ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research, volume 480
Proceedings of the 2020 5th International Conference on Modern Management and Education Technology (MMET 2020)

Coupling Vulnerability of Ecosystem and Poverty Occurrence—A Case Study of Poverty-Stricken Areas of Longnan in Qinba Mountain

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ABSTRACT
Our study was based on the division of the contiguously poverty-stricken areas of Qinba Mountain in China. To find the sustainable path of regional development, we used INVEST model to calculate the amount of ecosystem services in 27 areas of Longnan, to structure an index evaluation system, and to simulate the distribution space of regional ecosystem vulnerability. Coupling and coordinating model were also used to analyze the results of simulation and the incidence of poverty, and the coupling types and spatial distribution patterns were accurately to reach the following conclusions: The incidence of poverty in each area of Longnan was quite different, and the vulnerability of the poverty-stricken areas shows a spatial differentiation pattern, most of them are in the state of "high exposure" or "double stress". The relationship between vulnerability and poverty degree was obvious, the higher the vulnerability, the higher the risk of poverty. The coupling degree of vulnerability with poverty was spatially decreasing from north to south, and most areas have a high degree of coupling and coordinating, mainly in the south and middle of the study areas.
Keywords: *Occurrence of poverty, INVEST model, Vulnerability, Coupling analysis*

1. INTRODUCTION

In recent years, with the expansion of the global change, system vulnerability research, as one of the core issues in the research field, received extensive concern from governments and the world authority, such as the IPCC, IGBP, IHDP and other international organizations or international program. They make the issue as a priority and regard it as a sustainable direction at the end of the 20th century [1-5]. A relatively authoritative concept of system vulnerability was put forward by the IPCC in the third assessment report. They believed that vulnerability refers to the scope and degree of the system to sustained hazards from climate change, and it is a functional expression of various indicators within the system [6-10]. However, with further research, many scholars believe that the concept of vulnerability should not be limited to the discussion of natural system risks. "Human" as the most important interference variable of the environment should be given full attention. Scientists also should pay more attention to the vulnerability of the complex system caused by its coupling effects with the natural system [11-14]. For example, Gallopin proposes a common concept and framework for "vulnerability" in both natural and social systems, arguing that the world organization should broadly present a common theory of socio-economic change as an important agenda item for research of global change and vulnerability [15]. Lioubimtseva and Elena think vulnerability to climate change impacts is defined by three dimensions of human-environmental systems, such as exposure, sensitivity, and adaptive capacity [16]. At present, researches on ecosystem vulnerability mainly cover multi-dimensional fields such as nature, economy, society, culture, and system [17-20]. Due to the complexity of multi-system coupling, the connotation and simulation index of vulnerability have not yet formed a unified theory and method. Therefore, it remains a difficult problem in this field how to quantify the threshold of vulnerability and verify the evaluation results. In the human-land relationship, multiple "poverty" is the result of the multi-dimensional system, which is not only limited by the natural environment but also closely related to the society, culture, and system [21-23]. China has always attached great importance to poverty and made outstanding contributions to world poverty alleviation. The outline of poverty alleviation and development in rural China (2011-2020) issued by the State Council clearly points out that Chinese poverty alleviation tasks involve education, transportation, medical care, social security, population, ecology, and other aspects. Poor areas should not only get rid of economical poverty and achieve a well-off society but also pay attention to constructing an ecological environment, restoring natural grassland and forest land, and improving the adaptability to natural disaster risks, which coincides with the original goal of system vulnerability research. However, in the practice of poverty alleviation, ecological protection is often ignored as a marginal issue. In the long run, it will lead to increase development pressure on regional subsystems and stronger ecological sensitivity, which in turn will restrict economic growth and social stability, and then go against the sustainable development of poor areas. Research on the coupling relationship between ecosystem vulnerability and the occurrence of poverty is an important prerequisite for coordinating poverty alleviation work and ecological construction. It also benefits coordinating the balanced development of the system, implementing and scientifically evaluating the poverty alleviation work according to regional characteristics, and helping the deeply poor areas to move towards a sustainable path of ecological and economic society that is healthy and circular.

Our goal is to evaluate the coupling relationship between ecological vulnerability and economic poverty in poverty-stricken areas, explore whether the two primary driving factors are intrinsically related, find a sustainable development path for poor areas, improve the regional response capacity to natural disaster risks while developing economy, and provide more useful reference information for regional poverty alleviation work. In the paper, regional poverty and ecosystem vulnerability is seen as a whole issue, we think the ecological vulnerability types of poor areas is under the influence of human factors and natural factors, and provide a new perspective and thinking for poverty alleviation, which is typical and innovative.

2. OVERVIEW OF THE RESEARCH AREAS

Longnan is located to the southeast of Gansu province, which is in the transition zone from the second to the third step in mainland China. It is connected with Shaanxi in the east, Sichuan in the south, and strangles the three provinces of Shanxi, Sichuan, and Gansu. Its geographical position is between 104°01 '19 "to 106°35' 20" E and 32°35 '45 "to 34°32' 00" N. Longnan is the only region in Gansu province that belongs to the Yangtze system and has a subtropical climate. It is an important water and soil conservation area in the upper reaches of the Yangtze River. It is also an important ecological barrier on the eastern edge of the Qinghai-Tibet plateau and a key area for biodiversity protection in China. During the 12th Five-Year Plan Period, 80 towns and 822 key villages were selected from 183 key towns and 2433villages of the key areas for poverty alleviation, forming 27 contiguous poverty-stricken areas in Longnan. By the end of 2018, the poverty incidence rate of the whole city was as high as 13.5%, higher than the average level of the whole province.

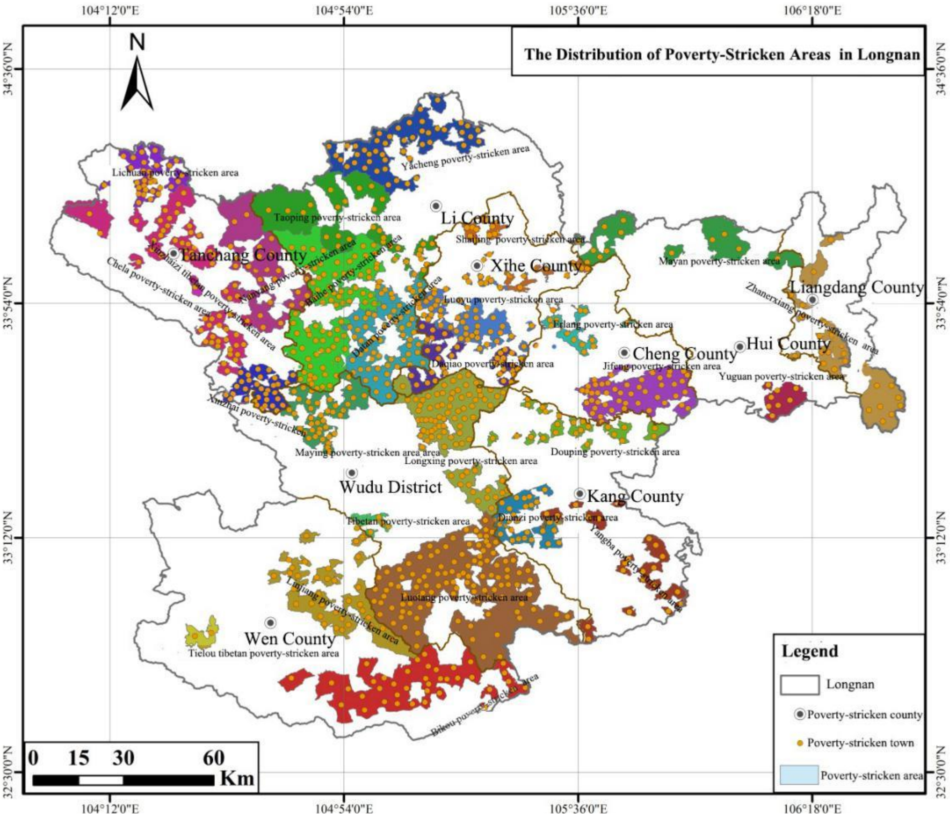

Fig.1 Distribution map of special poverty-stricken areas in Longnan

3. RESEARCH METHODS

3.1 Data sources

The social and economic data required by the research mainly come from Longnan statistical yearbook in 2017. The natural data came from China's meteorological science data sharing service. The data and sources required by the model are shown in Tab. 1. Other data, such as animal and plant names, were obtained by visiting The Big Data Center of Longnan. Poverty incidence data were obtained by visiting The Poverty Alleviation Office of Longnan.

Tab. 1 Model data sources and processing methods

Data Source	Required Data	Data Processing	Obtained Data	Resolution Ratio
China Meteorological Science Data Sharing Service Network	Average Daily Precipitation	Kriging Interpolation	Annual Rainfall	30m
China Meteorological Science Data Sharing Service Network	Wind Speed, Relative Humidity, Air Temperature, Sunshine Duration, etc.	Penman Model, Kriging Interpolation	Annual Potential Evaporation	30m

World Soil Database	Soil Texture Data	Nonlinear Fitting Soil AWC Estimation Model	Plant Available Water Content	30m
World Soil Database	Soil Depth	Space pickled membrane	Soil Depth	30m
Geospatial Data Cloud	Land Use Type	Digitalization, Rasterization	The Grid Diagram of Land Use type	30m
Geospatial Data Cloud	DEM Data	Hydrology module generation	The Map of Watershed Vector	—
Geospatial Data Cloud	DEM Data	Hydrology module generation	The Map of Watershed Vector	—
Hydrographic Station	Observations of Average Evaporation and Water Yield at Hydrological Stations	Model validation	Z Constant	—
Model Reference Data and The Results of Research in Similar Areas	Ground Code, Ground Description, Ground Vegetation Status, Maximum Depth of Vegetation, The Coefficient of Evaporation of Vegetation	—	Biophysical Table	—

3.2 Research methods

3.2.1 Vulnerability assessment model

Ecological vulnerability (VI) assessment in the study area is mainly simulated by the exposure (EI) - sensitivity (SI) - adaptability (AI) model [6]. Among them, exposure reflects the factors which are most easily to suffer from risk and stress, sensitivity indicates the probability that the system may turn into a disaster when it is attacked by adverse events, and adaptability refers to the ability of the system resisting disasters and recovering itself if damaged. These three interacting elements contained in vulnerability lead to the instability of the regional system. The functional relationship between the three factors is shown in formula 1. Vulnerability is positively correlated with exposure and sensitivity, and negatively correlated with adaptability. According to regional characteristics and relevant research results, the following indicators are selected as specific indicators for vulnerability assessment of the study area (as shown in Tab. 2). The data adopts range standardization to eliminate the dimension and confirms the weight of the index by combining the Entropy Weight Method and AHP Method [24]. Due to the limitation of space, the article is pushed to the process of specific references.

$$VI = EI + SI - AI \tag{1}$$

Tab. 2 Indicator system for vulnerability assessment of regional man land system

Domain layer	Elements layer	Index layer
Exposure	Economic pressure	Proportion of Agricultural Output
		Economic Density
	Population pressure	Proportion of Sloping Land above15 Degrees
		Urbanization Level
		Population Density
Sensitivity	Meteorological	Annual Sunshine Duration
		Extreme Weather Events
	Topography	Elevation Height
	Vegetation	Vegetation Coverage

	Disasters	Frequency of Natural Disasters
	Ecosystem Service Provision	Supply Capacity of water
		Purification Capacity of water
		Storage Capacity of Water and Soil
		Storage Capacity of Carbon
		Biodiversity
Adaptability	Regional Security	Fiscal Revenue
		Per Capita of Annual Return of farmland to Forest Subsidies
	Medical and Health Care	Rate of Participation of Rural Cooperative Medical care
	Education	College Degree or above
	Infrastructure construction	Road Density
	Food security	Per Capita Amount of Grain
	Human health	Mortality Rate

3.2.1.1Ecosystem services assessment

InVEST Model is an integrated assessment model of ecosystem services and trade-offs jointly developed by Stanford University Environmental Forest Research Institute, World Wildlife Fund (WWF) and Nature Conservation Society (TNC) in 2007 [25]. In this paper, the supply Capacity of water, purification Capacity of water, Storage Capacity of Water and Soil and Storage Capacity of Carbon modules of the model are used to measure the amount of regional ecosystem services.

Biodiversity refers to the variety species which include genetic variation and ecosystem complexity of all organisms (animals, plants and microorganisms) in a period and area. Its calculation formula is as follows:

$$BI = R_V \times 0.25 + R_P \times 0.25 + D_E \times 0.3 + R_T \times 0.2 \tag{2}$$

Where, BI is biodiversity index, R_V is the normalized wildlife richness, R_P is the normalized abundance of wild vascular plants, D_E is the diversity of ecosystem types after normalization, and R_T is the richness of threatened species after normalization. According to The National Environmental Protection Standard HJ623-2011 Regional Biodiversity Evaluation Standard of the People's Republic of China, the weight of biodiversity index in Longnan was determined by Delphi Method and AHP Method [26].

3.2.1.2 Coupling coordination degree model of ecological vulnerability and poverty occurrence

The coupling model is used to measure the degree of interaction and influence among various elements of the multi-system. In order to calculate the relationship between the system vulnerability and the occurrence of poverty in the poverty-stricken areas of Longnan, the paper established the coupling model [27], as shown below:

$$C_2 = 2\left\{\frac{u_1 \times u_2}{(u_1+u_2)^2}\right\}^{\frac{1}{2}} \tag{3}$$

Where, C2 is the coupling degree of ecosystem vulnerability and poverty, u1 is the poverty index ranking, and u2 is the vulnerability ranking, where the larger u1 is, the higher of poverty degree is, and the larger u2 is, the higher of system vulnerability degree is.

Although the degree of coupling can describe the degree of interaction between the two systems, it does not indicate whether the development of the two systems is coordinated. In this paper, a coordination degree model is introduced to show the level of coordination development between the two systems. The formula is as follows:

$$T = \alpha u_1 + \beta u_2 \tag{4}$$

$$D = C_2 \times T \tag{5}$$

Where, D is the coupling coordination degree, α and β are the undetermined coefficients of the system. Since poverty alleviation is as important as reducing system vulnerability, each coefficient is given a weight of 0.5.

4. RESULT ANALYSIS

4.1 Analysis of the occurrence characteristics of contiguous poverty-stricken areas in Longnan

Compared with the whole province, Longnan has a worse natural environment, infrastructure, education, and medical conditions. The causes of poverty are diverse. In order to avoid collinearity between the multidimensional poverty measurement and the ecosystem vulnerability assessment, the most intuitively representative factor "income" is selected as the standard of measurement for the occurrence of regional poverty.

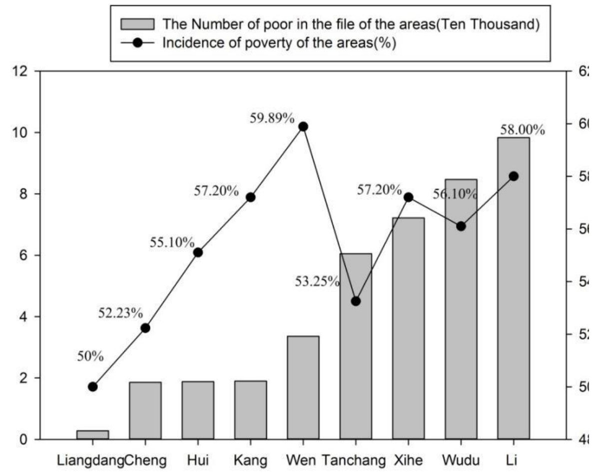

Fig. 2 The statistics of poverty in various counties and districts in Longnan

Longnan has a different population base, and the incidence of poverty is also different. Li County has the largest number of the poor. Wen County has the highest incidence of poverty. Li County consists of four poverty zones, involving 20 townships including 20 key poverty townships identified in 2001 and 176 registered impoverished villages identified in 2014. Wen County consists of three poverty zones, involving 13 townships including 13 key poverty townships determined in 2001 and 91 registered impoverished villages determined in 2014. Other areas where poverty is more serious are Wudu District, Kang and Hui Country.

4.2 Vulnerability assessment of poverty-stricken areas

4.2.1 Evaluation of ecosystem services in poverty-stricken areas

Based on the INVEST Model simulation results, the 25 poverty-stricken areas in Longnan have a total area of 9247.69 km2, accounting for 33% of the total land area. The total capacity of water supply in the impoverished areas is 1.833 billion m^3, accounting for 35% of the total. The output of nitrogen and phosphorus in Longnan is respectively between 0-3311.72 kg/km2 and 0-324.05kg/km2. The total amount of nitrogen and phosphorus in the 25 poverty-stricken areas respectively was 1083.43×104kg and 66.45×104kg, accounting for 34.74% and 38.29% of the total amount in Longnan. The total amount of Storage Capacity of Water and Soil in the 25 poverty-stricken areas was 9.66×108t, accounting for 33.95% of the total. The Storage Capacity of Carbon in the 25 poverty-stricken areas was 7,519.38 t, accounting for 39.49% of the total. The biodiversity of the poverty-stricken area in Longnan is between 0.23 and 0.63, and there are 7 poverty-stricken areas with high biodiversity, including Bikou, Linjiang, and Tilou Tibetan inhabited poverty-stricken areas of Wen Country, Maying, Luotang, Longxing and Tibetan inhabited poverty-stricken areas of Wudu District.

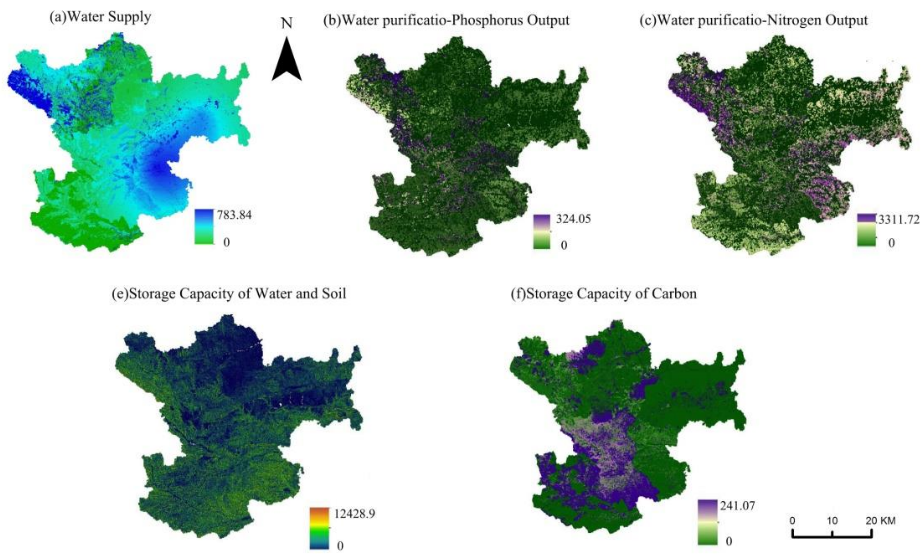

Fig. 3 Simulation of ecosystem output in Longnan

4.2.2 Spatial distribution pattern of vulnerability in poverty-stricken areas

The distribution pattern of vulnerability in the poverty-stricken areas of Longnan shows an insertion pattern distribution, in which the high vulnerability areas are concentrated in Bikou, Tielou and Linjiang poverty-stricken areas of Wen County, Jifeng and Erlang poverty-stricken areas of Cheng County. The two are far apart in space and present two different vulnerability patterns. The high vulnerability of Wen County is caused by high sensitivity and low adaptability. Natural disasters occur frequently in the area, and roads are often damaged by floods and mudslides. The fiscal revenue in the whole region is also at a low level, and the ability to deal with system risks is extremely poor. The high vulnerability of Cheng County is caused by high exposure and sensitivity. The climate in the region is cold and wet, which is extremely sensitive to external pressure. In addition, the population concentration and high level of urbanization increase the pressure of regional development. The region is highly vulnerable to both high exposure and high sensitivity.

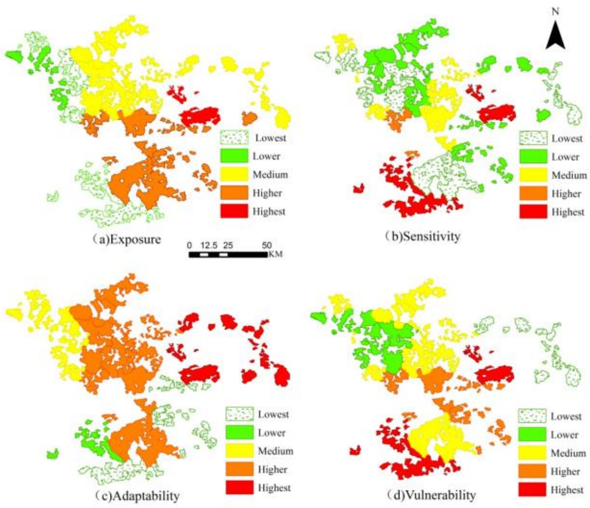

Fig. 4 The spatial pattern of vulnerability in poverty-stricken areas in Longnan

4.3 Coupling analysis between vulnerability and poverty

4.3.1 Classification of different types of vulnerability and poverty degree

According to the ranking of vulnerability and poverty, the different types of the poverty-stricken areas in Longnan are divided, where, the vulnerability index is expressed by GVI, and the poverty degree is expressed by GPI. When $-1 \leq$ GVI-PVI ≤ 1, the areas are defined as "double stress type" or "Double benefit type". If the grade of both indicators is greater than or equal to "medium", the areas are regarded as "Double stress type". Otherwise, the areas are regarded as "Double benefit type". When GVI and PVI>1, the areas are defined as "Ecological sub-health type ", When GVI-PVI<-1, the areas are regarded as "Economic development restricted type ".

4.3.2 Coupling analysis of vulnerability and poverty index

To further analyze the relationship between regional ecosystem vulnerability and poverty, according to the coupling coordination model, the coupling and coupling coordination index in 27 poverty-stricken areas are calculated, and the different types are divided. The spatial distribution pattern is shown in Fig. 4. Overall, the coupling degree between vulnerability and poverty shows a decreasing trend from north to south. Among them, there are 5 areas with extreme coupling degrees, accounting for 18.52% of the total, 10 areas with high coupling degrees, accounting for 37.04% of the total, 10 areas with medium coupling degrees, accounting for 37.04% of the total, and 2 areas with mild coupling degrees, accounting for 7.41% of the total. There are 3 extreme coordinated areas, accounting for 11.11% of the total, 12 high coordinated areas, accounting for 44.44% of the total, 9 mildly disordered areas, accounting for 33.33% of the total, and 3 highly disordered areas, accounting for 11.11% of the total.

Most of the poverty-stricken areas in Longnan are in a highly coordinated and mildly disordered state.

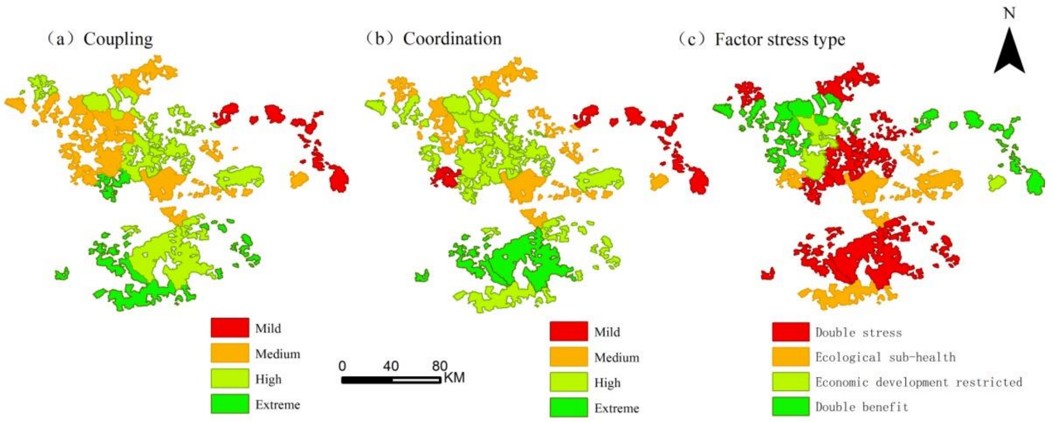

Fig. 5 The spatial distribution pattern of coupling degree of poverty area

On the basis of the coupling, the two indexes of coupling coordination should be further seen as a whole to investigate the degree of mutual influence and restriction. Compared with the evaluation result of the coupling, the coupling coordination would better reflect the essence of the issue, and the result would be more comprehensive and complete. The higher the degree of coupling coordination is, the greater the degree of correlation and the interaction between the two indicators is. The distribution of extremely coordinated and maladjusted areas is disordered. The key areas of the former are mainly distributed in Luotang and Linjiang areas in the south of the research area, which are basically recession coordination types. The poverty and the harsh environment restrict and influence each other, so the development model needs to break the cycle of environment and poverty. The region with extremely low coupling coordination degree occupies a small proportion in Longnan, which belongs to the "Double benefit type", accounting for only 11.11% of the research area; and the system vulnerability has little restriction on poverty, which is an ideal state in the regional development model.

5. CONCLUSIONS

Based on the division of the contiguous poverty-stricken areas in Qinba Mountain, the paper used INVEST model to calculate the amount of ecosystem services in 27 districts of Longnan, built an index evaluation system to simulate the space distribution of regional ecosystem vulnerability, used the union patterns, analyzed the correlation between them, discussed the intrinsic causes of poverty and ecology coupling coordination model to analyze the relationship between the simulation results and the incidence of poverty, divided the coupling and the spatial distribution of vulnerability, conclusions are obtained:

(1) The vulnerability of poverty-stricken areas shows a spatial differentiation pattern. The areas with high and low vulnerability are disordered. Most of the areas are in the state of "high exposure" or "double stress", where they are highly vulnerable.
(2) The vulnerability of the system in the extremely poverty-stricken areas is closely related to the poverty degree in terms of grade. The difference in grade is not obvious, which indicates that the higher the vulnerability is, the higher the risk of poverty will be. Most areas are coupled with "double stress".
(3) The degree of coupling between vulnerability and poverty is spatially decreasing from north to south. The coupling and coordination degree of most areas concentrated in the south and the middle area are relatively high. The mildly coupled or coordinated areas are small and mainly located in the eastern region, with a light degree of restriction on each other.

Poverty and ecological vulnerability are both manifestations and results of regional unsustainable development under the joint action of multidimensional factors, there is often a linear relationship between the internal causes of the two. In order to avoid invalid results, the paper uses "income" as the direct evaluation index to measure poverty degree, however, the underlying causes of poverty are often complex and changeable. Therefore, it is not objective to use only a single standard to measure the poverty degree for a region, which is one of the defects of the study and needs to be improved and discussed in future studies. The study area is located to western of China, which is also an important ecological barrier with deep poverty, geography is one of the main reasons for the development status. How to effectively identify the common influencing factors of ecological vulnerability and multidimensional poverty, maintain stable human-land relationship, develop sustainable ecological economy, and reduce economic poverty through environmental protection is one of the important directions in the future.

ACKNOWLEDGMENT

This research was funded by the National Natural Science Foundation of China, Grant No. 41801208; Innovation Fund project for Colleges and Universities in Gansu Province in 2020, Grant No. 2020B-094

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