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Evaluation of Cultivated Land Quality in Semiarid Sandy Areas: A Case Study of the Horqin Zuoyihou Banner

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Abstract: Objective: The evaluation of cultivated land quality from the regional perspective and the clear level and change in cultivated land quality in the whole region can better guide the construction of cultivated land quality, carry out scientific optimization allocation, improve grain production capacity, and promote the sustainable use of cultivated land. Research methods: The utilization of local resources and natural conditions were comprehensively considered, and the evaluation was carried out from the four dimensions of ecology, quantity, spatial structure and scale to comprehensively reflect the level of regional cultivated land utilization. Results: (1) The cultivated land quality level of the Horqin Zuoyihou Banner is low, and the pressure of regional water resources is great. Some cultivated land is located in the area with poor natural conditions, and there are many thin and narrow cultivated areas of land. The area of cultivated land that can be carried by regional water resources under current irrigation is 184,492.17 hm^2, and that under water-saving irrigation is 259,703.72 hm^2, which are lower than the current cultivated land areas. (2) During the study period, the total amount and spatial distribution of cultivated land changed greatly, and there were good natural conditions and utilization conditions of newly added cultivated land, but the quality of cultivated land from the regional perspective showed a downward trend. The dynamic attitude of cultivated land change was 0.99%. (3) According to the evaluation results, the cultivated land was divided into the following four categories: priority protection type, optimization and coordination type, gradual conversion type and priority conversion type, which accounted for 34.18%, 30.59%, 28.83% and 6.40% of the total cultivated land area, respectively. Conclusions: There is a sharp contradiction between the supply and demand of water resources, and the quality of cultivated land in the region is low and shows a downward trend, which is not conducive to the sustainable use of regional land resources. In this regard, the Horqin Zuoyihou Banner should actively curb the growth of cultivated land, develop water-saving irrigation processes, strengthen ecological environment protection, and systematically optimize the layout of cultivated land on the premise of ensuring ecological security according to the actual conditions of different regions.

Keywords: semiarid sandy area; cultivated land quality; cultivated land resources; sustainable development; optimized layout

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1. Introduction

Cultivated land is an important part of land resources and the foundation of food security, which is important to social stability and sustainable development [1]. Scientific evaluation of the cultivated land quality is of great significance to maintain sustainable development of cultivated land resources [2]. However, the evaluation process is influenced by many factors, such as the research scale, method, and object [3–5]. Inappropriate and imperfect evaluation makes it difficult to obtain an overall understanding of the cultivated land quality, thus notably impeding the formulation of practical and effective measures by decision makers. With the development of society and the economy, the demand for land has experienced highly notable changes [6]. These changes in cultivated land resources, such as non-agriculturalization, soil pollution, and degradation of the ecological environment, have caused a decline in the cultivated land quality, especially in semiarid sandy areas [7,8]. Therefore, scientific evaluation of the cultivated land quality in semiarid sandy areas has become an important research topic for the sustainable utilization of cultivated land resources [5,9].

The evaluation methods of cultivated land quality can be divided into three categories. The first category is derived from the early land evaluation method, in which the land potential (three levels of the potential level, potential sublevel, and potential unit) is classified based on soil characteristics, and the land quality is reflected by the gradual change in land potential productivity [10]. From the perspective of land suitability, the Food and Agriculture Organization (FAO) (1976) divided land into four levels, i.e., class, type, subtype, and unit, to promote land evaluation development. Although this method is easy to implement, due to the complexity of land resources, a single sample of soil quality cannot fully reflect the land quality [11].

The second category entails the selection of indicators that can effectively characterize the cultivated land quality and the construction of a comprehensive land quality evaluation system through the expert scoring method, comprehensive index evaluation method, analytic hierarchy process and other methods. The purpose is to measure the status and changes in the cultivated land quality with clear values [5,12]. For example, Zhao et al. [13] selected 28 indicators from 5 aspects of physical and chemical properties, including nutrient, management, sanitation and ecological environment status aspects, to construct a farmland quality evaluation system through the analytic hierarchy process and established a comprehensive farmland quality evaluation index. Evaluation of the cultivated land quality was carried out according to this comprehensive evaluation index. Compared to traditional evaluation methods, this category of methods can comprehensively consider the complexity of the cultivated land quality. However, a long period of time is required to summarize experience, and this category overly relies on expert experience, especially in regard to indicator selection and scoring [14]. If there are subjective factors in expert experience or sample uncertainty and deficiency, this can lead to inaccurate evaluation results.

The third category is mainly based on geographical information systems (GIS), global positioning systems (GPS), and remote sensing (RS) (3S) technology and automatic mapping technology [15–17]. For example, Wang et al. [18] obtained moderate resolution imaging spectroradiometer (MODIS) images with a resolution of 1 km to measure the quality of regional cultivated land and analyzed its temporal and spatial changes based on RS and GIS technology. Yuan et al. [19] employed geological detectors to explore the improvement potential of the cultivated land quality based on the provincial land scale. These methods have improved the accuracy of cultivated land spatial data and the efficiency of data acquisition and analysis. However, it remains difficult to comprehensively investigate the entire area only considering plots as research units.

The above analysis shows that although the existing cultivated land quality assessment methods based on a single soil quality assessment are gradually developing towards a relatively complete cultivated land quality assessment system, the research means and research techniques have been improved, effectively ensuring the comprehensive, dynamic and quantitative development of cultivated land quality assessment. However, some of these methods are subjective and incomplete, and are limited to some specific cultivated land spaces. In addition, most of these methods take plots as the research unit in the evaluation process, and have not considered the decline in cultivated land quality caused by unreasonable land use. Especially for arid and sandy areas with fragile ecological environments and poor site conditions, the use of cultivated land should pay special attention to the influence of cultivated land on the whole regional ecology, while ensuring food security. At present, the research on cultivated land quality lacks systematization and integrity and does not put forward effective development measures for decision makers. However, the shortcomings of the above methods can be realized by comprehensively evaluating the quality of cultivated land on the basis of ensuring ecological security, considering the macro, meso and micro levels from the perspective of the whole region. Specifically, at the macro level, the surplus and shortage of regional cultivated land was evaluated with the constraint of regional water resources. At the middle level of villages and towns, the rationality of the spatial structure of cultivated land was reflected by the security level of landscape patterns. At the micro plot level, combined with the regional natural conditions, the current scale level is revealed to reflect the quality of cultivated land from the regional perspective. Therefore, we believe that the quality of cultivated land can be evaluated more comprehensively based on the regional perspective and comprehensive consideration of macro, meso and micro levels.

Based on this, from the regional perspective, this study defined the cultivated land quality in the semiarid sandy area using a comprehensive evaluation of the cultivated land quality in the semiarid sandy area on the basis of ensuring local ecological security, and proposed the cultivated land optimization scheme. Firstly, from the four dimensions of ecology, quantity, spatial structure and scale, based on the macro, meso and micro levels, the cultivated land quality in the study area was comprehensively evaluated to explore the current situation of cultivated land quality. Secondly, we aimed to clarify the dynamics of cultivated land use change, analyze the impact of cultivated land change on cultivated land quality, and provide a basis for the classification of cultivated land resource optimization types. Finally, based on the evaluation and change analysis of cultivated land quality, according to the evaluation results of different dimensions and combined with the index interpretation method, different cultivated land optimization types were divided, and the direction and measures of regional cultivated land optimization were proposed [5,20].

2. Materials and Methods

2.1. Materials

2.1.1. Study Area

The Horqin Zuoyihou Banner is located in Tongliao, Inner Mongolia Autonomous Region, China, and lies between 121°30′~123°42′ E and 42°40′~43°42′ N, encompassing approximately 1148 km^2 and comprising 12 towns (Figure 1).

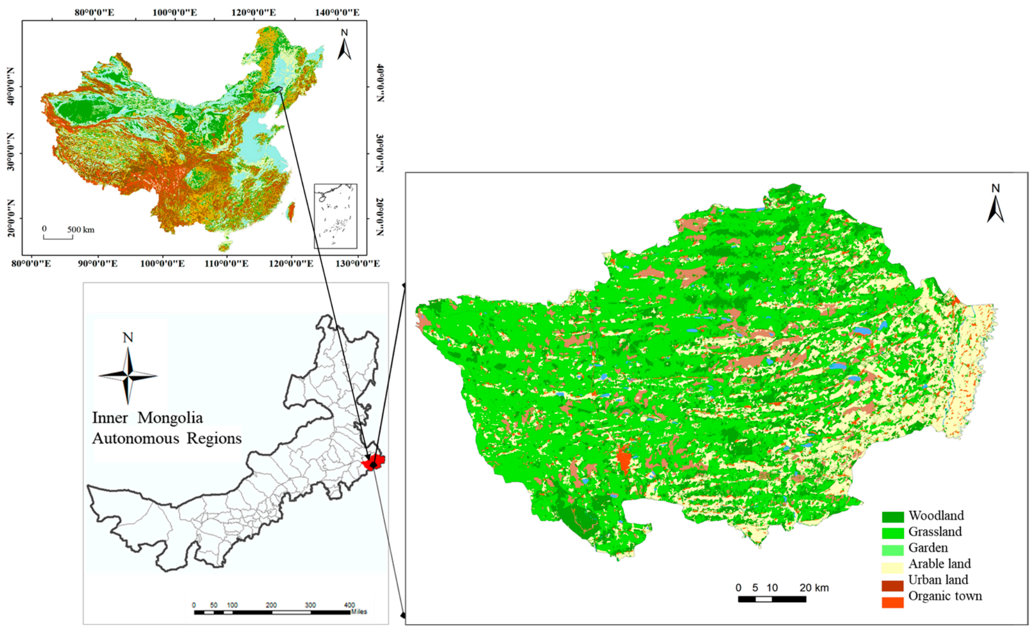

Figure 1. Study area location.

The average annual rainfall is 428 mm, the average annual temperature reaches 5.6 °C, and the area exhibits a temperate continental monsoon climate [21]. The landform types are dominated by striped plains, ridged dunes and depressions between the dunes and gentle sandy land, which constitute ecologically fragile zones and interlaced zones of agriculture and animal husbandry [22]. The total land area of the Horqin Zuoyihou Banner is 1,150,031.15 hm^2, of which 1,032,855.54 hm^2 comprises agricultural land (including 177,617.92 hm^2 of woodlands, 585,850.30 hm^2 of grasslands, 43.84 hm^2 of garden land, and 269,343.46 hm^2 of arable land), accounting for 89.8% of the total land area.

This area belongs to the transitional zone between arid and semiarid areas. The ecological environment is fragile, and the contradiction between the water supply and demand is sharp, which is typical and representative. Therefore, the Inner Mongolia Horqin Zuoyihou Banner was selected as a typical case to conduct empirical research.

2.1.2. Data Sources

The data in this study included the following types: (1) data of the land use types were derived from current land use data pertaining to the Horqin Zuoyihou Banner for 2012 and 2018; (2) water resource data were obtained from the Plan for Sustainable Development and Utilization of Water Resources in the Horqin Zuoyihou Banner; (3) vegetation coverage information was retrieved from Landsat 8 remote sensing data, with a resolution of 30 m for 2012 and 2018, as downloaded from the China Geospatial Data Cloud; (4) demographic and economic data were acquired from the 2019 and 2020 Inner Mongolia Statistical Yearbooks; (5) digital elevation model (DEM) data were obtained from the China Geospatial Data Cloud, namely, Advanced Spaceborne Thermal Emission and Reflectance Radiometer Global Digital Elevation Model version 2 (ASTER GDEM v2) 30 m $\times$ 30 m data; (6) meteorological data were obtained from daily precipitation data from 1980 to 2013 at 5 meteorological stations in the Horqin Zuoyihou Banner and surrounding areas.

2.2. Research Framework

Our research goal is based on a regional perspective, thereby adopting the Horqin Zuoyihou Banner as the research object, and the status and change characteristics of cultivated land were evaluated in the four dimensions of the ecology, quantity, spatial structure, and scale. Directions and measures were proposed to achieve cultivated land optimization for reasonable drought planning, and valuable suggestions were provided to ensure sustainable use of land resources in semisandy areas. After reviewing the main literature and theories, we divided the research ideas of this article into the following four parts: (1) based on a regional perspective, we evaluated the cultivated land quality in the study area in the four dimensions of the ecology, quantity, spatial structure, and scale and explored the current characteristics of the cultivated land quality; (2) in these four dimensions, we considered 2012–2018 as the research period to explore the cultivated land quality in the study area. (3) According to the evaluation results, the index interpretation method was applied to classify the different cultivated land optimization types and determine the optimal layout of cultivated land. (4) Considering the obtained research results, a discussion and analysis were conducted, and policy recommendations were proposed. The research framework is shown in Figure 2.

2.3. Research Methods

2.3.1. Cultivated Land Quality Evaluation Method

In this research, local resource utilization and natural conditions were comprehensively considered in the cultivated land quality evaluation, the cultivated land quality was assessed in the four dimensions of the ecology, quantity, spatial structure, and scale, and the level of regional cultivated land utilization was completely reflected.

(1) Ecological dimension

Regarding water resources as a constraint, the irrigable area verification algorithm was introduced to measure the ability of regional water resources to support arable land [23].

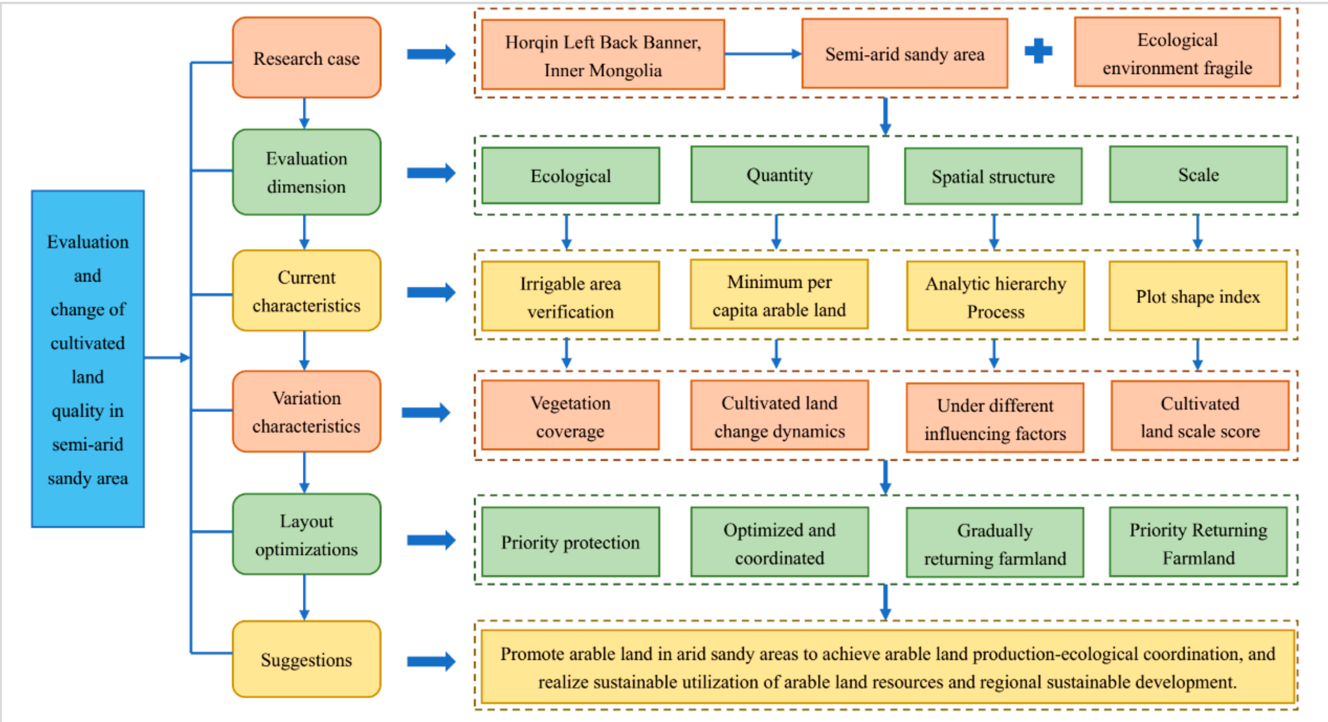

Figure 2. Research framework for the evaluation of the cultivated land quality in semiarid sandy areas.

First, the amount of available irrigation water was calculated. According to the principle of water balance, the maximum available irrigation water is the water available in the region (including water rights of transit rivers), after deducting the water consumed by various industries. The equation is

$$W = W_a - W_1 - W_2 - W_3 - W_4 - W_5 \tag{1}$$

where W is the maximum available irrigation water, W_a is the regional water available, W_1 is the water consumption of the forestry, animal husbandry and fishery industries, W_2 is the water consumption of the secondary industry, W_3 is the water consumption of the tertiary industry, W_4 is the domestic water consumption, and W_5 is the ecological environment water consumption.

Second, typical crops were selected. Since corn is the main food crop in the Horqin Zuoyihou Banner, accounting for more than 95% of the total sown area of grain, spring corn was selected as a typical crop for the calculation of the irrigated area [24].

Third, the irrigated area was calculated using the current irrigation method. The irrigation area is equal to the ratio of the available irrigation water to the irrigation quota. The equation is

$$S_{max} = \frac{Q}{T} \tag{2}$$

where S_{max} denotes the irrigation area, Q denotes the available irrigation water, and T denotes the irrigation quota under different irrigation methods. In regard to the Plan for Sustainable Development and Utilization of Water Resources in the Horqin Zuoyihou Banner, combined with the existing irrigation methods, the irrigation quota under the current irrigation method was determined as 2300 m^3/hm^2.

Fourth, the irrigated area under the water-saving irrigation method was obtained. Drip irrigation, with the best performance in terms of economic benefits, technical effects, and environmental benefits, was selected as the main water-saving irrigation method to explore and calculate the irrigated area under the water-saving irrigation method through the water balance method. The equation is

$$T = \frac{ET_a - P_e}{\eta} \tag{3}$$

where T denotes the irrigation quota under shallow drip irrigation, ET_a denotes the water demand of the crop, P_e denotes the effective precipitation during the growth cycle, and η denotes the irrigation water utilization coefficient. Among these parameters, the effective precipitation during the growth period was 265.85 mm, and the irrigation water utilization coefficient η was set to 0.87.

(2) Quantity dimension

Quantitative evaluation of the cultivated land mainly considered the food supply situation and reflected the quantity of cultivated land in the region by analyzing the difference between the required and existing areas of cultivated land, thereby indicating the cultivated land quality in the quantitative dimension. In this study, the minimum per capita area model was introduced for analysis. The equation is

$$S_g = \beta \frac{G_{pc}}{P_{qn}} \tag{4}$$

where S_g denotes the minimum per capita arable land area, β denotes the self-sufficiency rate of grain, which is set to 100%, G_{pc} denotes the per capita food consumption standard, which adopts the Chinese standard to achieve a well-off level, i.e., 400 kg/year per capita, P denotes the grain yield per capita, q denotes the grain ratio, and n is the multiple crop index.

(3) Spatial structure dimension

In the evaluation of the spatial structure of cultivated land, indicators were selected that affect the cultivated land distribution, the cultivated land combination was represented, and land parcels were evaluated as a unit, which reflected the overall layout of the development and utilization of cultivated land by people (please refer to related research). Four factors were selected, namely topographical conditions, precipitation, distance from residential areas, and ratio of agricultural to pastoral land, to carry out a comprehensive evaluation and analysis of the spatial structure by using the analytic hierarchy process to determine the weight of each element [5,25].

(4) Scale dimension

In the cultivated land scale evaluation, the achievable potential of cultivated land utilization was determined by analyzing the spatial morphological characteristics of the cultivated land. This study employed the landscape shape index. Moreover, the closer the index value is to 1, the more regular the shape [26]. The equation is

$$L = \frac{0.25C_i}{\sqrt{S_i}} \tag{5}$$

where L denotes the landscape shape index, C_i denotes the perimeter of the cultivated land block, and S_i denotes the area of the cultivated land block.

Finally, in the abovementioned calculation of the cultivated land quantity, the spatial structure and scale analysis results were superimposed to obtain a comprehensive evaluation score of the cultivated land quality. A higher score generally suggests that the plot is more compatible with the local population and natural conditions and a higher quality of cultivated land.

2.3.2. Cultivated Land Quality Change Evaluation

Based on the aforementioned evaluation dimensions, this study explored the characteristics of cultivated land quality change in terms of the ecology, quantity, spatial structure, and scale to facilitate the adjustment and optimization of regional cultivated land, as follows:

(1) Ecological dimension

Relevant studies have demonstrated that the change in vegetation coverage can characterize the desertification degree of land [27]. When the vegetation coverage is low and the desertification problem is serious, the cultivated land quality is low. In contrast, the cultivated land quality is high. This study analyzed the impact of vegetation coverage changes on the cultivated land quality from an ecological perspective. Here, we mainly measured the impact of newly added farmland and lost farmland on the ecological environment in the whole banner. The equation is

$$NDVI = \frac{B2 - B1}{B2 + B1} \tag{6}$$

$$VFC = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \tag{7}$$

where $NDVI$ is the normalized difference vegetation index, $B1$ and $B2$ denote the image sensing red band and near-infrared reflectance value, respectively, VFC is the vegetation coverage and $NDVI_{max}$ and $NDVI_{min}$ denote the maximum and minimum $NDVI$ values, respectively, throughout the growing season.

(2) Quantity dimension

To reflect the degree of notable changes in the amount of cultivated land within the study area during a certain period, this study introduced the single dynamic degree of land use for quantitative analysis [28]. The equation is

$$D = \frac{L_b - L_a}{L_a} * \frac{1}{T} * 100\% \tag{8}$$

where D denotes the dynamics of cultivated land changes within the region during the study period, L_a and L_b denote the cultivated land areas at the beginning and end, respectively, of the study period, and T denotes the study period. $D > 0$ indicates that the cultivated land increases, and $D < 0$ indicates that the cultivated land decreases. The higher the absolute value of D, the greater the regional cultivated land change is.

(3) Spatial structure dimension

Cultivated land in the Horqin Zuoyihou Banner is largely restricted by natural geographical conditions, and distribution changes affect the maintenance of the cultivated land quality and sustainable development of the region. Based on the above analysis, this study considered the rationalization and scientific evaluation of regional cultivated land utilization through the changes in the spatial distribution of cultivated land under different influencing factors (topographical conditions and precipitation were chosen as factors with a notable impact, as indicated in Table 1).

(4) Scale dimension

From the perspective of the plot and regional levels, this study mainly focused on the following three aspects: the change in cultivated land scale, the scale of newly added cultivated land, and the distribution change between the cultivated land scale and topographical conditions [29]. When the scales of cultivated land parcels and newly added cultivated land increase and the matching degree between the cultivated land scale and topographical conditions is improved, the cultivated land quality is enhanced. In contrast, the cultivated land quality declines.

Table 1. Cultivated land spatial structure evaluation factor grading standards.

Variables	Weights	Index Grading Standard									
		100	90	80	70	60	50	40	30	20	10
Terrain level	0.27	3–6		7–8				1–2			9–10
Precipitation	0.39	>490		410–490			350–410			≤350	
Tillage distance	0.18	≤200		200–600			600–1000			>1000	
Proportion of agricultural and pastoral land	0.16	≤1/7		1/5–1/7			1/5–1			>1	

2.3.3. Optimization of Cultivated Land Resources

This research is based on the three major principles of ecological protection, adaptation to local conditions, and farming convenience, according to the evaluation results of the spatial structure and scale in a previous article, and the index interpretation method was employed to classify the optimization types in the two dimensions of the spatial structure and plot scale [17,30], including priority protection, optimized and coordinated, gradually returning farmland, and priority returning farmland (Table 2). Specifically, cultivated land with both an excellent spatial structure and scale conditions was classified as the priority protection type. Cultivated land with an excellent spatial structure and moderate scale or a moderate spatial structure and large scale was classified as the optimized and coordinated type. Cultivated land with both a poor spatial structure and scale conditions was classified as the preferential farmland conversion type, and the remaining combination types were classified as the gradual conversion from the farmland type. We applied this method to improve the cultivated land quality in the region and realize sustainable use of cultivated land based on the different optimization types.

Table 2. Classification criteria for the optimization types based on the spatial structure and scale.

Optimization Types	Classification Standard and Grade Combination
Priority protection	(1,1), (1,2), (2,1), (2,2)
Optimized and coordinated	(1,3), (1,4), (2,3), (3,1), (3,2)
Gradually returning farmland	(1,5), (2,4), (2,5), (3,3), (3,4), (4,1), (4,2), (4,3), (5,1), (5,2)
Priority returning farmland	(3,5), (4,4), (4,5), (5,3), (5,4), (5,5)

3. Results

3.1. Current Cultivated Land Quality Evaluation

Based on the evaluation results of the cultivated land quality in the different dimensions, the cultivated land quality in the Horqin Zuoyihou Banner is relatively low. The area of cultivated land in the Kezuohou Banner exceeds the water resources' carrying capacity of the region and far exceeds the population demand. The spatial structure should be optimized, but the cultivated land scale varies significantly.

In the ecological dimension, the area of cultivated land exceeds the regional water resources' carrying capacity. Based on the principle of water supply and demand balance, the available irrigation water for cultivated land is calculated as 424.3×10^6 m^3. Under the current irrigation and water-saving irrigation methods, 184,492.2 and 259,703.72 hm^2, respectively, can be irrigated, at overload levels of 84,851.3 and 9639.7 hm^2, respectively. This indicates that the water resources in Horqin Zuoyihou Banner are under great pressure and the cultivated land is in a state of serious overload.

In the quantity dimension, the current supply level of arable land is much higher than the population consumption level (Figure 3a). The minimum arable land requirement is 39,676.6 hm^2 based on food security in the Horqin Zuoyihou Banner, which accounts for 15% of the existing arable land, with an area surplus of 229,666.87 hm^2. We adopted the natural breakpoint method to classify the ratio value to reflect the cultivated land quality level in the quantitative dimension; Ganqika, Maodaotu, and Shuangsheng are located in level-I districts, where cultivated land matches the supply and demand of the local population, and the cultivated land quality is relatively high. Hailutu, Charisu, Aduqin, and Nugustai are located in level-III areas, where the existing cultivated land far exceeds the required area, indicating overexploitation, and the cultivated land quality is low.

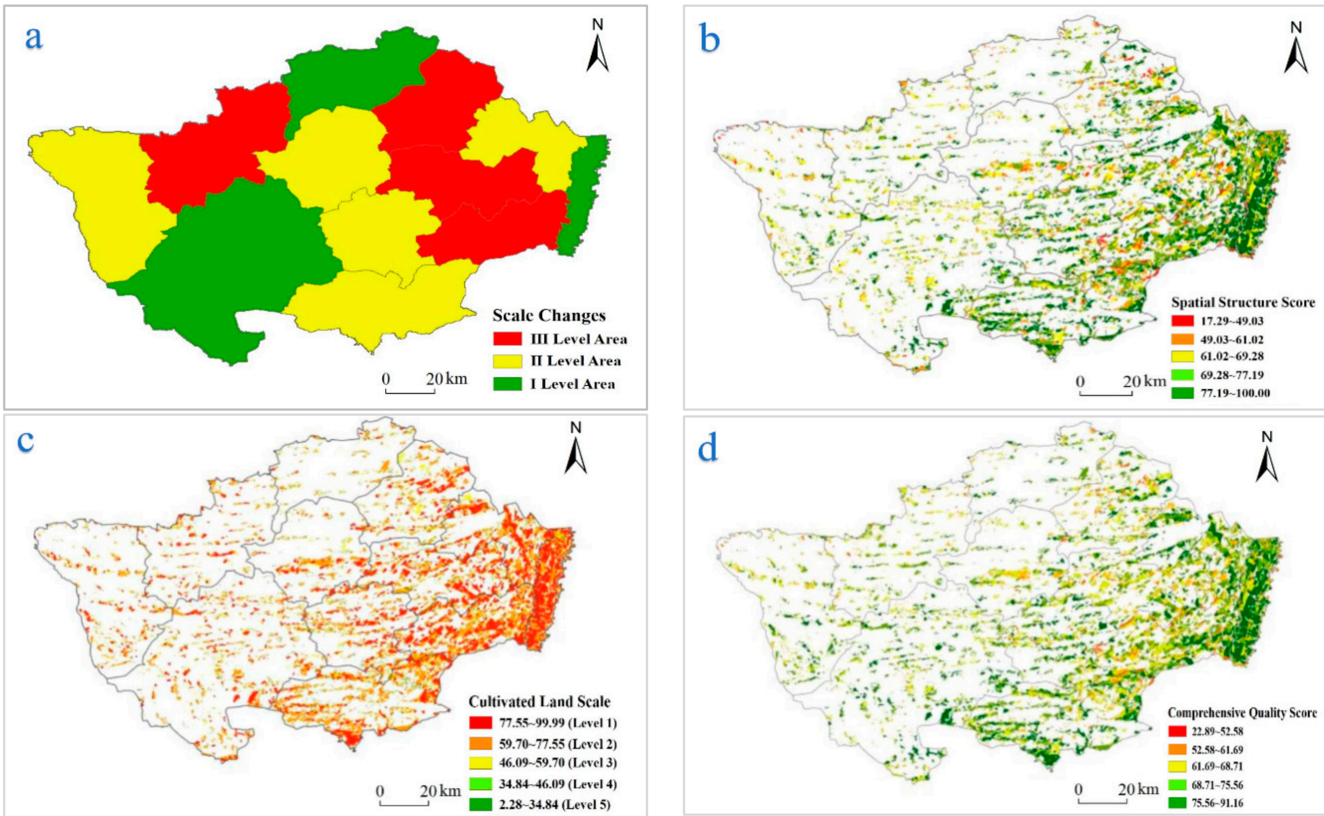

Figure 3. Evaluation results of the current status of cultivated land in the Horqin Zuoyihou Banner. (**a**) shows the quantity distribution of cultivated land; (**b**) shows the evaluation results of the spatial structure; (**c**) shows the scale distribution of cultivated land; and (**d**) shows the comprehensive evaluation results of the cultivated land quality.

In the spatial structure dimension, the evaluation score of the spatial structure of cultivated land in the Horqin Zuoyihou Banner ranges from 17.3 to 100 (Figure 3b). As such, the area of medium- to high-level cultivated land (with a score $\geq$ 69.3) reaches 178,885.4 hm^2, accounting for 66.4% of the total cultivated area. This cultivated land is mainly distributed in Charisu, Changsheng and Shuangsheng, where rainfall and topography are relatively superior and positively contribute to the regional spatial structure. From the perspective of towns, the spatial structure level of the different towns notably varies, which suggests that to improve the spatial structure of regional cultivated land, the regional cultivated land layout should be optimized.

In the scale dimension, level-1 and level-2 land areas account for 41.1% and 37.8%, respectively, of the cultivated land area, level-3 land accounts for 12.2% of the cultivated land area, and level-4 and level-5 land areas account for a relatively small proportion of the cultivated land area, namely 8.55% (Figure 3c). Level-1 land accounts for a relatively large proportion of the entire banner. In the whole banner, there are five towns, which occupy a relatively large area of level-1 land. Moreover, there are seven towns, which occupy a relatively large area of level-2 land. The former phenomenon is convenient for mechanized farming, while the latter phenomenon does not facilitate the development of modern agriculture.

In summary, the comprehensive quality score of arable land in the Horqin Zuoyihou Banner mainly matches the median value (with arable land $\geq$ 61.71), accounting for 53.97% of the total area of arable land in the banner (Figure 3d). Cultivated land with a higher cultivated land quality is largely distributed in Shuangsheng, Changsheng, and Jinbaotun, where natural conditions are better and more suitable for farming. Cultivated land with poor quality is present in Hailutu, Aduqin, and Jiergalang, exhibiting many small-scale cultivated land areas and overdevelopment. In addition, cultivated land areas at different quality levels are distributed in each town, indicating that each town has a certain potential for cultivated land quality improvement.

3.2. Cultivated Land Quality Change Evaluation

The results revealed that the quality of cultivated land in the Horqin Zuoyihou Banner exhibited a downward trend during the study period. Within the context of water shortages, the amount of cultivated land is still increasing, surface vegetation is severely damaged, and the problem of land desertification has intensified. This is not conducive to the sustainable use of cultivated land resources in the entire region.

From the perspective of the ecological dimension, the overall vegetation coverage is reduced. Among the newly added cultivated land from 2012 to 2018, high-coverage land accounted for 89.26% of the total area, but cultivated land with a reduced vegetation coverage after land conversion accounted for 75.2% of the newly added cultivated land (Figure 4a). This suggests that the development of cultivated land has increased the risk of land desertification. Moreover, the vegetation coverage in most cultivated areas of land has increased, indicating that ecological management efforts have achieved a certain level of success (Figure 4b). While the vegetation coverage in 78% of the lost cultivated land has been reduced, most cultivated land has been converted into construction land, which has intensified the ecological pressure on the whole banner.

In the quantity dimension, the area of cultivated land in the Horqin Zuoyihou Banner increased by 15,114.8 hm^2 annually, and the dynamic degree of cultivated land change reached 0.99% (a relatively high degree of change) from 2012 to 2018 (Figure 4c,d). Due to the different natural and socioeconomic conditions in each town, the change in cultivated land in each town significantly differed. Among the various towns, the dynamic change degrees in Hailutu, Charisu, Jinbaotun, and Jiergalang were higher than the average level, at 4.5%, 1.5%, 1.6%, and 1.0%, respectively.

From the perspective of the spatial structure dimension, the degree of matching of cultivated land changes with natural conditions declined (Figure 4e,f). First, cultivated land increase mainly occurred within the topography range of levels 4–9, but 55.9% of the newly added cultivated land was located in the transition zone of sandy land, with poor natural conditions and poor suitability. Second, cultivated land increase was mainly concentrated in the 400–490 mm annual rainfall range, accounting for 94.7% of the total area. However, 5.26% of the newly added cultivated land was located in unsuitable areas. In these areas, natural rainfall cannot meet the needs of crops, thus easily causing land desertification. Finally, the increase in cultivated land area was mainly concentrated within the 0–800 m range of the residential area, accounting for 83.3% of the total increase.

From the perspective of the scale dimension, the scale score of most cultivated land did not change from 2012 to 2018, and the overall cultivated land scale remained relatively constant. The scale score of 3715.4 hm^2 of cultivated land decreased, accounting for 1.5% of the cultivated land area. The scale score of 8765.9 hm^2 improved, accounting for 3.5% of the total cultivated land area (Figure 4g). The scale of the newly added arable land was relatively high, dominated by level-1 and level-2 land. The increase amounts were 5275.8 and 6350.2 hm^2, accounting for 37.87% and 42.0%, respectively, of the newly added arable land (Figure 4h). However, the phenomenon of spontaneous reclamation of small-scale arable land also occurred, and the degree of matching with the microtopography distribution declined.

3.3. Cultivated Land Resource Optimization

Based on the evaluation results of the spatial structure and scale of cultivated land, the cultivated land in the Horqin Zuoyihou Banner was divided into priority protection, optimized and coordinated, gradually returning farmland, and priority returning farmland types. These categories accounted for 34.2%, 30.6%, 28.8% and 6.4%, respectively, of the total cultivated land area (Table 3 and Figure 5). Priority protection cultivated land exhibits excellent natural conditions, is convenient for mechanized farming, and farmers are highly motivated to plant. The spatial structure of the optimized and coordinated cultivated land is good, but the level of the cultivated land scale and spatial structure is moderate, and this category provides certain development potential. Gradually returning farmland exhibits poor scale and natural conditions and a low planting efficiency. Priority conversion farmland exhibits less rainfall, with poor farming conditions, and crops cannot grow optimally.

Table 3. Statistics of the areas of the optimal types of cultivated land utilization in the Horqin Zuoyihou Banner.

Towns	Priority Protection/hm^2	Optimized and Coordinated/hm^2	Gradually Returning Farmland/hm^2	Priority Returning Farmland/hm^2
Haitulu	6321.80	10,124.21	7539.18	2541.25
Charisu	12,637.83	12,345.39	8148.55	4727.22
Jinbaotun	8505.52	8413.46	5238.30	3445.44
Jiergalang	5250.63	6674.70	5488.78	2901.13
Aduqin	4726.50	6835.61	5037.37	1744.78
Ganqika	8635.62	11,827.93	8281.03	2173.71
Nugusitai	3841.20	4044.30	2898.06	1431.79
Changsheng	14,441.26	10,803.82	10,835.17	4345.36
Agula	3334.52	3460.78	3452.83	1958.35
Maodaotu	596.78	2219.04	3037.95	755.94
Chaolutu	2854.03	3402.03	1902.99	4906.50
Shuangsheng	11,690.97	5703.42	4510.12	3348.60
Total	82,836.66	85,854.69	66,370.33	34,280.07

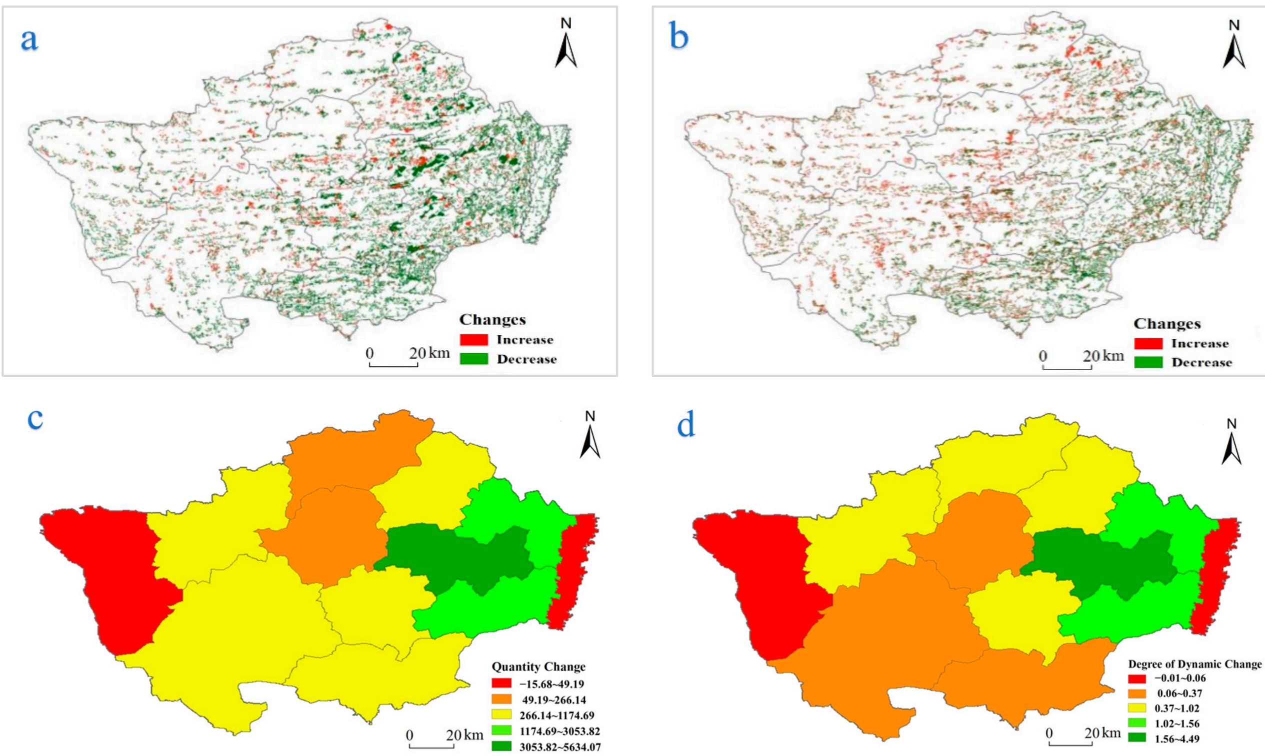

Figure 4. *Cont.*

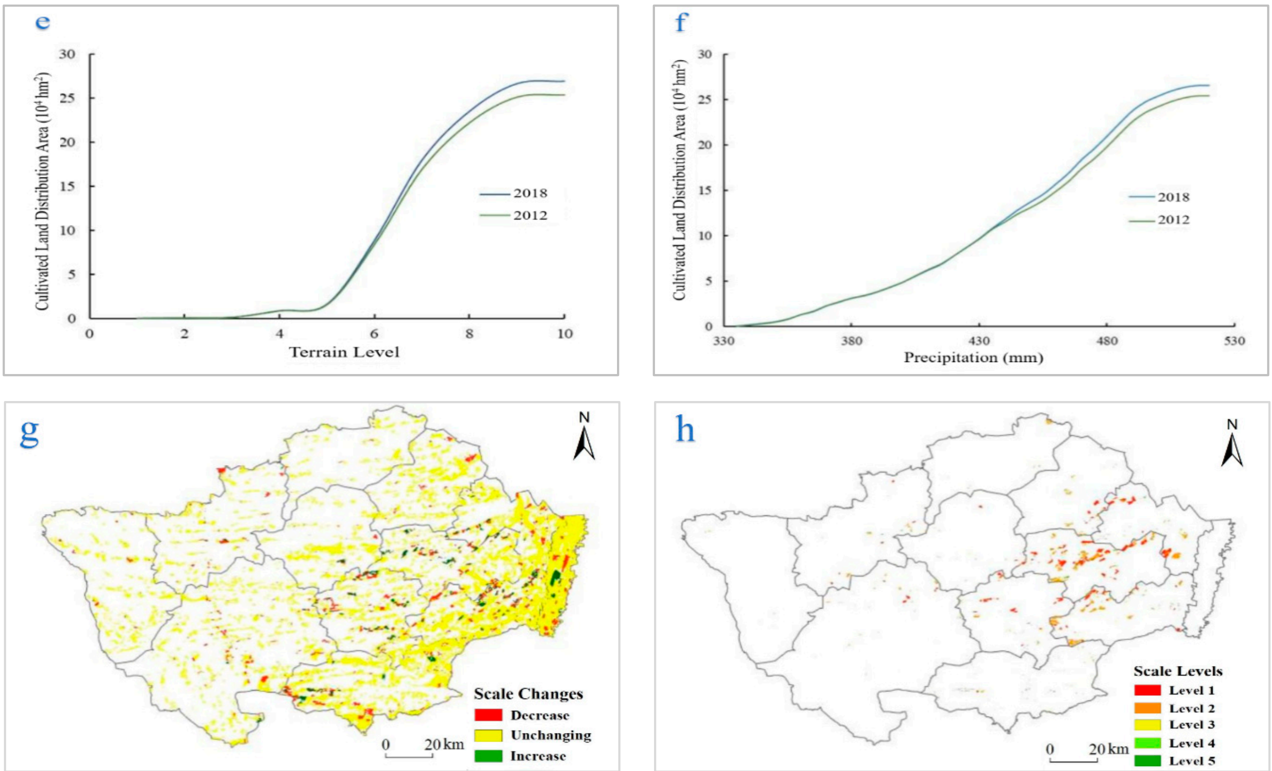

Figure 4. Results of cultivated land quality change in the Horqin Zuoyihou Banner. (**a**) shows the change in vegetation coverage in newly added cultivated land, (**b**) shows the change in vegetation coverage in lost cultivated land, (**c**) shows the change in the amount of cultivated land, (**d**) shows the dynamic change in cultivated land, (**e**) shows the change in the distribution of cultivated land under the influence of the topographic level, (**f**) shows the change in the distribution of cultivated land under the influence of precipitation, (**g**) shows the change in the scale of cultivated land, and (**h**) shows the change in the scale of newly added cultivated land.

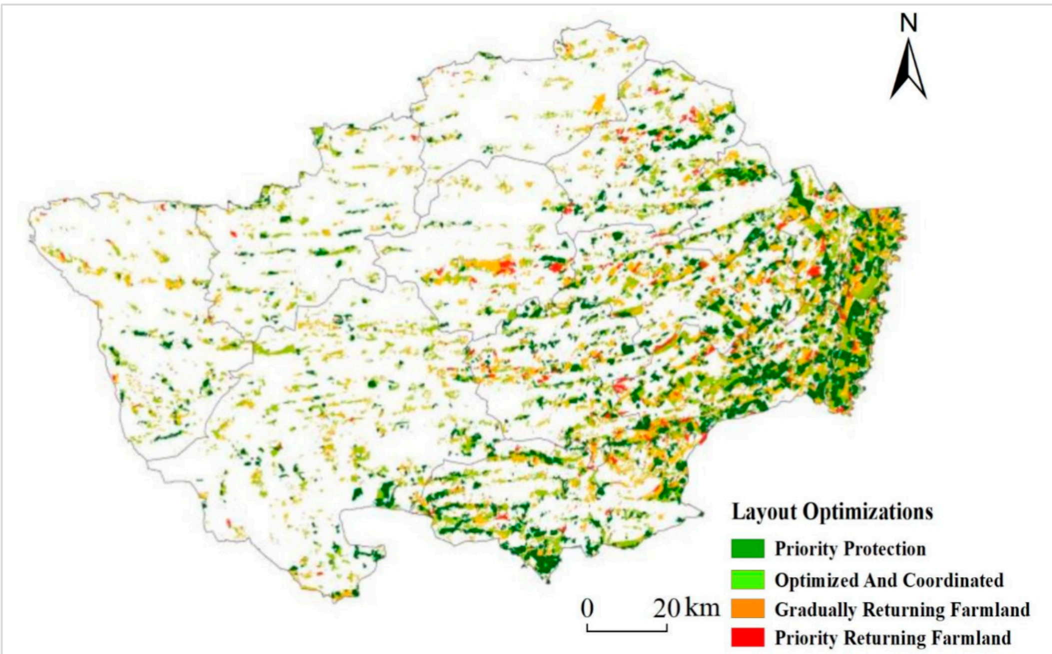

Figure 5. Optimized layout of cultivated land in the Horqin Zuoyihou Banner.

According to the distribution in each township, the cultivated land quality in Charisu, Jinbaotun, Changsheng and Shuangsheng is relatively high, and priority protection cultivated land accounts for the largest proportion of cultivated land in these towns. Agula, Chaolutu and Maodaotu are located in the northwest part of the banner, with poor natural conditions, and gradually returning farmland accounts for the largest proportion. The ecology should be prioritized, and the Project of Returning Farmland to Forestland and Grassland should be implemented. In conclusion, among the towns, each optimization type occupies a certain proportion of the area (Table 3 and Figure 5). This suggests that towns should formulate targeted measures to improve and optimize cultivated land to improve the regional quality.

4. Discussion

As a typical representative semiarid sandy area, the Horqin Zuoyihou Banner exhibits a sharp contradiction between the supply and demand for water resources, and the current cultivated land utilization method is not conducive to the sustainable utilization of regional land resources. From an ecological perspective, even if the water-saving irrigation mode was adopted, the amount of cultivated land in the Horqin Zuoyihou Banner would still exceed the water resources' carrying capacity, which indicates that the existing cultivated land is overloaded and that the current land use pattern is unsustainable [31]. From a quantitative perspective, the current supply of cultivated land is much higher than the level of population consumption. Against the background of land desertification and groundwater decline, excessive areas of cultivated land could result in a more fragile ecological environment, which does not promote the sustainable development of cultivated land [32,33]. From the perspective of the spatial structure, the high-level regions in the spatial structure evaluation are mainly distributed in the southeast, where the level of the spatial structure differs significantly. This indicates that it is necessary to optimize the layout of cultivated land and improve the matching degree between cultivated land and farming conditions in the eastern region to improve the regional arable land spatial structure level. From the perspective of the scale, both large and medium cultivated land areas exist, in addition to narrow cultivated land, with serious fragmentation problems. The occurrence of cultivated land not only reduces economic benefits but also threatens the coordinated development of production and ecology.

Fortunately, the Horqin Zuoyihou Banner has promoted ecological construction in recent years, and the implementation of both artificial and natural afforestation projects has achieved remarkable results, which has resulted in cultivated land quality improvement. However, with the development and utilization of cultivated land, ecological problems remain prominent, such as land desertification. From an ecological perspective, the vegetation coverage in certain areas exhibits an increasing trend, and a large area of land, which is important to the ecological environment, has been reclaimed. In contrast, vegetation has been destroyed, thereby reducing the quality of regional cultivated land. From a quantitative perspective, the Horqin Zuoyihou Banner strictly implements the farmland protection policy to control the farmland amount and food security, but many farmland development activities still occur in the eastern region, where the natural conditions are better [34]. From the perspective of the spatial structure, cultivated land has mainly increased in areas with suitable conditions, but cultivated land has also increased in areas with little precipitation and unsuitable terrain conditions, which aggravates the risk of land desertification. From the perspective of the scale, the scale of cultivated land in most areas has remained relatively stable. However, private reclamation of small-scale cultivated land has occurred in areas with good natural conditions, which is not conducive to the improvement in farming efficiency.

In general, the traditional approach of choosing grain as the key link still persists in the Horqin Zuoyihou Banner under the constraints of water resources, and extensive farming remains a common pattern in semiarid sandy areas. A large amount of grassland has been reclaimed as cultivated land, while cultivated land has been newly added in areas unsuitable for cultivation, such as those with poor terrain conditions and low rainfall. This development model is obviously unsustainable. Moreover, the Horqin Zuoyihou Banner is located in an ecologically fragile semiarid sandy area, where the existing cultivated land is of a low quality. Extensive reclamation can aggravate the contradiction between production and ecology [35]. Therefore, the Horqin Zuoyihou Banner should prohibit the reclamation of wasteland to control the increase in the cultivated land amount, implement land improvement projects to constrain land desertification, and develop water-saving irrigation methods to make full use of water resources and maximize the benefits of cultivated land utilization. Most importantly, the Horqin Zuoyihou Banner should systematically optimize the cultivated land layout, under the premise of ensuring ecological safety based on systematic evaluation of the cultivated land quality, to promote the coordinated development of ecology and production [36].

Based on the optimization types that are divided into the different dimensions, the following suggestions are proposed to optimize the layout of cultivated land. First, the priority protection type should fully embrace its advantages to maximize its scale benefits. Specific measures include increasing the construction of irrigation and drainage facilities and field road engineering facilities to improve soil salinization and erosion [37]. Second, scattered plots of the optimized and coordinated type should be merged through land leveling projects, and infrastructure should be enhanced to increase the economies of scale. Specific measures include improving field road engineering to increase road accessibility and developing water-saving measures, such as drip irrigation and sprinkler irrigation. In the process of remediation, attention should be given to the ecological safety of the spatial structure of cultivated land to avoid cultivated land fragmentation and vulnerability. Third, regarding the gradually returning farmland type, the structure of agricultural production should be adjusted to gradually reduce the utilization intensity, and this type should be included in the Project of Returning Farmland to Forestland and Grassland. The government should implement relevant policies and provide certain subsidies to expand the channels available to farmers to increase income and promote the restoration of natural ecological functions through gradual cultivated land conversion [38]. Fourth, in terms of the priority returning farmland type, ecological environment protection should be adopted as the main goal, and priority should be given to returning farmland to forestland and grassland to improve the regional ecological quality.

5. Conclusions

This study defined the cultivated land quality and established a method to evaluate the cultivated land quality in semiarid sandy areas based on a regional perspective to explore the cultivated land quality change trend in the Horqin Zuoyihou Banner. Directions and measures were proposed for cultivated land optimization. On the one hand, choosing the whole region as the research unit enriches the existing evaluation methods of the cultivated land quality that are dependent on plots as the research unit, considering the changes in cultivated land quality that are attributed to human activities and the impact on the whole region [39]. On the other hand, constructing an evaluation system of the cultivated land quality from multiple dimensions can comprehensively measure the cultivated land quality and its variations to propose a more practical optimization layout and policy recommendations.

Based on our findings, the area of cultivated land in the Horqin Zuoyihou Banner exceeds the regional water resources' carrying capacity and far exceeds the population demand. The cultivated land quality is low, exhibiting a downward trend as a whole, which is not conducive to the sustainable use of arable land resources throughout the entire region. Therefore, the spatial structure should be optimized. In addition, due to the differences in natural and socioeconomic conditions, the cultivated land quality in each town reveals significant differences. Therefore, it is necessary to evaluate the quality and change trend of cultivated land in the four dimensions of the ecology, quantity, spatial structure and scale in semiarid sandy areas with a similar development status to that of the Kezuohou Banner. Moreover, the different regions should, based on actual conditions, consider the characteristics of the four types, namely the priority protection, optimized and coordinated, gradual returning farmland, and priority returning farmland types, to optimize the cultivated land layout. It is hoped that this study can provide practical methods for the evaluation of the cultivated land quality in China and other regions worldwide and offer policy recommendations for the sustainable use of cultivated land resources in arid sandy areas.

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