Spatial Evolution of Rural Poverty and Remoteness Characteristics in the Loess Plateau Region: Postprint

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Date: 2021-04-14T00:00:00+00:00

Abstract

Taking county-level administrative units as the research unit and based on statistical data and temporal distance data, this study employs methods such as global autocorrelation and grouping analysis to explore the spatiotemporal pattern differentiation of rural poverty in the Loess Plateau region from 2010 to 2015, and uses a location remoteness model to evaluate the remote characteristics of rural poverty levels and types. The results indicate: (1) The depth of rural poverty in the Loess Plateau region is more severe than the breadth of poverty; poverty types are dominated by "double-low" and "low-breadth-high-depth" types, and high-value areas of rural poverty incidence and poverty gap rate exhibit regional differentiation characteristics. (2) Rural poverty as a whole follows a gradually weakening development path, with the proportion of "double-high" type counties and districts significantly decreasing. High-value areas of poverty incidence gradually contract toward the Liupan Mountain area, while high-value areas of poverty gap rate form local hotspots in the Yanshan-Taihang Mountain area. (3) Contiguous destitute areas highly overlap with rural poverty-returning areas; breadth poverty-returning areas are concentrated in the Ningxia Liupan Mountain area and Lüliang Mountain area, while depth poverty-returning areas are concentrated in the Yanshan-Taihang Mountain area. (4) In the current urban-rural territorial system, the location remoteness of counties and districts from central cities shows a significant positive correlation with poverty incidence, but no significant correlation with poverty gap rate. Counties and districts that are extremely remote from provincial capitals should focus on the positive spillover effects of neighboring prefecture-level city development, and in transportation construction should emphasize strengthening their highway connections with prefecture-level cities.

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Spatial Evolution and Remote Characteristics of Rural Poverty in the Loess Plateau Region

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Abstract: Taking county-level administrative units as the research scale and based on statistical data and time-distance data, this study analyzes the spatiotemporal differentiation of rural poverty patterns in the Loess Plateau region in 2010 and 2015 using methods such as global spatial autocorrelation and grouping analysis, and evaluates the remote characteristics of rural poverty levels and types through a location remoteness model. The results indicate that: (1) The depth of rural poverty in the Loess Plateau is more severe than its breadth, with poverty types predominantly characterized as "double-low" and "low breadth but high depth." High-value areas of rural poverty incidence and gap rate exhibit regional differentiation features. (2) Overall, rural poverty follows a gradually weakening development trajectory, with the proportion of "double-high" type counties significantly decreasing. High-value areas of poverty incidence gradually concentrate in the Liupan Mountain area, while high-value areas of poverty gap rate form local hotspots in the Yanshan-Taihang Mountain area. (3) Contiguous destitute areas highly overlap with rural poverty-returning areas. Breadth-based poverty-returning areas are concentrated in the Ningxia Liupan Mountain and Luliang Mountain areas, while depth-based poverty-returning areas are concentrated in the Yanshan-Taihang Mountain area. (4) In the current urban-rural regional system, the location remoteness of counties from central cities shows a significant positive correlation with poverty incidence, but no apparent correlation with poverty gap rate. Counties extremely remote from provincial capitals should focus on leveraging the positive spillover effects of neighboring prefecture-level cities, emphasizing the strengthening of highway connections with these cities in transportation infrastructure development.

Keywords: rural poverty; spatiotemporal pattern; spatial autocorrelation; location remoteness; Loess Plateau

Introduction

Poverty has long been a prominent challenge in the socio-economic development of countries worldwide. "Eliminating all forms of poverty" is the primary goal of the United Nations' 2030 Agenda for Sustainable Development [1]. From the 18th National Congress of the Communist Party of China to the end of 2020, China achieved remarkable success in poverty alleviation. According to China's poverty standard based on rural per capita net income (constant 2010 prices), rural poor population decreased from 16.60 million to 9.899 million between 2012 and 2020, with the poverty incidence rate dropping from 10.2% to 2.6%, making a tremendous contribution to global poverty reduction [2]. However, by the end of 2018, China still had over 300 national-level poverty-stricken counties, 26,000 poor villages, and 16.60 million poor people. Notably, while absolute poverty in rural China is expected to be eliminated by the end of 2020, the relativity and complexity of poverty will persist. After 2020, rural poverty in China will enter a new stage characterized by transformative secondary poverty and relative poverty, presenting new features such as multidimensional poverty [3]. Rural poverty-stricken areas are the focus of poverty alleviation and rural revitalization. Scientifically identifying poverty-stricken areas and types to achieve long-term and stable poverty alleviation goals holds significant strategic and practical importance for promoting regional rural revitalization and addressing unbalanced and insufficient rural development.

Domestic and international scholars have achieved abundant results based on regional poverty theories and methods. In terms of poverty measurement indicators, studies have measured poverty levels through basic poverty indices (poverty incidence and poverty gap rate), poverty intensity index, and the "double threshold" method [4-5]. Regarding poverty impact factors, research has analyzed poverty mechanisms through geographical location, resource endowment, social institutions, and public facilities [6-9]. Concerning the relationship between transportation and poverty, studies have emphasized the poverty reduction effects of transportation infrastructure by exploring the coupling between transportation accessibility and poverty [10-12]. Overall, although research on poverty geography has gradually enriched and its impact on poverty alleviation practice has increased, existing studies have several limitations: research indicators mostly focus on the breadth of rural poverty [13-14], with insufficient exploration of rural poverty depth, making it difficult to diagnose the severity of poverty in deeply impoverished areas; research standards predominantly use rural per capita net income (constant 2010 prices) [15], but considering individual differences and temporal changes in poverty-stricken areas, poverty standards should vary across different regions; research content mostly focuses on operational mechanisms of different poverty-causing factors in poor areas [16-17], while studies on the impact of transportation location on rural poverty remain relatively weak.

Based on this, this paper takes the Loess Plateau region—characterized by dual economic and ecological vulnerability in China—as the research object, using county-level administrative units as the basic scale. Combining GIS technology, this study analyzes the attribute and type characteristics and spatiotemporal evolution patterns of rural poverty in the Loess Plateau from quantitative measurement and spatial expression perspectives, and explores the relationship between location remoteness and rural poverty in the urban-rural regional system, aiming to provide decision-making basis and theoretical support for poverty alleviation work in the new stage of rural development in the Loess Plateau.

Study Area

The Loess Plateau region is located in north-central China (107°~114°E, 32°~41°N), characterized by a fragile ecological environment, weak rural economy, and lagging infrastructure. The Loess Plateau scope adopted in this study follows the "Comprehensive Management Planning Outline for the Loess Plateau Region (2010-2030)" issued by the National Development and Reform Commission in 2011, covering 7 provinces (autonomous regions) including Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, and Henan, 40 prefecture-level cities (states, leagues), and 340 counties (banners, cities, districts) [18]. The landform types are complex and diverse, with terrain sloping from northwest to southeast, divided into 5 comprehensive management zones (Fig. 1). In 2015, the Loess Plateau region had a total population of 126 million, including 74.4038 million rural residents, accounting for 58.95% of the total population; among them, the number of rural residents receiving minimum living security was 6.0701 million, accounting for 8.16% of the rural population, which is 14.95% lower than the national average [19]. The region involves 3 contiguous destitute areas (Liupan Mountain, Luliang Mountain, and Yanshan-Taihang Mountain areas), 66 national-level poverty-stricken counties, and 44 key counties for national poverty alleviation and development within contiguous destitute areas, making rural poverty issues particularly typical.

Methods

2.1.1 Poverty Measurement

Poverty Incidence Rate. The poverty incidence rate is the proportion of poor population to total population, reflecting the breadth of poverty. It measures the scale and density of poverty in a region. The calculation formula is:

$$H = \frac{n}{N} \times 100\%$$

where H is the poverty incidence rate; N is the total rural household registration population; n is the number of rural minimum living security recipients.

Poverty Gap Rate. The poverty gap rate calculates the ratio of the total gap between each poor person' s net income and the poverty line to the total income required to reach the poverty line, reflecting the depth of poverty in a region. The calculation formula is:

$$I = \frac{\sum_{i=1}^{q}(1 - \frac{Y_i}{\pi})}{q} \times 100\%$$

where I is the poverty gap rate; Y_i is the income of the i-th poor individual ($Y_i \leq \pi$); π is the poverty line; q is the number of poor individuals; μ is the average income of the poor population.

2.1.2 Spatial Autocorrelation Model

Spatial autocorrelation analysis includes global and local spatial autocorrelation analyses. Global autocorrelation analysis can determine the spatial distribution pattern of rural poverty across county-level administrative regions in the Loess Plateau. Based on county-level poverty incidence and poverty gap rates, Moran's I statistic is used to measure the spatial autocorrelation of rural poverty in the Loess Plateau. The calculation formula is:

$$I = \frac{n}{S}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}$$

where n is the number of county-level administrative regions in the study area; x_i and x_j are observed values of spatial units; $\bar{x}$ is the mean of observed values; w_{ij} is the spatial weight matrix; S is the sum of the spatial weight matrix.

2.1.3 GIS Grouping Analysis

Grouping analysis is a comprehensive clustering method that combines attribute factors and spatial characteristics of research objects [22]. Based on rural poverty incidence and poverty gap rates of each county-level administrative region, the pseudo-F statistic is used to classify rural poverty types in the Loess Plateau. The calculation formula is [23]:

$$\text{pseudo-}F = \frac{(SST-SSE)/SSE}{(n_c-1)/(n-n_c)}$$

where $SST = \sum_{i=1}^{n}\sum_{k=1}^{n_v}(V_{ik}-\bar{V}_k)^2$ represents total sum of squares; $SSE = \sum_{i=1}^{n_c}\sum_{j=1}^{n_i}\sum_{k=1}^{n_v}(V_{ijk}-\bar{V}_{ik})^2$ represents within-group sum of squares; n is the number of county-level administrative regions in the study area; n_i is the number of counties in group i; n_c is the number of groups; n_v is the number of variables used for grouping; V_{ijk} is the value of variable k for county j in group i; $\bar{V}_k$ is the mean value of variable k for all counties; $\bar{V}_{ik}$ is the mean value of variable k for all counties in group i.

2.1.4 Location Remoteness

To examine the geographical location conditions of different county-level administrative regions, this study introduces the concept of location remoteness [24]. First, the central city where each county is located is selected as the reference object; second, parameter α is introduced to represent the location remoteness status of each county within the province. This study uses time distance based on path calculation to characterize location remoteness. The calculation formula is [25]:

$$\alpha = \frac{T_i}{\frac{1}{m}\sum_{j=1}^{m} T_j}$$

where α represents the time-distance remoteness to its prefecture-level city or provincial capital city; T_i represents the time distance from county i to its prefecture-level city or provincial capital city; T_j represents the time distance from the j-th county in the province to its prefecture-level city or provincial capital city; n and m represent the number of counties respectively.

The threshold selection for remoteness refers to the method proposed by Sun Wei et al. [26], where a county is considered locationally remote only when its distance to the central city exceeds the average distance of all counties in the province to their central cities; otherwise, it is defined as not remote. Specifically: when $\alpha < 1.0$, it indicates not remote; when $1.0 \leq \alpha < 1.5$, it indicates remote; when $\alpha \geq 1.5$, it is defined as extremely remote.

2.2 Data Sources

The vector boundary data of county-level administrative units in the Loess Plateau region used in this study were obtained from the 1:1,000,000 national fundamental geographic database (http://www.webmap.cn/) downloaded from the Geospatial Data Cloud website. Socio-economic statistical data were sourced from statistical yearbooks of various provinces and municipalities in 2010 and 2015, as well as the official website of the Ministry of Civil Affairs of the People' s Republic of China. For poverty standard values, the rural resident minimum living security standards published by the Ministry of Civil Affairs for 340 counties were adopted. Highway time distances were calculated using the Gaode Map path calculation tool; railway time distances were queried using the 2015 national train timetable, with the time cutoff being December 2015.

Results

3.1.1 Spatial Evolution Characteristics of Rural Poverty Levels

From 2010 to 2015, the rural poverty incidence rate in the Loess Plateau decreased from 10.68% to 8.66%, and the rural poverty gap rate decreased from 71.88% to 69.66%, both showing a declining trend. This indicates that against the backdrop of national poverty alleviation efforts, the overall rural poverty level in the Loess Plateau is on a benign development trajectory. Meanwhile, the depth of rural poverty is relatively more severe than its breadth. Global autocorrelation tests revealed (Table 1) that Moran' s I index for poverty incidence decreased, indicating weakening "contiguous" clustering, while Moran' s I index for poverty gap rate increased, indicating strengthening "contiguous" clustering.

In terms of spatial evolution of rural poverty incidence, in 2010, the Loess Plateau had a relatively high overall rural poverty incidence, presenting a low-high-higher spatial pattern from southeast to northwest (Fig. 2). High-value areas (poverty incidence > 15%) were mainly distributed in the central-western Liupan and Luliang Mountain areas (contiguous destitute areas). These areas are primarily located in the Loess Plateau gully region and loess hilly-gully region, with undulating terrain, crisscrossing gullies, inconvenient external communication, and poor economic development conditions, resulting in high poverty incidence levels. Low-value areas (poverty incidence < 5%) were mainly located in the border region of Shanxi, Shaanxi, and Henan in the southeastern Loess Plateau. These areas are primarily situated in river valley plains with flat terrain, convenient irrigation, good natural conditions, and lower rural poverty incidence levels.

By 2015, high-value areas of poverty incidence decreased significantly, but "contiguous" clustering strengthened noticeably, concentrating in the western Liupan Mountain area (Fig. 2), while poverty incidence in the Luliang Mountain and central Inner Mongolia areas declined substantially. Simultaneously, the spatial distribution range of low-value counties (poverty incidence < 5%) expanded significantly, extending into central Shanxi and western Henan on the original basis, with relatively widespread distribution also existing in the Shaanxi-Inner Mongolia border region.

Regarding spatial evolution of rural poverty gap rates, in 2010, high-value areas (poverty gap rate > 80%) were widely distributed across the Liupan and Luliang Mountain areas (Fig. 2). These contiguous destitute areas suffer from fragile geographical capital, lagging infrastructure, and insufficient household development capacity, resulting in deep poverty and difficult poverty alleviation. In contrast, central Inner Mongolia and central Shanxi areas, adjacent to their provincial capitals and influenced by the radiation and driving effects of large cities, had lower rural poverty gap rates. With the in-depth implementation of targeted poverty alleviation policies, by 2015, high-value areas of poverty gap rate in the Loess Plateau shifted from multiple "contiguous" distributions to discrete distributions, with distribution scope also decreasing (Fig. 2). Specifically, the Liupan Mountain area showed low-value "contiguous" clustering of poverty gap rates, while the high-value area scope in the Luliang Mountain area also declined. Notably, the Yanshan-Taihang Mountain area has harsh resource and environmental conditions, weak industrial foundations, and households face rising poverty gap rates under exogenous shocks such as natural disasters and health issues.

3.1.2 Spatial Evolution Characteristics of Rural Poverty Types

Using ArcGIS' s grouping analysis tool, based on rural poverty incidence and poverty gap rates of each county, the Loess Plateau region was divided into four poverty type zones: "double-low" type, "high breadth but low depth" type, "low breadth but high depth" type, and "double-high" type (Fig. 3). In

2010, rural poverty types in the Loess Plateau were mainly "double-low" and "low breadth but high depth" types, with overall relatively low breadth of rural poverty across counties. From 2010 to 2015, the proportion of "double-high" type counties significantly decreased from 21.98% to 15.14%; the proportion of "high breadth but low depth" type counties significantly increased from 14.24% to 21.45%; while proportions of "low breadth but high depth" and "double-low" type counties remained relatively stable. Overall, rural poverty types are trending toward benign development.

Examining "double-high" and "double-low" type counties, in 2010, "double-high" type counties were concentrated in the central-western Liupan Mountain area of the Loess Plateau (Fig. 3), indicating that the Liupan Mountain area has large poor populations and deep poverty, representing the most severe poverty issues in the Loess Plateau. This is primarily because this region has fragile ecological environments, scarce water and soil resources, and regional development heavily depends on natural conditions. By 2015, through industrial poverty alleviation, relocation, and infrastructure development assistance implemented by the government, the number of "double-high" type counties decreased significantly, dropping to 51 counties mainly distributed in the Liupan Mountain area.

From 2010 to 2015, the proportion of "double-low"type counties remained around 48%. In 2010, "double-low" type counties were mainly distributed in a semi-ring pattern along the eastern edge of the Loess Plateau (central Inner Mongolia, eastern Shanxi, and Guanzhong area). These areas have relatively minor terrain undulation, good coupling of water and soil for agricultural development, and convenient access to public services due to proximity to provincial capitals. However, some counties in Xinzhou and Changzhi cities in Shanxi Province, with relatively weak economic foundations, transformed from "double-low" type to "low breadth but high depth" type, indicating unstable benign status.

Regarding "high breadth but low depth" and "low breadth but high depth" type counties, "high breadth but low depth" type counties were relatively dispersed in 2010. By 2015, they mainly evolved from "double-high" type and were concentrated in the Liupan Mountain area. "Low breadth but high depth" type counties were mainly distributed in the Luliang Mountain area and Ningxia Liupan Mountain area in 2010. Due to constraints from ecological environment and human capital, these counties easily fall into a vicious cycle of "population growth - environmental degradation - poverty intensification." By 2015, "low breadth but high depth" type counties spread from the Luliang Mountain area to surrounding regions, indicating that poverty depth remains to be optimized.

3.1.3 Spatial Evolution Characteristics of Rural Poverty Alleviation and Return

From 2010 to 2015, the mean change rate of rural poverty incidence in counties across the Loess Plateau was -13.52%, and the mean change rate of poverty gap rate was -15.88%, with both poverty alleviation and poverty return phenomena coexisting. The Loess Plateau region demonstrated strong poverty alleviation efforts in terms of poverty breadth, with significantly reduced poverty coverage. However, Liangcheng County and Zuoyun County, located in the Shanxi-Inner Mongolia provincial border area, are prone to extreme poverty due to administrative marginalization effects, with poverty depth increasing by 3.52% and requiring focused attention in poverty alleviation work.

From the spatial pattern of rural poverty level change rates, between 2010 and 2015, counties with declining poverty incidence accounted for 94.41%, indicating overall reduction in rural poverty breadth. Counties with decline rates exceeding 20% were mainly distributed in northern Shaanxi and western Inner Mongolia. However, due to frequent drought and natural disasters in Ningxia, most rural populations face long-term disaster-induced poverty return risks, with poverty incidence showing an overall upward trend. From 2010 to 2015, the poverty gap rate decreased in 89.41% of counties, with the most significant declines in the Liupan and Luliang Mountain areas as national contiguous destitute areas (Fig. 4). Meanwhile, marginal poor households in the Yanshan-Taihang Mountain area and eastern Shanxi have unstable economic foundations and weak capacity to resist risks from disasters, disease, and market fluctuations, showing rising poverty gap rates.

Poverty alleviation and return are characterized by difficulty, complexity, and repetitiveness [27]. The Loess Plateau region has achieved remarkable overall poverty alleviation results, but the vulnerability of the poverty-alleviated population remains high. Current poverty alleviation efforts should not only emphasize the quantity of poverty alleviation but also focus on its quality. For poverty-stricken areas, especially contiguous destitute areas, poverty alleviation should both increase farmers' income and emphasize risk reduction to enhance the risk resistance capacity of rural populations, thereby achieving stable poverty alleviation.

3.2 Remote Characteristics of Rural Poverty in the Loess Plateau

Based on the poverty levels and types of each county in 2010 and 2015, and their location remoteness from central cities, this section identifies the influence of remote characteristics of the urban-rural regional system on poverty attributes in the Loess Plateau. All counties in the Loess Plateau region have highway connections with their prefecture-level cities, while 69.35% of counties have railway connections with their provincial capitals. When statistically analyzing location information of counties from provincial capitals, this study excludes counties without railway connections to provincial capitals.

3.2.1 Analysis of Remote Characteristics of Rural Poverty Levels Regarding location remoteness based on prefecture-level cities, the location remoteness of counties in the Loess Plateau averages 1.09, generally belonging to the remote category, indicating that highway conditions still need optimization. The proportion of not-remote counties is 53.37%. As remoteness from prefecture-level cities increases, the mean rural poverty incidence rises from 7.85% to 10.16%, while the poverty gap rate shows no obvious pattern.

In terms of location remoteness based on provincial capitals, the mean rural poverty incidence in counties without railway connections is 9.95%, higher than the 7.68% in counties with railway connections; the mean poverty gap rate is 69.83%, similar to the 69.35% in counties with railway connections. The mean location remoteness of counties with railway connections to provincial capitals is 1.08, slightly remote. Among them, the proportion of not-remote counties is 30.94%, with lower poverty incidence (6.94%) and poverty gap rate (70.08%). As location remoteness from provincial capitals increases, rural poverty incidence shows an upward trend (Fig. 6), while poverty gap rate shows no significant change (Fig. 6). In 2015, among counties experiencing breadth-based and depth-based poverty return, the proportions of remote and extremely remote counties from provincial capitals were both 100%, distributed in contiguous destitute areas. This indicates that railway transportation conditions in the Loess Plateau region still have considerable room for improvement, and railway connections with provincial capitals have positive significance for improving rural poverty incidence, but limited effect on alleviating poverty gap rates.

3.2.2 Analysis of Remote Characteristics of Rural Poverty Types In terms of location remoteness based on prefecture-level cities (Fig. 7), the change in proportions from "double-low" to "double-high" type counties gradually decreases with increasing remoteness. Among not-remote counties from prefecture-level cities, "double-low" type accounts for the largest proportion (61.46%), while "double-high" type accounts for the smallest (31.25%), indicating that highway traffic location is closely related to regional poverty types. Therefore, improving the road network structure connecting counties to prefecture-level cities and accelerating the construction of transportation arteries, county-connecting highways, and rural roads can enhance counties' access to public services from prefecture-level cities, thereby promoting the flow and upgrading of local resources, industries, and populations to improve rural poverty conditions.

Regarding location remoteness based on provincial capitals (Fig. 7), the change in proportions from "double-low" to "double-high" type counties shows an "n" shape with increasing remoteness, indicating that the influence of provincial capitals based on railways on extremely remote counties has experienced attenuation and "fracture," making extremely remote areas become urban "shadow zones" of provincial capitals. Among counties not remote from provincial capitals, "double-low" type (62.3%) and "low breadth but high depth" type (74.19%) have obvious advantages; while "double-high" type counties account for 59.09% of remote and extremely remote counties from provincial capitals, indicating relatively weak railway transportation conditions. Provincial capitals have high administrative levels and strong effects. Improving railway transportation location for not-remote and remote counties has more significant impact on solving rural poverty problems; for counties extremely remote from provincial capitals, transportation location should emphasize strengthening highway connections with prefecture-level cities.

The essence of regional poverty is a manifestation of the coupling misalignment among "people," "land," and "industry" [28]. This study focuses on the Loess Plateau region. Regarding poverty standards, it uses minimum living security data based on rural household registration published by the Ministry of Civil Affairs to analyze the spatial evolution patterns of poverty breadth and depth, and deeply explores the location remote characteristics of poverty levels and types under different transportation modes and urban hierarchies. However, in recent years, with the implementation of targeted poverty alleviation and rural revitalization strategies, China' s poverty alleviation landscape has undergone significant changes. Due to data availability limitations, this study' s data has the defect of relatively low standards in later periods [29]. Predicting the spatial pattern of China' s rural relative poverty after 2020, when absolute poverty is eliminated under current poverty standards, represents the main direction for subsequent research.

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