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# Arrangement of High-standard Basic Farmland Construction Based on Village-region Cultivated Land Quality Uniformity

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**Abstract:** As an important constitute of land consolidation, high-standard basic farmland construction is an important means to protect the quantity, quality and ecological environment of cultivated land. Its target not only lies in the increase of cultivated land quantity, but also the improvement of cultivated land quality, agricultural production conditions and ecosystem environments. In the present study, the quality evaluation method and construction arrangement of cultivated land were explored to facilitate the process of decision-making and implementation for high-standard basic farmland construction (HSBFC) with administrative village as the unit. Taking the land comprehensive improvement project area in Quzhou County, Handan City, Hebei Province as a case study, the whole process of the study comprised of three steps: 1) establishment of the evaluation model of cultivated land quality uniformity based on regional optimum cultivated land quality, and construction of the uniformity evaluation index system from the aspects of soil fertility quality, engineering quality, spatial quality and eco-environment quality, according to the new concept of cultivated land quality; 2) calculation of cultivated land quality uniformity by grading indicators, assigning scores and weighting sums, exploring the local homogenization characteristics of regional cultivated land quality through spatial autocorrelation analysis, and analyzing the constraints and transformative potential of barrier factors; 3) arrangement of HSBFC according to the principle of concentration, continuity and priority to the easy operation. The results revealed that the value of farmland quality uniformity for the administrative villages in the study area was between 7.76 and 21.96, and there was a difference between various administrative villages. The regional spatial autocorrelation patterns included High-High (HH), Low-Low (LL), High-Low (HL) and Low-High (LH). These indicate that regional cultivated land quality has local homogenization characteristics. The most restrictive factors in the study area were the medium and low transformation difficulty indexes, including soil organic matter content, farmland shelterbelt network density, field regularity and scale of the field. In addition, there were also high transformation difficulty indicators in some areas, such as sectional configuration. The project area was divided into four partitions: major construction area, secondary construction area, general construction area, and conditional construction area. The cultivated land area of each subarea was 1538.85 ha, 1224.27 ha, 555.93 ha, and 1666.63 ha, respectively. This comprised of 30.87%, 24.56%, 11.15% and 33.42% of the total project area, respectively. The evaluation model and index system could satisfy the evaluation of farmland quality and diagnosis of obstacle factors to facilitate the subsequent construction decision. The present study provides reference for the practice of regional HSBFC, and a new feasible idea and method for related studies.

**Keywords:** high-standard basic farmland; cultivated land quality uniformity; barrier factor; arrangement

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## 1 Introduction

Cultivated land consolidation (CLC) is the core content of land consolidation (LC) (Cay and Uyan, 2013). As a form of CLC in China, high-standard basic farmland construction (HSBFC) is essential for ensuring rural

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development and for optimizing national territory arrangement (Tang et al., 2017), and is supported by land consolidation projects (LCPs) (Liu et al., 2014). It is to build the basic farmland which has the advantages of centralized connection, facilities matching, high and stable yield, sound ecology, strong resistance to disaster, and adaptation to modern agricultural production and management (Tang et al., 2014). According to China's land consolidation planning (2011–2015), 53.33 million ha high-standard basic farmland aims to be built by 2020 which lays the foundation for fully raising the quality of cultivated land and ensuring national grain security. At present, China has started to carry out the work of HSBFC, but in the process of construction, there appeared many problems about overall allocation, such as the mismatch between capital input and natural endowments of cultivated land, repeated construction, scattered investment, low construction efficiency, low benefit, *etc*. The important reason is the process of LC has experienced major problems such as the long duration of projects, the high operational costs involved in consolidation, the conflicts between the stakeholders involved (Demetriou et al., 2012). Therefore, scientific LC planning and overall arrangement of LCPs on the basis of fully understanding the natural, social and economic conditions of the region through ex-ante evaluation are particularly important. China's land consolidation planning (2011–2015) also required LCPs to plan regarding regional balance and land resource difference (Cui et al., 2016). Many studies have focused on finding an effective way for ex-ante evaluation of LC. The ex-ante evaluation involves interdisciplinary research, including the cost-benefit analyses, environmental impact assessment, social impact studies, land consolidation potential evaluation, cultivated land quality (CLQ) evaluation and investment implementation condition evaluation, *etc.* (Van Huylenbroeck et al., 1996; Coelho et al., 2001; Crecente et al., 2002; Touriño et al., 2003; Demetriou et al., 2012; Zhang et al., 2013; Kong et al., 2014; Tang et al., 2017). On the basis of those evaluations, many planning or decision-making models or systems have been constructed to carry out LC planning and overall arrangement of LCPs.

Aiming at the process of HSBFC planning and arrangement, many studies have focused on farmland consolidation zoning, including construction area delineation and sequential design, which are based on ex-ante evaluation (Jiang et al., 2015). CLQ evaluation has been regarded as the core basis, and socioeconomic conditions evaluation as a supplement by means of barrier factor combination, four quadrant method, K-means clustering, spatial autocorrelation method, *etc.* (Feng et al., 2012; Wang et al., 2013; Cui and Liu, 2014; Tang et al., 2014; Xue et al., 2014; Zhang et al., 2014; Xiong et al., 2015; Zhu et al., 2015; Zhai et al., 2015; Sun et al., 2016). Overall, in the process of farmland consolidation zoning, two problems need to be discussed. The first problem is the selection of evaluation and decision-making unit. Cultivated land patches were often chosen as the evaluation and decision-making units to pursue a finer degree. However, CLC is a systematic behavior with regional characteristics, and all kinds of engineering and biological measures are carried out in a certain region. From the point of view of serving CLC, the evaluation and decision-making units tend to be systematic and large-scale in the evaluation of CLQ and consolidation potential. In practice, a consolidation scale is also required, which is not for a specific land patch, but for a certain region. At the same time, LC is generally organized by the town and implemented by administrative villages (Zhang and Zhao, 2006). Therefore, the method of HSBFC arrangement with the administrative village as the decision-making unit was explored according to the evaluation and practice characteristics of CLC, which has theoretical and practical significance and makes it convenient for HSBFC decision-making, organization and implementation. The second problem is the definition of the connotation and structure of CLQ. In the foregoing studies, the connotation definition, evaluation structure and index selection of CLQ are different. This not only includes the CLQ evaluation of natural attributes, but also the comprehensive evaluation of multiple attributes, such as the natural endowment of cultivated land, facilities, spatial layout, social economy, *etc.* (Tyler et al., 1987; Shao et al., 2006, 2007; Qian et al., 2015; Zhu et al., 2015). Du et al. (2016) revealed that the definition and evaluation structure of CLQ remains not unified at present, and the need for the diversified uses of mankind endows cultivated land with diverse elements, components and functions, extending CLQ from a single natural attribute to multiple attributes of nature, economy and society. A new concept of CLQ was also put forward, including soil fertility quality, engineering quality, spatial quality, eco- environment quality, and aesthetic and cultural quality. This reflects the multiple functions and quality characteristics of cultivated land.

Therefore, in view of these two problems encountered by previous HSBFC studies, with reference to previous research ideas, and taking the land comprehensive improvement project area in Quzhou County, Hebei Province as the study case, we explored a new HSBFC arrangement system, including CLQ evaluation model with the administrative village as the decision-making unit, evaluation index system based on the new concept of CLQ and farmland consolidation zoning method based on the local homogenization characteristics of regional CLQ and barrier factors restriction. The purpose of the present study was to explore the method of regional CLQ evaluation and HSBFC arrangement based on the new concept of CLQ, with the administrative village as the decision-making unit. This would provide reference for improving the construction efficiency and benefits in regional HSBFC practice, and a new feasible idea and method for related studies.

## 2 Materials and Methods

### 2.1 Study area

Quzhou County is located northeast of Handan City, Hebei Province, at geographical coordinates of 36°35′43″–36°57′56″N, 114°50′22″–115°13′27″E. The land comprehensive improvement project area is located northeast of Quzhou County (Fig. 1). The area is in the North China Plain, at an altitude of 15–46 m. This area experience flatter rain, has a gentle surface, prevails southerly, comprises of medium fertility loam, and has superior natural conditions, abundant agricultural resources and good production conditions. The site covers an area of 5932.37 ha, and the region is located across three towns and 46 administrative villages, with an agricultural population of 41 631, a cultivated land area of 4592.98 ha, and a rural residential area of 533.29 ha. The Quzhou County Land Consolidation Planning (2011–2020) determined the project area, and carried out three types of rural land comprehensive consolidation projects, including high-standard basic farmland construction, rural residential land consolidation, and reserved land development of suitable cultivated land. The construction scale of the high standard basic farmland was 4948.77 ha, in which 186.65 ha of cultivated land will be added. The construction included flatting of the field, strengthening of farmland infrastructure construction including field road, water conservancy project and farmland shelter-belt, reclaiming of wastelands, and guiding the cultivated land concentrated connection, in order to meet the requirements of mechanized farming. In turn, this would promote large-scale land management, land quality and grain production capacity, and provide protection for food security.

### 2.2 Data sources

The following important data were extracted and included: 1) the 1∶10 000 database of land use change investigation of Quzhou County in 2014, the overall land use planning (2010–2020) and land consolidation planning (2011–2020) where the land comprehensive improvement project area, project area scale and HSBFC target was confirmed, and related data layers; 2) the supplemented data of cultivated land quality gradation results and data of the investigation and evaluation on cultivated land fertility from which the related indexes of cultivated land quality were extracted; 3) the 0.5-m Pléiades-1 remote sensing data in 2014 and deep wells data in the project area, from which data on farmland infrastructure such as road, forest, irrigation and drainage engineering were extracted and modified; 4) the soil survey data and soil sampling data, from which soil quality related indexes were measured, supplemented and corrected. In order to ensure the accuracy of the data, the geography and projection coordinate system were unified, and topological error checking was carried out. The vector data of different sources were superimposed to provide index attributes for each cultivated land patch. The higher precision index data was further segmented on the basis of the cultivated land patches.

### 2.3 Research Methods

#### *2.3.1 Evaluation model for village-region CLQ uniformity*

In this section, with the administrative village as decision-making unit, a model for evaluating CLQ uniformity based on the patch quality of cultivated land was developed. The construction of the model was based on the connotation and principle of the coefficient of variation (CV) that measures the relative change/fluctuation

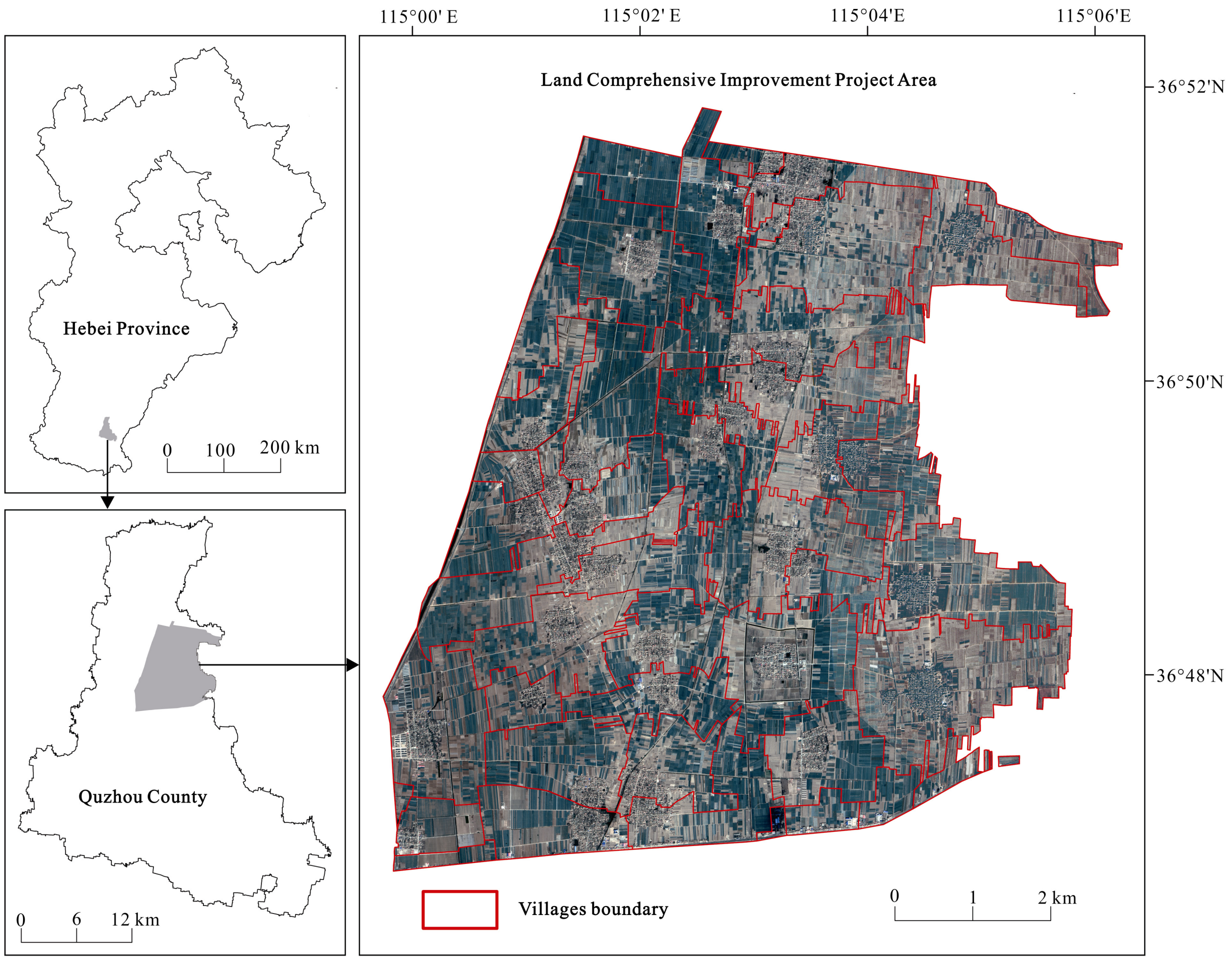


**Fig. 1** Location and administrative division of study area

of geographical elements in time and space, and was improved according to the spatial structure characteristics of village-region CLQ. The village-region farmland was divided into several patches by field roads, irrigation ditches and canals, among which the quality difference formed the relative change/fluctuation in village-region CLQ. On this basis, in order to characterize the village-region CLQ and ensure the quality comparability between villages, the bias of quality was not based on the average quality level, but on regional optimum quality levels. Thus, the quality level was characterized through the comprehensive restrictive level of each barrier factor, according to the principle of the barrier factor diagnosis model used in the land use evaluation research (Wang and Dong, 2015; Zhu et al., 2015), which embodied the dispersion degree of each index relative to the regional optimal level. The number of cultivated land was measured by patch area under different quality grades. Hence, village-region CLQ could be regarded as the population of the area weighted component of patch quality, and not the simple quantity sample population. Therefore, the standard deviation in the CV formula was converted to the area weighted standard deviation shown in Equations (1)–(3).

$$P_i = \begin{cases} \sqrt{\sum_{j=1}^{n} a_{ij}\left(S_{ij} - S_{\max}\right)^2 / A\left(1 - 1/n\right)} & n > 1 \\ 0 & n = 1, S_{ij} = S_{\max} \\ \sqrt{\sum_{j=1}^{n} a_{ij}\left(S_{ij} - S_{\max}\right)^2 / A\left(1 - 1/(n+1)\right)} & n \geq 1, S_{ij} \neq S_{\max} \end{cases} \quad (1)$$

$$C_i = P_i / S_{i\max} \quad (2)$$

$$G = \sum_{i}^{15} C_i \times w_{ai} \tag{3}$$

where $P_i$ was the area weighted standard deviation of the $i$th quality index relative to the regional optimum quality level, the higher the $P_i$, the greater the deviation of the $i$th quality index relative to the highest quality level in the region, and the higher the restriction. When an index in the village area was only the optimal quality level, the $P_i$ was 0, indicating no deviation; $a_{ij}$ was the $i$th quality index and $j$th grading of cultivated land patch area in village, m$^2$; $A$ was the total area of cultivated land patches in village, m$^2$; $S_{ij}$ was the $j$th quality grading of the $i$th quality index; $S_{\max}$ was the optimum grading score for the $i$th quality index of the project area, $n$ was the grading number included in $i$th quality index of cultivated land in village, the weighted standard deviation calculation was based on the optimal quality classification, to avoid the situation of the denominator being 0, if there was no optimum quality grading of cultivated land in village, the area of the optimum quality grading was considered very small, which could be neglected compared with other quality grading area. Thus the number of quality grading in village included the optimal quality grading, the evaluation of which was $n$+1; $C_i$ was the village-region quality uniformity of $i$th index; $W_{ai}$ was the weight of each index; $G$ was the village-region CLQ uniformity. $G$ reflected the dispersion degree of the patch quality in the village relative to the optimal quality level in the region. The higher the $G$, the greater the dispersion degree, and the poorer the CLQ. Based on the patch unit quality, the CLQ uniformity of village unit was obtained, which could describe the quality level and dispersion degree of cultivated land in the village, and take into account the advantages of the two evaluation units in evaluation and decision-making respectively.

#### *2.3.2 Evaluation index system of village-region CLQ uniformity*

CLQ refers to the ability of cultivated land characteristics to satisfy the agricultural production, acquisition of economic interests and human well-being (Du et al., 2016). Because of complexity of the formation of CLQ, ill-informed about some factors affecting CLQ, and discrepancy of different regions in nature, society and economy, for a long time, there has been not an acknowledged theoretic system and comprehensive scheme in informing the indicators of CLQ evaluation (Shao et al., 2007). At present, there are three kinds of views on CLQ in academic circles. Under different historical conditions, the connotation of CLQ has been expounded from different levels and perspectives. The early agricultural productivity level is low, and natural conditions such as soil fertility, climate and the environment have a direct impact on cultivated land value. Scholars have considered that the quality of cultivated land is the sum of all kinds of natural and environmental factors (Liu et al., 2003), which form the view of CLQ based on natural attributes. With the development of social productive forces and the refinement of social division of labor, agriculture has gradually become the 'first industry' of the social economy, and cultivated land was also endowed with economic functions, including the introduction of economic conditions such as location and infrastructure conditions (Zhao and Guo, 1997), which forms the quality of cultivated land based on the dual nature of nature and the economy. With the continuous promotion of multifunctional land use research, the understanding of multiple attributes of cultivated land has gradually been strengthened (Kong et al., 2010; Chen et al., 2011; Shen et al., 2012), and the comprehensiveness of cultivated land elements and multi-functions of cultivated land use provides the cultivated land natural, economic, social and other multiple attributes. The formation of a CLQ view based on multiple attributes is the inevitable result of the historical development of cultivated land use and the evolution of people's ideological cognition. Based on this, Du et al. have put forward a new concept of CLQ, which includes soil fertility quality, engineering quality, spatial quality, eco-environment quality, aesthetics and cultural quality. As the background quality or inherent quality, soil fertility determines the potential productivity of cultivated land, which is the core of CLQ, and emphasizes stability (Reeves, 1997; Lilburne et al., 2004). As an additional quality of cultivated land, engineering quality influences the realization extent of the potential productivity of cultivated land, and is the important content of high standard basic farmland construction. It emphasizes the convenience and economy of agricultural production. Spatial quality mainly refers to the spatial morphological characteristics, spatial distribution characteristics and spatial location conditions of cultivated land patches. Eco-environment quality includes two aspects, ecology and the environment. Ecological quality refers to the ecological service function of soil and water conservation, air purification and climate regulation, which is an ecological subsystem of cultivated land. Environmental quality mainly refers to soil environmental capacity and the soil environment of cultivated land. Aesthetics and cultural quality are the aesthetic and cultural characteristics of cultivated land. Its quality is different and interacts with each other, which reflects the different characteristics and overall function of CLQ (Du et al., 2016).

On the basis of the new CLQ concept, and according to the characteristics of the evaluation model and CLQ in the study area, and the contents of the HSBFC, the evaluation index system of CLQ uniformity was constructed with indexes chosen from four aspects: soil fertility quality, engineering quality, spatial quality and eco-environment quality. Five indicators were selected for soil fertility quality: soil organic matter, surface soil texture, soil profile pattern, salinization degree and soil pH. On the basis of the soil survey data and the agriculture land quality gradation update results, the index values were supplemented and corrected based on the field sampling data. Three indicators were selected for engineering quality: road network density, irrigation guarantee rate and drainage condition. Irrigation guarantee rate and drainage condition were extracted from the gradation update results. As a corridor density index, road network density describes the spatial layout of the road in quantity, and is expressed by extracting the data of rural roads and highway layers in the survey database, and calculating the road length per unit area. Previous studies revealed that the suitable road density index for the North China plain area should achieve 63.2 m/ha (Lyu, 2015). Five indicators were selected for spatial quality: surface slope, field regularity, field scale, concentrated degree and cultivated radius. The field scale was extracted through the land change survey database. Generally speaking, the greater the patch area of the cultivated land, the better its connectivity and the easier it can achieve large-scale benefits (Tu and Lu, 2012). According to the 'criterion of high standard basic farmland construction', the farmland patch scale for the irrigation area in North China Plain is at least 10 ha. The field slope was extracted through DEM data. Field regularity was expressed as the patch shape index. The second China land survey technical specification listed 20 m width surface features as linear objects, while those between the surface features could be merged into the surface features (Tang et al., 2017). Thus, 10-m buffer zones were created for the cultivated land patches, and the intersecting patches were merged. The merged patch area was used as the concentration degree value (Wang et al., 2013). Ecological quality chose farmland shelterbelt network density as the index, mainly reflecting the effects of windbreak structures, regulating farmland microclimate, protecting the farmland and enhancing the overall ecological function of the farmland (Ding et al., 1993). This was calculated based on the data of remote sensing. Previous studies revealed that a farmland shelterbelt network density of 50 m/ha in the study area was acceptable (Lv, 2015). Environmental quality chose soil pollution degree as the index, mainly reflecting the soil environment quality of cultivated land. This was calculated based on the heavy metals and pesticide pollution data, and the comprehensive index of environmental pollution from the investigation and quality evaluation of the cultivated land fertility data.

Thus, an evaluation index system of CLQ uniformity was constructed (Table 1). Each index was quantified using the assignment method, according to the centesimal system. The optimal grading of each index was assigned 100 points, while other grades were assigned based on standard specifications such as the 'Regulation for gradation on agriculture land quality' (GB/T 28407-2012), 'Criterion of high standard farmland' (NY/T 2148-2012), 'Criterion of high-standard basic farmland construction' (TD/T 1033-2012), and related studies, construction requirements, and its influence to the CLQ level and the high standard basic farmland construction of indexes. These were adjusted by combining these with the actual situation. The analytic hierarchy process (AHP) of the weighting method, which was rigorous and easy to operate (Ozdemir, 2005), was used to set up the weights. In order to highlight the difference of CLQ in the study area, two indexes of the salinization degree and field slope, which were at the optimal level, were not selected for evaluation. The comparison of the importance of pairwise indexes was determined with reference to a related literature and combining these with the opinions of experts, as well as the differences and restrictions of indexes in the study area through the AHP. Both single and total hierarchical arrangements passed the conformance testing (random conformance rate, CR < 0.1).

**Table 1** Evaluation index system, index grading, assignment and weight of village-region CLQ uniformity

| Criterion level | Index level | Transformation difficulty | Grading and assignment | | | | | $w_{ai}$ | $w_{bi}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | 90 | 80 | 70 | 60 | | |
| Soil fertility quality | Soil organic matter/% | Middle | | | | [1.0,1.5) | [0.6,1.0) | 0.053 | 0.493 |
| | Surface soil texture | High | Loam | Clay | | Sand | | 0.076 | 0.311 |
| | Soil profile pattern | High | Whole body loan | Loam Clay/ Clay | Whole body clay | Sand/ Clay/Sand | Loam/ Sand/Sand | 0.107 | 0.196 |
| | Parameter determination/ mS/cm | – | <1 | (1, 2] | (2, 5] | | >5 | – | – |
| | pH | Low | [6.0,7.9) | [5.5, 6.0) / [7.9,8.5) | [5.0,5.5) / [8.5,9.0) | [4.5,5.0) / [9.0,9.5) | <0.6 / ≥9.5 | 0.038 | 0.133 |
| Engineering quality | Road network density/m/ha | Low | ≥63.2 | | [25, 63.2) | | <25 | 0.112 | 0.155 |
| | Irrigation guarantee rate | Low | Sufficient Satisfaction | Basic Satisfaction | General Satisfaction | | No Irrigation condition | 0.178 | 0.140 |
| | Drainage capacity | Low | Drainage sound | Basically sound | Drainage general | | No drainage system | 0.071 | 0.170 |
| Spatial quality | Slope of field/° | – | <2 | [2,6) | [6,15) | | [15,25) | – | – |
| | Field regularity | Low | ≤1.33 | (1.33,1.71] | (1.71,2.24] | | >2.24 | 0.086 | 0.127 |
| | Field scale/ha | Low | ≥60 | [30,60) | [10,30) | | <10 | 0.054 | 0.189 |
| | Cultivating radius/m | High | ≤100 | (100,500] | (500,1000] | | >1000 | 0.068 | 0.493 |
| | Concentration degree/ha | Low | ≥1000 | [500,1000) | [100, 500) | [50,100) | <50 | 0.082 | 0.115 |
| Eco-environment quality | farmland shelterbeltlt network density/m/ha | Middle | ≥100 | | [50,100) | | <50 | 0.056 | 0.311 |
| | Soil pollution degree/% | Middle | ≤0.7 | (0.7, 1] | (1, 2] | | | 0.019 | 0.196 |

Notes: $w_{ai}$ is the index weight of comprehensive evaluation of village-region CLQ uniformity; $w_{bi}$ is the relative weight of the difficulty of each index transformation in the calculation of the transformation potential of the obstacle index

#### *2.3.3 Calculation of the transformation potential of barrier index*

The spatial heterogeneity of natural and socioeconomic conditions leads to different barrier factors and restriction degrees on CLQ in different regions. At the same time, different barrier factors have different transformation difficulties, in accordance with the construction principle of 'easy things first'. The transformation difficulty of these selected barrier indexes was classified into three grades: high, medium and low. The transformation difficulty of soil background indexes can be determined through soil characteristic response times (CRTs). The longer the CRT, the more difficult it was to transform (Qu et al., 2012). The CRT of surface soil texture and soil profile pattern was above 100 yr, which were regarded as high difficulty indexes. The CRT of soil organic matter was 10–100 yr, which was an index with medium difficulty. The CRT of soil salinization was 1–10 yr. Agricultural land quality gradation data and sampling tests (conductivity was less than 1mS/cm) revealed that there was no salinization cultivated land in the study area. Hence, soil salinization was not listed as a barrier factor. The CRT of soil pH was 0.1–1.0 yr, which was an index with low difficulty. Road network density, irrigation guarantee rate and drainage condition could be improved through the construction and maintenance of farmland infrastructure with low costs within a short period of time (Guo et al., 2010), making this a low difficulty index. Farmland shelterbelt is the protection project. The survival and formation of trees into a protective forest requires time. At the same time, forest belts have a negative influence on farm land. Many farmers oppose forest belt planting, because trees can easily be destroyed or stolen. This requires the constant replacement of trees, making farmland shelterbelt network density a medium difficulty index (Niu et al., 2014). The project area was a plain with a mild topography, and the field surface has been leveled after a long period of comprehensive management, making it suitable for irrigation. Hence, slope was not listed as a barrier factor. Field regularity, field scale and concentration degree can be transformed through LC and block adjustment with low costs within a short period of time. Hence, it was listed as a low difficulty index. The soil in the study area was mainly polluted by heavy metals and pesticides. Hence, there was a need chemical degradation, biological measures, and the natural degradation of pesticides. Since the polluted area was small and the pollution degree was low, soil pollution was listed as a medium difficulty index. Cultivating radius reflects the farmland location condition. The farmland and residential sites were relatively stable. Hence, it was listed as a high difficulty index.

Through the AHP, the relative weights of these indexes in each grade were determined. The comparison of the importance of pairwise indexes was determined by referring to related literature and combining these with expert opinions. In order to strengthen the limits of these barrier indexes, the more difficult it was to transform the index, the more important the index became, and the greater the relative weight was. The relative weights of indexes in these three grades were presented as the $w_{bi}$ column in Table (1), and the sum of the relative weights of each index in each grade was 1. Both single and total hierarchical arrangements passed the conformance testing (random conformance rate, CR < 0.1).

The computational model of transformation potential of barrier indexes in village was constructed, and shown in Equation (4).

$$Q = \sum_{i}^{m} P_i \times w_{bi} \tag{4}$$

where $m$ was the number of indexes in each transformation difficulty grade, $w_{bi}$ was the relative weight of each index in each grade. $Q$ was the comprehensive transformation potential of each difficulty grade in village. The greater the $Q$, the lower the comprehensive transformation potential, and the stronger the comprehensive restriction of the index set.

#### *2.3.4 Local spatial autocorrelation analysis*

Spatial autocorrelation analysis is an important method to explore the correlation between geographic entities (Anselin, 1995). With cultivated land as a kind of geographical entity, in space, there must be a certain distribution law. The spatial aggregation and dispersion of CLQ can be used to reflect the local homogenization characteristics of CLQ. This can effectively accord with the gist of paying attention to the centralization and continuity of cultivated land in the construction of high standard basic farmlands. The local spatial autocorrelation index was used to characterize the spatial distribution of CLQ. The calculation method of local Moran's index of spatial factor $i$ was shown in Equation (6)(Moran, 1950).

$$I_i = x'_i \sum_{j=1}^{n} w_{ij} x'_j \tag{5}$$

where $I_i$ was the local Moran's index of factor $i$, $x'_i$ and $x'_j$ were the standard values of unit index properties, $w_{ij}$ was the spatial adjacency weight between the spatial units $i$ and $j$, $n$ was the number of units adjacent to the space unit $i$. By combining with the local spatial autocorrelation index and the Moran scatter plot, the spatial pattern was visualized (Li et al., 2010). The Moran scatter plot is divided into 4 quadrants which represent 4 different association types. The first quadrant and the third quadrant are positively correlated expressed in High-High (HH) and Low-Low (LL) respectively, the second quadrant and the fourth quadrant are negative correlation type expressed in High-Low (HL) and Low-Low (LH) respectively.

## 3 Results and Analysis

### 3.1 Local spatial autocorrelation analysis of village-region CLQ uniformity

By calculation using the ArcGIS software, the comprehensive evaluation values of village-region CLQ uniformity was from 12.92 to 21.57, and the mean value was 15.34. A certain difference existed in administrative villages in different regions. The $G$ values were taken as the property values of the local spatial autocorrelation analysis, which was established using the GeoDa095i software. It was found that the type of positive correlation was dominant, which included 13 HH villages and 15 LL villages, while 11 HL and 9 LH villages belonged to the negative correlation type.

Under the integration of limited resources, HSBFC provided more attention to centralized continuous development and construction with planned construction arrangements. The results of the spatial autocorrelation analysis with CLQ as the spatial variable revealed the spatial aggregation or discreteness characteristics of CLQ in a region. LL was a concentrated area of administrative villages with low $G$. The CLQ was high in the region that had a strong spatial positive correlation, good overall spatial connectivity and large space coverage, showing local high quality homogenization characteristics. In the process of carrying out the HSBFC, raising the CLQ of a certain part of the region would affect the improvement of quality of the rest of the cultivated lands affected by the spatial positive correlation. Therefore, this is suitable for concentrating resources in the short term, in order to promote continuous construction. LH was sporadically distributed in the study area, and was mostly adjacent to HH and LH, where the administrative villages with high CLQ were surrounded by low quality villages, and the homogeneity was poor with the spatial negative correlation. The development of the L sub region was bound to be affected by the surrounding low quality regions for the negative correlation. HL was opposite from LH, distributed around LL, and maintained a good spatial continuity with LL. Compared with LL, these two types were not suitable for centralized development and construction, but could be brought into medium to long term development and construction. HH was mainly distributed in the southeast side of the project area, and was opposite from LL with the low CLQ administrative villages clustered. This exhibited local low quality homogenization characteristics with a strong spatial positive correlation, and the amount of resources needed to realize its centralized and continuous development and construction was much higher. Therefore, it is not appropriate to concentrate development and construction in the short term. Based on the above analysis, LL was classified as a local high quality homogeneous area with the *G* between 7.76 and 14.76. LH and HL were classified as a local quality heterogeneous area with the *G* between 12.92 and 21.57. HH was classified as a local low quality homogeneous area with the quality uniformity of cultivated land between 15.73 and 21.96 (Fig. 2).

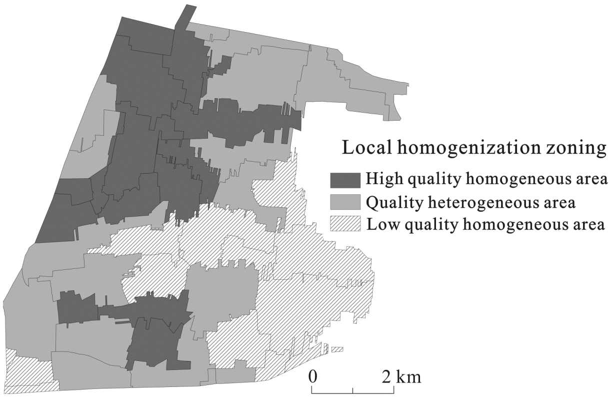


**Fig. 2** Local homogenization zoning of CLQ

### 3.2 Measurement of the barrier index transformation potential

By calculating the comprehensive transformation potential *Q* of all barrier indexes under each difficulty grade in each administrative village, *Q* was between 0.30 and 19.58 in the high transformation difficulty grade, between 0 and 32.84 in the medium transformation difficulty grade, and between 6.27 and 28.05 in the low transformation difficulty grade. There was significant difference in the administrative villages of the different regions. Using the natural breaks method, the comprehensive transformation potential in these three transformation difficulty grades was divided into three grades: high, medium and low. In the high transformation difficulty level, the comprehensive transformation potential was mainly in the high and medium level with 79.04% of the cultivated land of the study area. In the medium transformation difficulty level, the comprehensive transformation potential was mostly in the medium and low level with 82.17% of the cultivated land area. In the low transformation difficulty level, the comprehensive transformation potential was mainly in the high and medium level with 89.78% of cultivated land area. By comparing the ranges *Q* in these three transformation difficulty grades, it could be found that the comprehensive restriction of indexes under these three potential levels in the medium and low transformation difficulty grades was higher than the restriction in the high transformation difficulty transformation grade. This shows that indexes that were difficult to transform were less restrictive to CLQ, and the feasibility of improving CLQ in the project area was strong (Table 2).

HSBFC should give priority to regions with barrier factors that have low restriction and low transformation difficulty. A total of 21 combination types were obtained through the combination of transformation potential and transformation difficulty of administrative villages in the study area. From easy to difficult, these could be classified into four types: 1) the first grade transformation area included administrative villages that do not belonging to any low or medium transformation potential level in the high transformation difficulty level; 2) the second grade transformation area included two kinds of villages: the first kind was administrative villages that belong to the low transformation potential level in the non-high transformation difficulty level, and does not belong to the medium transformation potential

**Table 2** Classification statistic of renovation potential

| Transformation difficulty | High potential | | | Medium potential | | | Low potential | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cultivated area/ha | Proportion/% | *Q* | Cultivated area/ha | Proportion/% | *Q* | Cultivated area/ha | Proportion/% | *Q* |
| High | 1498.43 | 30.05 | 0.30–5.67 | 2442.25 | 48.99 | 6.34–10.11 | 1045.01 | 20.96 | 12.15–19.58 |
| Medium | 888.71 | 17.83 | 0–9.46 | 2133.07 | 42.78 | 11.19–19.20 | 1963.90 | 39.39 | 20.92–32.84 |
| Low | 1421.60 | 28.51 | 6.27–12.50 | 3054.74 | 61.27 | 13.07–17.15 | 5093.48 | 10.22 | 18.15–28.05 |

level in the high transformation difficulty level, while the second kind was administrative villages that belong to the medium transformation potential level under high transformation difficulty level, and does not belong to any low transformation potential level; 3) the third grade transformation area included administrative villages that belong to the low transformation potential level in the non-high transformation difficulty level, and belong to the medium transformation potential level in the high transformation difficulty level; 4) the fourth grade transformation area included two kinds of villages: the first kind was administrative villages that belong to the low potential level in the high transformation difficulty level, and the second kind was administrative villages that belong to the low potential level in the non-high transformation difficulty level. To date, 46 administrative villages in the study area have been classified into four types with transformation difficulty, from easy to difficult (Fig. 3).

In the first grade transformation area, indexes that generally have strong restriction, and are easy to be transformed in the whole project area, such as forest network density, field regularity and field scale were excluded. Other indicators were low in limits. The best quality could be achieved through minor modifications. The second grade transformation area included two kinds of cases. The first case had a reduced transformation potential in medium and low transformation

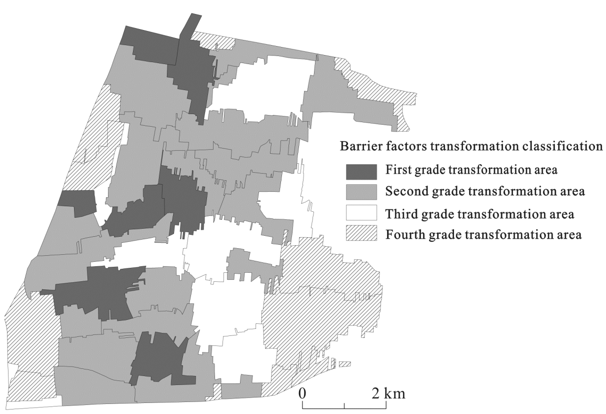


**Fig. 3** Barrier factors transformation classification

difficulty grades, and index restriction was enhanced, including soil pollution, farmland shelterbelt network density, irrigation guarantee rate, field scale, field regularity and concentration degree. In the second case, the transformation potential was reduced mainly in high transformation difficulty grade with the restriction of three indexes enhanced, especially for the cultivated radius. In the third grade transformation area, the restriction of soil pollution in the medium transformation difficulty grade and the concentration degree and road network density in the low transformation difficulty grade was enhanced. The fourth grade transformation area included two kinds of cases. In the first case, the transformation potential in the high transformation difficulty grade was further reduced with the indexes of cultivated radius and soil profile pattern. In the second case, index restriction was enhanced mainly in the medium and low transformation difficulty grade, including farmland shelterbelt network density, road network density, field scale and concentration degree. Overall, it could be concluded that indexes with generally strong restriction in the whole project area mostly belonged to the medium and low transformation difficulty grades, had great transformation potentials, and needs promotion within the whole area, such as soil organic matter, farmland shelterbelt network density, field regularity and field scale. Indexes with a large restriction difference in the study area needed to selectively undertake partial improvement, such as soil profile pattern, irrigation guarantee rate, road network density, and concentration degree.

### 3.3 High-standard basic farmland construction arrangement

According to the principle of concentration and continuity, and 'easy things first', and taking into account the characteristics of the local homogenization reflected in the local spatial autocorrelation pattern of CLQ, as well as the transformation difficulty and potential of these barrier factors, the arrangement of the high standard basic farmland construction in the study area was carried out. Combining these two zoning results, 12 combinations were obtained. Cultivated lands with high quality, centralized distribution, easy transformation barrier factors and high transformation potentials were prioritized during the construction. These 12 combinations were divided into four construction types: major construction area, secondary construction area, general construction area, and conditional construction area (Table 3, Fig. 4).

The major construction area contained 14 administrative villages, which had a cultivated land area of 1538.85 ha, accounting for 30.87% of the total cultivated land in the study area. This included the first and second grade transformation areas in the local high quality homogeneous area, which concentrated in the northern and southern side of the study area. The CLQ was good and similar to the optimum quality of the project area, with a $G$ value between 7.76 and 14.76. The barrier factors were less restrictive with high transformation potentials. This was the area where high quality cultivated lands were concentrated, and where internal quality was homogenized and affected by positive spatial correlation. Accordingly, the local reconstruction had a scale effect, and this area was suitable for the large-scale transformation and construction of barrier factors in the short term. The secondary construction area contained 11 administrative villages, which had a cultivated land area of 1224.27 ha, accounting for 24.56% of the total cultivated land in the study area. This included the third grade transformation area and the first and second grade transformation areas in the local quality heterogeneous area. The quality of cultivated land was medium to low, with a $G$ value between 12.92 and 17.38. Merely one village belonged to the high quality homogeneous area, but the barrier factors were more restrictive with low transformation potential. Other villages had low restrictive factors, but all belonged to the local quality heterogeneous area, which were mostly around the high and low quality homogeneous areas, and its dispersed spatial distribution was affected by spatial negative correlation. Accordingly, this was not suitable for large-scale transformation in a short time period. The general construction area contained four administrative villages, which had a cultivated land area of 555.93 ha, accounting for 11.15% of the total cultivated land in the study area. This included the third grade transformation area in the local quality heterogeneous area and the second grade transformation area in local low quality homogeneous area. The quality of cultivated land was medium to low, with a $G$ value between 13.93 and 18.20. Two administrative villages that belonged to the local quality heterogeneous area had higher barrier factors with low transformation potentials. At the same time, these were affected by spatial negative correlation. The other two administrative villages had high transformation potential barrier factors. These were regions that had low quality cultivated lands concentrated with spatial positive correlation, and the cost of transformation and construction was relatively high. The conditional construction area contained 17 administrative villages, which had a cultivated land area of 1666.63 ha, accounting for 33.42% of the total cultivated land in the study area. This included the fourth grade transformation area in the local quality heterogeneous area and the third and fourth grade transformation area in the local low quality homogenization area. The CLQ was poor, had a large gap with the optimum quality of the project area, and had a $G$ value between 14.47 and 21.95. The restrictive level of these barrier factors all belonged to a high level with low transformation potential, especially the administrative villages with low transformation potential in the high transformation difficulty grade. The six administrative villages that belonged to the local quality heterogeneous area was scattered in the study area, and was affected by the spatial negative correlation. The rest of the administrative villages were areas that had concentrated low quality cultivated lands, and the influence of the spatial positive correlation made the construction cost higher. This should be a long-term transformation process in the project cycle, which requires the targeted transformation of barrier factors, and gradually improvement of construction efficiency.

## 4 Discussion

In evaluating for CLQ, its natural and socioeconomic characteristics should be different from the evaluation units, but relatively homogeneous within the evaluation units. In the pursuit of fineness in the evaluation, and to reflect the attribute differences between units, the results of the survey and evaluation were mostly presented by taking the cultivated land patches as units in previous

**Table 3** Classification of combination types

| Construction arrangement | | Local spatial autocorrelation pattern | | |
|---|---|---|---|---|
| | | 1 (Low-Low) | 2 (Low-High/High-Low) | 3 (High-High) |
| Barrier factors transformation difficulty and potential | 1 | 6 | 1 | 0 |
| | 2 | 8 | 9 | 2 |
| | 3 | 1 | 2 | 6 |
| | 4 | 0 | 6 | 5 |

Note: The figures in the form represent the number of administrative villages for each combination (see Fig. 4)

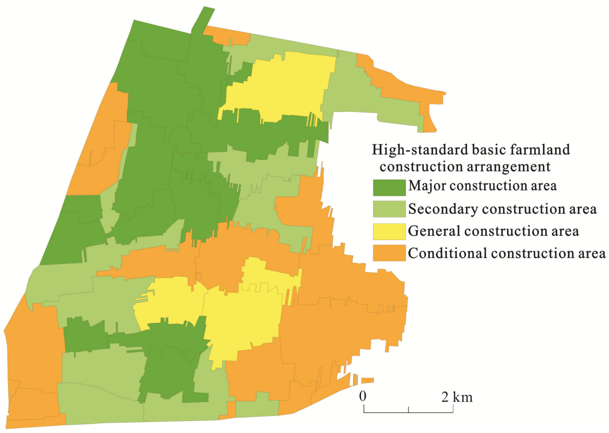


**Fig. 4** High-standard basic farmland construction arrangement

studies. However, CLC is a regional and large-scale systematic behavior that realizes the comprehensive promotion of regional CLQ and economies of scale (Zhang and Zhao, 2006; Pan et al., 2009; Zhang et al., 2013). From the point of view of serving CLC, the evaluation and decision-making units tend to be systematic. At the same time, the practice of CLC is generally carried out through planning within the scope of the county, organized by towns, and implemented by administrative villages (Zhang and Zhao, 2006). Socio-economic data were also counted based on administrative villages. Therefore, exploring the scientific method of CLQ evaluation and the arrangement of high standard basic farmland construction, with administrative villages as the decision-making units, would make it convenient for subsequent construction decision- making and organizing. It would also be convenient to carry out data docking when socio-economic condition corrections are needed. This conforms to the evaluation and practice characteristics from the CLC standpoint, and has certain theoretical and practical significance.

It is a statistical problem from component to the population to characterize CLQ in the village level through the CLQ in the patch level. The population level in similar problems is often characterized by calculating the average of each component. For example, through the area-weighted average of each cultivated land patch quality, the CLQ level in a certain area can be characterized (Wei et al., 2014; Xiong et al., 2014). However, the average characterizes more on the central tendency of a set of data, and its representativeness of the population is affected by the variance degree of the components. Thus, the standard deviation that characterizes the variation degree of components is also needed. However, the standard deviation is an absolute quantity. There is a lack of comparability when the averages or dimensions among different populations are different. This is similar to that in the present study, where the hierarchical data of each index constitutes a population. The coefficient of variability can be used to solve the limitations of these two statistics, and demonstrate its variability on the basis of central tendency (Bendel et al., 1989; Huang and Leung, 2009). Referring to the principle of coefficient of variation, the present study constructed a model of CLQ uniformity evaluation based on the regional optimal CLQ level, in order to more reasonably evaluate the CLQ in a certain area, and reflect the difference of CLQ between regions. At the same time, the uniformity of a single index can reflect the index restriction, and can be compared among different indexes. This can be used for the diagnosis and identification of barrier factors in regional cultivated lands, and is convenient for the subsequent decision-making for transformation and utilization, and the organization and implementation of high standard basic farmland construction practice. The model can also be applied to other regional evaluations, from component attributes to population attributes.

Characterizing the CLQ from the patch level to the village level involves the problem of space transformation from small scale to large scale. Therefore, scale dependence may have an impact on the application of the model (Kachanoski and de Jong, 1988; Friedman et al., 2001). The area of the administrative villages in the present study is relatively small and sensitive to regional environmental changes, which can meet the convenience requirement of organization and implementation in transformation practice, and guarantee the accuracy of the evaluation. The suitability for the evaluation of larger scale units remains to be studied.

Through spatial autocorrelation analysis, the aggregated or scattered distribution patterns of different quality cultivated lands were obtained, which reflected the local homogenization features of the CLQ, and were considered in the process of zoning. This can accord with the gist of the centralization and continuity of cultivated land during the high standard basic farmland construction. Both the spatial characteristics of the quantity and quality scale of the cultivated land were considered, which can easily form economies of scale in the process of its development and construction.

In the practice of HSBFC, when taking into account the support of project funds for construction content and the masses of expectations for solving practical problems through these projects, the most prominent barrier factor with the most pressing needs for transformation must be given attention (Zhong et al., 2012). Many studies have also focused on identifying one or few strongly restrictive factors for transformation, utilization and decision-making (Wang et al., 2013; Zhu et al., 2015; Zhao et al., 2016). In the long run, this is essential for ensuring maximum and sustainable benefits, in order to realize the comprehensive improvement of CLQ, and comprehensively consider the restrictions of each barrier factors. In the present study, the comprehensive transformation potential of different indexes was obtained by means of grading the transformation difficulty of the barrier indexes, and providing weights. Construction decisions were made while taking into account the restrictions of each barrier factor, which is beneficial to maximize the benefit of construction projects.

The present study focuses on methodology. This can provide reference for high standard basic farmland construction, and provide new ideas and methods for related research. In the future, study areas with a larger scope and a more heterogeneous environment should be selected. Due to the limitation of data sources, the evaluation index system needs to be improved, such as indexes of the ability for resistance to disaster.

## 5 Conclusions

The present study constructed the evaluation model and index system of CLQ uniformity, formed the method of HSBFC arrangement, and took Quzhou County as the case study. The conclusions are as follows.

(1) For the evaluation system, the model of village-region CLQ uniformity evaluation based on the regional optimum CLQ level was constructed by synthesizing the principle of variation coefficient, weighted standard deviation and obstacle factors diagnosis. The evaluation index system of CLQ uniformity was constructed from four aspects, according to the new concept of CLQ: soil fertility quality, engineering quality, spatial quality, and eco-environment quality. This could satisfy the CLQ evaluation of the village unit. Meantime, the quality uniformity of the single index reflected the degree of dispersion relative to the optimum level in the region, and reflected the restriction of the index, which could facilitate the identification of barriers, the diagnosis of restriction degree, and subsequent construction decision-making. This improved the scientificalness of the evaluation results and the operability of the application. In the present case, the CLQ uniformity in different administrative villages was between 7.76 and 21.96, and the evaluation system could identify the differences of CLQ between villages.

(2) For construction arrangement, according to the construction principle of 'easy thing first', the comprehensive transformation potential of different difficulty index sets was calculated on the basis of index restriction, and transformation difficulty zoning was carried out. According to the principle of 'centralization and integration', in addition to considering the quantity scale of cultivated land, the quality scale was also taken into consideration in local homogeneity zoning through the identification of local homogeneity by spatial autocorrelation analysis. These two zonings were combined and classified to make construction decisions, improving the scientificalness of the construction arrangement. In the present case, the difficulty zoning was divided into four grades. The indexes of the difficult transformation were weak to the CLQ, which allowed CLQ to be easily improved. Indexes with a generally strong restriction in the whole project area mostly belonged to the medium and low transformation difficulty grades, such as soil organic matter, farmland shelterbelt network density, field

regularity and field scale. These needed promotion within the whole area. Indexes that had large restriction differences were soil profile pattern, irrigation guarantee rate, road network density, and concentration degree. There was a need to selectively carry out partial improvements.

(3) For the final construction arrangement, this could be divided into four types: major construction area, secondary construction area, general construction area, and conditional construction area. According to the characteristics of CLQ in different types of areas, a differentiated high standard basic farmland construction arrangement could be carried out. In the major construction area, high quality cultivated lands were concentrated, and the main barrier factors had a high transformation potential. This is suitable for the large-scale transformation and construction of barrier factors in the short term. In the secondary construction area, the cultivated land had medium to low quality, and local quality homogeneity was poor, which was mainly affected by the spatial negative correlation. In the general construction area, the cultivated land had medium to low quality. This was distributed in the heterogeneous and low quality homogeneous areas, and the cost of transformation and construction improved. In the conditional construction area, the cultivated land had low quality. The main transformation potential of barrier factors was low. Villages belong to the local quality heterogeneous area and local low quality homogeneous area. The cost of the transformation and construction was high. For the project cycle, this should be a long-term transformation process, and construction efficiency should be gradually improved. In the present case, the cultivated land areas of the four areas were 1538.85, 1224.27, 555.93, and 1666.63 ha, respectively.

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