Analysis of Spatio-temporal Evolution and Driving Factors of Ecological Efficiency of Cultivated Land Use in the Guanzhong Plain (Postprint)

Authors: Jia Yajuan, Jun Gao, Xinqi Zhang

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Abstract

As an important major grain-producing area in western China, the study of ecological efficiency of cultivated land utilization in the Guanzhong Plain is of great significance for coordinating the contradiction between food security and sustainable resource utilization. Based on county-level panel data from 2013 to 2022, this study employs the Super-SBM model with undesirable outputs to quantify the ecological efficiency of cultivated land utilization, and systematically explores its spatio-temporal evolution characteristics and driving factors by combining spatial autocorrelation analysis and the geographical detector method. The results indicate that: (1) From 2013 to 2022, the overall ecological efficiency of the Guanzhong Plain exhibited a "U-shaped" evolution, forming a spatial gradient pattern of "high in the center, followed by the west, and low in the east." High-efficiency zones diffused westward with Xi' an and Xianyang as the core, while areas such as Tongchuan and Weinan remained in a low-efficiency state for a long period. (2) The spatial agglomeration characteristics of ecological efficiency are significant, with high-efficiency clusters expanding southward from Qian County, while low-efficiency clusters are stably concentrated in the east. (3) Natural, social, economic, and policy factors synergistically drive the spatial differentiation of efficiency. Among them, the influence intensity of factors such as annual precipitation and elevation evolved dynamically over time, while the promoting effects of urbanization rate and per capita disposable income of farmers continued to strengthen, and the interaction enhancement effect of multi-dimensional factors was significant.

Full Text

Preamble

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Analysis of the Spatiotemporal Evolution and Driving Factors of Ecological Efficiency of Cultivated Land Use in the Guanzhong Plain

Jia Yajuan[1], Gao Jun[1], Zhang Xinqi[2] (1. School of Management, Xi' an University of Finance and Economics, Xi' an 710100, Shaanxi, China; 2. International Business School, Hainan University, Haikou 570228, Hainan, China)

Abstract

As a vital grain-producing region in Western China, the Guanzhong Plain plays a crucial role in national food security. Researching the ecological efficiency of cultivated land use in this area is essential for coordinating the relationship between food security and resource conservation. The Guanzhong Plain faces significant pressure due to its high population density and intensive agricultural practices. Evaluating the ecological efficiency of its land use allows for a better understanding of how agricultural inputs—such as water, fertilizers, and energy—translate into economic outputs while minimizing environmental impacts. This balance is critical for achieving sustainable development goals in the region.

Addressing the conflict between resource utilization and sustainable development is of significant importance. Based on county-level panel data from 2013 to 2022, this study employs the Super-SBM model with undesirable outputs to quantify the ecological efficiency of cultivated land utilization. By integrating spatial autocorrelation analysis and the geographical detector method, the study systematically explores the spatio-temporal evolution and driving factors of this efficiency.

The results indicate that: (1) From 2013 to 2022, the overall ecological efficiency of the Guanzhong Plain exhibited a "U-shaped" evolutionary trend. Spatially, it formed a gradient pattern characterized by "highest in the central region, followed by the west, and lowest in the east." High-efficiency zones are centered around Xi' an and Xianyang, diffusing westward, while cities such as Tongchuan and Weinan have remained in a state of low efficiency for an extended period. (2) Spatial clustering characteristics of ecological efficiency are significant; high-efficiency clusters have expanded southward from Qian County, while low-efficiency clusters remain stably concentrated in the eastern region. (3) Natural, social, economic, and policy factors synergistically drive the spatial differentiation of efficiency. Among these, the influence intensity of factors such as annual precipitation and elevation evolves dynamically over time. Furthermore, the promotional effects of urbanization rates and per capita disposable income of farmers continue to strengthen, with significant interaction enhancement effects observed across multidimensional factors.

Keywords: Guanzhong Plain; Cultivated land use; Ecological efficiency; Super-SBM model; Geodetector

1. Introduction

Cultivated land is the fundamental resource for agricultural production and a critical component of the terrestrial ecosystem. In the context of global food security challenges and increasing ecological pressures, improving the ecological efficiency of cultivated land use has become a vital pathway for achieving sustainable agricultural development. The Guanzhong Plain, as a core agricultural region in Northwest China, faces the dual challenges of intensive resource consumption and environmental degradation. Understanding the spatial-temporal evolution and driving mechanisms of cultivated land use ecological efficiency in this region is essential for regional ecological protection and high-quality agricultural development.

Sustainable utilization is not only critical for national food security [**?**], but is also a fundamental requirement for maintaining ecosystem stability. Against this background, a systematic investigation into the enhancement of cultivated land utilization efficiency is of great significance [**?**].

[Figure 1: see original paper]

2. Materials and Methods

2.1 Study Area Overview

The Guanzhong Plain is located in the central part of Shaanxi Province, characterized by a semi-arid to semi-humid climate. It serves as a significant grain production base, contributing approximately 70% of the total grain production in Shaanxi Province [**?**]. The study area encompasses five prefecture-level cities—Xi' an, Xianyang, Baoji, Weinan, and Tongchuan—comprising a total of 48 county-level administrative units. However, rapid urbanization and industrialization in recent years have led to the fragmentation of cultivated land and increased non-point source pollution, necessitating a comprehensive evaluation of its land use efficiency from an ecological perspective.

2.2 Research Methods

2.2.1 Super-SBM Model To accurately measure the ecological efficiency of cultivated land use, this study employs the Super-SBM (Slack-Based Measure) model. Unlike traditional Data Envelopment Analysis (DEA) models, the Super-SBM model accounts for undesirable outputs and allows for the differentiation of multiple efficient units [**?**]. The mathematical expression for the efficiency score ρ^* is:

$$\min \rho^* = \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{r0}^g} + \sum_{l=1}^{s_2}\frac{s_l^b}{y_{l0}^b}\right)}$$

Subject to:

$$
\begin{aligned}
x_0 &= X\lambda + s^- \\
y_0^g &= Y^g\lambda - s^g \\
y_0^b &= Y^b\lambda + s^b \\
s^- \geq 0, \quad s^g &\geq 0, \quad s^b \geq 0, \quad \lambda \geq 0
\end{aligned}
$$

In this model, input indicators include labor, land, machinery, fertilizer, pesticides, diesel, agricultural film, and irrigation. The desirable outputs are total agricultural production value and grain yield, while undesirable outputs include carbon emissions and non-point source pollution.

2.2.2 Geodetector The Geodetector method is utilized to analyze the driving factors behind the spatial differentiation of ecological efficiency. By calculating the q value, we measure the explanatory power of different natural and socioeconomic factors:

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

Where L represents the stratification of the factor; N_h and N are the number of units in stratum h and the entire area; σ_h^2 and σ^2 are the variances of the strata and the total area.

2.3 Data Sources and Indicator Construction

Data are primarily sourced from the *Statistical Yearbook of Shaanxi Province* (2013–2022) and relevant municipal yearbooks for Xi' an, Xianyang, Baoji, Weinan, and Tongchuan. Carbon emission coefficients are derived from Cui et al. [?], and non-point source pollution calculations follow Wu et al. [?].

3. Results and Analysis

3.1 Temporal Evolution Characteristics

Based on the analysis of 48 counties from 2013 to 2022, the ecological efficiency of cultivated land use in the Guanzhong Plain exhibits a "U-shaped" trend. From 2013 to 2017, efficiency values decreased from 0.844 to 0.701 due to agricultural intensification and excessive chemical inputs. From 2017 to 2022, the index recovered to 0.833, driven by green development measures, ecological compensation policies, and water-saving technologies.

3.2 Spatial Distribution Characteristics

The spatial pattern exhibits significant heterogeneity [Figure 3: see original paper]. The efficiency presents a "high in the center, low in the periphery" concentric layered distribution, centered around Xi' an and Xianyang. High-efficiency zones migrated from east to west over the study period.

3.3 Spatial Autocorrelation Analysis

The Global Moran' s I was calculated to measure spatial association:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{n}(y_i - \bar{y})^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}$$

The results show significant spatial clustering, with high-efficiency clusters expanding southward from Qian County and low-efficiency clusters remaining concentrated in the eastern region.

4. Discussion and Policy Implications

The pursuit of eco-efficiency represents a critical strategy for harmonizing economic development and environmental preservation. Achieving this synergy requires: 1. **Technological Innovation:** Transitioning to cleaner production and utilizing machine learning to optimize resource allocation. 2. **Policy Support:** Implementing green fiscal policies and strict farmland protection to internalize environmental costs. 3. **Social Equity:** Ensuring the benefits of green growth are distributed equitably, fostering "green jobs" for rural residents.

This study provides a scientific basis for the national policy of "storing grain in the ground and storing grain in technology," supporting the sustainable management of regional cultivated land resources.

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