Postprint on the Coupling Relationship between Fragile Ecological Environment and Poverty in Gansu Province

Authors: Niu Ya-Qiong, Wang Sheng-Lin

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Abstract

Maintaining coordinated development between ecological environment and economic construction is one of the important strategies for national poverty alleviation and development in the new stage. Taking Gansu Province as an example, this study employs system coupling coordination theory to construct a multi-indicator comprehensive evaluation system for dual-system development, and measures and analyzes the evaluation scores of fragile ecological environment and poverty, their coupling coordination degree, and spatio-temporal differentiation in the study area from 2000 to 2014. The results indicate that: from a temporal perspective, the coupling coordination degree between fragile ecological environment and poverty in Gansu Province demonstrates an overall upward trend, and under the influence of factors such as policy adjustments, exhibits three distinct stages: low-level coupling coordination, coupling coordination degree growth, and high-level coupling coordination with ecological environment lag; from a spatial differentiation perspective, the coupling coordination degree between fragile ecological environment and poverty in Gansu Province increases from southeast to northwest, the spatial distribution of coupling coordination degree is unbalanced, fragile ecological environment and poverty coexist symbiotically, and it is necessary to fully emphasize and protect the ecological environment in poverty-stricken areas.

Full Text

Preamble

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Research on the Coupling Relationship Between Vulnerable Ecological Environment and Poverty in Gansu Province

Niu Yaqiong, Wang Shenglin*
College of Economics and Management, Gansu Agricultural University

Abstract

Maintaining coordinated development between ecological environment and economic construction is one of the important strategies in national poverty alleviation and development at the new stage. Taking Gansu Province as a case study, this research employs system coupling coordination theory to construct a multi-index comprehensive evaluation system for dual-system development. Using data from 2000 to 2014, we measured and analyzed evaluation scores for vulnerable ecological environment and poverty, their coupling coordination degree, and spatio-temporal variability. The results show that the coupling coordination degree between vulnerable ecological environment and poverty in Gansu Province exhibited an overall upward trend, but presented three distinct stages influenced by factors such as policy adjustments. From a temporal perspective, the coupling coordination degree increased from southeast to northwest, though spatial distribution remained unbalanced. Given that vulnerable ecological environment coexists with poverty, the strategic significance of protecting the ecological environment in impoverished areas should be given full consideration.

Keywords: vulnerable ecological environment; poverty; coupling

The *China Rural Poverty Alleviation and Development Outline (2011-2020)* issued by the State Council emphasizes the combination of poverty alleviation with ecological construction and environmental protection to promote coordination among economy, society, population, and environment. Impoverished regions in China often face dual pressures of ecological vulnerability and poverty [2-5]. Due to harsh natural conditions, scarce natural resources, fragile ecological environments, and severe ecological degradation, most impoverished populations reside in areas with ecologically fragile environments, making poverty also an ecological issue [6-7]. Both government and scholars have reached consensus on treating poverty alleviation and ecological protection as integral components of sustainable development in impoverished areas [8-12].

Analyzing the relationship between fragile ecological environments and poverty in impoverished regions is a crucial prerequisite for coordinating regional poverty alleviation with ecological protection and achieving sustainable economic development. In related research, scholars have studied fragile ecological environments from perspectives including regional identification methods, formation causes, and degree evaluation [13-18]. For instance, Sun Wu et al. [13] provided

a comprehensive logical summary of ecologically fragile zones from a spatial attributes perspective, while Ma Jun et al. [16] studied quantitative evaluation methods for fragile ecological environments. Regarding the relationship between fragile ecological environments and poverty, Janet A. Fisher noted that ecological theories and tools could enhance poverty alleviation effectiveness [19]. From the perspective of ecology-poverty relationships, framework theoretical analysis suggests that poverty alleviation must acknowledge social differentiation and understand ecological constraints [2,8-11,20]. Some scholars have conducted qualitative sociological analyses of this relationship, while others have performed quantitative correlation studies [3-4], concluding that ecological resources can prevent poverty rather than reduce it. Some researchers have also taken ecologically fragile counties and impoverished counties as study objects. However, quantitative analyses exploring the coupling relationship between fragile ecological environments and poverty remain relatively scarce, with most studies focusing on national-level analysis. Research on northwest inland regions facing severe ecological vulnerability and poverty remains blank, with most studies focusing on the vicious cycle of ecological destruction and poverty, while few examine how to break this cycle. This paper selects Gansu Province—a typical underdeveloped province in northwest inland China facing both issues—to conduct systematic spatio-temporal analysis of evaluation results based on constructed evaluation index systems for vulnerable ecological environment and poverty. We discuss how the two systems can achieve coordinated development and enter a virtuous cycle of ecological protection and poverty reduction.

1. Study Area Overview

Gansu Province is located in northwestern China, distributed in a narrow, dumbbell-shaped pattern from northwest to southeast, with geographical coordinates of···The region features complex and diverse landform types, numerous plateaus and mountains, and widespread desert and Gobi. Spanning subtropical, warm temperate, temperate, and plateau climate zones, the area includes arid, semi-arid, humid, and semi-humid zones. The region receives scarce precipitation and has poor water resource conditions. Gansu' s complex geographical environment and harsh natural conditions lead to frequent natural disasters such as freeze-thaw, mudslides, and landslides. Combined with human factors, the ecological environment continues to deteriorate, with severe soil erosion and land desertification. Most areas are in arid regions, making the natural environment diverse and fragile. Among them, counties with severe ecological vulnerability, moderate vulnerability, and slight vulnerability demonstrate the region' s representativeness in ecological environment research.

From a poverty alleviation perspective, Gansu has 43 national-level key poverty alleviation counties, accounting for 1/2 of county-level administrative units, with a poverty incidence rate as high as···The province exhibits large internal development disparities, complex poverty causes, deep poverty levels, and wide poverty scope. The development gap between urban and rural areas is significant, mak-

ing it highly representative among poverty-stricken provinces. Particularly in deep mountain and high-altitude areas, development is difficult, economically developed cities have weak radiating effects on surrounding underdeveloped areas, agricultural development is singular, and the exploitation of local characteristic industries such as tourism is low. Overall, infrastructure in impoverished areas lags behind, and the urban-rural dual structure is prominent. Therefore, studying the relationship between Gansu' s fragile ecological environment and poverty is necessary.

2. Research Methods and Data Sources

The concept of coupling originates from physics, referring to the phenomenon where two or more systems or motion forms influence each other through various interactions [21]. In this paper, the coupling relationship between fragile ecological environment and poverty refers to the interactive process where the two factors mutually influence and promote each other. Coupling degree measures the coordinated development degree among elements within a system. The degree to which the fragile ecological environment-poverty dual system interacts through respective coupling factors can be defined as the fragile ecological environment-poverty coupling degree. Thus, the fragile ecological environment and poverty constitute a coupled interactive entity that influences and constrains each other.

2.1 Coupling Degree and Coupling Coordination Degree Model

For coupling degree calculation, this study adopts the capacity coupling concept and coupling calculation model from physics. The coupling degree model for multiple interacting systems is: C = ···Since this paper only involves two subsystems—fragile ecological environment and poverty—the coupling degree function can be directly expressed as: C = 2√(U × U) / (U + U), where U and U represent Gansu Province' s fragile ecological environment index and poverty index, respectively. The value range of C is [0,1]. When C = 0, the coupling degree between the two is minimal; when C = 1, the coupling degree is maximal.

As an important indicator reflecting the coupling degree between Gansu's fragile ecological environment and poverty, coupling degree plays a significant role in judging the intensity of coupling effects between systems under certain spatiotemporal conditions. However, coupling degree cannot easily reflect the overall quality of coordination between regional fragile ecological environment and poverty. Therefore, it is necessary to construct a coupling coordination degree model: D = √(C × T), where D is the coupling coordination degree reflecting the coordinated development level between fragile ecological environment and poverty; C is the coupling degree; and T is the comprehensive evaluation index of fragile ecological environment and poverty. In practical applications, to ensure D (0,1), it is best to have T (0,1). a and b are undetermined coefficients. Since environmental and economic systems are equally important, this paper refers to Li Tao et al.' s coupling coordination research, setting a = b = 0.5.

The coupling coordination degree D is divided into four categories: 失调衰退区 (disharmony and decline zone), 过渡调和区 (transition and reconciliation zone), 协调发展区 (coordinated development zone), and 极度协调区 (extremely coordinated zone). Combined with scores from the two major systems, relationship discriminant characteristics are established to determine the coupling coordination relationship between the two systems.

Classification and criteria for the coordinated development of vulnerable ecological environment and poverty

2.2 Evaluation Index System Construction and Weight Determination

Since the connotation of fragile ecological environment includes both structural vulnerability and stress vulnerability, and poverty includes both survival status and development status, and given that research on fragile ecological environment, poverty, and their coupling coordination belongs to sustainable development research, the evaluation index selection must consider both aspects. Research on related index systems and models is relatively mature [21-24]. Under the guidance of principles including comprehensiveness, operability, and data availability, and based on the actual situation in Gansu, this paper constructs Gansu' s ecological environment vulnerability index system from structural and stress vulnerability perspectives, and Gansu' s human socio-economic poverty index from economic poverty and social poverty perspectives. It includes···measurement indicators for ecological environment vulnerability and···comprehensive measurement indicators for human socio-economic poverty.

Notably, this paper adopts a reverse measurement method to evaluate fragile ecological environment and poverty: smaller calculated evaluation index values indicate more fragile ecological environment and deeper poverty; larger values indicate better ecological protection and poverty reduction effectiveness. The formulas are as follows:

For data standardization: X_ij = (X_ij - min(X_j)) / (max(X_j) - min(X_j)) for positive indicators X_ij = (max(X_j) - X_ij) / (max(X_j) - min(X_j)) for negative indicators

For weight calculation using the entropy method: Y_ij = X_ij / ΣX_ij e_j = -k Σ Y_ij ln(Y_ij) d_j = 1 - e_j W_j = d_j / Σd_j

where k = 1/ln(m), m represents the number of evaluation years, and n represents the number of indicators.

Based on the above calculations, the weights for···ecological environment vulnerability indicators and···human socio-economic poverty indicators in Gansu Province were determined.

The index system of coupling relationship between eco-environmental vulnerability and poverty in Gansu Province

The weight of the measure index of the coupling relationship between ecological environment vulnerability and poverty in Gansu Province

2.3 Data Sources

The data used in this paper mainly come from the China Economic and Social Development Statistical Database. Some data were obtained from secondary sources such as articles and reports. Missing data for individual years were supplemented using interpolation with adjacent year values. For example, the 1998 soil erosion control area was filled using the average of adjacent years; the 2014 population density was calculated using year-end total population divided by Gansu' s land area; the 2014 year-end commonly cultivated land area was filled using simple moving average method; and 1998-2004 data···

Energy consumption was calculated using total energy consumption divided by total industrial output value; water consumption was calculated using total water consumption···All values were converted using comparable prices. Poverty incidence rate was calculated using the proportion of impoverished population in the permanent population. Human capital was calculated using the proportion of students in regular secondary schools and regular higher education institutions in the total permanent population.

3. Temporal Analysis of Coupling Coordination Between Vulnerable Ecological Environment and Poverty in Gansu

Based on weights calculated by the entropy method and substituted into formula (2), the evaluation indices for Gansu' s vulnerable ecological environment and poverty were obtained. Using the coupling model, results were derived. From a temporal perspective, we analyze the changes in coupling degree and coupling coordination degree between Gansu' s vulnerable ecological environment and poverty from 2000-2014 to clearly describe their interaction.

The coupling coordination degree between Gansu' s vulnerable ecological environment and poverty showed a continuous improvement trend from 2000-2014, rising from 0.2355 in 2000 to 0.6293 in 2014. The relationship evolved from the maladjustment and decline 磨合期 (run-in period) to the coordinated development adaptation period, with the coordinated development type transitioning from "maladjustment and decline—poverty severely lagging" to "coordinated development—ecological environment slightly lagging."

Numerical simulation of the coupling of vulnerable ecological environment and poverty in Gansu province from 2000 to 2014

Based on the specific changes in the coupling coordination degree evolution of the dual system of vulnerable ecological environment and poverty, and according to classification standards, Gansu' s 2000-2014 development process can be divided into three stages:

Stage 1 (2000-2004): Low-level coupling coordination stage. During this period, Gansu' s dual system coupling degree values ranged between 0.4516-0.4721, with generally low overall levels. The relationship between vulnerable ecological environment and poverty was significant, but coordination degrees were all less than 0.4, with most years belonging to the "maladjustment and decline—poverty severely lagging" type. The poverty system evaluation index grew slowly, showing a declining trend in 2003. Overall, the poverty evaluation index was far lower than the vulnerable ecological environment evaluation index. During this period, the implementation of the Western Development Strategy significantly increased fixed asset investment in Gansu, promoting development of energy industries like coal and petroleum and infrastructure construction. However, since most impoverished populations were distributed in remote areas with harsh natural conditions, these poverty-stricken regions had backward infrastructure, severely insufficient development of other industries, and relied on "eating from the sky" as their main survival method. Therefore, as population increased, farmers continuously intensified environmental destruction while depending on water and soil resources. The environmental evaluation index grew slowly with an average growth rate of only 0.27263.

Gansu' s rural absolute impoverished population was···million, showing that the impoverished population remained large. In mountainous and deep gully areas, various factors caused Gansu' s poverty index to···Due to Gansu' s poor economic foundation, the coupling coordination degree of the two systems showed negative growth, with the two systems in a state of severe maladjustment and decline, and existing malignant coexistence. The fragile ecological environment deepened poverty, while poverty caused greater destruction to the fragile ecological environment. The two systems were trapped in this vicious cycle of "destroying ecological environment—causing poverty—further destroying ecological environment."

Stage 2 (2004-2012): Coupling coordination degree growth stage. During this period, the coupling coordination degree of Gansu's vulnerable ecological environment and poverty systems increased year by year, showing a high-speed growth trend with an average annual increase of 0.0876. The coupling degree growth showed···The two systems transitioned from "maladjustment and decline —poverty severely lagging" to "transition and reconciliation—poverty slightly lagging," and finally to "coordinated development—poverty slightly lagging." Both Gansu' s vulnerable ecological environment index and poverty index grew slowly year by year, but both showed slight declines in···and···years respectively.

[Figure 1: see original paper] Coupling evolution of vulnerable ecological environment and poverty in Gansu from 2000 to 2014

Although still in the run-in period, the two systems recovered to pre-···development levels in···The small gap between coupling degree and coordination degree during this stage indicated improvements in both ecological environment and poverty reduction. All parties began attaching importance to environmental protection. Since entering the new century, participatory whole-village advance-

ment poverty alleviation reduced Gansu' s absolute impoverished population from···million to···million, and low-income impoverished population from···million to···million. Industrial wastewater and solid waste emissions decreased, causing environmental quality to improve slightly with economic development. After 2004, Gansu committed to developing···The improvement in ecological environment and reduction in impoverished population indicated that Gansu began breaking the vicious cycle of "destroying ecological environment—causing poverty." However, the poverty evaluation index showed overall stability, susceptibility to external policy adjustments and natural disasters, and long recovery periods.

In···year, the dual system coupling degree value declined, and the poverty evaluation index also decreased. The reason was that the Wenchuan Earthquake in 2008 caused severe damage in some Gansu areas. The coupling degree and coordination degree in···year were 0.4732 and 0.4843 respectively. Although the coupling coordination degree rose slowly, coordination between the two systems remained···due to internal and external environmental influences, showing "transition and reconciliation—poverty slightly lagging."

Stage 3 (2012-2014): High-level coupling coordination—ecological environment lagging stage. The two systems entered the coordinated development stage, with the poverty evaluation index U exceeding the vulnerable ecological environment evaluation index U , showing "coordinated development —ecological environment slightly lagging." Gansu' s anti-poverty efforts have entered a higher-level poverty alleviation and development stage. The "1236" plan for poverty alleviation and development accelerated poverty reduction. Large government poverty alleviation fund investments promoted construction of infrastructure and industrialization in impoverished areas, achieving certain effects in livelihood development for farmers in poverty-stricken areas with remarkable poverty alleviation results. These factors caused the continuous rise in poverty evaluation index U . Forest and grassland areas increased in poverty-stricken regions. The proposal of targeted poverty alleviation in 2013 made poverty alleviation more precise. Gansu actively promoted environmentally friendly society construction, improved ecological environments in impoverished areas, and some industries recognized ecological importance, conducting environmental governance and restoration. The ecological environment consequently improved, strengthening the correlation between the ecological environment and poverty systems. The systems transitioned from the first stage' s maladjustment and decline state to coordinated development state, breaking the poverty vicious cycle and entering a virtuous cycle of ecological restoration and poverty reduction.

4. Spatial Distribution of Coupling Coordination Between Vulnerable Ecological Environment and Poverty in Gansu

Due to Gansu' s elongated terrain, three major river basins, and four climate types within its territory, internal differences are extremely significant, and

provincial temporal sequence comparisons differ from municipal spatial comparisons. Based on the temporal analysis of Gansu' s overall vulnerable ecological environment and poverty coupling, it is necessary to further refine and compare indicators for each city to better conduct horizontal comparisons of Gansu' s ecological environment and poverty conditions. Using Gansu' s 14 prefecture-level cities and autonomous prefectures in 2014 as horizontal comparison units, we obtained the comprehensive evaluation indices, coupling degrees, and coordination degrees of each city' s vulnerable ecological environment and poverty through the system coupling model calculation.

The 14 cities' coupling coordination degrees were divided into three types: ecological environment lagging type, poverty lagging type, and mixed ecological environment-poverty lagging type.

Coupling degree and coordination degree of vulnerable ecological environment and poverty in Gansu Province in 2014

[Figure 2: see original paper] Spatial distribution of coupling coordination of vulnerable ecological environment and poverty in Gansu Province in 2014

Poverty lagging type is mainly distributed in the contiguous destitute areas of central and southern Gansu. The poverty index evaluation scores of these cities are all lower than ecological environment index evaluation scores, showing severe poverty lagging. The high disaster-induced poverty return rate is the main reason causing the coupling coordination type in these areas to be maladjusted and poverty-lagging. Since southern Gansu is mostly accompanied by high mountains and hills, the terrain determines small arable land quantity and poor agricultural natural conditions. The fragile ecological environment in central Gansu causes harsh agricultural production conditions, low land unit output, and low total output, reducing income for local farmers who rely primarily on agriculture. The extensive development path in impoverished areas further aggravates ecological degradation. Coupled with low-end industrial pollution from cities, the already extremely fragile ecological environment becomes even more vulnerable.

Mixed ecological environment-poverty lagging type is mainly distributed in central and eastern Gansu. Lanzhou and Baiyin belong to the transition reconciliation—ecological environment lagging cities, while Pingliang and Qingyang belong to the transition reconciliation—poverty lagging cities. Lanzhou's poverty index comprehensive ranking is···, while its fragile ecological environment index comprehensive ranking is 11th among the 14 cities, indicating severe ecological environment destruction in Lanzhou. Air pollution sources in Lanzhou come from coal-burning smoke and dust emissions, and industrial wastewater from the petrochemical industry in Xigu District is discharged into the Yellow River or seeps into groundwater, directly polluting···Baiyin City, located in the transition zone from the Tengger Desert to the Loess Plateau, suffers severe soil erosion and low forest coverage. Baiyin' s heavy industries, primarily non-ferrous metal smelting and processing, discharge large amounts of pollutants, making

the ecological environment extremely fragile, coupled with historical environmental protection debts. This explains Baiyin' s low ecological environment index ranking among the 14 cities. The Pingqing area, integrating old revolutionary base areas, ethnic regions, and impoverished areas, is one of Gansu' s most widely distributed poverty areas with poor disaster resistance capabilities. Many impoverished counties have long exhibited an unbalanced development phenomenon where "poverty alleviation foundation is too fragile."

Ecological environment lagging type is distributed in the five Hexi cities within Gansu' s inland river basin. The biggest constraint on socio-economic development in this region is water resource shortage. Most cities in this area are economically developed cities in Gansu. After years of economic construction and poverty alleviation policy implementation, they have achieved sustained economic growth and poverty reduction. The mutual mitigation and coordinated development effects between ecological environment and poverty are evident. However, due to excessive resource exploitation by large chemical enterprises, the ecological environment in this region is relatively lagging. As typical resource-based cities, the ecological environment is extremely harsh.

5. Conclusions

Based on system coupling coordination theory, this paper constructed evaluation index systems and reverse measurement models for Gansu' s vulnerable ecological environment and poverty. By calculating coupling degree and coupling coordination degree, we studied the coupling coordination status between Gansu' s vulnerable ecological environment and poverty from spatio-temporal perspectives.

From a temporal perspective, Gansu' s coupling coordination degree between vulnerable ecological environment and poverty showed an overall upward trend. After three development stages, it evolved from the initial "maladjustment and decline—poverty severely lagging" type to the "coordinated development —ecological environment slightly lagging" type. The evolution of coupling between Gansu' s vulnerable ecological environment and poverty demonstrates that fragile ecological environments cause poverty. If the two systems cannot develop coordinately, local populations will struggle to escape poverty within the vicious cycle of "destroying ecological environment—causing poverty," while local fragile ecological environments will suffer deeper destruction. Conversely, poverty also exacerbates ecological environment destruction. Therefore, during Gansu' s poverty alleviation process, the correlation between poverty alleviation and ecological protection must be strengthened, starting from their interactive mechanism. Ecological environment governance should be a prerequisite for poverty alleviation to prevent fragile ecological environments from eroding economic development achievements.

From a spatial perspective, the non-equilibrium of coupling coordination degree between Gansu' s vulnerable ecological environment and poverty systems is

significant. The comprehensive differences in location and economic foundation among cities are important causes of spatial disparities. The spatial distribution of coupling coordination degree increases from southeast to northwest, mainly because ecological protection and poverty alleviation···or one side hinders and restricts the other. Examining the overall comprehensive development level of both systems, the five Hexi cities in western Gansu have high coupling coordination degrees, indicating high comprehensive development levels and good coordination between ecological environment governance and poverty alleviation, with mutually promoting benign development. Central and southern Gansu' s contiguous destitute areas have lower coupling coordination degrees, indicating mutual constraints between the two systems.

Gansu' s vulnerable ecological environment coexists with poverty. Future poverty alleviation efforts should fully emphasize ecological environment governance and protection, and achieve poverty reduction through local ecological environment governance to prevent those not yet impoverished from returning to poverty. Improving the coordination between ecological environment governance and poverty alleviation···

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