City were calculated as 6.74 in 2015 and 6.33 in 2018, representing an improvement of 0.41 grades.

### 4.2 Spatial Distribution of Cultivated Land Quality Grades

[Figure 2: see original paper] Spatial distributions of cultivated land quality grade in Xining City in 2015 and 2018

In 2015, high-grade land was concentrated in Changning Town in southeastern Datong County and Dabaozi Town in Chengbei District, with smaller areas in central Huangzhong District. By 2018, high-grade land was mainly distributed in Handong Township in Huangzhong District and Chengbei District, with reduced area in grades two and three. Medium-grade land was distributed across all counties and districts, with minimal change between 2015 and 2018, concentrating primarily in central Huangzhong District and south-central Datong County. Low-grade land was widely distributed across all counties, mainly surrounding high- and medium-grade land and in mountainous peripheral areas. In 2015, low-grade land was predominant in Huangzhong District and Datong County, while in 2018 it was more common in Huangzhong District and Huangyuan County.

Compared with 2015, cultivated land quality in Xining City improved, declined, and remained unchanged over 4.524%, 7.206%, and 88.270% of the total area, respectively. The maximum quality grade improvement was 3 grades, occurring only in Chengzhong District. The largest area of improved land was 56,560.41 $hm^2$, accounting for 39.086% of total cultivated land and concentrated in central Huangzhong District, northern Datong County, and western Huangyuan County. The maximum quality grade decline was 2 grades, observed in Datong County and Chengbei District, with declined land area totaling 10,427.24 $hm^2$ (7.206% of total area). Unchanged land area was relatively small at 4.524%.

[Figure 3: see original paper] Distribution of cultivated land quality grade change in Xining City

### 4.3 Changes in Soil Nutrients Across Cultivated Land Quality Grades

Compared with 2015, soil organic matter content in high-grade land in 2018 increased significantly, with grade three showing the greatest improvement at 18.83% and its evaluation grade rising from level 3 to 2. Grade two organic matter content increased but its evaluation grade remained unchanged. Available phosphorus content in grades two and three decreased by 40.60% and 54.16%, respectively, with grade three evaluation grade declining and grade two unchanged. Readily available potassium content in grades two and three decreased by 57.04% and 41.75%, respectively, with both evaluation grades remaining unchanged.

In medium-grade land, soil organic matter content increased across all grades, with grades four and five increasing by 13.09% and 10.71%, respectively, though evaluation grades remained unchanged. Available phosphorus content showed mixed trends: grades five and six increased by 16.92% and 43.58%, respectively, with grade five evaluation grade improving by one level, while grade four decreased by 23.72% with unchanged evaluation grade. Readily available potassium content in grades four, five, and six showed minimal change with evaluation grades remaining stable.

In low-grade land, soil organic matter and available phosphorus content in grades seven, eight, and nine all increased. Organic matter evaluation grade in grade nine improved by one level, while available phosphorus evaluation grades in grades seven and nine improved by one level. Grade eight available phosphorus content increased but its evaluation grade remained unchanged. Grade ten showed minimal impact due to its small area proportion.

### 4.4 Field Validation of Cultivated Land Quality Grades

To verify the 2018 cultivated land quality evaluation results and spatial distribution, 15 sampling points across different quality grades were randomly selected for field investigation and laboratory analysis (Table 6). Soil nutrient content decreased with declining cultivated land quality grades, while altitude showed an increasing trend. The plow layer texture in high- and medium-grade land was primarily medium loam and heavy loam, while low-grade land was mainly sandy loam and clay. Topography, texture configuration, and effective soil layer thickness showed no significant differences across quality grades. The terrain position and irrigation conditions of validation sampling points met the requirements of corresponding cultivated land quality grades.

**Table 6** Area distribution of cultivated land quality grade change in Xining City

*Note: Negative values in quality grade change represent decline, positive values represent improvement; "-" indicates no corresponding quality grade change in the county/district; Datong County is the abbreviation for Datong Hui and Tu Autonomous County. The same below.*

**Table 7** Distribution characteristics of main soil nutrients in different cultivated land quality grades in Xining City

*Note: Organic matter, available phosphorus, and readily available potassium are average values for soil nutrients in the corresponding quality grade.*

**Table 8** Comparison of verification information of different cultivated land quality grades in Xining City

Comprehensive analysis comparing evaluation grades with main evaluation indices and actual conditions showed good consistency, indicating that the evaluation results accurately reflect the actual cultivated land quality status in Xining City.

## 5 Discussion

*Quality Grade of Cultivated Land* (GB/T33469-2016) represents China's first national standard for cultivated land quality grade evaluation, unifying evaluation scales and methods nationwide and providing scientific technical guidance. The standard's promulgation and implementation establish the foundation for scientifically assessing cultivated land quality protection status, promoting synchronized quality improvement and conservation, transforming agricultural production, and fostering sustainable development.

This study evaluated Xining City's cultivated land quality in 2015 and 2018. Under the implementation of relevant measures, overall cultivated land quality grades improved by 0.41. However, low-grade land remained dominant, accounting for 58.64%–60.13% of total cultivated land area, similar to the national situation where medium- and low-grade land predominates. The overall quality improvement primarily stemmed from increased areas of grades three, four, five, and seven.

Located in the Loess Plateau region of Northwest China, Xining has extensive sloping cultivated land that causes severe soil erosion, damages land resources, reduces land quality, and constrains sustainable economic and social development. High- and medium-grade land concentrated in central Huangzhong District and northern Datong County showed significant quality improvement between 2015 and 2018, while low-grade land distributed in mountainous peripheral areas and higher altitudes had poor irrigation conditions and severe soil erosion, leading to quality decline in some areas.

In recent years, Qinghai Province has implemented comprehensive management of soil erosion on sloping land and fertilizer reduction and efficiency enhancement programs, completing terracing of 15,800 $hm^2$ and reducing sloping land area, which has substantially improved agricultural production conditions and environments and effectively controlled soil erosion. Low-grade land distribution areas should be prioritized in future cultivated land quality improvement efforts.

Cultivated land quality is unstable and changes with cropping patterns, farmland infrastructure construction, and natural disasters, necessitating timely updates to ensure proper guidance for agricultural production. Future production and farmland construction should follow local realities, strengthen cultivated land and environmental protection, adapt measures to local conditions, adhere to the principle of mandatory retirement when necessary, and pursue green, high-quality, efficient, and locally characteristic agricultural development while ensuring stable and increasing cultivated land quality.

The study results align well with actual conditions, providing references for cultivated land protection and rational utilization in the region and theoretical foundations for implementing new-period cultivated land quality grade improvement and high-standard farmland construction projects. Compared with 2015, soil organic matter and available phosphorus content in 2018 both increased, with available phosphorus showing greater improvement and its evaluation grade rising by one level. Soil nutrient content decreased with declining cultivated land quality grades, while altitude increased.

## 6 Conclusion

This study employed fuzzy comprehensive evaluation to construct a cultivated land quality evaluation index system for Xining City, combined with GIS technology to evaluate cultivated land quality grades in 2015 and 2018, and analyzed spatiotemporal distribution patterns and soil nutrient characteristics. The main conclusions are:

1. The average cultivated land quality grades in Xining City were 6.74 in 2015 and 6.33 in 2018, showing an improvement of 0.41 grades. The overall improvement primarily came from grades three, four, five, and seven, with the combined area of high- and medium-grade land increasing by 1.49% compared to 2015.

2. Spatial distribution of cultivated land quality grades varied significantly between 2015 and 2018. High- and medium-grade land concentrated mainly in central Huangzhong District and northern Datong County, while low-grade land was distributed primarily in mountainous peripheral areas and higher-altitude regions. Quality-improved cultivated land mainly originated from Datong County, Huangyuan County, and Huangzhong District.

3. Compared with 2015, soil organic matter, available phosphorus, and readily available potassium contents in 2018 all increased, with the evaluation grade for available phosphorus content rising. Soil nutrient content decreased with declining cultivated land quality grades, while altitude showed an increasing trend.

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