Pol. J. Environ. Stud. Vol. 32, No. 2 (2023), 1159-1175
DOI: *10.15244/pjoes/156359* ONLINE PUBLICATION DATE: 2023-01-13

Original Research

Assessing the Spatiotemporal Pattern for Sustainable Green Poverty Reduction Capability: A Case Study in Jiangxi Province, China

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Received: 13 July 2022
Accepted: 7 November 2022

Abstract

The rich ecological resources in underdeveloped resource-rich areas are difficult to transform into economic advantages under the system of low-cost resources, a priceless environment and high-priced industrial products, resulting in a backward economic development level, serious relative poverty and a possible return to poverty at any time. Correctly evaluating the effect of green poverty reduction in underdeveloped resource-rich areas holds great significance for reducing relative poverty and ending the phenomenon of returning to poverty. Taking Jiangxi Province as an example, this paper uses the entropy weight method and the coefficient of variation to calculate the green poverty reduction index and each subdimension index of 80 counties (cities/districts) in Jiangxi Province, and analyzes the characteristics of the province's spatial and temporal evolution. It is found that the green poverty reduction index of Jiangxi Province rises overall, but the regional differences are obvious, and the increase in each subdimension index leads to an increase in the green poverty reduction index. The increase in the economic poverty reduction index is the main reason. The regional differences will persist, and balanced development will not be achieved in the short term.

Keywords: underdeveloped resource-rich areas, economic poverty reduction, public services, environmental protection

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Introduction

Since the Industrial Revolution, the levels of science and technology have been continuously improving, the ability of human beings to use and transform nature has been continuously enhanced, and social productivity has developed rapidly. However, in the process of rapid economic development, human beings have neglected the natural carrying capacity of the ecological environment, contributing to an excessive utilization of natural resources and an excessive discharge of pollutants, which have led to great damage to the ecological environment and a global ecological crisis. The greenhouse effect, ozone layer destruction, acid rain, pasture degradation, soil erosion and desertification pose great threats to human survival and development, forcing people to look for a sustainable development path that harmonizes the economy, society and the environment [1].

Although in 2020 China had achieved comprehensive poverty alleviation under the existing standards, the development is uneven, and regional differences are obvious. Thus, there is a long way to go to consolidate the achievement of poverty alleviation and to reduce relative poverty [2]. Especially in underdeveloped resource-rich areas, the rich ecological resources in these areas are difficult to transform into economic advantages under the system of low-cost resources, a priceless environment and high-priced industrial products, resulting in a backward economic development level, serious relative poverty, and a possible return to poverty at any time. On this basis, it is very important to correctly evaluate the effect of green poverty reduction in underdeveloped resource-rich areas to eliminate the return to poverty phenomenon, reduce relative poverty, and promote the construction of an ecological civilization and common prosperity.

At present, there is no clear concept of "green poverty reduction" internationally, and no scholars have constructed an index system for green poverty reduction. However, there are related index systems for green growth, the green economy and poverty reduction [3-5]. The most representative system is a complete green growth index system covering the economy, the environment and human well-being constructed by the Organisation for Economic Co-operation and Development (OECD) [6]. This system is widely used in the Netherlands, South Korea, the Czech Republic, Mexico and other countries, and it includes 14 secondary indicators and 23 tertiary indicators. The United Nations Environment Programme (UNEP) [7] built a green economy measurement framework that mainly covers three aspects: economic transformation, resource efficiency, and social progress and human well-being. Compared with the green growth index system built by the OECD, it better reflects social progress and human well-being. Some scholars have constructed a poverty reduction index system and evaluated the actual effects of poverty alleviation projects implemented in different countries [8-10], providing a context for China's environmental protection and poverty alleviation work.

Scholars' research on the evaluation of the green poverty reduction effect in China is still in the exploratory stage, and the research results are inconclusive. The effect of green poverty reduction is measured and evaluated mainly by constructing an index system for green poverty reduction [11-13]. Many scholars have constructed green poverty reduction index systems from different perspectives. Among them, the most influential is China's green poverty reduction index system constructed by Professor Qi Zhang of Beijing Normal University [14]. In 2014, Professor Qi Zhang and his team released the Report on China's Green Poverty Reduction Index (2014), which introduced the ideas and principles of building China's green poverty reduction index system in detail and calculated and compared the green poverty reduction index of 11 contiguous destitute areas, such as the southern foot of the Greater Khingan Range, through subjective empowerment and weighting [15, 16]. Liang Ruyue [17] based on the cloud model theory, comprehensively considering social and economic factors, and constructed a rural tourism development performance evaluation system from four dimensions: tourism economic growth, tourism industry competitiveness, structural coordination and income benefits, used the analytic hierarchy process to determine the weight of the indicators, and analyzed the green poverty reduction index in the Wuling Mountain area of Chongqing. Du and Zhang [18] used the entropy weight method to construct a green poverty reduction index system based on two dimensions, i.e., the degree of development of the green economy and the poverty reduction effect of poverty alleviation and development, and they analyzed the green poverty reduction effect in Ningde city, Fujian Province, over the previous 10 years. Based on the background of green development, Wang [19] introduced a pressure–state–response (PSR) model to build a green poverty reduction index system. Based on China's green poverty reduction index, Attahiru and Ibrahim [20] constructed a green poverty reduction effectiveness index from the perspective of green development, and this index was used to measure the effectiveness of green poverty reduction in reducing poverty. Connors et al. [21] explored the establishment of a green poverty reduction index system based on the relevant evaluation indicators of green development and poverty governance effectiveness, and they improved and revised the index system based on the characteristics of the changes in different poverty reduction stages and policies. Many scholars have also referred to China's green poverty reduction index system to measure the green poverty reduction index of different regions [22-24].

In summary, the construction of a green poverty reduction index system for China is in the exploratory stage, and the evaluation dimensions mainly cover the fields of the green economy, the poverty reduction effect, environmental protection and social development, providing important references for this paper. Jiangxi Province is one of the four provinces in the National Ecological Civilization Construction Experimental Zone and has strong ecological comparative advantages in mountains, water, forests, fields, lakes and grasses. It is also a famous old revolutionary base area and underdeveloped area in which the regional development is unbalanced. We take 80 counties (cities/districts) in Jiangxi Province as an example to explore the spatial and temporal characteristics of the green poverty reduction index of Jiangxi Province and the long-term evolutionary trend of the regional differences.

This paper advances the literature by answering the following three important research questions. First, how can we correctly understand green poverty reduction and establish a scientific evaluation index system to effectively measure the effect of green poverty reduction in 80 counties (cities/districts) in Jiangxi Province? Second, what are the spatial and temporal characteristics of the green poverty reduction index of Jiangxi Province? Third, will the regional differences in the green poverty reduction index of Jiangxi Province disappear over the long run?

Materials and Methods

Study Area and Data Sources

Jiangxi Province includes 100 counties (cities/districts) (Fig. 1), such as Nanchang County and the Xinjian District. However, due to the serious lack of data on 19 municipal districts, such as the Wanli District and Gongqingcheng city, to ensure the credibility of the research results, the research area of this paper includes only 80 counties (cities/districts), such as Nanchang County, regarding which data can be obtained, and the study period is from 2001 to 2018. The research data mainly come from the China Statistical Yearbook, China County Statistical Yearbook, China Forestry and Grassland Statistical Yearbook, Jiangxi Statistical Yearbook, Nanchang Statistical Yearbook, Jiujiang Statistical Yearbook, Jingdezhen Statistical Yearbook, Shangrao Statistical Yearbook, Yingtan Statistical Yearbook, Fuzhou Statistical Yearbook, Ji'an Statistical Yearbook, Xinyu Statistical Yearbook, and Yichun Statistical Yearbook as well as the statistical bulletins of national economic and social development of counties (cities/districts). Some data are calculated based on yearbook data. PM2.5 data are analyzed by ArcGIS, based on the PM2.5 data released by the Atmospheric Composition Analysis Group of Dalhousie University in Canada. The data of this website are estimated by using data from NASA satellites and ground monitoring stations, and the accuracy is good. In addition, to eliminate the influence of inflation, the per capita GDP of each county (city/district) is adjusted based on the GDP deflator in 2000, and the per capita net income of rural residents, the disposable income of urban households and the per capita balance of residents' savings deposits are adjusted based on the consumer price index in 2000.

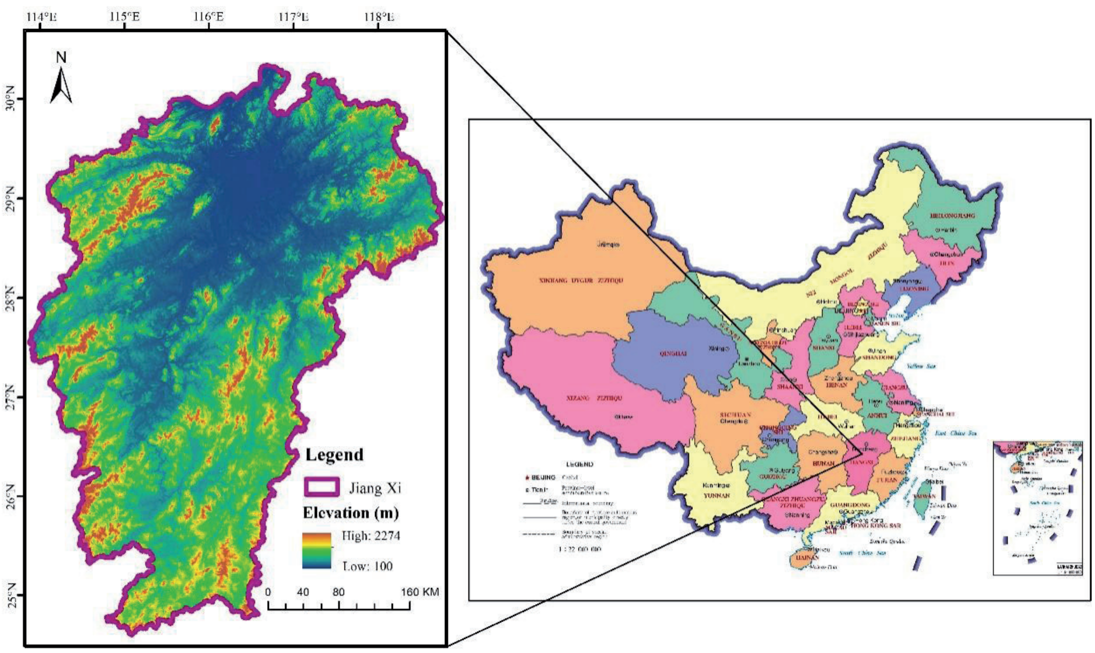

Fig. 1. The location of the study area.
Source of the map: The map is from the standard map of China issued by the Ministry of Natural Resources of the People's Republic of China, and the review number is GS (2019) 1684.

Construction of an Evaluation Index System for the Green Poverty Reduction Effect

In 2012, the United Nations Conference on Sustainable Development proposed the establishment of the Sustainable Development Goals (SDGs), and green development and poverty reduction are the prerequisites and paths to achieving the SDGs. Therefore, some scholars have introduced the concept of "green development" into poverty eradication work and proposed a new way of realizing poverty reduction, "green poverty reduction".

There is no clear concept of green poverty reduction internationally, and Chinese scholars' definition of green poverty reduction is mainly based on a precise poverty alleviation strategy, with the ultimate goal of ending absolute poverty. However, in 2020, China completely eliminated absolute poverty, and since then, the task of poverty alleviation has mainly been to alleviate multidimensional relative poverty with an insufficient development balance [25, 26]. With the transformation of poverty alleviation in China, the connotation of green poverty reduction will change accordingly. On this basis, this paper holds that, currently, while the concept of an ecological civilization is widely valued, poverty alleviation and development must resonate with ecological protection at the same frequency. Green poverty reduction is guided by the concept of green development, constantly expanding employment channels and income sources, improving the income level and endogenous motivation of low- and middle-income residents, promoting the coordinated development of the economy, society and the environment, and realizing green growth to benefit poor individuals.

According to the connotation of green poverty reduction, the key dimensions in the measurement of green poverty reduction mainly include three aspects: the economy, society and the environment. On this basis, this paper draws on the existing research results of many scholars, and determines the green poverty reduction index system in Jiangxi Province, which consists of 3 first-level indicators and 16 second-level indicators. The primary indicators consist of three aspects, i.e., economic poverty reduction, public services and environmental protection, and they comprehensively measure the effectiveness of green poverty reduction based on three aspects, i.e., the economy, society and the environment. The secondary indicators include per capita GDP, the urban-rural income gap ratio, the proportion of rural residents' per capita net income in the whole country, urban residents' the proportion of per capita disposable income in the whole country, per capita savings deposits, the incidence of rural poverty, the number of primary and secondary school students per 10,000 people, the number of beds in medical and health institutions per 10,000 people, the number of beds in welfare institutions per 10,000 people, the participation rate of basic medical insurance in urban and rural areas, the amount of chemical fertilizer applied per unit of arable land, the PM2.5 reduction rate, the reduction rate of industrial sulfur dioxide emissions, per capita water resources, the forest coverage rate and per capita forest area (see Table 1). The dimension of economic poverty reduction measures the improvement in the economic conditions of residents' families and is the most intuitive manifestation of regional material poverty. The public service dimension measures the supply level of public services such as education, medical care and social security in the region. The environmental protection dimension measures the improvement in the quality of the regional ecological environment.

Different from previous index systems, the green poverty reduction index system for Jiangxi Province constructed in this paper fully reflects the background of the period of the transition from ending absolute poverty to alleviating relative poverty in poverty alleviation as well as the characteristics of Jiangxi Province in terms of being rich in water resources, high in forest coverage, difficult to develop and highly likely to return to poverty after eliminating poverty. The system sets not only indicators reflecting the absolute degree of poverty in the region, such as the incidence of poverty, per capita GDP and the per capita balance of residents' savings deposits, but also indicators reflecting the relative degree of poverty of the region, such as the income gap ratio between urban and rural areas, the proportion of rural residents' net income in the whole country and the proportion of urban residents' net income in the whole country, to measure the sustainability of absolute poverty alleviation in Jiangxi Province and the relative degree of poverty compared with the national average. In the process of selecting specific indicators, we mainly refer to the China Green Poverty Reduction Index Report (2016) and the poverty reduction effectiveness measurement index system. Along with the rich characteristics of water resources and forest resources in Jiangxi Province, new indicators such as the PM2.5 reduction rate, per capita water resources, the proportion of rural residents' net income in the whole country and the proportion of urban residents' per capita disposable income in the whole country are added.

Green Poverty Reduction Index Measurement

(1) Entropy weight method to determine weights

The entropy weight method is an objective weight method that determines the weight value based on the amount of information provided by indicators. The greater the amount of information provided is, the greater the role in the comprehensive evaluation, and the greater the weight is [27, 28]. The specific calculation steps are as follows.

First, we should standardize the indicator s_{ij}. When s_{ij} is a positive indicator, its normalization formula is:

Table 1. Evaluation index system for green poverty reduction in Jiangxi Province.

Primary Indicators	Secondary Indicators	Indicator Properties	Weights
Economic Poverty Reduction	Per capita GDP (yuan)	+	0.1194
	Urban-rural income gap ratio (%)	-	0.0244
	Proportion of the per capita net income of rural residents in the whole country (%)	+	0.0687
	Proportion of the per capita disposable income of urban residents in the whole country (%)	+	0.0244
	Balance of savings deposits per capita (yuan/person)	+	0.0907
	Incidence of rural poverty (%)	-	0.0299
Public Services	Number of primary and secondary school students per 10,000 people (people/10,000 people)	+	0.0400
	Number of beds in medical and health institutions per 10,000 people (beds/10,000 people)	+	0.1014
	Number of beds in welfare institutions per 10,000 people (beds/10,000 people)	+	0.1122
	Participation rate of urban and rural basic medical insurance (%)	+	0.0660
Environmental Protection	Application amount of chemical fertilizer per unit of arable land (tons/1,000 hectares)	-	0.0104
	PM2.5 reduction rate (%)	+	0.0406
	Reduction rate of industrial sulfur dioxide emissions (%)	+	0.0213
	Per capita water resources (100 million cubic meters/10,000 people)	+	0.1128
	Forest coverage rate (%)	+	0.0316
	Per capita forest area (ha/person)	+	0.1062

$$s_{ij} = \frac{x_{ij} - x_{i\min}}{x_{i\max} - x_{i\min}} \quad (1)$$

When the indicator is negative, the normalization formula is:

$$s_{ij} = \frac{x_{i\max} - x_{ij}}{x_{i\max} - x_{i\min}} \quad (2)$$

Here, $x_{i\,max}$ represents the maximum value of the i-th indicator, $x_{i\,min}$ represents the minimum value of the i-th indicator, x_{ij} is the indicator value of the i-th indicator in year j, and s_{ij} is the i-th indicator's standardized indicator value in year j.

To unify and facilitate the calculation, the standardized values are shifted, and the formula is as follows:

$$r_{ij} = H + s_{ij} \quad (3)$$

Here, H is the magnitude of the index translation, which is generally taken as 1.

Then, the standardized data are used to construct the indicator data relationship matrix R.

$$R = \left(r_{ij}\right)_{m\times n} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (4)$$

In the formula, R is composed of the standardized indicator data, m represents the number of evaluation indicators, and n represents the number of years of the evaluation indicators.

Based on Equation (4), the entropy value e_i of the i-th indicator is calculated based on the entropy weight method:

$$e_i = -\frac{1}{\ln n}\sum_{j=1}^{n}\left(f_{ij}\ln f_{ij}\right) \quad (5)$$

$$f_{ij} = r_{ij}\Big/\sum_{j=1}^{n} r_{ij} \quad (6)$$

The formula for calculating the weight w_{1i} of each evaluation index is as follows.

$$w_{1i} = \frac{1-e_i}{m-\sum_{i=1}^{m} e_i} \tag{7}$$

(2) Coefficient of variation to determine weights

The coefficient of variation is the ratio of the mean value of an indicator to its standard deviation, which can effectively reflect the gap between each indicator. The coefficient of variation method directly obtains the weight value by calculating the information of various indicators, which is an objective method for calculating the weight. The calculation process is as follows.

The formula for calculating the coefficient of variation v_i of the i-th indicator is as follows.

$$v_i = \frac{\sigma_i}{\overline{\overline{x}}_i} \tag{8}$$

Here, σ_i represents the standard deviation of the i-th indicator, $\bar{x}_i$ represents the mean value of the i-th indicator, i = 1, 2, …, m, and the calculation formula of the weight ω_{2i} of each evaluation indicator is as follows:

$$w_{2i} = \frac{v_i}{\sum_{i=1}^{m} v_i} \tag{9}$$

(3) Coefficient of variation-entropy weight method combined weight

Since the entropy weight method does not consider the influence between indicators when calculating the indicator weight, the weight may be distorted. To make the indicator weighting more reasonable, this paper draws on the practice of determining weights based on the entropy weight method and the coefficient of variation to obtain weight ω_i.

$$\min F = \sum_{i=1}^{m} w_i \left(\ln w_i - \ln w_{1i}\right) + \sum_{i=1}^{m} w_i \left(\ln w_i - \ln w_{2i}\right) \tag{10}$$

In the formula, $\sum_{i=1}^{m} w_i = 1, w_i > 0$. Based on the Lagrange multiplier, the optimization problem of the equation above can be solved to obtain weight ω_i.

$$w_i = \frac{\sqrt{w_{1i} \cdot w_{2i}}}{\sum_{i=1}^{m} \sqrt{w_{1i} w_{2i}}} \tag{11}$$

(4) Green poverty reduction index calculation

The green poverty reduction index is a comprehensive measure value that reflects the coordinated development of the regional economy, society and environment. Therefore, the comprehensive evaluation method is used to calculate the green poverty reduction index, and green poverty reduction index Y is finally obtained.

$$Y = R \times W = r_{ij} \times w_{ij} \tag{12}$$

Results

Reduction Index

Based on the entropy weight method and the coefficient of variation, this paper uses MATLAB software to calculate the green poverty reduction index of 80 counties (cities/districts) in Jiangxi Province from 2001 to 2018, as well as the three subdimension indices of economic poverty reduction, public services and environmental protection. Additionally, it reveals the temporal and spatial differences in the green poverty reduction index of Jiangxi Province. Because of the different weights of the primary indicators, i.e., economic poverty reduction, public services and environmental protection, to reflect the comparability among different dimensions, the weights of these indicators are normalized.

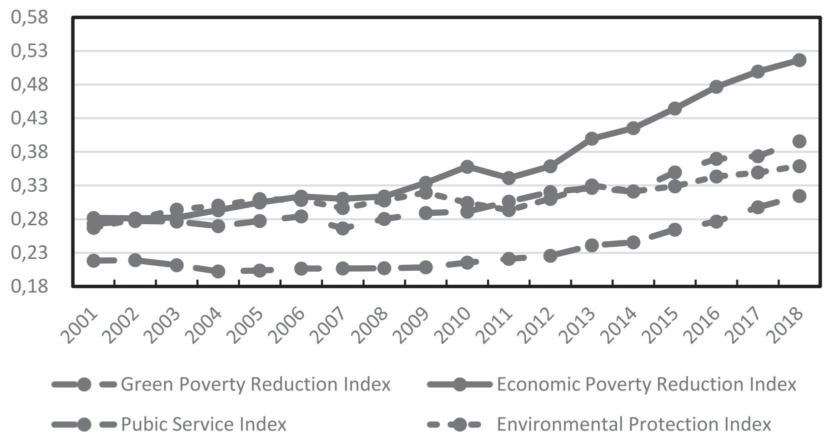

Fig. 2. Change trends of the green poverty reduction index and subdimension indices of Jiangxi Province, 2001-2018.

Spatial and Temporal Dynamic Changes

Based on the average value of the green poverty reduction index, economic poverty reduction index, public service index and environmental protection index of 80 counties (cities/districts) in Jiangxi Province over the years, the change trend chart of the green poverty reduction index and each subdimension index of Jiangxi Province from 2001 to 2018 (Fig. 2) is drawn to more clearly show the characteristics of the dynamic changes in the green poverty reduction index of Jiangxi Province.

As shown in Fig. 1, from 2001 to 2018, the green poverty reduction Index and the three sub-dimension indexes in Jiangxi Province showed a trend of ups and downs. The green poverty reduction index economic poverty reduction index, public service index and environmental protection index increased by 45.03%, 83.26%, 44.05% and 34.32%, respectively. The increase in each subdimension index jointly led to the rise in the green poverty reduction index, but the increase in the economic poverty reduction index is the main reason. From the specific changes in each year, the green poverty reduction index decreased only in 2003, 2004, 2007 and 2014 and increased in the other years. The overall change rate of the green poverty reduction index fluctuated little, and the largest increase in the green poverty reduction index was in 2015, up 8.88%, followed by 2018, up 5.94%. The green poverty reduction index fell the most in 2007, i.e., 6.29%. The economic poverty reduction index decreased only in 2002, 2007 and 2011 and increased in the other years. The overall change rate of the economic poverty reduction index fluctuated little, and the largest increase in the economic poverty reduction index was in 2013, up 11.43%, followed by 2016, up 7.27%. The economic poverty reduction index dropped the most in 2011, i.e., 4.69%. The public service index decreased only in 2003 and 2004 and increased in the other years. The rate of change of the public service index was generally small, and the largest increase in the public service index was in 2017, up 7.70%, followed by 2015, up 7.66%. The public service index decreased by 3.42% in 2003 and 4.37% in 2004. The environmental protection index fell only in 2006, 2007, 2010, 2011 and 2014 and increased in the other years. The change rate of the environmental protection index was generally small, and the largest increase in the environmental protection index was in 2013, up 6.49%, followed by 2012, up 5.65%. The largest decline in the environmental protection index was in 2010, with a decrease of 4.79%, followed by 2007, with a decrease of 3.91%.

Evolution of the Spatial Pattern

The last section mainly analyzed the change trend of the green poverty reduction index of Jiangxi Province from the perspective of the average value and could not reflect the evolutionary law of the spatial pattern of the green poverty reduction index of Jiangxi Province. On this basis, this section uses Stata 15.0 software and the kernel density function to estimate the dynamic evolutionary characteristics of the green poverty reduction index distribution in counties (cities/districts) in Jiangxi Province to reveal the evolutionary characteristics of the spatial pattern of the green poverty reduction index of Jiangxi Province.

(1) Evolutionary characteristics of the spatial pattern of the green poverty reduction index

First, taking the Gaussian distribution as the kernel function, the kernel density function of the cross-sectional distribution of the green poverty reduction index is obtained. On this basis, the kernel density curves of the green poverty reduction index distribution in Jiangxi Province are drawn for 2001, 2007, 2013 and 2018, as shown in Fig. 3. In the figure, the horizontal axis represents the value of the green poverty reduction index, and the vertical axis represents the density.

The kernel density estimation results of the green poverty reduction index in Fig. 3 show that the peak position of the kernel density curve of the green poverty reduction index moves to the left, the peak height increases, and the right tail shortens from 2001 to 2007. These results indicate that the overall level of the green poverty reduction index of Jiangxi Province decreased but that the degree of concentration of the green poverty reduction index of counties (cities/districts) increased. From 2007 to 2013, the curve continued to move to the right overall, and the peak height decreased, indicating that the overall level of the green poverty reduction index of Jiangxi Province increased during this period. However, the degree of concentration of the green poverty reduction index of counties (cities/districts) decreased, and the degree of dispersion increased. From 2013 to 2018, the curve continued to move to the right overall, and the peak changed from a "single peak" to "double peaks". These results indicate that the overall level of the green poverty reduction index of Jiangxi Province continued to improve. However, the degree of concentration of the green poverty reduction index of counties (cities/districts) decreased, and the degree of dispersion increased, gradually showing a polarization trend. In general, the overall level of the green poverty reduction index of Jiangxi Province increased from 2001 to 2018, and the degree of concentration of the green poverty reduction index of counties (cities/districts) decreased, showing no convergence characteristics.

(2) Evolutionary characteristics of the spatial pattern of the economic poverty reduction index

First, taking the Gaussian distribution as the kernel function, the kernel density function of the cross-sectional distribution of the economic poverty reduction index is obtained. On this basis, the kernel density curves of the economic poverty reduction index distribution in Jiangxi Province are drawn for 2001, 2007, 2013 and 2018, as shown in Fig. 4. In the figure, the horizontal axis represents the value of the economic

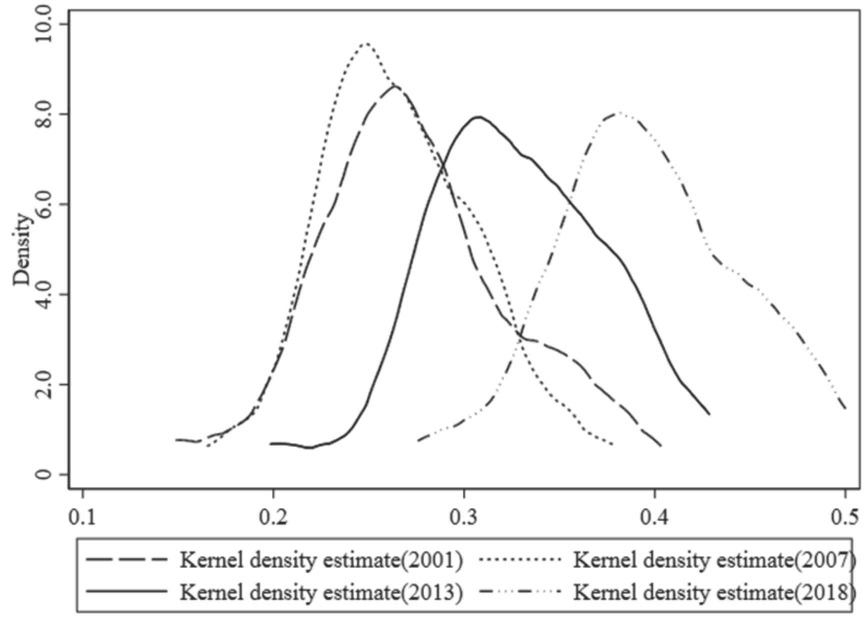

Fig. 3. Kernel density estimation of the green poverty reduction index.

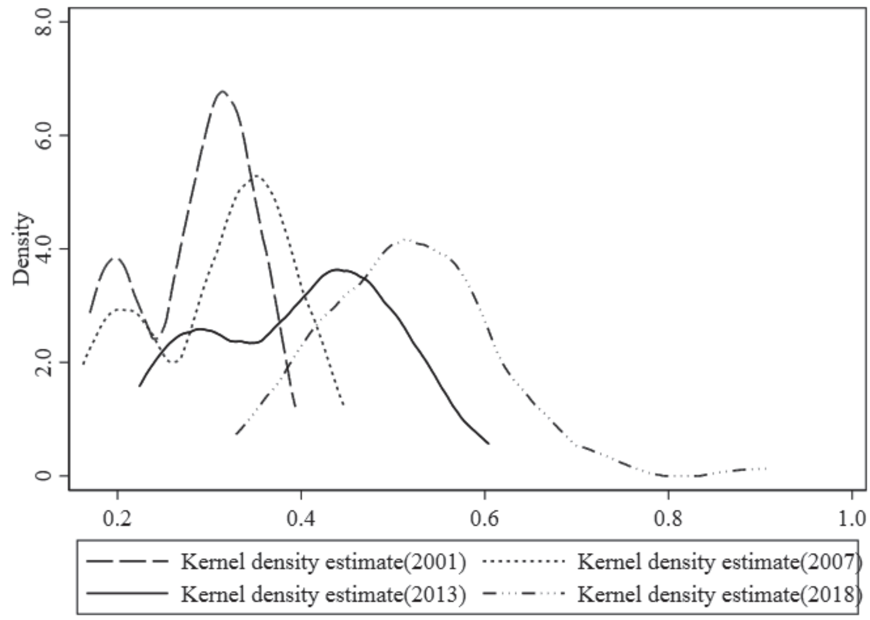

Fig. 4. Kernel density estimation of the economic poverty reduction index.

poverty reduction index, and the vertical axis represents the density.

The kernel density estimation results of the economic poverty reduction index in Fig. 4 show that the kernel density curve of the economic poverty reduction index moved to the right and that the peak height decreased from 2001 to 2007. These results indicate that the overall level of the economic poverty reduction index of Jiangxi Province improved. However, the degree of concentration of the economic poverty reduction index of counties (cities/districts) decreased and the degree of dispersion increased. From 2007 to 2013, the nuclear density curve of the economic poverty reduction index continued to move to the right overall, the peak height decreased, and the peak changed from a "peak" shape to a "wide peak" shape. These results indicate that the overall level of the economic poverty reduction index of Jiangxi Province continued to improve during this period but that the economic poverty reduction index of counties (cities/districts) increased at different speeds, resulting in a decrease in concentration and an increase in dispersion. From 2013 to 2018, the nuclear density curve of the economic poverty reduction index continued to move to the right overall, with the peak

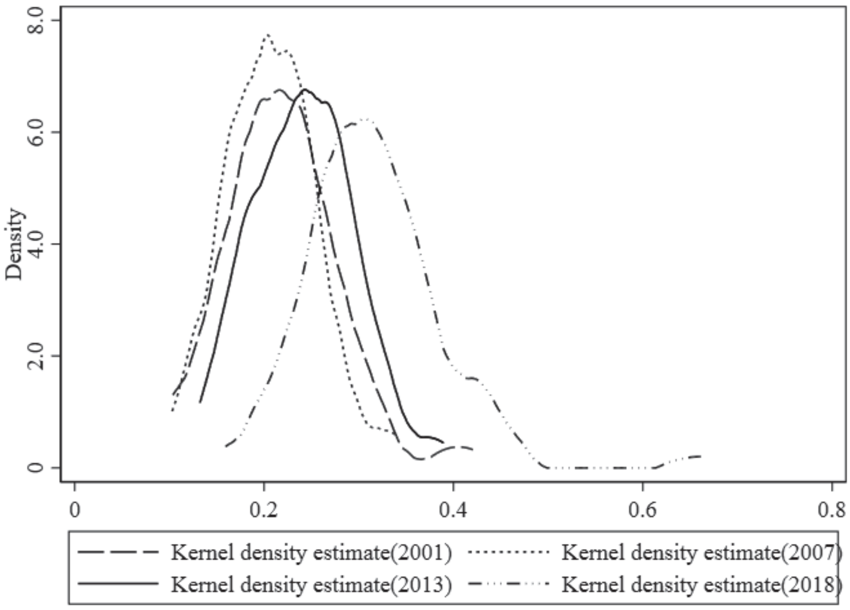

Fig. 5. Kernel density estimation of the public service index.

changing from "double peaks" to a "single peak" and the right tail extending continuously. These results indicate that the overall level of the economic poverty reduction index of Jiangxi Province continued to improve but that the economic poverty reduction index of some counties (cities/districts) increased rapidly, resulting in a widening gap in the economic poverty reduction index among counties (cities/districts). Overall, the overall level of the economic poverty reduction index of Jiangxi Province increased from 2001 to 2018, but the economic poverty reduction index of some counties (cities/districts) increased rapidly, which led to the widening gap and increasing dispersion of the economic poverty reduction index among counties (cities/districts).

(3) Evolutionary characteristics of the spatial pattern of the public service index

First, taking the Gaussian distribution as the kernel function, the kernel density function of the cross-sectional distribution of the public service index is obtained. On this basis, the kernel density curves of the public service index distribution in Jiangxi Province are drawn for 2001, 2007, 2013 and 2018, as shown in Fig. 5. In the figure, the horizontal axis represents the public service index value, and the vertical axis represents the density.

The results of the nuclear density estimation of the public service index in Fig. 5 show that the peak position of the nuclear density curve of the public service index did not obviously move from 2001 to 2007. Additionally, the peak height increased, indicating that the degree of concentration of the public service index of counties (cities/districts) of Jiangxi Province increased. From 2007 to 2013, the curve moved to the right overall, and the peak height decreased. These results indicate that the overall level of the public service index of Jiangxi Province improved during this period. However, the degree of concentration of the public service index of counties (cities/districts) decreased, and the degree of dispersion increased. From 2013 to 2018, the curve continued to move to the right overall. The peak height continued to decline, and the right tail continued to extend. These results indicate that the overall level of the public service index of Jiangxi Province continued to improve. However, the speed of improvement of the public service index of counties (cities/districts) was inconsistent, and the speed of improvement of the public service index in a few counties (cities/districts) was too fast, leading to the widening gap in the public service index of counties (cities/districts) and the decrease in the degree of concentration. In general, the overall level of the public service index of Jiangxi Province improved from 2001 to 2018, but the public service index in some counties (cities/districts) improved rapidly, which led to the widening gap and increasing dispersion of the public service index among counties (cities/districts).

(4) Evolutionary characteristics of the spatial pattern of the environmental protection index

First, taking the Gaussian distribution as the kernel function, the kernel density function of the cross-sectional distribution of the environmental protection index is obtained. On this basis, the kernel density curves of the environmental protection index distribution in Jiangxi Province are drawn for 2001, 2007, 2013 and 2018, as shown in Fig. 6. In the figure, the horizontal axis represents the environmental protection index value, and the vertical axis represents the density.

The results of the nuclear density estimation of the environmental protection index in Fig. 6. show that the peak position of the nuclear density curve of the environmental protection index moved to the left, the peak height increased, the peak changed from a "wide

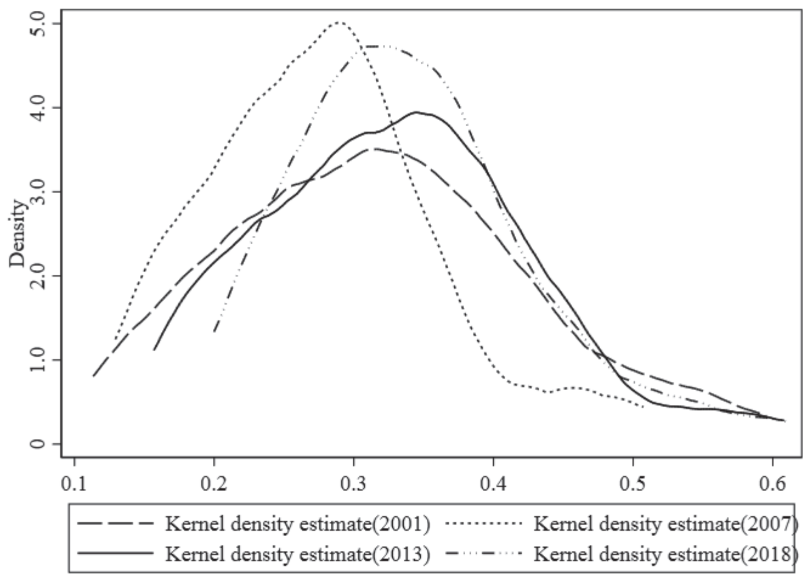

Fig. 6. Kernel density estimation of the environmental protection index.

peak" shape to a "sharp peak" shape, and the left tail shortened. These results show that the overall level of the environmental protection index of Jiangxi Province declined but that the degree of concentration of the environmental protection index of counties (cities/districts) increased. From 2007 to 2013, the curve crest moved to the right, the crest height decreased, and the crest changed from a "peak" shape to a "wide peak" shape. These results indicate that the overall level of the environmental protection index of Jiangxi Province improved during this period but that the speed of improvement of the environmental protection index of counties (cities/districts) was inconsistent, resulting in a decrease in concentration and an increase in dispersion. From 2013 to 2018, the position did not move obviously, the peak height increased further, and the left tail shortened. These results indicate that the environmental protection index level of counties (cities/districts) with a low environmental protection index level in Jiangxi Province improved, making the degree of concentration of the environmental protection index of counties (cities/districts) increase. However, it still did not show a convergence trend. In general, from 2001 to 2018, the environmental protection index of counties (cities/districts) with a low environmental protection index in Jiangxi Province increased rapidly, increasing the concentration of the environmental protection index of counties (cities/districts).

Long-Term Evolutionary Trend of the Regional Differences

The kernel density function estimation results above show that there are regional differences in the green poverty reduction index of Jiangxi Province. However, they fail to reveal whether the regional differences in the green poverty reduction index have existed for a long time. In this section, the Markov chain method is used to investigate the dynamic change law of the relative position of each county (city/district) in the cross-sectional distribution of the green poverty reduction index to reveal the long-term evolutionary trend of the regional differences in the green poverty reduction index.

(1) Analysis of the long-term evolutionary trend of the regional differences in the green poverty reduction index

Based on the calculation results of the green poverty reduction index of counties (cities/districts) in Jiangxi Province, the green poverty reduction index of counties (cities/districts) is discretized into four levels: the low level, medium-low level, medium-high level and high level. To analyze the change law of the regional differences in the green poverty reduction index, Markov matrices of the green poverty reduction index in the 2001-2009, 2009-2018 and 2001-2018 periods are calculated (Table 2). In Table 2, the number of samples indicates the number of counties (cities/districts) falling in each state level type in the initial period, the diagonal transition probability indicates the probability that the county (city/district) green poverty reduction index level type does not shift, and the nondiagonal transition probability indicates the probability that the county (city/district) green poverty reduction index level type shifts upward or downward.

Based on the Markov chain estimation results of the green poverty reduction index in Table 2, the following conclusions are obtained.

1. The fluidity of the green poverty reduction index is relatively low. Through observation, it is found that the diagonal probability value is higher than the nondiagonal probability value in the three different time periods. This results indicates that regardless of the time period, the level type of the green poverty

Table 2. Markov transition matrix of the green poverty reduction index.

Time period	Type	Number of samples	Low level	Low-medium level	Medium-high level	High level
2001-2009	Low level	260	0.8000	0.1962	0.0038	0.0000
	Low-medium level	198	0.2121	0.6212	0.1566	0.0101
	Medium-high level	120	0.0083	0.2000	0.6583	0.1333
	High level	62	0.0000	0.0000	0.2581	0.7419
2009-2018	Low level	99	0.6364	0.3434	0.0202	0.0000
	Low-medium level	160	0.0750	0.5438	0.3813	0.0000
	Medium-high level	230	0.0000	0.0652	0.6044	0.3304
	High level	231	0.0000	0.0000	0.0823	0.9178
2001-2018	Low level	359	0.7549	0.2368	0.0084	0.0000
	Low-medium level	358	0.1508	0.5866	0.2570	0.0056
	Medium-high level	350	0.0029	0.1114	0.6229	0.2629
	High level	293	0.0000	0.0000	0.1195	0.8806

reduction index tends to maintain the status quo and that the probability of transferring to other level types is relatively small. In addition, a shift in the green poverty reduction index level types of counties (cities/districts) mostly occurs in adjacent states, and the probability of leap-forward development is very small. These results indicate that it is difficult for the green poverty reduction index of counties (cities/districts) in Jiangxi Province to achieve leap-forward development.

2. The green poverty reduction index of each county (city/district) is concentrated. For the whole study period (2001-2018), the probability of counties (cities/districts) in the initial period maintaining the low level type in the following years is 0.7549, and the probability of an upward transfer is only 0.2451. The probability of counties (cities/districts) with a high level in the initial period maintaining a high level in the following years is 0.8806, and the probability of a downward transfer is only 0.1194. The probability of counties (cities/districts) that were in the low-medium level type and the medium-high level type in the initial period maintaining the low-medium level type and the medium-high level type in the following years is 0.5866 and 0.6229, respectively. In summary, the results show that the green poverty reduction index of Jiangxi Province has a certain degree of agglomeration.

With the help of the Markov transition matrix, the change law of the level types of the green poverty reduction index was analyzed above. On this basis, the long-term equilibrium state of the green poverty reduction index grade distribution is analyzed by calculating the initial distribution and steady-state distribution probabilities of the green poverty reduction index. Table 3 shows the initial distribution and steady-state distribution probabilities of the green poverty reduction index. From the probability value of the steady-state distribution of each level type, regardless of the type the green poverty reduction index belongs to at the beginning of the period, after a period of time, the probability that the green poverty reduction index of each county (city/district) belongs to the low level type is 0.3627, the probability that it belongs to the low-medium level type is 0.3124, the probability that it belongs to the medium-high level type is 0.1956, and the probability that it belongs to the high level type is 0.1294. These results indicate that the green poverty reduction index of Jiangxi Province is still scattered among the four level types. Comparing the initial distribution probability with the steady-state distribution probability, we see that the probability of the green poverty reduction index in the medium-high level type and high level type increases, while the probability in the low-medium level type and low level type decreases. Additionally, the proportion of the low level type and low-medium level type in the steady-

Table 3. Initial distribution and steady-state distribution probabilities of the green poverty reduction index.

Horizontal Type	Low level	Low-medium level	Medium-high level	High level
Initial Distribution	0.4125	0.3375	0.1500	0.1000
Steady-State	0.3627	0.3124	0.1956	0.1294

Table 4. Markov transition matrix of the economic poverty reduction index.

Time period	Type	Number of samples	Low level	Low-medium level	Medium-high level	High level
2001-2009	Low level	233	0.9356	0.0644	0.0000	0.0000
	Low-medium level	257	0.0195	0.8366	0.1440	0.0000
	Medium-high level	137	0.0000	0.0365	0.8978	0.0657
	High level	13	0.0000	0.0000	0.0000	1.0000
2009-2018	Low level	127	0.7795	0.2126	0.0079	0.0000
	Low-medium level	101	0.0297	0.5446	0.4158	0.0099
	Medium-high level	209	0.0000	0.0239	0.7034	0.2727
	High level	283	0.0000	0.0000	0.0106	0.9894
2001-2018	Low level	360	0.8806	0.1167	0.0028	0.0000
	Low-medium level	358	0.0223	0.7542	0.2207	0.0028
	Medium-high level	346	0.0000	0.0289	0.7804	0.1908
	High level	296	0.0000	0.0000	0.0101	0.9899

state distribution accounts for 67.51%. Therefore, if the green poverty reduction index of Jiangxi Province continues to change based on this trend, the difference in the green poverty reduction index among counties (cities/districts) will persist, and balanced development will not be achieved in the short term.

(2) Analysis of the long-term evolutionary trend of the regional differences in the economic poverty reduction index

To analyze the change law of the regional differences in the economic poverty reduction index, the Markov matrices of the economic poverty reduction index in the 2001-2009, 2009-2018 and 2001-2018 periods are calculated (Table 4). In Table 4, the number of samples indicates the number of counties (cities/districts) falling in each state level type in the initial period. The diagonal transition probability indicates the probability that the county (city/district) economic poverty reduction index level type remains unchanged in different time periods, while the nondiagonal transition probability indicates the probability that the county (city/district) economic poverty reduction index level type shifts upward or downward.

Based on the Markov chain estimation results of the economic poverty reduction index in Table 4, the following conclusions are obtained.

1. The fluidity of the economic poverty reduction index is relatively low. Through observation, it is found that the diagonal probability value is higher than the nondiagonal probability value in the three different time periods. This result indicates that regardless of the time period, the level of the economic poverty reduction index tends to maintain the status quo and that the probability of transferring to other level types is relatively small. In addition, a shift in the economic poverty reduction index level types of counties (cities/districts) mostly occurs in adjacent states, and the probability of leap-forward development is very small. These results show that it is difficult for the economic poverty reduction index of counties (cities/districts) in Jiangxi Province to achieve leap-forward development.
2. The economic poverty reduction index of each county (city/district) is concentrated. For the whole study period (2001-2018), the probability of counties (cities/districts) in the initial period maintaining the low level type in the following years is 0.8806, and the probability of an upward transfer is only 0.1194. The probability of counties (cities/districts) in the early stage of the high level type maintaining the high level type in the following years is 0.9899, and the probability of a downward transfer is only 0.0101. The probability of counties (cities/districts) that are in the low-medium level type and the medium-high level type in the initial period maintaining the low-medium level type and the medium-high level

Table 5. Initial distribution and steady-state distribution probabilities of the economic poverty reduction index.

Horizontal Type	Low level	Low-medium level	Medium-high level	High level
Initial Distribution	0.4375	0.4750	0.0875	0.0000
Steady-State	0.3959	0.4118	0.1743	0.0180

type in the following years is 0.7542 and 0.7804, respectively. In summary, the results show that the economic poverty reduction index of Jiangxi Province has a certain degree of agglomeration.

With the help of the Markov transition matrix, the change law of the economic poverty reduction index level type was analyzed above. On this basis, by measuring the initial distribution and steady distribution probabilities of the economic poverty reduction index, the long-term equilibrium state of the grade distribution of the economic poverty reduction index is analyzed. Table 5 shows the initial distribution and steady-state distribution probabilities of the economic poverty reduction index. From the probability value of the steady-state distribution of each level type, regardless of the type the economic poverty reduction index belongs to at the beginning of the period, after a period of time, the probability that the economic poverty reduction index of each county (city/district) belongs to the low level type is 0.3959, the probability that it belongs to the low-medium level type is 0.4118, the probability that it belongs to the medium-high level type is 0.1743, and the probability that it belongs to the high level type is 0.0180. These results indicate that the economic poverty reduction index of Jiangxi Province is still scattered among the four level types. Comparing the initial distribution probability with the steady-state distribution probability, we see that the probability of the economic poverty reduction index in the medium-high level type and high level type increases, while the probability of the low-medium level type and low level type decreases. Additionally, the proportion of the low level type and low-medium level type in the steady-state distribution accounts for 80.77%. Therefore, if the economic poverty reduction index of Jiangxi Province continues to change based on this trend, the difference in the economic poverty reduction index among counties (cities/districts) will persist, and balanced development will not be achieved in the short term.

(3) Analysis of the long-term evolutionary trend of the regional differences in the public service index

To analyze the change law of the regional differences in the public service index, the Markov matrices of the public service index in the 2001-2009, 2009-2018 and 2001-2018 periods are calculated (Table 6). In Table 6, the number of samples indicates the number of counties (cities/districts) falling in each state level type in the initial period. The diagonal transition probability indicates the probability that the county (city/district) public service index level type remains unchanged in different time periods, while the nondiagonal transition probability indicates the upward or downward transition probability of the county (city/district) public service index level type.

Based on the Markov chain estimation results of the public service index in Table 6, the following conclusions are obtained.

1. The fluidity of the public service index is relatively low. Through observation, it is found that the diagonal probability value is higher than the nondiagonal probability value in the three different time periods. This result indicate that regardless of the time period, the level type of the public service index tends to maintain the status quo and that the probability of transferring to other level types is relatively small. In addition, a shift in the public service index level types of counties (cities/districts) mostly occurs in adjacent states, and the probability of leap-forward development is very small, which shows that it is difficult for the public service index of counties (cities/districts) in Jiangxi Province to achieve leap-forward development.
2. The public service index of each county (city/district) is concentrated. For the whole study period

Table 6. Markov transition matrix of the public service index.

Time period	Type	Number of samples	Low level	Low-medium level	Medium-high level	High level
2001-2009	Low level	231	0.7836	0.1991	0.0087	0.0087
	Low-medium level	186	0.2473	0.5215	0.2043	0.0269
	Medium-high level	143	0.0210	0.3077	0.5245	0.1469
	High level	80	0.0250	0.0875	0.3375	0.5500
2009-2018	Low level	130	0.6692	0.2154	0.1000	0.0154
	Low-medium level	165	0.0727	0.5939	0.2970	0.0364
	Medium-high level	205	0.0146	0.0927	0.5707	0.3220
	High level	220	0.0045	0.0091	0.0727	0.9136
2001-2018	Low level	361	0.7424	0.2050	0.0416	0.0111
	Low-medium level	351	0.1652	0.5556	0.2479	0.0313
	Medium-high level	348	0.0172	0.1810	0.5517	0.2500
	High level	300	0.0100	0.0300	0.1433	0.8167

Table 7. Initial distribution and steady-state distribution probabilities of the public service index.

Horizontal Type	Low level	Low-medium level	Medium-high level	High level
Initial Distribution	0.3375	0.2125	0.2750	0.1750
Steady-State	0.2922	0.2423	0.2435	0.2221

(2001-2018), the probability of counties (cities/districts) in the initial period maintaining the low level type in the following years is 0.7424, and the probability of an upward transfer is only 0.2576. The probability of counties (cities/districts) with a high level in the initial period maintaining a high level in the following years is 0.8167, and the probability of a downward transfer is only 0.1833. The probability of counties (cities/districts) that are in the low-medium level type and the medium-high level type in the initial period maintaining the low-medium level type and the medium-high level type in the following years is 0.5556 and 0.5517, respectively. In summary, there is a certain degree of agglomeration in the public service index of Jiangxi Province.

With the help of the Markov transition matrix, the change law of the level type of the public service index was analyzed above. On this basis, the long-term equilibrium state of the public service index grade distribution is analyzed by measuring the initial distribution and steady distribution probabilities of the public service index. Table 7 shows the initial distribution and steady-state distribution probabilities of the public service index. From the probability value of the steady-state distribution of each level type, regardless of the type the public service index belongs to at the beginning of the period, the probability that the public service index of each county (city/district) belongs to the low level type is 0.2922, the probability of belonging to the low-medium level type is 0.2423, the probability of belonging to the medium-high level type is 0.2435, and the probability of belonging to the high level type is 0.2221. These results show that the public service index of Jiangxi Province is evenly dispersed among the four level types, the difference in the public service index among counties (cities/districts) will persist, and balanced development will not be realized in the short term.

(4) Analysis of the long-term evolutionary trend of the regional differences in the environmental protection index

To analyze the change law of the regional differences in the environmental protection index, Markov matrices of the environmental protection index in the 2001-2009, 2009-2018 and 2001-2018 periods are calculated (Table 8). In Table 8, the number of samples indicates the number of counties (cities/districts) falling in each state level type in the initial period. The diagonal transition probability indicates the probability that the county (city/district) environmental protection index level type remains unchanged in different time periods, while the nondiagonal transition probability indicates the upward or downward transition probability of the county (city/district) environmental protection index level type.

Based on the Markov chain estimation results of the environmental protection index in Table 8, the following conclusions are obtained.

Table 8. Markov transition matrix of the environmental protection index.

Time period	Type	Number of samples	Low level	Low-medium level	Medium-high level	High level
2001-2009	Low level	159	0.8113	0.1572	0.0314	0.0000
	Low-medium level	157	0.1592	0.5478	0.2166	0.0764
	Medium-high level	148	0.0203	0.3041	0.4527	0.2230
	High level	176	0.0000	0.0114	0.2443	0.7443
2009-2018	Low level	192	0.7813	0.1979	0.0208	0.0000
	Low-medium level	185	0.1568	0.5243	0.3135	0.0054
	Medium-high level	183	0.0109	0.2678	0.5137	0.2077
	High level	160	0.0000	0.0063	0.2375	0.7563
2001-2018	Low level	351	0.7949	0.1795	0.0256	0.0000
	Low-medium level	342	0.1579	0.5351	0.2690	0.0380
	Medium-high level	331	0.0151	0.2840	0.4864	0.2145
	High level	336	0.0000	0.0089	0.2411	0.7500

Table 9. Initial distribution and steady-state distribution probabilities of the environmental protection index.

Horizontal Type	Low level	Low-medium level	Medium-high level	High level
Initial Distribution	0.2875	0.2125	0.2125	0.2875
Steady-State	0.2653	0.2282	0.2372	0.2693

1. The fluidity of the environmental protection index is relatively low. Through observation, it is found that the diagonal probability value is higher than the nondiagonal probability value in the 2001-2009 and 2001-2018 periods. In the 2009-2018 period, the probability of the low level type transferring to the low-medium level type is the highest, and the probability of the other level types maintaining the status quo is the highest. In general, the level of the environmental protection index tends to maintain the status quo, and the probability of transferring to other levels is relatively small. In addition, a shift in the environmental protection level types of counties (cities/districts) mostly occurs in adjacent states, and the probability of leap-forward development is very small, which shows that it is difficult to achieve leap-forward development of the environmental protection index of counties (cities/districts) in Jiangxi Province.
2. The environmental protection index of each county (city/district) is concentrated. For the whole study period (2001-2018), the probability of counties (cities/districts) in the initial period maintaining the low level type in the following years is 0.7949, and the probability of an upward transfer is only 0.2051. The probability of counties (cities/districts) with a high level in the initial period maintaining a high level in the following years is 0.7500, and the probability of a downward transfer is only 0.2500. The probability of counties (cities/districts) that were in the low-medium level type and the medium-high level type in the initial period maintaining the low-medium level type and the medium-high level type in the following years is 0.5351 and 0.4864, respectively. In summary, the results show that the environmental protection index of Jiangxi Province has a certain degree of agglomeration.

With the help of the Markov transition matrix, the change law of the environmental protection index level types was analyzed above. On this basis, the long-term equilibrium state of the environmental protection index level distribution is analyzed by calculating the initial distribution and steady-state distribution probabilities of the environmental protection index. Table 9 shows the initial distribution and steady-state distribution probabilities of the environmental protection index. From the probability value of the steady-state distribution of each level type, regardless of the type the environmental protection index belongs to at the beginning of the period, after a period of time, the probability that the environmental protection index of each county (city/district) belongs to the low level type is 0.2653, the probability of belonging to the low-medium level type is 0.2282, the probability of belonging to the medium-high level type is 0.2372, and the probability of belonging to the high level type is 0.2693. These results shows that the environmental protection index of Jiangxi Province is evenly dispersed among the four level types, the differences in the environmental protection index among counties (cities/districts) will persist, and balanced development will not be realized in the short term.

Conclusions

The scientific and reasonable measurement of green poverty reduction is an important issue, and in this regard, the construction of a green poverty reduction index system is a core issue. By reviewing the relevant literature on green poverty reduction, we find that research on green poverty reduction in the English-language literature mainly focuses on conducting feasibility studies of environmental protection and poverty reduction. Additionally, it mainly focuses on the role of payment for ecosystem services in achieving the dual goals of ecological protection and poverty reduction. Currently, in China, green poverty reduction is relatively understudied, and studies on the combination of green development and poverty reduction are rare. The indicators used in the current literature include the human development index, green growth index, better life index, and the Poverty Alleviation Office monitoring index system. However, most of the indicators used may be flawed, as they oversimplify the measurement of green poverty reduction to a single dimension or a couple of dimensions, which is far from a comprehensive consideration of the actual complex situation of poverty reduction.

Green sustainable poverty reduction may be one of the best ways for resource-rich poverty-stricken areas to eliminate poverty. The current paper redefines the concept of green poverty alleviation based on the focus of China's post-poverty alleviation era, and it extracts three key dimensions to measure the effect of green poverty alleviation, including economic poverty alleviation, public services and environmental protection. Green poverty reduction is reflected not only in the improvement in income levels but also in the comprehensive effects on ecological protection and social development. Combined with the actual situation of contiguous destitute areas in underdeveloped provinces, the green poverty reduction index and three subdimension indices of 80 counties in Jiangxi Province from 2001 to 2018 are demonstrated in detail in our paper. In addition, the green poverty reduction effect and spatial differentiation characteristics of the counties are explained, and we further analyze the spatial and temporal differences in the counties. In the context of ecological civilization construction, the establishment of a regional green poverty reduction index system may advance existing theoretical research on green poverty reduction and provide implications for the practice of green poverty reduction in resource-rich poverty-stricken areas.

Taking Jiangxi Province as an example, this paper comprehensively evaluates the effect of green poverty reduction in underdeveloped resource-rich areas by using the entropy weight method and the coefficient of variation, and it analyzes its temporal and spatial evolutionary characteristics. It is found that the green poverty reduction index of Jiangxi Province has increased overall but that the regional differences are obvious. Based on the dynamic change characteristics, from 2001 to 2018, the green poverty reduction Index and the three sub-dimension indexes in Jiangxi Province showed a trend of ups and downs. Among them, the green poverty reduction index, economic poverty reduction index, public service index and environmental protection index increased by 45.03%, 83.26%, 44.05% and 34.32%, respectively. The increase in each subdimension index jointly led to the rise in the green poverty reduction index, with the increase in the economic poverty reduction index being the main reason. From the perspective of the spatial evolutionary characteristics, the overall level of the green poverty reduction index of Jiangxi Province increased from 2001 to 2018, showing no convergence characteristics. The economic poverty reduction index and public service index of some counties (cities/districts) improved rapidly, resulting in a widening gap between the economic poverty reduction index and public service index of counties (cities/districts) and an increase in the degree of dispersion. Additionally, the concentration of the environmental protection index of counties (cities/districts) increased. From the long-term evolutionary trend, the fluidity of the green poverty reduction index and each subdimension index of each county (city/district) is relatively low, regional differences will persist, and balanced development will not be achieved in the short term.

Acknowledgments

This work was supported by The National Social Science Fund of China (grant number 22CJY048). This work was also supported by The National Social Science Fund of China (grant number 22CZZ029).

Conflict of Interest

The authors declare no conflicts of interest.

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