Journal of Environmental Management 264 (2020) 110439

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Research article

The spatial differentiation of quality of rural life based on natural controlling factors: A case study of Gansu Province, China

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ARTICLE INFO

Keywords:
Quality of rural life (QRL)
Spatial differentiation
Natural controlling factors
Geographical detection
Gansu province

ABSTRACT

The laws of regional differentiation of county development and influencing factors on the quality of rural life (QRL), affect not only the vital interests of rural residents but also the scientific implementation of rural revitalization strategy. In this paper, taking 87 counties (cities, districts) of Gansu Province as the region of study, we constructed five-dimensional model of QRL index. Then, Pearson correlation, spatial coupling, geographical detector and tradeoff analysis methods were used to analyze the QRL's spatial differentiation and quantitively identify its natural controlling factors. Further, we discussed the mechanism of spatial differentiation of QRL in Gansu Province and provided recommendations for improving QRL. The results show that: (1) QRL in Gansu Province is characterized by spatial heterogeneity and agglomeration, and decreases from west to east. There are five hot spots and four cold spots of QRL. (2) Altitude, slope, precipitation, and distance to the provincial capital (DTTPC) are the natural controlling factors of spatial differentiation of QRL in Gansu Province. Their influences are quantified to be 0.19, 0.37, 0.37 and 0.20, respectively. (3) The tradeoff between QRL and precipitation is the strongest, with root mean square deviation (RMSD) of 0.293. The tradeoff between QRL and altitude/slope/DTTCC are of medium level and decrease successively, with values of 0.238, 0.255 and 0.2 respectively. (4) According to the different influences of natural controlling factors on QRL, Gansu Province was classified into three regional types: natural environment restricted type, resource abundance restricted type and economic location restricted type. Thus, we can improve the QRL on the basis of identifying driving mechanisms in different regions, make policies according to local conditions, and further promote the rural development.

1. Introduction

Rural and urban development as well as their interaction are always associated with the development of human society, and have thus been extensively studied and discussed (Wang et al., 2017; Yang et al., 2018; Chang and Jin, 2016). With rapid industrialization and urbanization in China, the economic, spatial and social patterns in its rural areas have changed, and the quality of rural life (QRL) has been greatly improved. However, there are still some problems. For example, the income of rural residents is far lower than that of urban residents. Rural areas often have poor public services, health care system, education system, cultural entertainment, social security system, etc (Saleh, 2015a; 2015b, 2015c). Moreover, the environmental quality in rural areas is decreasing (Aguilera et al., 2018; Zhang et al., 2018; Hoang et al., 2008). In the context of increasing socio-economic transformation in China, rural areas are receiving more attention. The full development of society based on people orientation requires attention to the social life of residents and the full development of human beings, and the improvement of QRL is one of its important contents (Kay et al., 2012; Liu, 2018; Tu and Long, 2017). QRL has been receiving more attention from the government and academia (Boncinelli et al., 2015; Dai et al., 2018; Anderson and Bell, 2000).

"Quality of life", as an academic term, was first proposed in 1958 by J. K Galbraith, an American economist, in his book "The Affluent Society". It was first defined as "people's comprehensive evaluation of their lives", including life satisfaction, inner contentment and self-realization in society (Galbraith, 1958). Since 1970s, Europe, US and Former Soviet Union have carried out extensive research on the evaluation of quality of life and then the focus has gradually transited from theoretical research to application stage (Gilbert et al., 2016; Galbraith, 1958; Peng et al.,

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https://doi.org/10.1016/j.jenvman.2020.110439
Received 24 January 2019; Received in revised form 20 February 2020; Accepted 13 March 2020
Available online 26 March 2020

2009). Due to different social systems and economic development patterns, countries have different focuses in the study of quality of life. For example, US and Canada, which are mainly based on free economy, pay more attention to subjective quality of life based on individual feelings and mainly measure the subjective quality of life by "satisfaction" and "happiness" (Mccrea et al., 2011). Compared with US, Europe emphasizes the importance of objective indicators and focuses on "people's ability to meet their needs", but in recent years there has been an increasing combination of objective and subjective indicators (Peng et al., 2009; Wang, 2000; ŠOltés and Nováková, 2009; Kamp and Leidelmeijer, 2003). After development for more than a half century, quality of life has become a field of study that attracts interests from western researchers in sociology, economics, psychology, medicine, philosophy, geography and planning (Cheatle, 1991; Mickel and Dallimore, 2009; Wallace, 1973). Compared with that in above-mentioned countries, the research on quality of life in Asia, Africa and Latin America started relatively late, and the depth and breadth of research, especially in Africa and Latin America, lags behind that in US and Europe (Gould, 1986; Majeed, 2018; Stahl et al., 2003). In addition, most of previous research mainly focuses on quality of urban life, including comparison of quality of life among different cities, analysis of living standards in different neighborhoods within cities and study of the quality of life of minority social groups in cities, whereas QRL receives little attention (Aroca et al., 2017; Kassomenos et al., 2016; Michelangeli, 2015).

QRL is an important indicator of rural economic development level and directly related to the benefits and well-being of rural residents (Huang et al., 2018; Janmaimool and Denpaiboon, 2016; Tran et al., 2018). However, with rapid urbanization and industrialization, rural decline is becoming a severe problem, which significantly affects the sustainable development of rural areas and inhibits the improvement of QRL (Bi, 2014; Li and Zhang, 2012; Ma et al., 2019a, Ma et al., 2019; Watson and Deller, 2017). In August 2017, Chinese researcher Liu Yansui published a paper entitled "Revitalize the world's countryside" in *Nature*, which emphasizes "the need to promote rural revitalization in the process of global urbanization" (Liu and Li, 2017a, 2017b). In October 2017, Chinese President Xi Jinping pointed out in the report of the 19th National Congress that "The three rural issues are fundamental issues relating to national economy and people's livelihoods. Solving the three rural issues should be always taken as a top priority in the work of the whole party and we should implement rural revitalization strategy." (Xi, 2017). In September 2018, China officially issued the Rural Revitalization Strategy Plan (2018–2022). The overall requirements are "prosperous industry, ecological livability, rural civilization, effective governance, and prosperous life", among which prosperous life is the basis (The State Council of China, 2018). Promoting urban-rural integration, ensuring rural livelihood security and improving QRL have quickly become the focus of social attention and the hotspot of research.

Currently, the academic community has achieved a series of research results about the quality of life. However, the research on the regional differences of quality of life and natural factors based on geospatial analysis method is few. Global research on QRL is mainly qualitative, and there is a lack of quantitative research on the mechanism of spatial differentiation of QRL. Furthermore, more attention has been paid to provincial and municipal scale than the county scale.

In this paper, 87 counties/districts in Gansu Province of China were taken as the region of study. By using geographical detector model, spatial data exploration and tradeoff analysis methods, we analyzed the spatial differentiation of QRL in these counties/districts and identified its natural controlling factors. We further revealed the characteristics of spatial differentiation of QRL and its dynamic mechanism. Finally, the region of Gansu Province was classified into different types according to their QRL and natural controlling factors. The results can provide useful information for improving QRL and effectively implementing the rural revitalization strategy.

2. Overview of the region of study

2.1. Natural geography

Located in the inland of western China, Gansu Province is characterized by an overall northwest-southeast direction on the map and a vast territory (Fig. 1). It is also located in the intersection of the northwest arid region, the Qinghai-Tibet alpine region and the eastern monsoon region. Thus, it is the only province in China that has three natural geographical regions. Gansu Province is also an ecological hub with special ecological functions, fragile and diverse ecological environments, and great ecological importance in western China. Gansu Province is between 92°13′ E and 108°46′ E as well as between 32°31′N and 42°57′ N. The difference in longitude between the east and the west is greater than 16° and the east-west distance is about 1520 km. The time difference between the east and the west is 1 h and 8 min. The difference in latitude between the north and the south is greater than 10° and the north-south distance is about 1655 km. Overall, Gansu Province is located in the mid-latitudes of the eastern hemisphere. The total area of the province is 42.58×10^4 km^2, and the terrain tilts from southwest to northeast. The altitudes of valley regions in Longnan area and in the lower reaches of Shule River in Jiuquan City are relatively low, whereas those of the rest of Gansu Province are above 1000 m. The areas of mountains and plateaus account for about 70% of the total land area of Gansu Province. Since Gansu Province is in inland China, warm and humid air currents from oceans are difficult to reach this region, it is not easy to form precipitation and the climate in most areas is dry. Overall, it has a continental temperate monsoon climate.

2.2. Social economy

Gansu Province has jurisdiction over 14 cities (or prefectures) and 87 counties (or districts). It can be divided into five regions: Longzhong region (Lanzhou City, Dingxi City, Baiyin City, and Linxia prefecture), Hexi Corridor region (Jiuquan City, Jiayuguan City, Zhangye City, Jinchang City and Wuwei City), Longdong region (Pingliang City and Qingyang City), Longdongnan region (Tianshui City and Longnan City), and Gannan region (Gannan prefecture). Many economic indicators of Gansu Province are poor than those of other provinces of China. In 2017, the GDP of Gansu Province was 767.7 billion Yuan and per capita GDP was 29,326 Yuan, both showing an increasing trend. From 2010 to 2017, the GDP of Gansu Province had an annual average growth rate of 10.58%, higher than that of the country in the same time period. The population of Gansu Province accounted for 1.89% of total population of the country. However, its GDP accounted for only 0.93% of that of the country, social fixed asset investment accounted for 0.89% of that of the country, and general public budget revenue accounted for only 0.48% of that of the country. Gross agricultural product and the yields of main agricultural products both accounted for about 2.0% of those of the country. The GDP of Gansu Province was only about 30% of those of Shanghai City or Liaoning Province, 10% of those of Guangdong Province or Jiangsu Province. Furthermore, the difference has been enlarging. Among the 12 provinces (municipalities and autonomous regions) in western China, Gansu Province only ranked 8th in terms of GDP. Its further development is limited by market, capital, technology, ecology, environment and human resource. In 2017, the urbanization rate of Gansu Province was 46.39% and the urbanization rate of permanent residents reached 50%. The per capita disposable income of urban residents in Gansu Province was 27,763.4 Yuan, and the per capita net income of farmers in Gansu Province was 8076.1 Yuan. In 2011–2017, the annual average growth rates of both exceeded 11%.

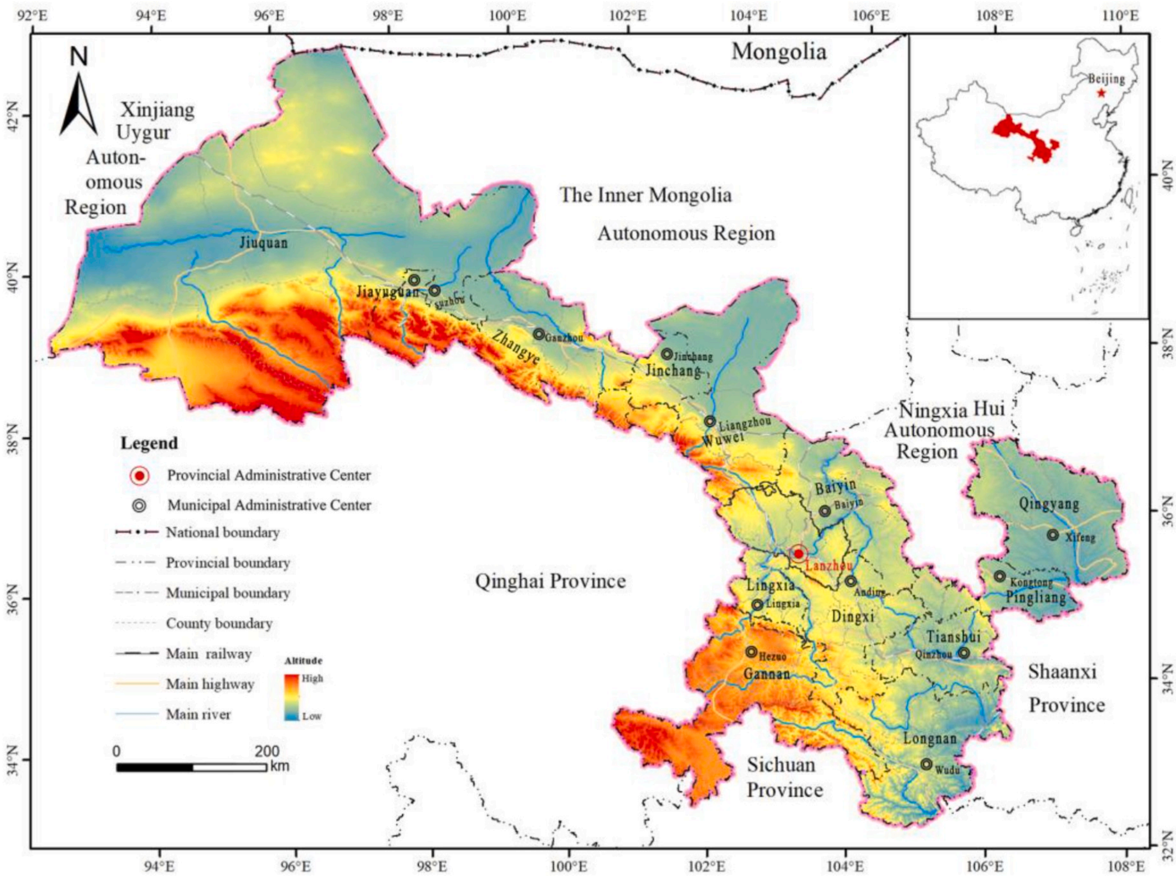

Fig. 1. Illustration of the location and administrative division boundaries of Gansu province as well as its road, rivers and altitude distribution.

3. Data sources and research methods

3.1. Data sources

The data used in this paper came from five sources: (1) Basic maps. Topographic map (1:250,000) and vector administrative boundary (1:250,000) for Gansu Province were obtained from Gansu Province Surveying and Mapping Bureau. (2) Basic data about population, income and expenditure, living conditions and culture, infrastructure, public services, *etc*. in Gansu Province, from *Gansu Province Development Yearbook 2017*, *Gansu Province Rural Areas Yearbook 2017*, *China Statistical Yearbook 2017*, *China Rural Areas Yearbook 2017*, *etc*. (3) DEM data, from geographic data space cloud. By image correction and slope analysis, data about ground slopes and altitudes of 87 counties (including districts and county-level cities) in Gansu Province were obtained. (4) The distances to the city center and the provincial center, obtained by GIS spatial neighborhood analysis based on Google Maps. The per capita arable land area in 2016 was calculated based on the population and cultivated land area in each county in Gansu Province. (5) Precipitation data, from Gansu Province Meteorological Bureau.

3.2. Research methods

3.2.1. Evaluating QRL

(1) Constructing evaluation index system for QRL

Constructing a comprehensive and effective evaluation index system is the key to accurately evaluating and quantifying QRL in the 87 counties of Gansu Province. The evaluation index system for QRL is a complex system, consisting of multi-attribute and multi-level subsystems. From the perspective of nature-society-economy, this paper fully considered the basic requirements of index selection including comprehensiveness, purposiveness, scientificity and operability as well as other requirements including policy relevance, multi-dimensional comprehensiveness, research object specificity and data availability. In addition, the selection of indexes is consistent with the quality of life evaluation standards used at home and abroad. Therefore, we did a lot of research on published papers related to the quality of life, and selected the most valuable ones as a reference (Dai et al., 2018; Ma et al., 2019a, Ma et al., 2019; Tang et al., 2014) to build indictors system, which composed of five dimensions (Table 1). Before the data analysis and evaluation, in order to eliminate the influence of dimension and value size on the results, the positive and negative standardized processing method was used to preprocess the indicators. Then, their values are concentrated between 0 and 1. On this basis, the index weight is determined by the variation coefficient method of objective assignment.

During evaluation of QRL at country scale in Gansu Province, the initial data were standardized to eliminate the influence of dimension and numerical size on the results. If a greater value is more conducive to system development, then the index is a positive index, and equation (1) will be used for its standardization. If a smaller value is more conducive to system development, then the index is a negative index and equation (2) will be used for its standardization. The equations are as follows:

Positive index:

$$Z_i = \frac{C_i - \min(C_i)}{\max(C_i) - \min(C_i)} \tag{1}$$

Negative index:

$$Z_i = \frac{\max(C_i) - C_i}{\max(C_i) - \min(C_i)} \tag{2}$$

Table 1
Evaluation index system for QRL in Gansu Province and weights of indexes.
(2) Calculating index weight

Target layer	Aspect layer	Index layer	Index weight	Positive or negative
QRL *A*	Income and expenditure B_1 (0.1123)	Per capita disposable income of rural residents Z_1 (Yuan)	0.0564	+
		Per capita consumption expenditure of rural residents Z_2 (Yuan)	0.0491	+
		Engel's coefficient of rural residents Z_3 (%)	0.0271	−
		Ratio of urban to rural per capita disposable income Z_4 (%)	0.0244	−
	Living conditions and cultural life B_2 (0.2238)	Per capita housing area of rural residents Z_5 (m^2/person)	0.0483	+
		Proportion of cultural entertainment and education expenditure in household consumption expenditure Z_6 (%)	0.0296	+
	Infrastructure B_3 (0.1836)	Electricity consumption per 10,000 households Z_7 (km·h)	0.0644	+
		Tap water usage in rural areas Z_8 (%)	0.0194	+
		Access rate of public transportation lines in rural areas Z_9 (%)	0.0362	+
		Rural broadband coverage Z_{10} (%)	0.0310	+
		Agricultural mechanization rate Z_{11} (%)	0.0369	+
		Agricultural technology popularization rate Z_{12} (%)	0.0136	+
		Rural cable television popularization rate Z_{13} (%)	0.0525	+
	Public services and social security B_4 (0.1186)	The number of teachers per 1000 people Z_{14}	0.0374	+
		Rate of participation in new rural cooperative medical system Z_{15} (%)	0.0673	+
		Number of hospital beds per 1000 people Z_{16}	0.1699	+
		Proportion of health care expenditure in household consumption expenditure Z_{17} (%)	0.0456	+
		Proportion of rural laborers with a high school degree or higher Z_{18} (%)	0.0421	+
	Ecological environment B_5 (0.3618)	Rate of centralized treatment of rural domestic garbage Z_{19} (%)	0.0261	+
		Rate of centralized treatment of sewage Z_{20} (%)	0.0921	+
		Forest coverage Z_{21} (%)	0.0304	+

where C_i and Z_i are the initial and standardized value of *i*th index of each county in Gansu Province in 2016, respectively; max{C_i} and min{C_i} are the maximum and minimum values of *i*th index, respectively.

In order to reduce the influence of subjective factors on evaluation results, coefficient of variation was used to assign weight to each index. The procedures are as follows:

$$\delta_i = \frac{D_i}{\overline{Z}_i} \tag{3}$$

$$W_i = \frac{\delta_i}{\sum_{i=1}^{n}\delta_i} \tag{4}$$

where δ_i, D_i, $\overline{Z_i}$ and W_i are the coefficient of variation, mean square error, mean and weight of *i*th index, respectively (Table 1).

(3) Calculating QRL

Weighted summation was used to calculate QRL in the 87 counties in Gansu Province. The equation is as follows:

$$QRL = \sum_{i=1}^{n} W_i \times Z_i \tag{5}$$

where Z_i is the standardized value of *i*th index, W_i is weight of *i*th index, and *n* is the number of indexes.

According to relevant literatures and in combination with the results of this paper (Gilbert et al., 2016; Galbraith, 1958; Peng et al., 2009), the QRL of Gansu Province was classed into five levels using ArcGis10.0 Natural Breaks Classification: level I ($0 \le QRL \le 0.18$), level II ($0.18 < QRL \le 0.24$), level III ($0.24 < QRL \le 0.30$), level IV ($0.30 < QRL \le 0.38$), and level V ($0.38 < QRL \le 1$).

3.2.2. *Pearson's correlation analysis*

QRL was taken as a dependent variable. Altitude (X_1), slope (X_2), precipitation (annual average value, X_3), distance to the city center-DTTCC (X_4), distance to the provincial capital-DTTPC (X_5) and per capita cultivated land area-PCCL (X_6) were taken as independent variables. Then, Pearson correlation coefficient method was used to analyze the relationship between independent variables and dependent variable. Two confidence levels (0.05 and 0.01) were set and two-tailed test was performed. On this basis, the influence of each factor on QRL was analyzed.

$$C(QRL, X_i) = \pm max\{|C_1(QRL, X_i)|, |C_2(QRL, X_i)|\} \tag{6}$$

$$C_2(QRL, X_i) = \pm max\{|C_1(lnQRL, X_i)|, |C_1(QRL, lnX_i)|, |C_1(lnQRL, lnX_i)|\} \tag{7}$$

where X_i is *i*th independent variable, $C_1(QRL,X_i)$ is the Pearson correlation coefficient between *QRL* and X_i, $C_2(QRL,X_i)$ is the Pearson correlation coefficient between *QRL* and the logarithm of X_i, $C(QRL,X_i)$ is the Pearson correlation coefficient between *QRL* and X_i. The sign (positive or negative) of coefficient is consistent with that of the original value.

3.2.3. *Geographical detector model*

Factors that possibly determine the spatial differentiation of QRL were introduced into the geographical detector model (Liu and Li, 2017a, 2017b; Wu et al., 2018). In order to detect the spatial correlation between factor A and QRL, the map layer of QRL is overlaid onto the map layer of factor A. In the *h*th type of factor A (corresponding to one or more subregions), the discrete variance of QRL is denoted as σ_h^2. The influence of factor A on QRL is quantified as follows:

$$q = 1 - \frac{1}{n\sigma^2}\sum_{h=1}^{L} n_h\sigma_h^2 \tag{8}$$

where n_h is the number of samples in *h*th type (corresponding to one or more subregions) of factor A, *n* is the number of samples in whole study region H ($n = \sum_{h=1}^{L} n_h$), *L* and σ^2 are classification number and variance of factor A, respectively, and *q* is the degree of influence of influential factor on QRL. The value of *q* is in [0,1]. The greater the value of q, the more significant the influence of influential factor on QRL.

3.2.4. *Calculation of tradeoff*

Benefit for a single objective is defined as the relative deviation from the mean for a given observation by Bradford and D'Amato (Bradfordand and D'Amato, 2012). Root mean square deviation (RMSD) is used as a quantitative indicator of the tradeoff between QRL and its possible influential factors. Before calculation, the data were standardized to eliminate the influence of dimension on results. The RMSD is calculated

Citations of Geodetector:
[1] Wang JF, Li XH, Christakos G, Liao YL, Zhang T, Gu X & Zheng XY. 2010. Geographical detectors-based health risk assessment and its application in the neural tube defects study of the Heshun region, China. International Journal of Geographical Information Science 24(1): 107-127.
[2] Wang JF, Zhang TL, Fu BJ. 2016. A measure of spatial stratified heterogeneity. Ecological Indicators 67: 250-256.

as follows:

$$\text{RMSD} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} (Z_i - \overline{Z})^2} \tag{9}$$

where $\overline{Z}$ is the mean value of the i number of c_i. The tradeoff is defined as the root mean squared error of the individual benefits (Eq. (9)), and increases with distance to the 1:1 line, where the benefits of two variables are equal (Bradfordand and D'Amato, 2012; Lu et al., 2014) (Fig. 2). The relative position of the point to the 1:1 line indicates which objective is more beneficial at the given condition. Point D is more beneficial for objective 1 and point B is more beneficial for objective 2. The tradeoff at Point C is weaker than that at Point B or Point D. The tradeoff at Point A is zero. This figure is modified from Lu et al. (2014).

This method provides an effective indicator for quantifying the relationships between QRL and other variables. However, it only provides a rough description of the comparison of the two variables. This paper attempts to describe the relationship between QRL and variables in a more detailed way. Then, we divides the area into four quadrants: "High-High", "Low-High", "Low-Low", and "High-Low" (Fig. 2). In Fig. 2, the "High-High" region indicates high value of a variable and high QRL; the "Low-Low" region indicates low value of a variable and low QRL. In this way, we can clearly distinguish the relationship between each variable and QRL in 87 counties of Gansu Province.

4. Results

4.1. Spatial differentiation of QRL in Gansu Province

4.1.1. Spatial pattern of QRL

There was significant spatial variation of QRL in Gansu Province, with QRL decreasing from west to east (Fig. 3a). Among the five regions of Gansu Province, Hexi Corridor region to the west of Wushaoling ridge was characterized by relatively high QRL, following by Longzhong region with Lanzhou city as its center, Longdongnan, Longnan and Gannan regions were characterized by relatively low QRL. The average value of QRL in Gansu Province was 0.2787. There were 35 counties with QRL higher than the average value, accounting for only 40.23% of all counties investigated. In Hexi Corridor region, the QRL of 95% of counties were higher than 0.3. There was a great difference in QRL among the counties investigated. The QRL of Jinchuan district was the highest, reaching 0.7473. It was 0.2792 higher than that of Jiayuguan City (a county-level city, regraded as a county in this study), and ranked 2nd among the 87 counties investigated. The QRL of Maqu County was the lowest with a value of only 0.1322.

There was also spatial concentration of counties with the same level of QRL (Table 2 and Fig. 3a). Counties with level-V QRL were mainly distributed in Hexi Corridor region, accounting for 81.82% of all counties with level-V QRL. Counties with level-IV QRL were mainly distributed in cluster in Hexi Corridor, Longzhong and Longdong regions, accounting for 42.86%, 23.81% and 33.33% of all counties with level-IV QRL, respectively. Counties with level-III QRL were mainly distributed in regions except Hexi Corridor region. In Longzhong region, counties with level-III QRL were closely around counties with level-IV QRL. Counties with level-II QRL were distributed narrowly in Longzhong and Longdongnan regions, accounting for 81.48% of all counties with level-II QRL. This distribution presented a shape of strip. Counties with level-I QRL were distributed in Longdongnan and Gannan regions, accounting for 76.92% of all counties with level-I QRL. Hotspot analysis tool was used for local spatial autocorrelation analysis (Fig. 3b). High values of QRL were concentrated in two large and three small hot spot regions, all in Hexi Corridor region, especially the middle of Hexi Corridor region. Low values of QRL were concentrated in one large cold spot region and three small cold spot regions surrounding it, mainly in Longzhong, Longdongnan and Gannan regions.

4.1.2. Division of Gansu Province based on QRL

According to the spatial distribution of QRL, classification of QRL and administrative division of the province, Gansu Province was divided to clearly show the spatial variation of QRL. The grouping tools within the ArcGIS 10.2 Mapping Clusters toolset were used to group element attributes under spatial constraints. Under the condition of ensuring the original spatial connection of administrative areas as much as possible, the grouping analysis used connected graph (minimum spanning tree) to find the natural grouping of county-level administrative areas in Gansu Province. The spatial constraint method used in grouping analysis was Delaunay triangulation, that is, the elements in the group have at least one natural neighborhood shared with another element in the same group. In addition, the optimum group number was determined based on R^2. The calculation results showed that when the group number was 5, the value of R^2 reached 0.8. R^2 increased continuously with the increasing group number. Therefore, Gansu Province was divided into five regions with different QRL levels (Fig. 3c): low-QRL region (QRL is low and cannot meet the needs of human survival and development), relatively low-QRL region (QRL is relatively low and inadequately meets the needs of human survival and development), medium-QRL region (QRL is fair and basically meets the needs of human survival and development), relatively high-QRL region (QRL is relatively high and relatively suitable for human survival and development), and high-QRL region (QRL is high and suitable for human survival and development).

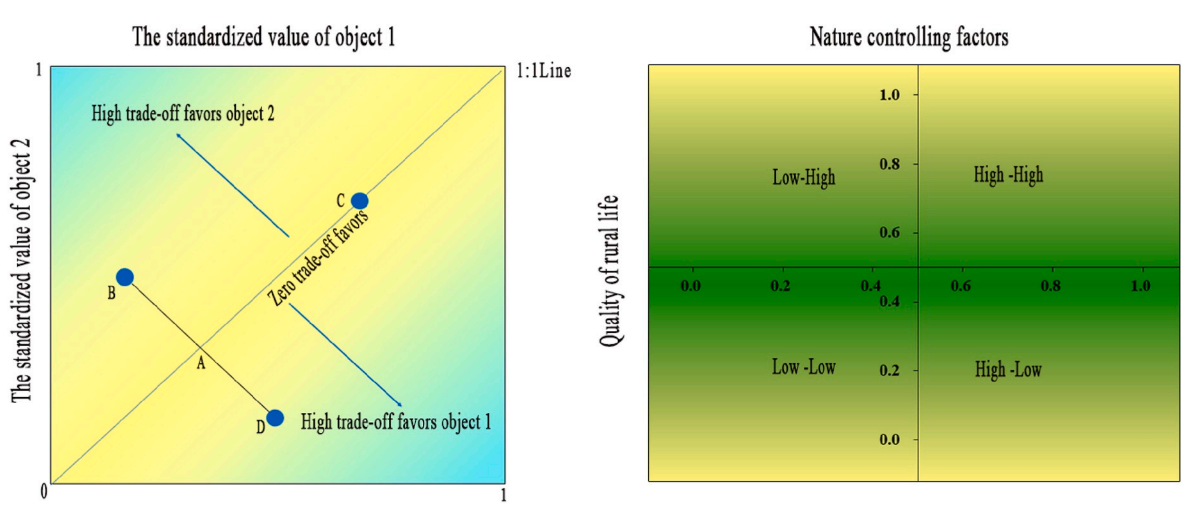

Fig. 2. Illustration of tradeoff between two objectives.

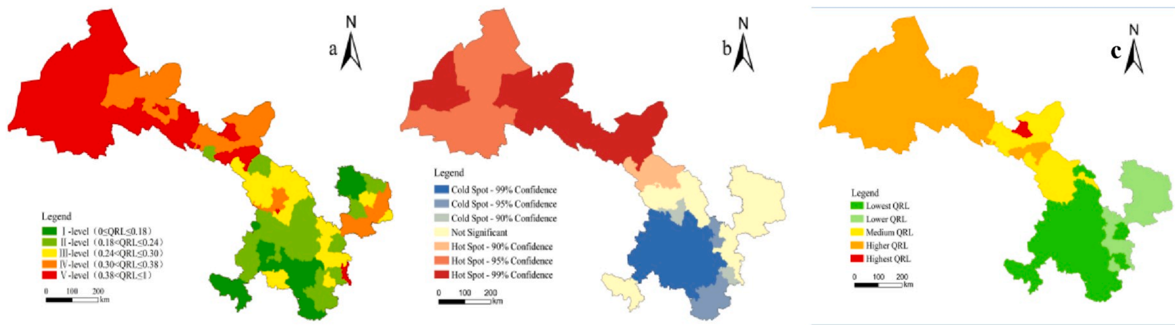

Fig. 3. (a) The spatial distribution of QRL. (b) The hot/cold spots of QRL. (c) Grouping analysis of QRL.

Table 2
The number of counties with different levels of QRL in the five regions of Gansu Province.

Classification of QRL	Hexi Corridor region	Longzhong region	Longdong region	Longdongnan region	Gannan region	Total
I ($0 \leq QRL_j \leq 0.18$)	0	2	1	4	6	13
II($0.18 < QRL_j \leq 0.24$)	2	14	2	8	1	27
III($0.24 < QRL_j \leq 0.30$)	0	6	5	3	1	15
IV($0.30 < QRL_j \leq 0.38$)	9	5	7	0	0	21
V ($0.38 < QRL_j \leq 1$)	9	1	0	1	0	11
Total	20	28	15	16	8	87

The grouping analysis results were compared with QRL incidence hotspot map. The distribution of low-QRL region, high-QRL region and relatively high-QRL region was highly consistent with that of cold spots and hot spots, showing strong agglomeration characteristics. With Lanzhou city as boundary, the regions to the east of Lanzhou city were all low-QRL and relatively low-QRL regions, as number reached 59. The Moran's I of QRL was 0.20, indicating concentrated distribution. The regions to the west of Lanzhou city (including Lanzhou City) were relatively high-QRL and medium-QRL regions (except that Jinchuan district was a high-QRL region), as number reached 27. Many of these regions far from the provincial capital (Lanzhou City) were with good economic development. The Moran's I of QRL was 0.27, also indicating concentrated distribution.

4.2. Identification of natural controlling factors of QRL

QRL is comprehensively affected by multidimensional factors. Among them, natural geographic factors basically determine the pattern of QRL. They mainly include topography, geomorphology, water, cultivated land resources, *etc.*, and have a significant influence on the spatial differentiation of QRL. In this paper, Pearson correlation, spatial coupling and geographic detector analyses were used to identify the natural controlling factors of spatial differentiation of QRL.

4.2.1. Pearson correlation analysis

The results of Pearson correlation analysis showed that QRL was correlated with altitude, slope, DTTPC and precipitation (Fig. 4). QRL

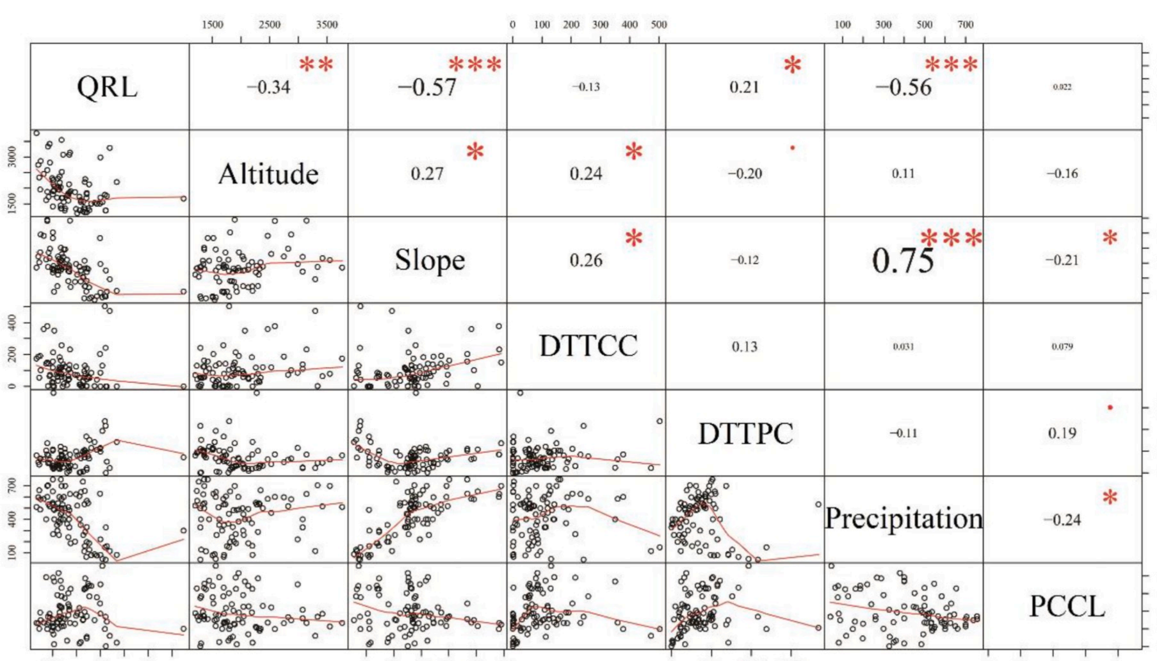

Fig. 4. Pearson correlation analysis of QRL and six essential factors.

was negatively correlated with altitude at the 99% confidence level, with correlation coefficient of −0.34. QRL was negatively correlated with slop and precipitation at the 99.9% confidence level, with correlation coefficients of −0.57 and −0.56, respectively. QRL was positively correlated with DTTPC at the 95% confidence level, with correlation coefficient of 0.21. QRL in Gansu Province was mostly affected by natural environmental factors and then by economic location. Thus, the higher the altitude, the greater the slope, the more the precipitation and the shorter the DTTPC, the lower the QRL.

4.2.2. Spatial coupling analysis

Table 3 shows the spatial coupling of the classification results of QRL and the six essential factors (EF). The proportions of complete match (0 in Table 3 represents complete match) between the classification result of each essential factor and QRL were 20.42%, 37.28%, 9.77%, 10.51%, 34.28% and 20.78%, respectively. The degree of match between QRL and altitude, slope, DTTPC as well as PCCL were relatively high, as well as that between QRL and other factors were relatively low (Appendix B). Therefore, altitude, slope, DTTPC and PCCL were main factors affecting the spatial differentiation of QRL.

4.2.3. Geographical detector analysis

Geographical detector model was used to perform spatial detection of QRL and the six essential factors. The influences ($L_{A,P}$) of the six essential factors on QRL were quantified to be 0.19, 0.37, 0.37, 0.10, 0.20 and 0.07, respectively. Among the six factors, slope and precipitation had the strongest influence on QRL, followed by altitude, slope, precipitation and DTTPC, and PCCL had the weakest influence on QRL.

According to results of Pearson correlation, spatial coupling and geographical detector analyses, altitude, slope, precipitation and DTTPC were the natural controlling factors of spatial differentiation of QRL in Gansu Province.

4.3. Tradeoff analysis of QRL in Gansu Province

Root mean square deviation (RMSD) was used to quantify the tradeoff relationship between QRL and the six essential factors (Fig. 5). QRL of Jinchuan district was 0.7473, far higher than that of other counties. If Jinchuan district was included, it would influence the spatial pattern of other counties when the tardeoff relationship diagram was generated. Therefore, Jinchuan district was excluded in the calculation to better reflect the actual situation.

There was a significant difference in the tradeoff relationship between QRL and the six factors (Fig. 5). The tradeoff between QRL and precipitation was the strongest, with RMSD of 0.293. The tradeoff between QRL and altitude, slope as well as DTTCC were of medium level and decreased subsequently. The tradeoff between QRL and DTTPC as well as PCCL were smaller than 0.2., the tradeoff between QRL and PCCL was only 0.168. This indicated that natural factors (precipitation, altitude and slope) were key factors influencing QRL in the study region. Economic location and cultivated land area had relatively weaker influence on QRL. In terms of distribution, the tradeoff relationships of QRL with altitude, DTTCC and DTTPC were characterized by low-low and low-high. The proportion of counties with low-low tradeoff relationship exceeded 50%. The proportion of counties with low-low tradeoff between QRL and DTTPC reached 61.63%. This demonstrated that low values of QRL were concentrated in low-altitude counties that were close to city center or provincial capital. The tradeoff relationships between QRL and slope were characterized by low-high, low-low and high-low. The number of counties with low-high, low-low and high-low tradeoff between QRL and slope accounted for 36.05%, 39.53% and 23.25% of all counties investigated, respectively. This revealed that the counties with small slope had relatively great difference in QRL. There were still many counties with small slope and low QRL. The tradeoff relationships between QRL and precipitation were characterized by low-high and high-low, mainly distributed at both sides of the diagonal of the two opposite quadrants (Fig. 5c). The number of counties with high-low tradeoff between QRL and precipitation accounted for 48.84% of all counties investigated. This suggested that the QRL of certain regions in Gansu Province was low, though they had much precipitation. The tradeoff relationships between QRL and PCCL were distributed in all four quadrants (Fig. 5f), indicating that PCCL had a weak influence on QRL.

Table 3
Spatial coupling analysis of QRL and six essential factors (%).

Coupling	X_1	X_2	X_3	X_4	X_5	X_6
−4	0	0	0.22	0	0	0
−3	0.73	0.02	7.63	3.2	5.11	2.77
−2	7.66	3.81	10.71	13.75	4.7	5.86
−1	22.86	25.47	13.06	11.51	16.31	22.6
0	20.42	37.28	9.77	10.51	34.28	20.78
1	26.5	21.1	2.81	9.93	9.75	16.53
2	4.98	8.09	4.55	13.12	8.76	5.45
3	0	0.04	31.07	6.85	14	6.51
4	16.84	4.17	20.18	31.13	7.11	19.5

4.4. Division of Gansu Province based on controlling factors of QRL

QRL in Gansu Province gradually decreased from west to East, and was mainly affected by four natural control factors of altitude, slope, precipitation and DFTPC. According to administrative division, city was taken as the evaluation unit, and the geographical detector model was used for multi-level detection to quantify the influence ($L_{A,P}$) of each factor on QRL in each city (Table 4). QRL in 14 cities were affected by the 6 factors to varying degrees. In order to effectively identify the main factors affecting QRL in each city, factors with $L_{A,P}$ greater than 0.4 were taken as the controlling factors. If $L_{A,P}$ values of factors of a city were all very small, then the factor with the greatest $L_{A,P}$ was taken as the controlling factor. According to $L_{A,P}$ value and the type of controlling factor, the whole study region was classified into three types of QRL regions: natural environment restricted region, resource abundance restricted region, and economic location restricted region (Fig. 6).

Table 4 and Fig. 6 show that Zhangye City, Jiayuguan City, Pingliang City were natural environment restricted regions. The QRL in Jiayuguan City was mainly influenced by the slope ($L_{A,P} = 0.472$), and the influences of other factors were relatively weak. The QRL in Zhangye City and Pingliang City were mainly influenced by precipitation ($L_{A,P} =$ 0.474 and 0.841, respectively). The number of resource abundance restricted regions was small and only two (Lanzhou City and Qingyang City). The QRL in these two cities were mainly influenced by PCCL ($L_{A,P}$ = 0.731 and 0.831, respectively). The number of economic location restricted regions was the largest, reaching nine. The QRL in seven cities were mainly influenced by DTTCC ($L_{A,P}$ of Jinchang City was the greatest and reached 1). The QRL of the remaining two cities were mainly influenced by DTTPC ($L_{A,P} = 0.272$ and 0.578, respectively).

5. Discussion

5.1. The mechanism of spatial differentiation of QRL in Gansu Province

The spatial differentiation of QRL is affected by many factors. Among them, natural factors are fundamental and driving factors. By Pearson correlation, spatial coupling and geographical detector analyses, altitude, slope, precipitation and DTTPC were the natural controlling factors of spatial differentiation of QRL in Gansu Province. The mechanism of these controlling factors affecting QRL was analyzed. The results can provide guidance for improving QRL, constructing a well-off society and promoting rural revitalization.

(1) Altitude is the height of each geographical unit in relation to sea level. Gansu Province is long in east-west direction and has a

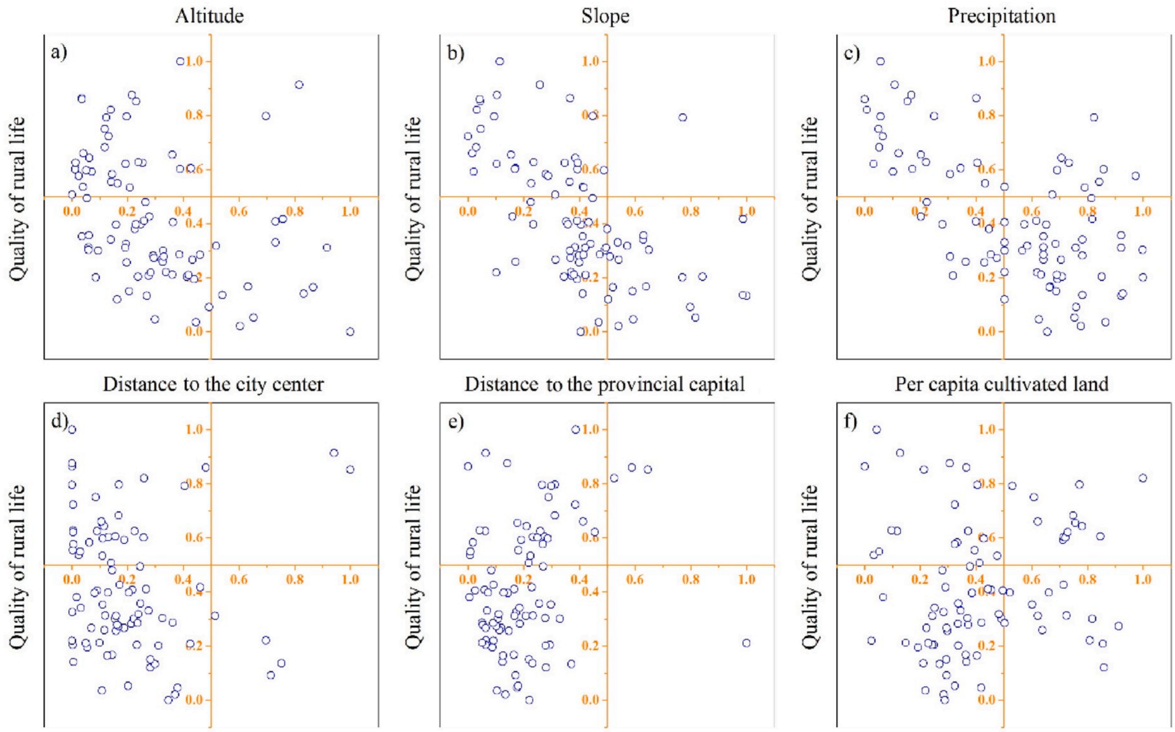

Fig. 5. Tradeoff analysis of QRL and the six essential factors.

Table 4
The influences of six factors on QRL in 14 cities of Gansu Province and classification of these cities.

Cities	X_1	X_2	X_3	X_4	X_5	X_6	Impoverished region type
Lanzhou	0.096	0.013	0.400	0.374	0.369	0.731	Resource abundance restricted region
Baiyin	0.011	0.111	0.469	0.966	0.426	0.521	Economic location restricted region
Jinchang	0.221	0.038	1.000	1.000	0.006	0.221	Economic location restricted region
Tianshui	0.172	0.010	0.206	0.529	0.039	0.166	Economic location restricted region
Wuwei	0.323	0.151	0.789	0.970	0.616	0.029	Economic location restricted region
Zhangye	0.216	0.184	0.474	0.048	0.002	0.048	Natural environment restricted region
Pingliang	0.257	0.036	0.841	0.375	0.512	0.003	Natural environment restricted region
Jiuquan	0.178	0.029	0.078	0.924	0.885	0.897	Economic location restricted region
Jiayuguan	0.002	0.472	0.002	0.001	0.007	0.002	Natural environment restricted region
Qingyang	0.276	0.023	0.403	0.522	0.001	0.831	Resource abundance restricted region
Dingxi	0.438	0.150	0.238	0.457	0.293	0.228	Economic location restricted region
Longnan	0.128	0.006	0.161	0.061	0.272	0.005	Economic location restricted region
Linxia	0.061	0.008	0.331	0.398	0.578	0.331	Economic location restricted region
Gannan	0.051	0.103	0.268	0.883	0.102	0.038	Economic location restricted region

complex rugged terrain, with crisscross distribution of plains, mountains and hills. Altitude greatly affects production and life in rural areas. Hexi Corridor region in Gansu Province has a relatively flat terrain and the transportation is convenient. Therefore, the living conditions of farmers in this region are relatively good. Longzhong, Longdong and Longdongnan are Loess hilly and gully areas, characterized by broken terrain. This have caused great inconvenience to people's production and life, as well as limited the development of social economy. Fig. 5a suggest that the altitude increases from northwest to southeast of Gansu Province. Fig. 2 shows that QRL decreases from northwest to southeast. In Longzhong, Longdongnan and Gannan regions, the terrain is very steep and not suitable for large-scale agricultural production. Therefore, the yields of agricultural products are low and the sources of farmers' income are limited, resulting in low QRL. In Hexi Corridor and Longdong region, the terrain is flat, agricultural production increases quickly, social economy develops rapidly and farmers have rich sources of income. Thus, the QRL is relatively high.

(2) Slope is an important indicator of regional topography and has important influence on the structure and mode of agricultural production. Proper agricultural production activities vary with slope. For rural agricultural production, slope degree lower than 15° is suitable for crop planting. The smaller the slope, the more suitable it is for crop growth. In addition, topography is an important factor affecting the construction of traffic roads and other facilities as well as the development of social economy. There tend to be more agricultural production and employment opportunities in regions with flat terrain and the income of farmers is also relatively high. Fig. 5 and Appendix B suggest that the slope increases from northwest to southeast of Gansu Province. Fig. 2 shows that QRL decreases from northwest to southeast of Gansu Province. In Longzhong, Longdongnan and Gannan regions, the terrain is very steep and not suitable for large-scale agricultural production. Therefore, the yields of agricultural products are low and the sources of farmers' income are limited, resulting in low QRL. In Hexi Corridor and Longdong region, the terrain is flat, agricultural production increases quickly, social

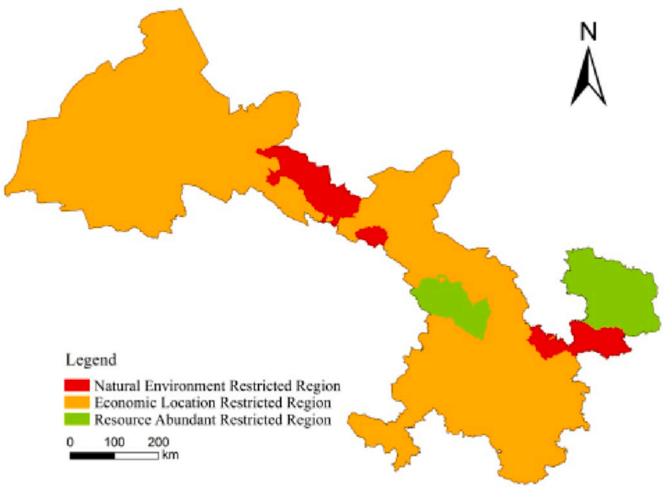

Fig. 6. Regional distribution of QRL.

economy develops rapidly and farmers have rich sources of income. Thus, the QRL is relatively high.

(3) Precipitation has a significant negative influence on QRL. Gansu Province is a typical semi-arid region, with precipitation increasing from west to east. Dunhuang City at the westernmost of Gansu Province has the least annual average precipitation, only 38.5 mm. Kang county at the southeast end of Gansu Province has the most annual average precipitation, reaching 756 mm, about 19.6 times of that in Dunhuang City. However, the QRL of Dunhuang is 0.42, and that of Kang county is only 0.2, even lower than 1/2 of the former. Generally, the more the precipitation, the more conducive it is to agricultural production, the higher the farmers' income and the higher the QRL. However, Gansu Province tends to have a contrary situation. Hexi Corridor has little precipitation, but farmers' income is high due to relatively well-developed irrigated agriculture. In 2016, the disposable income of farmers in Aksay Kazak Autonomous County in this region was the highest in Gansu Province and reached 22,879 Yuan. The precipitation in Longdongnan region exceeds 600 mm. However, most farmlands are non-irrigated, the agricultural production conditions are poor and farmers' income is low. In 2016, the disposable income of farmers in Hui County of Longdongnan region was only 7083 Yuan. The disposable income of farmers in Dangchang County was the lowest in this region and only 5250 Yuan. Therefore, although precipitation is a main factor influencing QRL in Gansu Province, its influence is related to the influence of natural geographical factors such as terrain since there is great difference in natural conditions among various regions of Gansu Province.

(4) DTTPC reflects the access to the economic resources and public services in provincial capital. Generally, the shorter the DTTPC, the more the access to the economic resources and public services in provincial capital. However, this paper shows that QRL is positively correlated with DTTPC (*i.e.*, the longer the DTTPC, the higher the QRL). Although the provincial capital has the most developed health care system, education system, social security system, banking system and other services or facilities in the province, these do not pose positive influence on the improvement of QRL in neighboring areas. Surprisingly, the more distant a region is from the provincial capital, the higher the QRL. There are two main reasons for this phenomenon. First, this paper focused on the QRL (not quality of urban life). The various facilities and services in the provincial capital are mainly provided for urban residents and seldom used by rural residents. Second, Gansu Province is long and narrow, and there exists a significant difference in development level among various regions. The key to rural development is not the distance to city center or provincial capital, but natural factors such altitude, slope, *etc.*

5.2. Measures to improve the QRL in Gansu Province

In view of the three types of impoverished regions, their controlling factors and China's goal of comprehensive realization of a well-off society in 2020, this paper has the following suggestions on how to improve QRL in Gansu Province.

(1) Government should develop regional promotion strategies closely based on the types of impoverished regions. Natural environment restricted region is characterized by large slope and high altitude, which are not conducive to crop planting. Therefore, infrastructure construction should be carried out first, and characteristic ecological agriculture is then developed based on local advantages. Resource abundance restricted region has limited cultivated lands. Thus, large-scale agricultural production is not supported. It is necessary to promote the construction of infrastructures such as irrigation systems, optimize the allocation of land resources and improve the yields of lands. In addition, strengthening the labor training, providing employment opportunities and increasing labor export are necessary. Economic location restricted region is characterized by a lack of infrastructure and public service facilities. Farmers' demands for consumption, health care, education, *etc.* have not been met. It is important to strengthen the construction of infrastructure and public service facilities, expand the capacity and completeness of facilities, and vigorously develop regional characteristic economy.

(2) Government should make changes in the mode and mechanism of development according to the controlling factors of spatial differentiation of QRL. Overall, the economic development in Gansu Province lags behind that in many other regions of China. This is obvious in rural areas. Natural factors, including the altitude, slope, precipitation and DTTPC, mainly limit the rural development and improvement of QRL in Gansu Province. However, these factors cannot be changed within a short period of time. Therefore, the QRL in Gansu Province should be improved by changing other factors instead of these natural ones. For example, road network construction should be enhanced to strengthen the communication between regions with low QRL and the other regions. Local government can actively explore and establish a benefit link between new economic organizations and farmers in regions with low QRL, support new economic organizations such as farmers' professional cooperatives and industrial associations, emphasize the efficiency of production and operation, and highlight their role in improving QRL. In addition, labor skills and labor cooperation should be improved in regions with low QRL.

(3) Since there is an interaction among the factors affecting QRL, measures to improve QRL need to be matched with each other to achieve the desired effect. It is necessary to establish a powerful mechanism to ensure that all measures can be coordinated and implemented. In addition, to improve QRL, researchers should focus on the spatial characteristics of different geographical regions, variations in the production and lifestyles of different geographical regions, as well as the mode, approach and strategy of ecological reconstruction.

6. Conclusions

(1) QRL in Gansu Province is characterized by spatial heterogeneity and agglomeration, and decreases from west to east. The region with high QRL is mainly concentrated in two larger hot spots and

three smaller hot spots. the region with low QRL is mainly concentrated in one larger cold spot area, surrounded by three smaller cold spot areas. The regions with low and high QRL are highly consistent with the distribution characteristics of corresponding cold and hot spot regions, and show a strong clustering.

(2) The QRL is the result of natural and human factors. Among them, the natural one is the basis. Altitude, slope, precipitation and DFTPC are main natural factors that affect the spatial differentiation of QRL in Gansu Province. All their LA,P values are greater than 0.19, among which slope and Precipitation have a decisive effect on QRL, with LA,P value of 0.37; DFTCC and PCCL have a relatively small impact on QRL, with LA,P values of only 0.1 and 0.07, respectively.

(3) There is a significant difference in tradeoff relationship between QRL and the six essential factors. The tradeoff between QRL and precipitation is the strongest, with RMSD of 0.293. The tradeoff between QRL and altitude/slope/DTTCC are in the middle level and decrease successively, with RMSD of 0.238, 0.255 and 0.2 respectively. The trade-off strengths of QRL, DFTPC and PCCL are less than 0.2, and the trade-off strength of PCCL is only 0.168.

(4) According to the influences of different natural controlling factors on QRL, Gansu Province is classified into three regional types: natural environment restricted type, resource abundance restricted type and economic location restricted type. The natural environment restricted type is distributed in Zhangye, Pingliang and Jiayuguan, which are mainly affected by the slope and Precipitation. The resource abundance restricted type is mainly distributed in Lanzhou and Qingyang, mainly being affected by PCCL. The number of economic location restricted type is the greatest. They are distributed in nine urban areas, affected by DFTCC (7 cities) and DFTPC (2 cities) respectively.

(5) This study provides a reference for improving the QRL of Gansu Province, building a well-off society in an all-round way, and promoting the strategy of Rural Revitalization. In addition, it has an important guidance for other rural regions in China to implement the strategy of Rural Revitalization.

Declaration of competing interest

The authors declare no conflict of interest.

CRediT authorship contribution statement

Fang Fang: Conceptualization, Data curation, Writing - review & editing. **Libang Ma:** Writing - original draft, Funding acquisition, Methodology. **Hao Fan:** Visualization, Investigation. **Xinglong Che:** Validation. **Meimei Chen:** Supervision.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Grant No. 41661105).

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