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The nexus between regional eco-environmental degradation and rural impoverishment in China

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ABSTRACT

Regional environmental degradation and impoverishment interact and restrict each other. While acknowledging this relationship, little is known about the extent of their impact. By integrating multi-source data, this study used econometric models and spatial analysis techniques to explore the geographical distribution pattern of rural poverty in China, identify the key factors affecting rural improvement and quantitatively reveal the relationship between regional eco-environmental degradation and improvement. The results show that complex geographical environment, fragile ecological environment, frequent natural disasters, endemic diseases prevalent and the aging of social subjects do affect and even aggravate rural impoverishment in China. Terrain relief degree was identified as a determinative factor of rural poverty in China, and the rural poverty rate increases by 0.3–0.45% for every 1-m increase in terrain fluctuation. Further analysis showed that distribution of poverty-stricken population in rural China overlaps spatially with areas with fragile ecology, high incidence of geological disasters, poor geographical environment and aging population. The impact of eco-environmental degradation on poverty depends on the types of eco-environmental problems faced by the poor. The types of poverty-stricken areas in rural China can be divided into five categories: disaster-driven, endemic disease-driven, eco-environment degradation-driven, ecological protection restricted and grain-producing restricted. Poverty alleviation, disaster risk prevention, disease reduction and ecological environmental protection need to be promoted in collaboration. Differentiated and targeted anti-poverty measures for different types of poverty are urgently needed.

1. Introduction

Eliminating poverty and narrowing disparities have always been a worldwide problem (Heilig, Zhang, Long, Li, & Wu, 2006; Coulthard, Johnson, & McGregor, 2011; Liu, Liu, & Zhou, 2017; Zhou et al., 2019; Turok & Borel-Saladin, 2018). Extensive and in-depth work have been done about poverty from the perspectives of economics, politics and sociology, which is not only helpful to deepen the understanding of the mechanism of poverty, but also provides decision support for the formulation of anti-poverty policies (Tickamyer & Duncan, 1990; Fan, Hazell, & Thorat, 2000; Ellis & Mdoe, 2003; Du, Park, & Wang, 2005; Carter & Barrett, 2006; Ravallion & Chen, 2009; Alkire and Foster, 2011; Mani, Mullainathan, Shafir, & Zhao, 2013). Between 1990 and 2015, the number of people living in extreme poverty worldwide has dropped from 1.895 billion to 736 million (World Bank, 2018). Nevertheless, in the new era, global poverty alleviation are facing some challenges, such as extreme regional imbalance in poverty reduction progress (World Bank, 2018), the gradual agglomeration of poor people to specific areas (Cuaresma et al., 2018; Kennedy & Norman, 2005; Zhou & Liu, 2019), the slowdown of poverty reduction (World Bank, 2018), and the increasingly prominent problem of individual multi-dimensional poverty (Alkire & Foster, 2011; Decancq, Fleurbaey, & Maniquet, 2019), which seriously restrict the realization of the goal of sustainable development in 2030 (Cuaresma et al., 2018). By the end of 2015, sub-Saharan Africa have 56% of the world's poor and its number of poor people does not decrease but increasing (World Bank, 2018). This has forced Science magazine to focus on why poverty reduction efforts in Sub-Saharan Africa are almost zero since 2005 (Kennedy & Norman,

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2005). Facing the goal of sustainable development of the United Nations in 2030, it is urgent to go back to the distribution of the global poor, the formation mechanism of poverty and how to alleviate poverty, which provides opportunities and challenges for focusing on poverty issues from geographical perspective (Zhou, Guo, Liu, Wu, & Li, 2018; Zhou & Liu, 2019). Geography studies man-environment relationship with regional, comprehensive and space-time characteristics (Wu, 1991). As a branch of human geography, geography of poverty (GOP) is a discipline that studies the geographical distribution, spatial characteristics and driving mechanisms of poverty, and the poverty-environmental nexus as well as antipoverty ways (Zhou & Liu, 2019).

With human-environment relationship as core, geography has long been concerned about the poverty-environment interactions (Wu, 1991; Gray & Moseley, 2005). Previous studies have shown that there is a vicious circle between poverty and eco-environmental degradation (Althor, Mahood, Witt, Colvin, & Watson, 2018; Barbier & Hochard, 2018a,b; Bird & Shepherd, 2003; Cheng et al., 2018; Gray & Moseley, 2005; Liu et al., 2017; Scherr, 2000; Watmough, Atkinson, Saikia, & Hutton, 2016; Zhou et al., 2019). Impoverishment has been identified as a root cause of environmental degradation (Bremner, López-Carr, Suter, & Davis, 2010; Gray & Moseley, 2005; Lonergan, 1993). In turn, eco-environmental degradation destroyed the ecosystems and led to loss of farm lands, unemployment and diseases (Aluko, 2004). Regional impoverishment and environmental degradation coexist (Angelsen, 1997). Environmental degradation can often be related to poverty, but there is not necessarily a direct causal link (Jahan & Umana, 2003). But it is also argued that the environmental degradation had a direct impact on the level of poverty in small-scale fishing systems (Nayak, Oliveira, & Berkes, 2014). Resource degradation reduces the productivity of the poor and makes them more susceptible to shocks of extreme events (Gray & Moseley, 2005). Poverty is also one of the important factors that aggravate resource degradation (World Bank, 1996). Land degradation threatens the livelihood and the poor, but the degradation-poverty link is complex (Barbier & Hochard, 2018a,b). Alleviating the impact of poverty on ecosystem needed a radical socioecological reaction (Ioris, 2016). A recent study shows that poverty is the main cause of environmental degradation in developing countries (Masron & Subramaniam, 2019). Geographical and environmental factors impact and even determine the spatial distribution of the poor (Chen, Wu, He, Bi, & Wang, 2018; Zhou & Xiong, 2018). The impact of geographical environment on the regional poverty depend on the types of environmental problems faced by the poor (Reardon & Vosti, 1995). The existing theories reflecting the poverty-environment nexus mainly include geographic environmental determinism, geographic capital, poverty spatial trap and poverty isolation effect (Bird & Shepherd, 2003; Guriev & Vakulenko, 2015; Kraay & McKenzie, 2014; Liu et al., 2017). There is a consensus that poverty and environmental degradation are cause and effect each other, but these studies only qualitatively reveal the relationship between poverty and resource and environmental degradation, and still lack of quantitative empirical research conclusions.

China is one of the most prominent poverty-stricken countries in the world, and its distribution of poverty-stricken population has obvious geographical characteristics (Liu et al., 2017). Focusing on poverty from a geographical perspective helps to reveal the underlying mechanism of regional impoverishment (Zhou et al., 2018; 2019). Extensive and in-depth researches have been done to focus on China's poverty issues from a geographical perspective, such as geographical patterns and differentiational mechanisms of poverty, spatial poverty traps and geographical identification of multidimensional poverty-stricken areas (Bird & Shepherd, 2003; Gray & Moseley, 2005; Jalan & Ravallion, 2002; Li, Long, Tu, & Wang, 2015; Liu, Zhou, & Liu, 2016; Liu & Xu, 2016). The spatial scale of poverty research is gradually deepening from regional, provincial, country and village scales to households and even individuals (Du et al., 2005; Wan, 2007; Wang & Chen, 2017), focusing not only on rural poverty, but also on urban poverty (Chen et al., 2006, 2019; Gilbert, 2016; Hjorth, 2003; Hui, Zhong, & Yu, 2016, 2015; Jabeen & Guy, 2015; Li et al., 2019; Liu et al., 2017; Lo & Wang, 2018; Mitlin, 2003; Rakodi, 1995). These efforts certainly help enrich our understanding of the nature of poverty. Geographical environment is considered to be an important factor affecting poverty. However, it is recognized that fragile ecological environment, natural disaster and complex topography aggravate regional poverty, but few studies have quantitatively measured the environment-poverty nexus. The key aims of this study was to identify the dominant geographical factors affecting regional impoverishment and quantitatively reveal the relationship between regional eco-environmental degradation and impoverishment. Furthermore, the regional types of poverty in rural China are delineated, and the corresponding countermeasures for poverty reduction are put forward.

2. Theoretical framework

This study contributes to the existing literature on mechanism behind regional impoverishment. On the one hand, it assembles multiple databases to reveal the geographical patterns of poverty in China and their differentiation mechanisms. On the other hand, it helps policymakers make trade-off between poverty alleviation, disaster mitigation and ecological protection. Regional poverty or improvement is the result of the imbalance of factor coupling in the regional system of human-environment relationship. It is affected by many factors, such as geographical conditions, ecological environment and socio-economic level. According to the factors causing poverty, rural poverty in China includes ecological poverty, disease poverty, disaster poverty, economic poverty, institutional poverty and old-age poverty (Fig. 1).

Complex geographical environment, fragile ecological environment and natural disaster shocks usually lead to or aggravate regional poverty, which in turn further aggravates the destruction of the ecological environment and increases the possibility of disaster events (Akter & Mallick, 2013; Barbier & Hochard, 2018a,b; Bird & Shepherd, 2003; Gray & Moseley, 2005; Hallegatte, Vogt-Schilb, Bangalore, & Rozenberg, 2016). The two-way causality exists between disaster impact, ecological environment degradation and regional poverty. The eco-environmental degradation is mainly manifested in land desertification, soil erosion, rocky desertification, thinning of soil layer and decline of land capacity, thus affecting the income and livelihood of peasant households. Poverty promotes eco-environment deterioration and the deteriorating eco-environment further deepens poverty. Due to a lack of alternatives, farmers in fragile ecological areas are often forced to engage in unsustainable activities such as deforestation, overgrazing and agricultural production on marginal land, resulting in ecological degradation (Sietz, Lüdeke, & Walther, 2011). Conversely, environmental degradation reduces land productivity, affects farmers' income growth and increases the possibility of falling into poverty. Poverty-constrained options cause the poor to deplete resources in an unsustainable way (Holden, 1996). Rapid population growth leads to the overexploitation of marginal land (Dasgupta, Deichmann, Meisner, & Wheeler, 2005). This interaction of pauperization and environmental degradation forms a vicious circle. Actually, ecologically fragile zones are the most typical areas of environmental degradation and the most poverty-stricken regions (Liu et al., 2015; Tallis, Kareiva, Marvier, & Chang, 2008). In addition, ecological protection is also one of the important factors of regional poverty. Ecological protection zones are important water conservation zones and traditional cultural protection zones, which often need to make a trade-off between protection and development. Owing to its special ecological function, ecological reserves are often left undeveloped and impoverished (Sheppard, Moehrenschlager, McPherson, & Mason, 2010).

Natural disasters not only cause casualties and damage housing, infrastructure and public services, but also affect people's mental and physical health. Natural disasters can also damage farmland and infrastructure. Recovery after disasters requires a large amount of capital investment. It usually takes a long time for the affected areas to recover

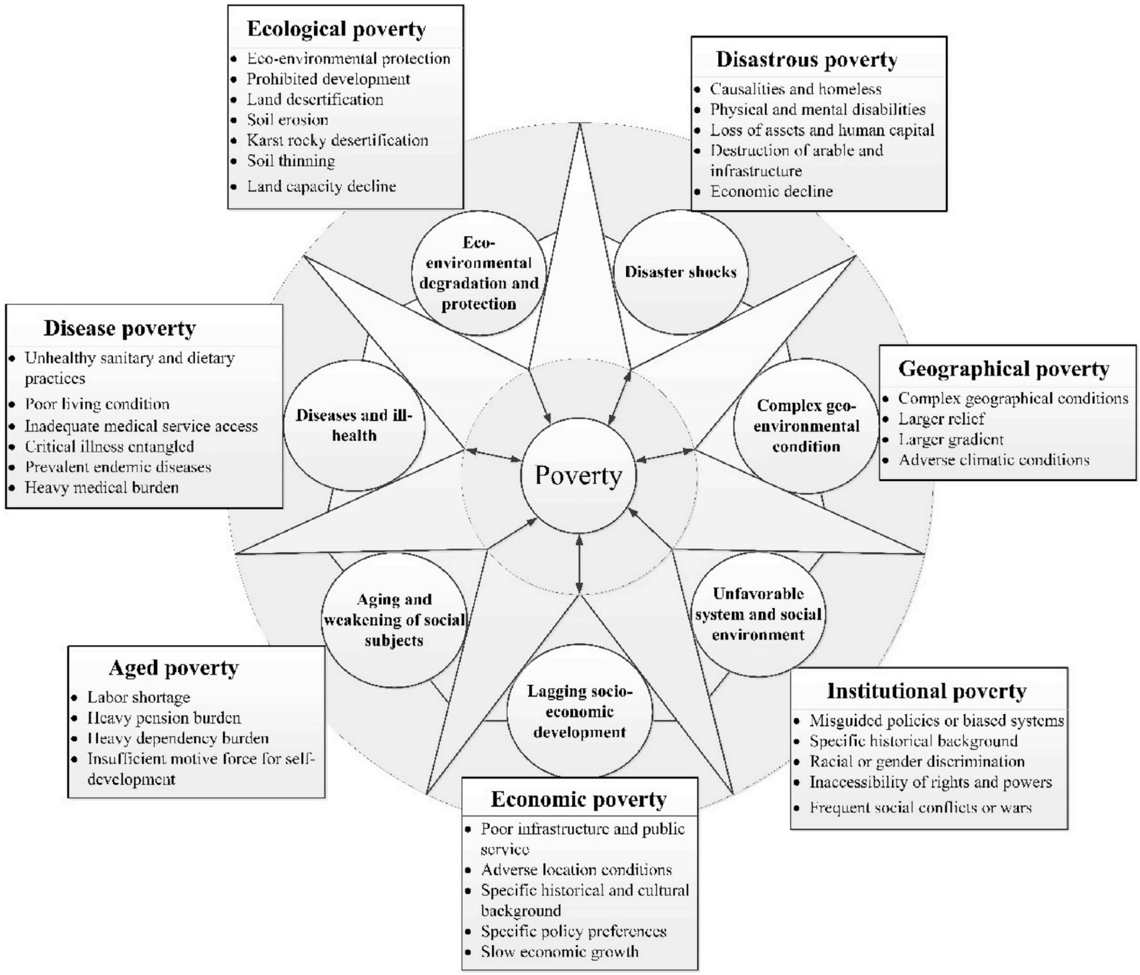

Fig. 1. Mechanism of regional poverty or impoverishment.

to the pre-disaster level of economic development. The loss of human capital and property the affected families further restrict their variable capacity to develop themselves, thus plunging them into poverty (Hallegatte et al., 2016).

Poverty and poor health are inextricably linked. Poverty is both a cause and a consequence of poor health. For the poor, ill-health is said to be fundamental cause of poverty, mainly because poor people are forced to live in unhealthy environments without decent shelter, clean water or adequate sanitation (Peters et al., 2008; Wen, Browning, & Cagney, 2003). In poverty-stricken areas, the level of medical service facilities is usually backward. Unhealthy not only leads to poverty, but also prolongs the duration of poverty (Sverdlik, 2011). Disease can also aggravate the medical burden of poor families, which in turn will lead to a lack of labor force and poverty. Thus, poverty and ill-health are generally believed to be have a bidirectional causality relationship (Bhutta, Sommerfeld, Lassi, Salam, & Das, 2014; Bonds, Keenan, Rohani, & Sachs, 2010; McIntyre, Thiede, Dahlgren, & Whitehead, 2006; Wagstaff, 2002). In addition, man is the subject of society and the object of individual poverty. Excessive aging will not only lead to labor shortage, but also increase the pension burden of family and society for the aged, resulting in the lack of endogenous power in economic development (Oris, Gabriel, Ritschard, & Kliegel, 2017). The old are vulnerable to natural disasters and prone to fall into poverty (Lefebvre, Pestieau, & Ponthiere, 2018; Zhou, Li, Wu, Wu, & Shi, 2014).

Unfavorable location conditions, backward infrastructure and public services, fragile ecological environment and frequent disasters generally lead to the slow economic development of a region (Chen et al., 2019; Liu et al., 2017; Long, Tu, Ge, Li, & Liu, 2016a; Mitlin, 2003). At the same time, in these areas, the information is blocked, the market is not open enough, the free flow of urban and rural elements is not smooth, and the aging population leads to the lack of endogenous development power, thus forming a vicious circle, i.e., poverty→slow economic development→falling into a more poverty-stricken state. Of course, it can't be denied that most of the economic poverty-stricken areas belong to the overlapping areas of ecological, disaster and aging poverty. In addition, misguided policies or biased systems, racial or gender trends, lack of rights, frequent social conflicts, wars, political uncertainty and other factors in a country or region can also lead to social instability and increase poverty in the region.

3. Materials and methods

3.1. Data sources

The data used in this study include three types: statistical or census data, vector and raster data. The statistics include data on the incidence of poverty or poor population at the county level by the end of 2014, which was provided by China's provincial poverty alleviation departments and calculated by per capita net income of farmers in counties based on the national poverty line (2300-yuan RMB). The census data come from the data of China's 2010 population census by county, which is used to calculated the rural aging rate of each county. The impact data of natural disasters such as earthquakes, landslides and debris flow from 1949 to 2018 are available from the Emergency Events Database (EMDAT) (https://www.emdat.be). Vector spatial distribution datasets include geological hazards (debris flow, landslide), karst, endemic diseases, key ecological function areas (KEFA) and nature reserves (NRs). The data on debris flow distribution were sourced from "China's Debris Flow Distribution and Disaster Risk Zoning Map" (http://www.mountain.csdb.cn). The distribution map for landslide hazards was obtained from Center for International Earth Science Information Network (CIESIN) of Columbia University (Dilley et al., 2005). The 2015 seismic ground motion parameter zonation map was obtained from the Chinese Earthquake Administration, which contains the distribution of peak ground acceleration (PGA). Referring to the previous studies (He et al., 2018; Wu, Wang, He, Wang, & Li, 2017), we defined the area where the PGA value in the seismic ground motion parameter zonation map is greater than 0.2 g as the earthquake-prone area. The data on the Karst distribution data in southern China comes from China Karst Science Data Center (www.karstdata.cn). The spatial distribution of the KEFA and the NRs are available from the National Main Function Zone Planning (http://www.gov.cn/zwgk/2011-06/08/content_1879180.htm). The distribution datasets on Keshan disease, Kashin-Beck disease and endemic fluorosis are from the Atlas of Endemic Diseases and Environment of China (AEDEC) (CCAEDE, 1989). The raster datasets on soil erosion (1 km resolution), land desertification (100 m resolution) and digital elevation model data (DEM, 90 m resolution) were provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn).

3.2. Methods

3.2.1. Data processing

The slope grade and terrain relief are extracted from DEM data. Usually, the slope gradient can divide into five grades, i.e., micro-slope (less than 5°), lighter gentle slope (5–8°), gentle slope (8–15°), lighter steep slope (15–25°) and steep slope (more than 25°) (GAQSIQC, 2009). Land reclamation is strictly prohibited in places with slopes greater than 25° in China. Accordingly, we calculated the slope area of each county with a slope greater than 25° and above. Topographic undulation or terrain relief refers to the difference between the highest elevation and the lowest elevation in a specific area, reflecting the relative difference of the ground. The terrain relief of each county is also calculated from DEM data. The 2862 county-level boundary data (excluding Taiwan, Hong Kong and Macro) are from the Resource and Environment Data Center of CAS. Based on the Chinese AEDEC, the distribution of endemic disease-prone areas was obtained by digitizing the geographic information system.

3.3. Multiple regression analysis

We used the multivariate linear regression model to explore the impact of geographical environment, endemic diseases, aging and other factors on rural poverty, and identify the leading factors affecting rural impoverishment. In this model, the dependent variable is the incidence of poverty, and the independent variable includes slope, terrain relief, precipitation, ecological environment, ecological protection, endemic disease areas, aging rate and so on. The regression model can be expressed as follows:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \cdots + \beta_{15} X_{15} + \varepsilon$$

Here, Y_i is incidence of poverty in rural areas; β_0 is a constant term; β_i is regression coefficient; X_j is the independent variables; ε is the error term. The independent variables include terrain relief degree (*Relief*), the proportion of area above 25° slope in each county (*slope25*), the counties with an average annual precipitation of less than 200 mm (*PA200*), the proportion of soil erosion area above intensity to the area of each county (*Erosion*), the proportion of desertification area in each county (Dissert), whether it belongs to karst counties (*Karst*), whether it belongs to debris flow-prone counties (*Debris_flow*), landslide-prone counties (*Landslide*) and earthquake-prone counties (*Earthquake*), whether it belongs to key eco-functional (*KEFR*) and natural reserve counties (*NRR*), whether it belongs to Kashin-Beck disease (*KBD*), Keshan disease (*KSD*) and endemic fluorosis (*EDF*) and the proportion of rural population over 65 years old in each county (*AGE*). We set the variables such as *PA200*, *Dissert*, *Karst*, *Debris_flow*, *Landslide*, *Earthquake*, *KEFR*, *NRR*, *KBD*, *KSD* and *EDF* as dummy variable, means that 1 indicates yes and 0 means no.

3.4. Spatial overlaying analysis

Spatial overlaying analysis was used to explore the poverty situation in different geographical environment and problem regions. These regions include geographical environment areas, ecologically fragile areas, geological hazard- and earthquake-prone areas, ecological protected areas and endemic areas. In this study, topographic relief and slope extracted by DEM were used to reflect the geographical environment conditions of a county. Among the factors of ecological fragility, we mainly focused on the main areas of ecological fragility in China, such as land desertification area, soil erosion area above intensity, karst rocky desertification area and glacier permafrost area. For natural disasters, we only focused on geological disasters and earthquakes because of their tremendous impact on China's social and economic development. For the protection of ecological environment, the KEFA and the NRs were included. Only three endemic diseases, i.e., Kashin-Beck disease, Keshan disease and endemic fluorosis, were focused in this study. According to the AEDEC, the endemic diseases in China mainly include Kashin-Beck disease, Keshan disease, endemic fluorosis and endemic thyroid (iodine deficiency disorders, IDD) (CCAEDE, 1989). However, in the past 30 years, salt iodization has basically eliminated IDD in China, so this study does not consider local IDD (Xinhua Agency, 2018). The regional types of poverty are delineated through spatial overlaying analysis (Fig. 2).

4. Result analysis

4.1. Rural poverty in China

By the end of 2014, China had 14 centralized and contiguous poverty-stricken areas (CPAPD), 832 impoverished countries, 128,000 poor villages and more than 70 million rural poor (EDCYPAD, 2015; Liu et al., 2017; Long, Tu, & Ge, 2016b). These poverty-stricken people are mainly distributed in the deep-rocky mountainous, ecologically fragile, disaster and endemic-prone areas (Liu et al., 2017, 2016; Long & Liu, 2016). China's 832 poverty-stricken counties include 592 state-designated poverty-stricken counties and 680 CPAPD counties, of which 440 counties have two types of poverty overlapping (Liu et al., 2016). Further statistics showed that nearly 80% of the poverty-stricken population in China is concentrated in these 832 poverty-stricken counties, of which 50.15% are located in 14 CPAPD counties (EDCYPAD, 2015).

The country's rural poor are mainly concentrated in the central and western regions. Of the 2862 counties in China, by the end of 2014, 790 counties have no poor population, and the rural poverty rate in 567 counties was less than 5%, and that in 698 counties was more than 5% and less than 15% (Fig. 3). Furthermore, the incidence of poverty in 423 counties is more than 25%, of which 21 counties have a poverty incidence of more than 50%. Obviously, China's rural poverty presents a pattern of small decentralization and large agglomeration.

4.2. Key factors affecting rural poverty

Table 1 lists descriptive statistics of the variables for China's 2862 counties. The results demonstrated that at the end of 2014, the average incidence of poverty in rural areas at county level in China was 10.49%, with a maximum of 80.68% and a minimum of zero. In terms of topographic complexity, the average topographic relief in China is 40.7 m with the maximum of 165.89 m and the minimum of 2.36 m. The

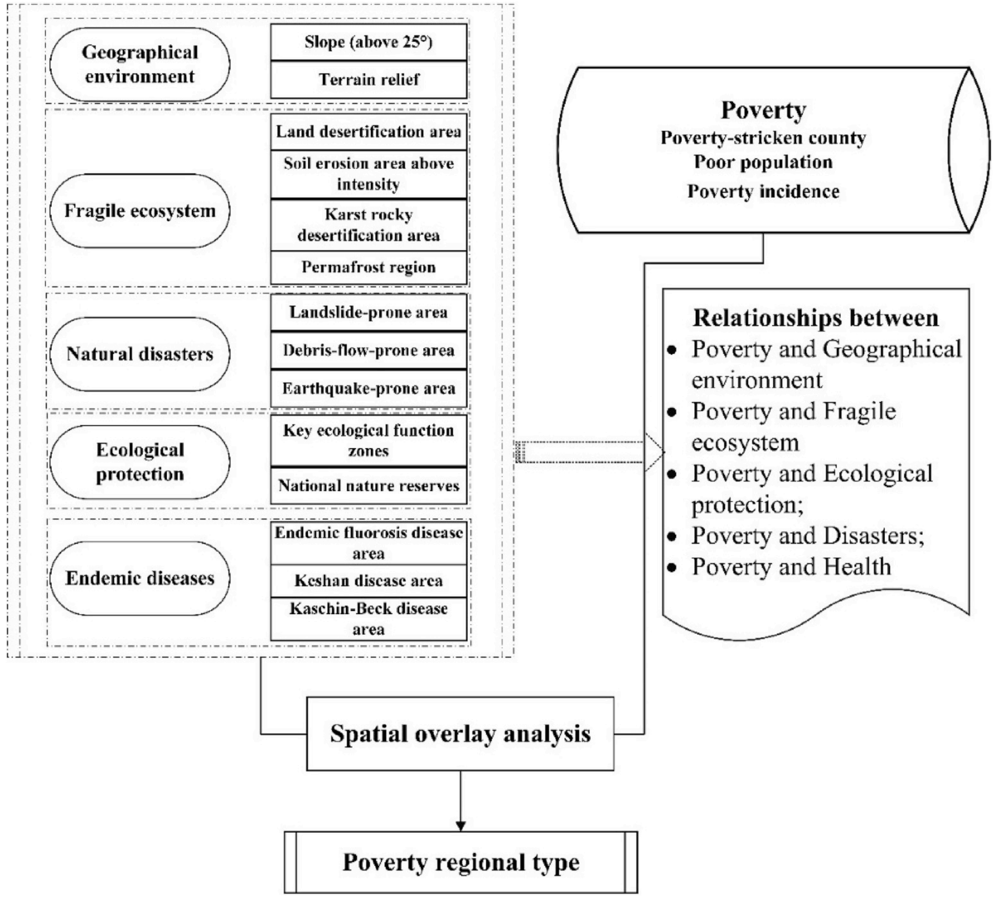

Fig. 2. The framework of the nexus between regional eco-environmental degradation and impoverishment.

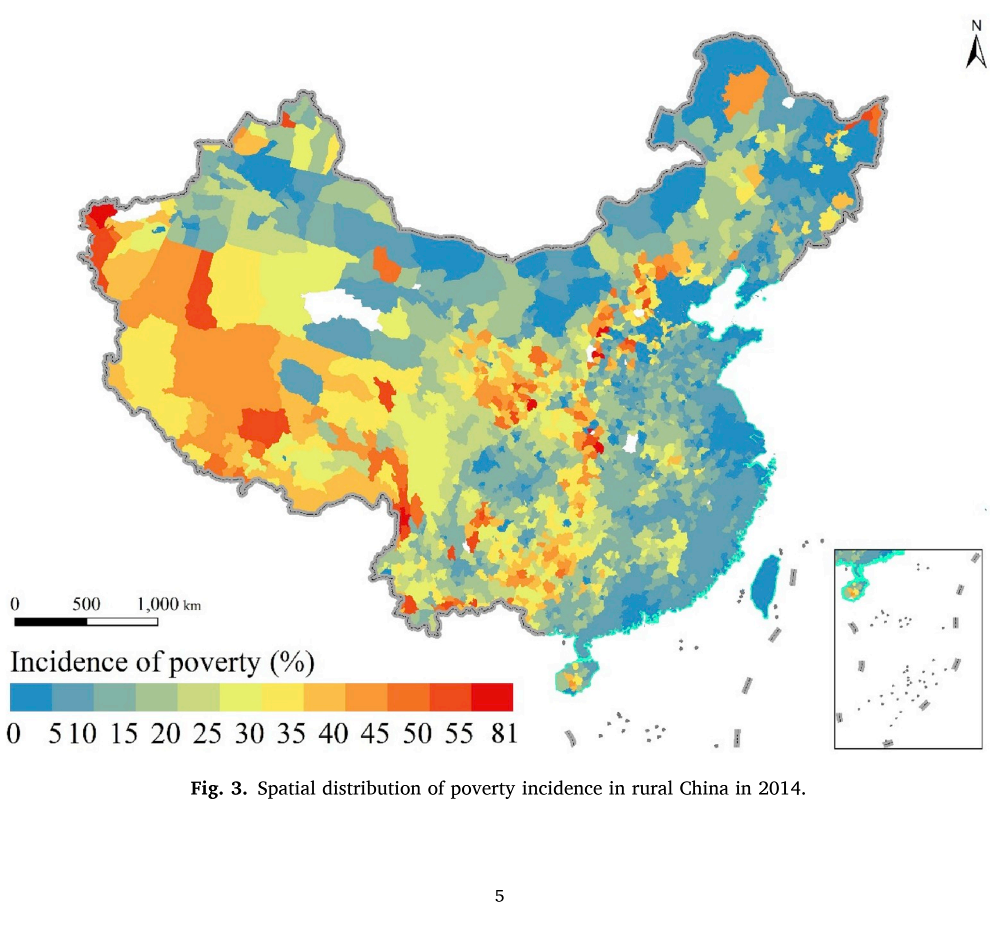

Fig. 3. Spatial distribution of poverty incidence in rural China in 2014.

Table 1
Descriptive statistics of variables.

Variables	Min.	Max.	Avg.	S.D.	VAR.
HCR (%)	0	80.68	10.49	12.43	154.44
Relief (m)	2.36	165.89	40.07	33.76	1140.02
slope25 (%)	0	74.76	6.72	11.38	129.53
PA200 (0/1)	0	1.00	0.06	0.23	0.05
Erosion (%)	0	96.98	5.44	13.71	188.03
Dissert (%)	0	93.40	3.04	11.24	126.36
Karst (0/1)	0	1.00	0.19	0.39	0.15
Debris_flow (0/1)	0	1.00	0.36	0.48	0.23
Landslide (0/1)	0	1.00	0.16	0.37	0.14
Earthquake (0/1)	0	1.00	0.26	0.44	0.19
KEFR (0/1)	0	1.00	0.23	0.42	0.18
NNR (0/1)	0	1.00	0.18	0.38	0.15
KBD (0/1)	0	1.00	0.09	0.29	0.09
KSD (0/1)	0	1.00	0.10	0.29	0.09
EDF (0/1)	0	1.00	0.60	0.48	0.24
AGE (%)	0	24.75	7.61	4.56	20.76

Notes: *N* is the number of sample counties; *HCR* is head count ratio of poverty; *Relief* is terrain relief degree; *slope25* is the proportion of area bove 25° slope in each county; *PA200* refers to counties with an average annual precipitation of less than 200 mm; *Erosion* indicated that the proportion of soil erosion area above intensity to the area of each county; *Dissert* indicates the proportion of desertification area in each county; *Karst* refers to whether it belongs to karst counties, and 1 indicates yes and 0 means no; *Debris_flow*, *Landslide* and *Earthquake* refer to whether it belongs to debris flow-prone counties, landslide-prone counties and earthquake-prone counties, respectively; *KEFR* and *NNR* refer to whether it belongs to key eco-functional and natural reserve counties, respectively; *KBD*, *KSD* and *EDF* refer to whether it belongs to Kashin-Beck disease, Keshan disease and endemic fluorosis, respectively; and *AGE* is the proportion of rural population over 65 years old in each county.

average area with slopes above 25° is 6.72% with the maximum of 74.76% and the minimum of zero. The average area of land desertification and soil erosion in each county in China is 3.04% and 5.44%, respectively, with a maximum of 93.4% and 96.68%. Of China's 2862 counties, 160 counties have an average annual precipitation of less than 200 mm, belonging to arid regions, of which 58 ones are state-designated poverty-stricken counties. For disaster-prone areas, China's 1,044, 465 and 765 counties are located in debris flow, landslide and earthquake-prone areas, respectively. For ecological protection zones, China has designated 666 key ecological function zones and 503 nature reserve counties. There are 309 Keshan disease-prone counties, 303 Kashin-Beck disease-prone counties and 1535 endemic fluorosis-prone counties in China. In addition, the average proportion of people over 65 years old in each county in this country is 7.61%, with a maximum of 24.75%. According to the United Nations definition of population aging, a country with more than 7% of the population aged over 65 is an aging country (Liu, Guo, & Zhou, 2018).

Table 2 provides estimates for the impact of geographical environment and rural aging on rural poverty for China's 2862 counties, 2075 counties with poor populations and 832 state-designated poverty-stricken counties. The results showed that terrain relief degree, aridification, land erosion, earthquake, ecological protection, Kaschin-Beck disease and aging positively affected rural poverty, which indicates that adverse geo-environment aggravates rural impoverishment. From the standardized estimation coefficient, terrain relief degree is the main leading factor of rural poverty in China. The incidence of rural poverty increases by 0.3–0.45% for every 1-m increase in terrain fluctuation. Surface fluctuation has a more obvious effect on poverty in poor counties. In addition, the area with slope greater than 25° has a significant positive impact on the incidence of rural poverty in the poverty-stricken counties. Recent studies have also demonstrated that complex terrain conditions are one of the main causes of rural poverty in Qinghai Tibet Plateau, Yunnan Guizhou Plateau, Loess Plateau and other regions in China (Li et al., 2019; Wang et al., 2018; Zhou et al., 2019; Zhou & Xiong, 2018). The complex topography has a positive impact on the

Table 2
Estimated results for the impact of geographical environment on poverty in China.

Variables	The total of China	Counties with poor population	Poverty-stricken counties
Relief	0.32***	0.30***	0.45***
slope25	−0.07	−0.09	0.29***
PA200	0.05**	0.04*	0.19***
Erosion	0.12*	0.11***	0.09***
Dissert	0.04**	−0.03	−0.07
Karst	0.07***	0.02	−0.11
Debris_flow	0.14***	0.13***	0.01***
Landslide	0.01	−0.03	0.04
Earthquake	0.05***	0.07***	0.07***
KEFR	0.25***	0.26***	0.19***
NNR	−0.01	−0.01	0.01
KBD	0.16***	0.16***	0.10**
KSD	0.07**	−0.06	−0.03
EDF	0.02	−0.02	−0.05
AGE	0.00	0.05*	0.15***
Constant	1.20***	6.32***	12.91***
F(*p*)	128.60***	67.07***	11.93***
Adjust R^2	0.40	0.33	0.17
Observations	2862	2075	832

Dependent variable: *HCR*; Independent variables: *Relief*, *slope25*, *PA200*, *Erosion*, *Dissert*, *Karst*, *Debris_flow*, *Landslide*, *Earthquake*, *KEFR*, *NNR*, *KBD*, *KSD*, *EDF* and *AGE*.
* Indicate statistical significance at the 10% level; ** Indicate statistical significance at the 5% level; *** Indicate statistical significance at the 1% level.

spatial distribution of poverty-stricken countries, and about 72% of the poverty-stricken counties have an average terrain relief of over 50 m in China (Zhou & Xiong, 2018).

In addition, aridity and soil erosion are also identified as important factors affecting rural poverty. Land desertification and rocky desertification aggravate rural poverty in China, but their impact on the incidence of poverty in counties with poor population and poor counties are not obvious. Debris flow and earthquake disasters also aggravate rural poverty, but the impact of landslides on rural poverty is also insignificant. Eco-environmental protection and Kashin-Beck disease prevalent restrict rural development, leading to rural poverty. In addition, poverty is also exacerbated by the ageing of rural areas in poverty-stricken areas. These results demonstrated that complex terrain, fragile ecological environment, endemic diseases prevailing, ecological environment protection and aging have jointly aggravated rural poverty in China.

The greater the surface relief, the more complex the terrain and geomorphic characteristics, the higher the cost of infrastructure construction and public services, the relatively backward infrastructure construction, and the slow socio-economic development. At the same time, the per capita cultivated land resources in these areas are seriously insufficient. As population growth, residents of these areas are forced to reclaim marginal land, thus destroying the ecological environment, leading to soil erosion and ecological environment degradation, which in turn restricts the development of regional social economy, thus increasing poverty. This phenomenon is more obvious in the poor areas of Southwest China, especially in the deep poverty areas.

4.3. The links between poverty and geo-environment, disaster and disease

4.3.1. Geographical conditions

Geographical distribution of China's 832 poverty-stricken counties is shown in Fig. 4. These counties are mainly concentrated in the Loess Plateau, Qinling-Daba Mountains, and Yunnan-Guizhou Plateau. Of the 832 poverty-stricken counties, 39.55% had complex topography with an average slope greater than 15°, while only 23% are relatively flat with an average slope less than 8°. Even 36 counties have an average slope of more than 25°. Furthermore, the topographic characteristics of poverty-stricken counties in China are also complex, with the maximum

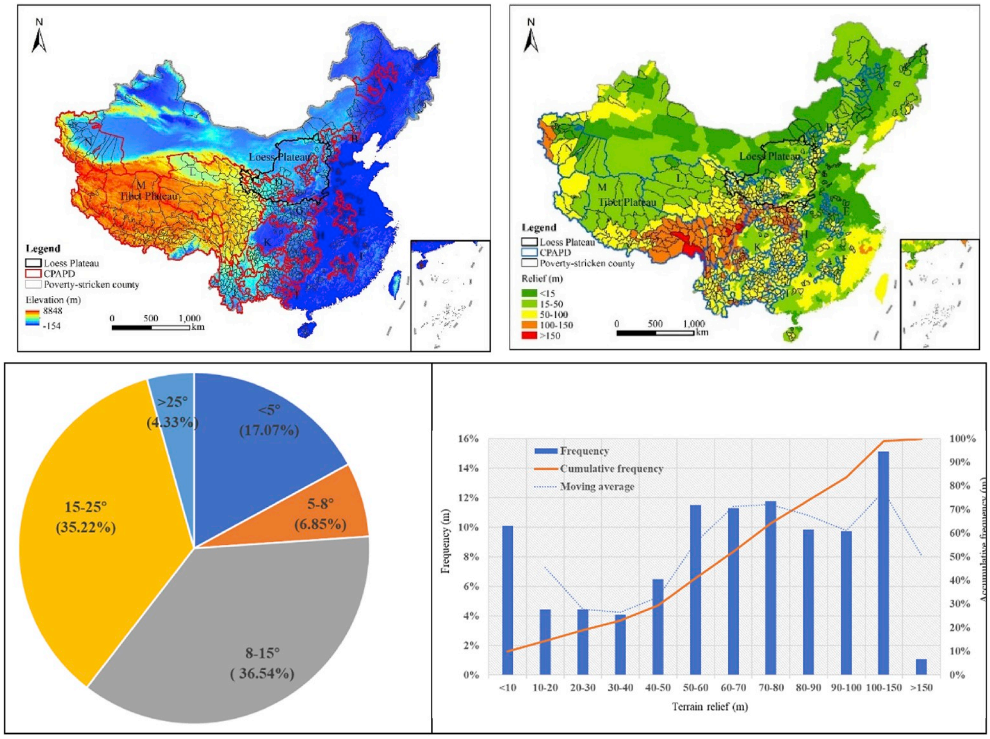

Fig. 4. Elevation (left) and terrain relief (right) in China. Notes: CPAPD refers to China's 14 contiguous poor areas with particular difficulties.

topographic fluctuation greater than 150 m. Further statistics show that only 84 poverty-stricken counties (10.1%, a total of 832 poverty-stricken counties) in China have a relief of less than 100 m, and 9 poverty-stricken counties have a relief of more than 150 m and 126 poverty-stricken counties have relief of 100–150 m. Complex terrain in poor areas is not conducive to the improvement of infrastructure conditions and public service. Geo-environment influences regional socio-economic development through transportation, infrastructure, industry and population mobility. Adverse geographic environmental impacts even limit regional socio-economic development, resulting in overall poverty in a region.

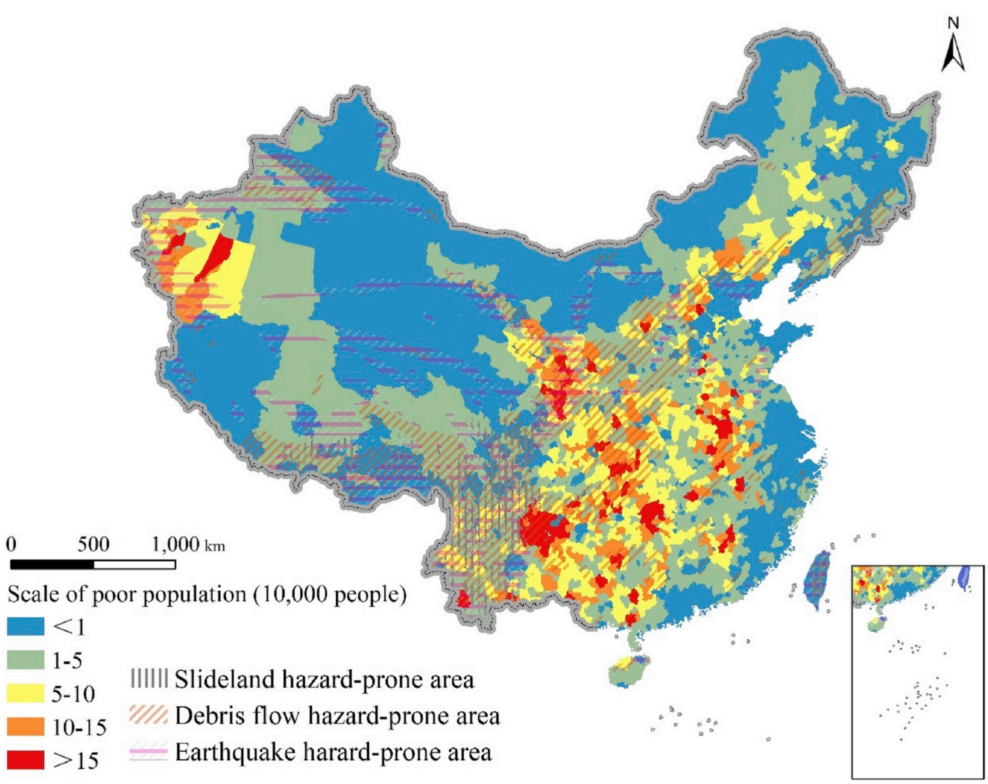

Fig. 5. Spatial distribution of the poor in hazard-prone area in China.

4.3.2. Natural disasters aggravate poverty

As one of the countries with the most frequent natural disasters in the world, China's natural disasters have the characteristics of overlapping of multi-hazards, extensive distribution, high frequency and heavy losses (Zhou et al., 2014). Among the natural disasters occur in China, geological disasters and earthquakes have the most significant impact on socioeconomic development. Geological hazards frequently occurring mainly include landslides, debris flows, ground collapses, ground fissure and land subsidence. There are 2.9 million square kilometers in debris flow-prone areas in China, which are distributed in 1044 counties in China, covering 46.55 million rural poor people. In addition, landslides are also one of the most common geological hazards in China. There are 0.04 million square kilometers in landslide-prone areas, mainly distributed in Sichuan, Yunnan, Guizhou, Qinghai, Gansu and other provinces, which covers 465 counties, with an estimated 14.95 million rural poor populations (Fig. 5). The incidence of poverty is relatively high in natural disaster-prone areas. This may be due to the fact that natural disasters can lead to casualties and property losses in the affected areas, damage to cultivated land resources, infrastructure and public services, and at the same time, it can exert a potential impact on the hearts and physiology of the affected people, resulting in slow economic development in the affected areas, so that they fall into poverty (Alcántara-Ayala, 2002; Carter, Little, Mogues, & Negatu, 2007; Fothergill & Peek, 2004; Watts, 2017).

Earthquakes can also cause or exacerbate rural poverty. China is also an earthquake-prone country because of frequent crustal activities in the intersection zone between the Eurasian plate and the Pacific plate. During the period 1949–2018, 154 earthquake disasters occurred in China, affecting 76.43 million people, resulting in 379,000 deaths and a direct economic loss of $111 billion. The earthquake-prone areas with peak acceleration greater than 0.2 g include 157.9 square kilometers, involving China's 765 counties with 21.1 million rural poor people by the end of 2014. More importantly, China's disaster-prone areas and poverty-stricken areas overlap in space. Spatial analysis results show that that China's 335 counties are located in debris flow and landslide prone areas with 12.36 million rural poor people, and 250 counties are located in landslide prone areas, debris flow prone areas and earthquake prone areas, involving 8.54 million rural poor people (Fig. 5). Previous studies have also shown that earthquakes can aggravate poverty (Dunford & Li, 2011; Sun, Chen, Ren, & Chang, 2010). For example, in 2008, the Wenchuan earthquake in Sichuan Province of China caused the incidence of poverty in the disaster area to rise by more than 30% (Sun et al., 2010).

Obviously, the frequent natural disasters in China have aggravated its rural improvement. Approximately 36%, 16% and 26% of the counties in China have suffered from debris flow, landslide and earthquake disasters, respectively, coving 66%, 21% and 30% of the rural poor in 2014. What's worse, about 8.7% of the counties in the country are located in mudslides, landslides, earthquakes and other disaster-prone counties, which in 2014 included 12.17% of its rural poor population. Therefore, disaster reduction is the key to poverty reduction and should be placed on the priority agenda of poverty reduction.

4.3.3. Ecological fragile drives poverty

China is one of the countries with extremely fragile ecological environment in the world. The fragile ecological environment area accounts for more than 60% of the national territory area, which was mainly distributed in arid and semi-arid areas of Northwest China, alpine areas of the Qinghai-Tibet Plateau, karst areas of Southwest China and the Loess Plateau (SEPAC, 2006; Liu et al., 2015). Further statistics show that there are 124,000 square kilometers of desert and sandy land and 387,000 square kilometers of Gobi in China, of which 95.37% of the sandy land is concentrated in Xinjiang, Inner Mongolia, Qinghai and Gansu provinces (EESDC, 2006). Our statistical result show that land desertification areas in China are mainly distributed in 823 counties, covering the country's 20.34 million rural poor in 2014. Land desertification areas with a large number of poor people are mainly located in southwest and north of Xinjiang, northwest of Qinghai, northwest of Gansu as well as central and western Inner Mongolia (Fig. 6). Land desertification areas are characterized by heavy wind and sand, frequent disasters, harsh natural conditions, weak infrastructure and lack of water resources (Wang, Pan, Wang, Shen, & Lu, 2013). Unsustainable human activities, overgrazing and lack of water resources exacerbate land degradation and desertification, which in turn exacerbates poverty.

Soil erosion destroys human living environment and aggravates regional poverty. Most of the rural poor live in soil erosion areas with insufficient natural endowments, poor agricultural production conditions, frequent disasters and fragile habitats (Bunce, Rodwell, Mee, & Gibb, 2009). Soil erosion restricts the effective use of resources and increases environmental pressure, which has become the root cause of ecological deterioration and poverty. Further poverty accelerates soil erosion and ecological deterioration, forming a vicious circle of poverty–population pressure–soil erosion–ecological deterioration–poverty aggravation (Bunce et al., 2009; Di, Ning, & Lu, 2006). China is one of the countries with the most serious soil erosion in the world. Soil erosion will not only cause soil degradation and land productivity decline, but also cause water pollution and flood disasters. The area of soil erosion above mild level in China is about 4.63 million square kilometers, accounting for about half of the national territory. The Loess Plateau is the most serious area of soil erosion in China. The area of soil erosion accounts for 80% of the area of the Loess Plateau and 38.8% of the total area of soil erosion in China. According to the average erosion modulus (AEM), soil erosion intensity can be divided into six types, i.e., micro, mild, moderate, intensity, extreme intensity and severe erosion (DCRES, 1995).[1] There are 1.63 million square kilometers of soil erosion areas with intensity or above, which was mainly distributed in China's 1597 counties. Among them, 640 countries belong to China's national poverty-stricken counties, accounting for 76.9% of the country's poor counties with 85% of the rural poor (Fig. 6).

Alpine region is also a fragile area of ecological environment in China. Alpine mountainous area is a mountainous area with high altitude, perennial low temperature and perennial frozen soil layer, which has the prominent characteristics of abominable climate conditions, soil depletion, single productive structure, low cultural quality of the masses and backward rural infrastructure construction. China's permafrost region covers an area of about 1.75 million square kilometers, accounting for 18.25% of the country's territory (Wang, 2006). These permafrost areas are mainly distributed in Qinghai-Tibet Plateau, Pamir Plateau, Northeast Greater Hinggan Mountains and other areas, which involves 256 counties and include 3.73 million rural poor people (Fig. 6).

Karst area is also one of the fragile ecological environment areas. Karst rocky desertification (KRD) is a process of land degradation due to intensive human activities and unsustainable land use practices, characterized by soil erosion, bare bedrock and low soil productivity (Wang, Liu, & Zhang, 2004; Yan & Cai, 2015). The KRD is one of the most prominent eco-environment problems in China, which weakens the stability and sensitivities of ecosystem and accelerates the deterioration of ecological environment. It is mainly manifested by soil erosion,

[1] Micro-erosion: Northwest Loess Plateau (AEM < 1000 t/km^2 a), Northeast Black Soil Region/North Rocky Mountain Area (AEM < 200 t/km^2 a), Southern Red Soil Hilly Region/Southwest Rocky Mountain Area (AEM < 500 t/km^2 a); Mild erosion: Northwest Loess Plateau (1000 t/km^2 a < AEM < 2500 t/km^2 a), Northeast Black Soil Region/North Rocky Mountain Area (200 t/km^2 a < AEM < 2500 t/km^2 a), Southern Red Soil Hilly Region/Southwest Rocky Mountain Area (500 t/km^2 a < AEM < 2500 t/km^2 a); Moderate Erosion: 2500 t/km^2 a < AEM < 5000 t/km^2 a; Intensity erosion: 5000 t/km^2 a < AEM < 8000 t/km^2 a; Extreme Intensity Erosion: 8000 t/km^2 a < AEM < 15000 t/km^2 a; Intense erosion: AEM > 15000 t/km^2 a (Ministry of Water Resources of China (MWR), 2008).

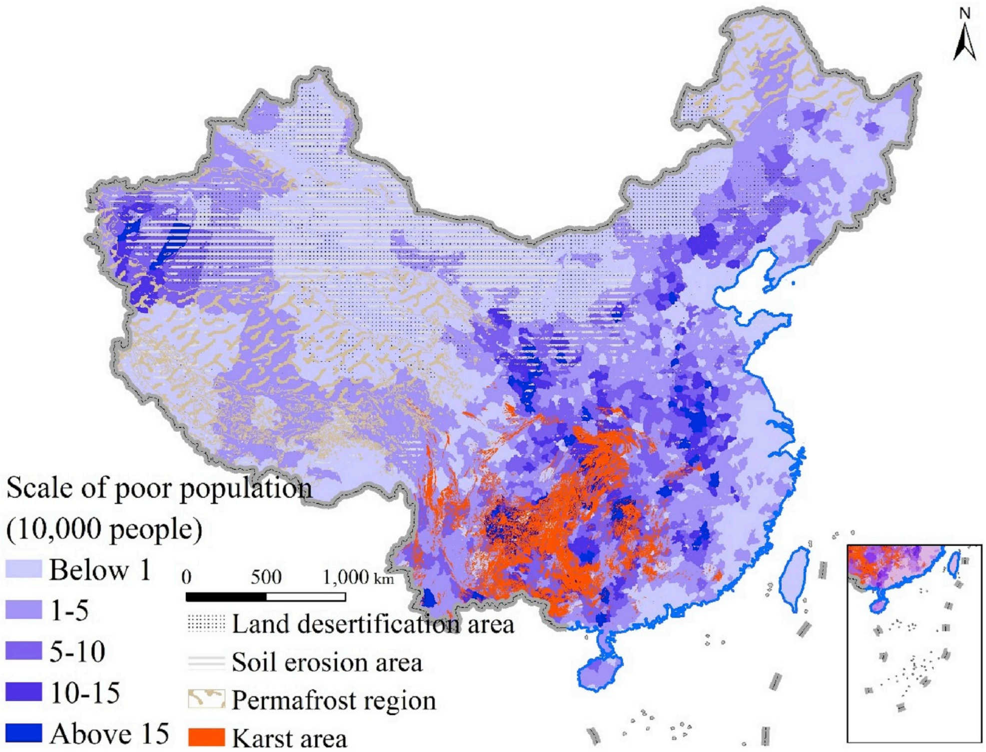

Fig. 6. Spatial distribution of the poor in ecologically vulnerable areas in China.

frequent natural disasters and degradation of ecosystem, often resulting in loss of land productivity, difficulties in drinking water for human and livestock, and aggravates poverty in Karst areas (Wang, 2003). Rocky desertification in karst area China is the largest country in the world with a karst area of about 1.5 million square kilometers (Yan & Cai, 2015). The country's karst landforms are mainly concentrated in eight southern provinces' 553 counties and covered about 32.55 million rural poor population. The area of rocky desertification in Guizhou Province, which is the most serious in China, accounts for 70% of its land area and distributes its 88 counties. There were 7.45 million poor people in China's KRD areas, accounting for 9% of the poverty-stricken people in the whole country. Rural poverty in southwestern China is known as karst poverty. In the rocky desertification area, there is a lack of vegetation and serious soil erosion, which is often accompanied by serious difficulties in drinking water for people and animals. Rocky desertification will directly lead to soil thinning, which not only worsens the agricultural production conditions and ecological environment, but also makes the people lose the basic conditions for survival. Therefore, ecological migration is an important way to poverty alleviation and development in rocky desertification areas, such as Mashan County, Guizhou Province.

Eco-environmental degradation and impoverishment often intertwined together. Most of the fragile ecological areas in China are located in the ecotone of ecological transition and vegetation, and in the compound ecotone of agriculture, animal husbandry, forestry, etc., which are the areas with prominent ecological problems, relatively backward economy and poor people's life (Liu, Huang, Yang, & Zhong, 2014; Peng, Pan, Liu, Zhao, & Wang, 2018). For a long time, China's eco-environmental vulnerable areas have been faced with severe challenges due to the extensive economic growth mode, the prominent contradiction between human and land, and the insufficient capacity of ecological monitoring and supervision. It has the following characteristics: grassland degradation, serious land desertification, high intensity of soil erosion, frequent natural disasters, aridification, shortage of water resources, and prominent contradiction between resources and environment, all of which lead to the backward economic development in ecologically fragile areas and the difficulty of increasing farmers' income (Cao et al., 2011; Zhang, Long, Wu, & Wang, 2017; He, Shen, & Zhang, 2018). China's soil desertification area, glacial permafrost area and rocky desertification area respectively cover 28%, 9% and 19% of its counties, respectively, including 28%, 5% and 10% of its rural poor population in 2014. The eco-environmental fragile areas have become key areas of poverty alleviation and development in rural areas of China.

4.3.4. Tradeoff between ecological protection and development

There has to be a trade-off between eco-environmental protection and poverty alleviation and development. In June 2011, the State Council issued the National Main Function-Oriented Zone Planning, which divides the whole China's territorial space into the development-optimized areas, development-prioritized areas, development-restricted or development-prohibited areas (Fan, Sun, Zhou, & Chen, 2012; Liu et al., 2018; NDRC, 2011). The spatial distribution of poverty-stricken areas in China is highly coupled with national KEFA and development-restricted zones. The KEFA's functional orientation is to ensure ecological security and provide ecological products as the main function. China's KEFA involve its 666 counties and municipalities, accounting for 53% of the country's land area with 3.24 million rural people population. The KEFA in Tibet, southwestern Qinghai, southwestern Xinjiang, southern Gansu, western Hubei and the borders of Guizhou, Guangxi and Hunan provinces have a higher incidence of poverty (Fig. 7).

Prohibited development zones (PDZs) are protected areas of natural and cultural resources at all levels established according to law. The PDZs include national nature reserves, world cultural and natural heritage, national scenic spots, national forest parks and national geological parks. At present, there are 319 NNRs in China, accounting for 9.67% of the total land area, which are distributed in its 503 counties and cities and covers 19% of the country's rural poor population. The poverty belt around the capital (PBAC) of China is a typical example of eco-protective poverty. Apart from the causes of water shortage and land degradation, the PBAC is largely to support the ecological construction of the capital, and its resource utilization and economic development are limited. The

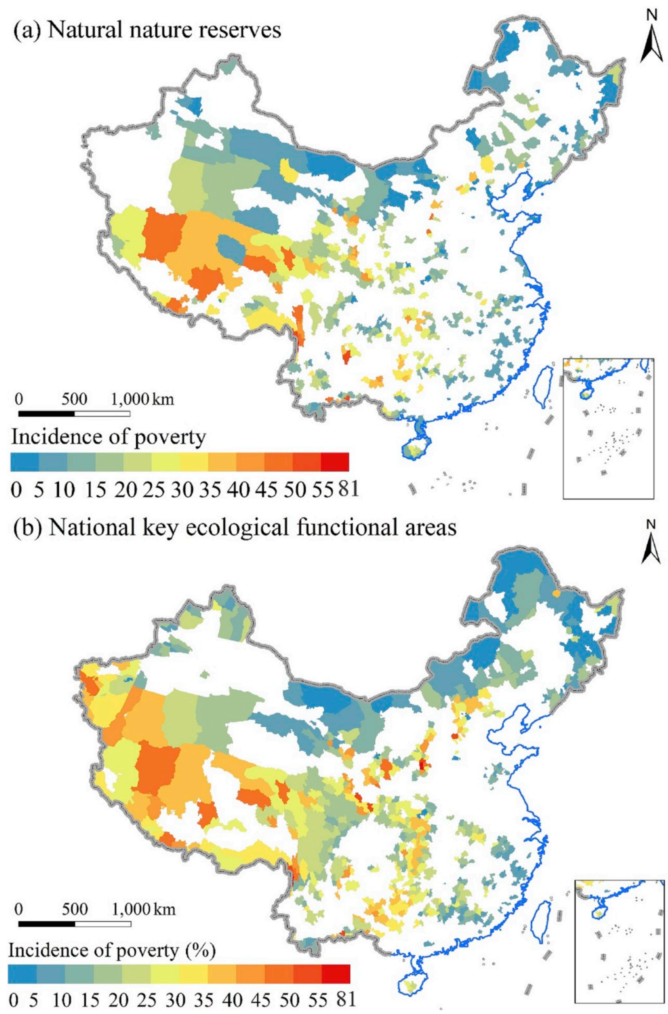

Fig. 7. Poverty situation in national nature reserve (a) and key ecological functional areas (b).

PBAC is the ecological umbrella of the capital area and the key implementation area of the national green for grain project and the project of sand control in Beijing, Tianjin and Hebei (Sun et al., 2016). It is also the water source of Beijing, the capital of China and 80% of Beijing's water sources come from this region. The PBAC includes 25 state-designated poverty-stricken counties in Baoding, Chengde and Zhangjiakou of Hebei Province. By the end of 2014, there were 3672 poor villages and 23.97 million rural poor people with a poverty incidence of 32% in the PBAC. Ecological protection area is of great importance to reduce or prevent ecosystem deterioration. Due to the needs of national ecological environment protection, large-scale development and intense human activities are forbidden in the ecological protection area, and the residents in these areas are highly dependent on resources. The national ecological protection policy is the main cause of poverty in nature reserves. Therefore, the ecological protection area needs to strengthen the ecological compensation and establish a perfect ecological compensation mechanism.

4.3.5. *Poverty due to illness*

Endemic disease (ED), also known as environmental disease, is a regional disease caused by biogeochemical factors, production and lifestyle factors. China is one of the countries with serious EDs in the world, and 80% of the country have EDs. The EDs have long threatened the health and life of the mass, constituting one of the most important public health problems in rural China. The common and highlighted EDs in China include Keshan disease, Kashin-Beck disease (KBD), endemic fluorosis and endemic arsenism. By then end of 2017, there were still 8000 Keshan disease patients, 486,700 Kashin-Beck disease patients and more than 10 million water-deficient endemic fluorosis patients in China (NHC, 2018). According to the AEDEC, there are 309 Keshan disease-prone counties, 303 Kashin-Beck disease-prone counties and 1535 endemic fluorosis-prone counties in China (Fig. 8). The ED is a disease that the poor are susceptible to. Poverty due to illness is prominent among the population in the disease area (Jin, 2018). Statistics show that there are 11.96 million, 4.29 million and 60 million rural poor people in the Keshan disease-prone counties, the Kashin-Beck disease-prone counties and the endemic fluorosis-prone counties, respectively. Generally, poor areas have slow economic development, poor health care conditions and high incidence of local diseases. In turn, the high incidence of local diseases will increase the medical burden of the poor groups and reduce the labor force, resulting in the lack of their own development motivation, thus falling into poverty. Poverty caused by endemic diseases is more individual poverty. Reducing the medical burden of the poor in the areas with high incidence of endemic diseases is vital for them to get rid of poverty.

4.3.6. *The old-age poverty of rural social subjects*

The aging society is the inevitable form of the development of human society. According to the United Nations classification criteria for ageing,[2] China has entered an ageing society as early as the late 1990s. In 2000, the proportion of people over 65 was 7.1%, and in 2017 it rose to 11.4%. The trend of rural aging is more obvious. In 2000, the aging rate of rural population was 7.5%, only higher than 0.4% of the whole country, and in 2015 it rose to 12.03%, higher than 1.96% of the whole country (Wang & Wang, 2014). At present, China's social security system is still in the primary stage, the elderly social security system is not perfect, most of the rural elderly lack of stable income sources and service security, easy to fall into poverty, and the incidence of aging poverty is higher than other groups.

With the aggravation of population aging, the rural elderly poor has gradually become a special group. Over the past 10 years, the number of the elderly poor has shown a significant upward trend. The existing studies showed that in 2003, about 20–25 million rural elderly people aged 60 years and over were in poverty in rural China with the poverty rate range from 13% to 17% (Zhu, 2005). That is to say, there was one poor elderly among the six-elderly people. By 2014, China had 48.95 million elderly people living below the international poverty line of 1.9$ a day with a poverty rate of 23.09%. Among them, 32.44 million elderly poor people live in rural areas with a poverty rate of 35.88% (Zhu & Fan, 2017). That is, there is one absolutely poor population among the three rural elderly. Spatially, 82.46% of the counties in China have entered an aging society in 2010. By 2014, there are 84,368 poor villages, 20.83 million poor households and 64.21 million poor people in these aging counties (Fig. 9). Undoubtedly, the problem of poverty among the elderly has become increasingly prominent, which poses a severe challenge to the national pension and social security system. Poverty of the elderly will become a social problem that developing countries need to solve for a long time. It urgently needs to strengthen the role of social security system in coping with poverty among the elderly.

4.4. *Regional types of rural poverty*

Poverty reduction is a complex systematic project, which requires targeted poverty reduction measures. Based on the spatial distribution map of poverty-causing factors and poverty-stricken counties in different regions, the poverty in rural China can be divided into five types: disaster-driven, endemic disease-driven, eco-environment

[2] According to the standard of the United Nations population aging, if the proportion of the elderly population (aged over 65 years) in a country or region exceeds 7%, it will enter the aging society.

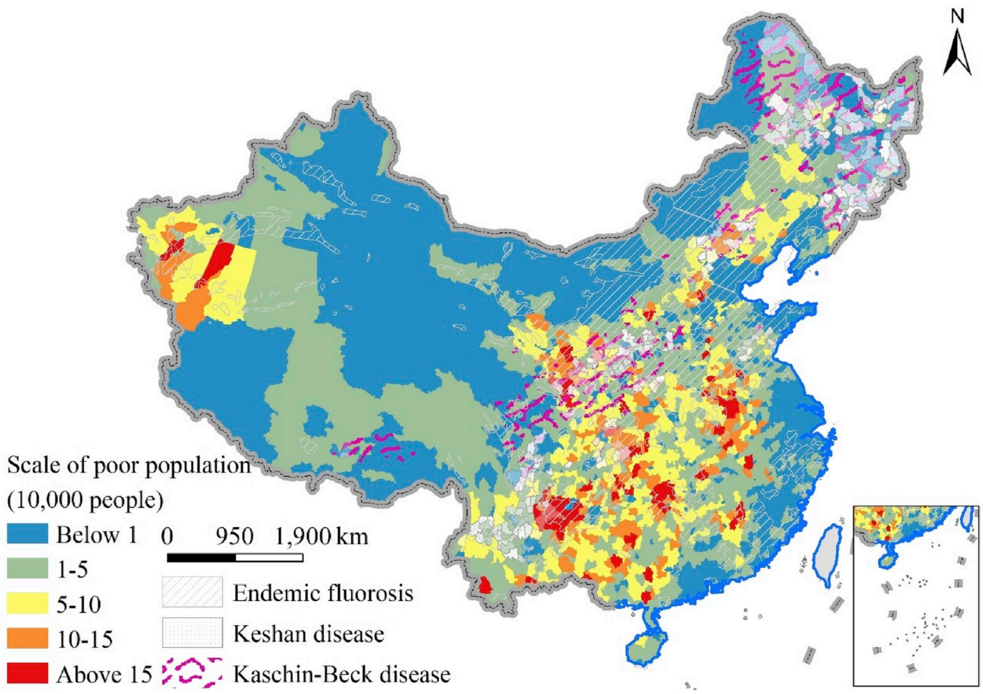

Fig. 8. Distribution of the poor in endemic disease areas in China.

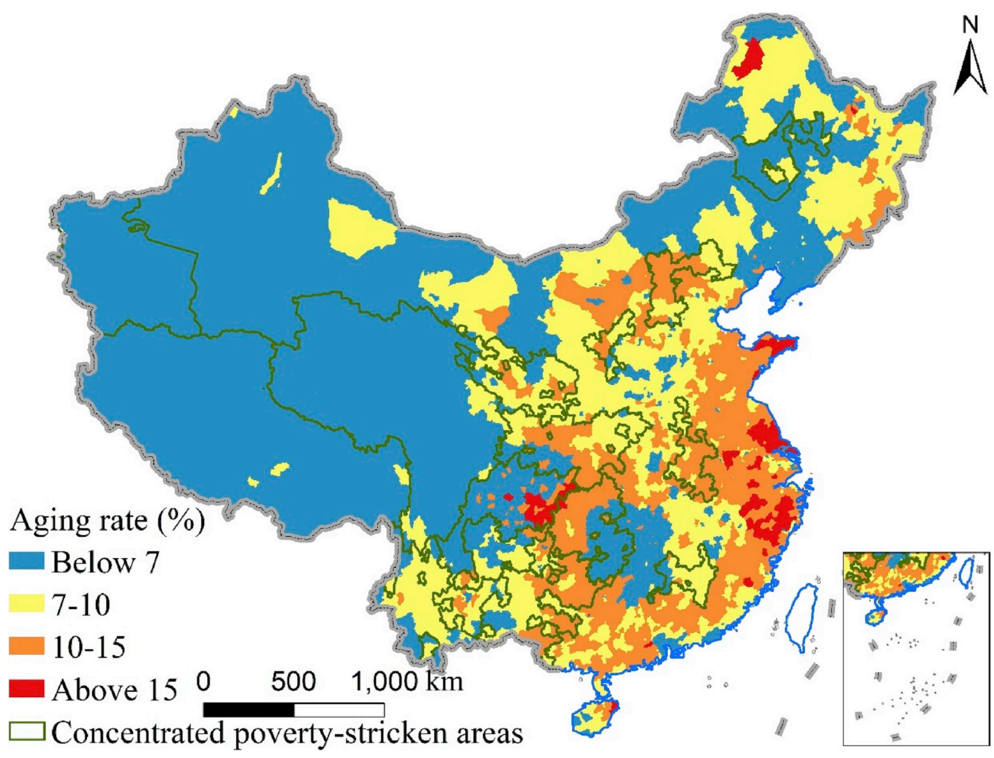

Fig. 9. Spatial distribution of the elderly population (aged over 65 years) in rural China.

degradation-driven, ecological protection-restricted and grain-producing-restricted (Fig. 10). More prominently, China's poverty-stricken areas, ecologically fragile areas, endemic disease-prone areas, disaster-prone areas and aging areas are highly overlapping in space. This means that poverty, disease and disasters are intertwined in most parts of China.

Spatially, poverty in southwestern China is mainly driven by natural disasters, rocky desertification and soil erosion, that in the northwest region by drought and desertification, that in the Qinghai-Tibet Plateau by natural disasters, cold climatic conditions, lack of resources, ecological protection and other factors, that in the Loess Plateau by natural disasters, soil erosion and fragile ecological environment, and that in the northeast region is mainly driven by ecological protection and endemic diseases. Poverty in China's second-tier terrain is driven by endemic diseases, natural disasters and ecological protection. Furthermore, the main grain-producing areas in central China can only produce

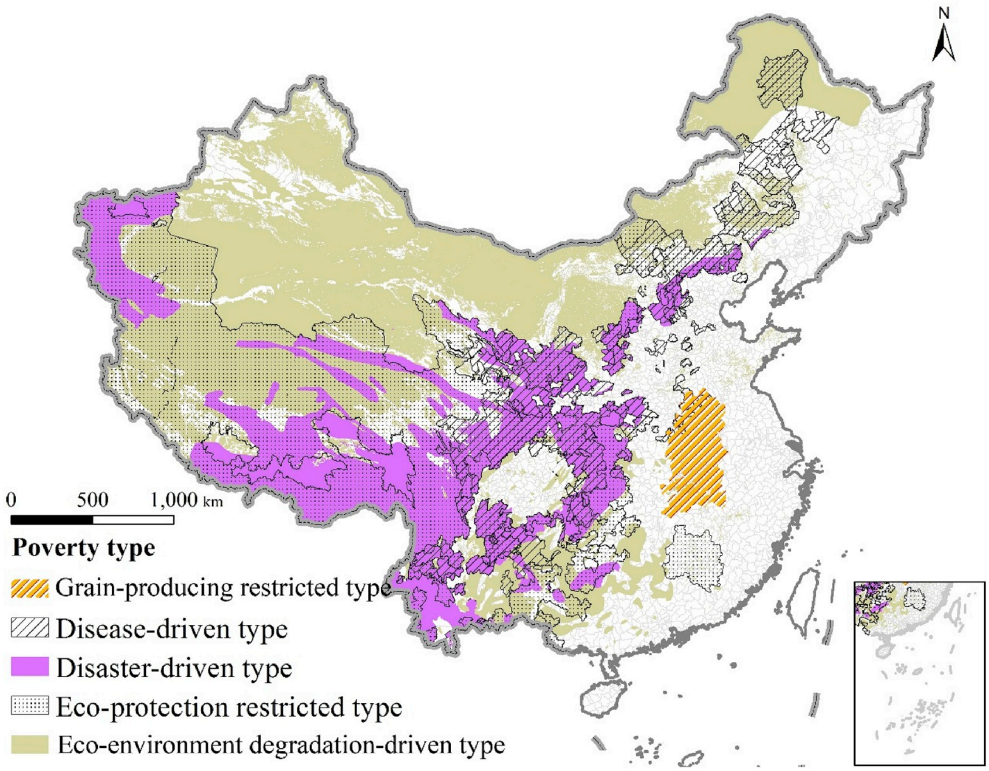

Fig. 10. Regional types of poverty in rural China.

grain to ensure the country's food security. Influenced by the fluctuation of grain prices in the international market and the low comparative effect of grain planting, the region has fallen behind economically and socially, and has long been in a state of poverty.

5. Discussion

Poverty alleviation needs to be coordinated with disaster reduction and disease reduction. Disasters drive millions of people worldwide into extreme poverty every year (Akter & Mallick, 2013; Hallegatte et al., 2016; Hallegatte & Rozenberg, 2017; Rodriguez-Oreggia, De La Fuente, De La Torre, & Moreno, 2013). Disaster-prone areas are also areas where the poor are concentrated (Liu et al., 2017). Poverty creates disadvantageous conditions that make the poor more vulnerable to natural hazards. Lack of infrastructure, inadequate supply of public services and backward medical facilities in poverty-stricken areas make their residents more vulnerable to natural disasters and illness, thus falling into a vicious circle of poverty, disaster impact, deterioration of health and more poverty. To achieve the target of eradicating extreme poverty of UN's Sustainable Development Goals (SDGs) by 2030, it must put disaster risk management and disease alleviation at the heart of poverty eradication efforts and break the vicious circle of poverty. Poverty alleviation can make the poor less vulnerable to disasters, and disaster mitigation can prevent people from falling into poverty again. Therefore, it is an urgent need for both strategic and practical steps to address the relationships between poverty alleviation, disaster risk management and health improvement at global, national and local levels.

Fully understanding the relationship between poverty and geo-environment is the basis of adapting to the changing environment and the premise of realizing sustainable regional development. The poverty-stricken areas tend to have the characteristics of fragile ecological environment and ecological degradation. Poverty cause land degradation and desertification, and land degradation further aggravate poverty. Effective anti-poverty policies need to fully understand the mechanism and geographical types of poverty, and on this basis, classify and implement targeted poverty reduction measures according to local conditions. Of course, it is also necessary to actively adapt to regional environmental changes and take appropriate interventions to mitigate the impact of human activities on the regional environment.

Poverty has the characteristics of complexity, multidimensionality, dynamicity and regionality (Liu et al., 2017; Powell, Boyne, & Ashworth, 2001; Zhou & Liu, 2019). Reducing individual and regional poverty should be carried out simultaneously. Regional poverty is an external manifestation of the regional system of human-environment relationship, which involves natural resource endowment, geographical environment, human and social economic factors. Individual poverty is actually a viable poverty (Sen, 1982). Individual poverty and regional poverty interweave and influence each other (Zhou & Liu, 2019). Individual poverty has a cumulative amplification effect, which will form regional poverty to a certain extent. Regional poverty, in turn, affects the environment and ability of individuals to lift themselves out of poverty. Thus, poverty alleviation needs to coordinate with individual poverty alleviation and regional poverty alleviation, but they have different emphases. Poverty targeting is a prerequisite for effective poverty reduction. It is necessary and urgent to target the real poor and poor regions and adopt precise measures, as the current targeted poverty alleviation practices in China. Alleviating regional poverty needs to increase investment in infrastructure, increase the availability of public services and create an environment for the poor to get out poverty. Individual poverty reduction needs to focus their health status, education and housing security, and stimulate their endogenous motivation and enable them to lift themselves out of poverty (such as no worries about food and clothing, being guaranteed of housing safety, basic medical care and nine-year compulsory education in China, i.e., *liang buchou, san baozhang*). It is undeniable that fostering economic growth may still be one of the most effective ways over the long-term in reducing individual poverty (Barbier & Hochard, 2018). Certainly, targeting investments directly to improving the livelihoods of the rural poor is also of great concern. In practice, land consolidation is also an effective way to alleviate individual poverty by promoting resource capitalization in poverty-stricken areas (Wu, Feng, & Zhou, 2019; Zhou et al., 2019, 2018).

For different types of regional poverty, targeted poverty reduction measures are also needed. For disaster driven poverty-stricken areas, disaster prevention and mitigation, and the resolution of major natural disaster risks are effective means to reduce poverty. For the poverty-stricken areas driven by the degradation of ecological environment and limited by ecological protection, migration is a good choice (Lo, Xue and Wing, 2016; Liu et al., 2017; Lo & Wang, 2018). It should strengthen the ecological compensation and improve the ecological compensation mechanism. For the endemic disease driven poverty-stricken areas, it should increase the construction of medical and health facilities, strengthen the medical team, and improve the medical security system. For the poverty-stricken areas with limited grain production, the compensation standard for grain production should be enhanced and the stabilization of domestic grain prices should be guaranteed.

6. Conclusions

Poverty has been one of the world's most persistent development challenges. Eradicating poverty is the common mission of mankind. Poverty includes absolute poverty and relative poverty. The relative poverty cannot be eradicated, it can only be alleviated. Poverty research will be an eternal global theme accompanying human existence. Understanding the mechanism of poverty, the types of poverty-stricken areas and the law of their differentiation is the premise of poverty alleviation. Geographical exploration of regional impoverishment can help to deepen the understanding of the process of impoverishment and its differentiation mechanism. This study integrated geographic environment, natural disasters, ecological environment, poverty and socio-economic multisource data to explore the geographical pattern of rural poverty in China, reveal the nexus between regional eco-environmental degradation and poverty, and to delimit the geographical types of poverty in rural China. The results demonstrate that China's rural impoverishment has obvious regional differentiation law. The country's poverty-stricken areas are mostly concentrated in the deep-rocky mountains, alpine regions, ecologically fragile areas, disaster-prone areas and endemic disease areas in the central and western regions. The spatial distribution of poverty in China overlaps with that in fragmented terrain, fragile ecological environment, natural disaster-prone areas, endemic disease areas and ecological protection zones. Terrain relief degree, aridification, land erosion, earthquake, ecological protection, Kaschin-Beck disease and aging positively affect the country's rural impoverishment. To some extent, the geographical capital formed by the interaction of spatial location and natural environmental conditions plays a decisive role in regional impoverishment. Terrain relief degree is the main leading factor of rural impoverishment in China, and the rural poverty rate increases by 0.3–0.45% for every 1-m increase in topographic relief. Further analysis shows that in 2014, 8.7% of the rural poor in China were in the areas prone to landslides, mudslides and earthquakes, 28% in the land desertification area, 10% in the karst rock desertification area and 19% in the national forbidden development area.

Regional eco-environmental degradation is closely related to and interacts with impoverishment. Regional types of China's rural impoverishment can be divided into five categories, i.e., disaster-driven, endemic disease-driven, eco-environment degradation-driven, ecological protection restricted and grain-producing restricted. China has an overlapping region of multiple problems, such as poverty, disease and disaster. Disaster reduction, poverty alleviation and disease prevention should be coordinated. Therefore, poverty reduction measures need not only comprehensive means, but also targeted measures aimed at a leading cause of poverty. Faced with the goal of UN's 2030 SDGs for eliminating poverty and the complexity of the regional system of man-environment relationship, it is necessary to explore the establishment of a sustainable development mechanism to coordinate and promote effective disaster reduction, poverty reduction, disease reduction and ecological environment protection. More attention should be paid to the investment in infrastructure and public services and the benefit of relevant policies for regional poverty, while for individual poverty, it needs to intervene from the perspectives of medical treatment, education, housing, drinking water and sanitation, and break the intergenerational transmission of poverty and stimulate the endogenous development power of the poor groups and promote regional socio-economic development and income growth of the poor groups. It is worth mentioning that since 2014, China has been implementing the targeted poverty alleviation strategy, which not only creates a regional development environment, improves the transportation infrastructure and increases the supply of public services in poor areas, vigorously supports and develops industries, but also reduces poverty from the dimensions of housing safety, medical care, education and social security at the level of farmers. Through these measures, at the end of 2018, China's rural poor population decreased from 98.99 million at the end of 2012 to 16.6 million, and the incidence of poverty decreased from 10.2% to 1.7%. Poverty reduction has achieved remarkable results, and regional overall poverty has been effectively solved. China's successful experience and model of targeted poverty alleviation can provide benefit references for other developing countries in the world, especially sub-Saharan African countries. Nevertheless, China's relative poverty will exist for a long time, and it is still crucial to establish a long-term mechanism to solve and prevent it.

This study is only a preliminary exploration of the regional types of poverty-stricken areas and their differentiational mechanism. It is urgent to reveal the essence of poverty by means of modern technology such as artificial intelligence, big data and Internet of Things, aiming at poverty-stricken areas and groups, and to implement policies for poverty. This provides opportunities and challenges for deepening the study of poverty in geography. It urgently needs to accelerate the development of poverty geography. Poverty eradication has always been a global problem, and it is necessary to strengthen the cooperation of poverty geographers all over the world.

Declaration of competing interest

The authors declare that they have no competing interests.

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