Zoning and Evaluation of Development Potential of Arable Unused Land in the Tianshan North Slope Economic Belt: A Case Study of Fukang City, Xinjiang (Postprint)

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Abstract

Xinjiang region possesses relatively abundant unused land resources, and the rational development and utilization of such land in this area can help alleviate the increasingly severe human-land contradictions and ensure regional food security to a certain extent. This study takes Fukang City as the research area, employs the ecological niche suitability model, and selects twelve indicators including soil salinity, soil layer thickness, soil texture, organic matter content, landform type, forest coverage rate, irrigation guarantee rate, soil erosion modulus, $ 10℃ accumulated temperature, distance from rivers, average runoff per unit area in the watershed, and annual of unused land suitable for development, with a potential for new cultivated land of 15,222.92 hm^2; Zone II has 12,875.69 hm^2 of unused land suitable for development, with a potential for new cultivated land of 10,155.41 hm^2; Zone III has 5,008.84 hm^2 of unused land suitable for development, with a potential for new cultivated land of 4,165.35 hm^2; Zone IV has 878.67 hm^2 of unused land suitable for development, with a potential for new cultivated land of 753.78 hm^2; and unused land in Zone V is entirely unsuitable for development and utilization. Potential zoning can provide theoretical reference for the development and utilization of unused land in Fukang City from both temporal and spatial perspectives, and holds certain guiding significance for exploring differentiated development and utilization models for unused land in the future.

Full Text

Introduction

With the in-depth implementation of China' s Western Development Strategy, the central government has increased policy support and financial investment

in the western border regions. Xinjiang serves as the gateway for China' s westward opening under the New Silk Road Strategy and plays a vital role in the Western Development initiative. As China' s largest provincial-level administrative region, Xinjiang covers approximately one-sixth of the country' s total land area. In 2013, unused land in Xinjiang reached 1.022$\times$10^{7}$ hm^2, accounting for 61.36% of the region' s total land area, indicating substantial potential for unused land development. However, the northwestern oasis areas of Xinjiang represent ecologically fragile zones in China. Blind exploitation of unused land resources could cause immeasurable damage to these vulnerable ecosystems, necessitating differentiated development policies [1]. Water resources are particularly critical for agricultural development in Xinjiang' s oasis regions, and agricultural production consumes large quantities of water. Therefore, development direction and scale must be determined according to the principle of "determining land use based on water availability and promoting comprehensive development," in line with regional water resource distribution patterns. Traditional approaches to unused land development have focused solely on reclaiming more cultivated land without adequately considering land suitability or post-development quality maintenance. This often results in thin, loose topsoil after conversion, exacerbating soil salinization, desertification, and wind-sand disasters, especially when windbreak and sand fixation measures are inadequate and agricultural water resources are scarce. Thus, unused land development in ecologically fragile areas must adopt differentiated strategies based on resource endowment, development suitability, and relevant ecological conditions.

Domestic scholars continue to actively explore effective differentiated development approaches for existing unused land, employing various research methods. Wei Shichuan et al. [2] used limiting condition and weighted index methods to evaluate unused land suitability in the Yellow River Delta, proposing seven development models based on their findings. Ni Jiupai et al. [3] constructed an evaluation index system for regional unused land development, assessing development potential using improved analytic hierarchy process, entropy weight method, and comprehensive evaluation to classify unused land in Chongqing into four potential grades. Lei Shuxia et al. [4] evaluated ecological vulnerability in Datong City, Shanxi Province using fuzzy comprehensive evaluation, then assessed suitability of arable unused land within different vulnerability zones, concluding that development should proceed in a specific spatial and temporal sequence due to high ecological risks and limited arable unused land. Wu Kening et al. [5] drew on agricultural land classification results and relevant evaluation factors from classification regulations to assess unused land quality grades, evaluating potential for cultivated land supplementation and grain production capacity through quality grade conversion, and categorized unused land development projects into three grades to support farmland requisition-compensation balance policies. Liu Changsheng et al. [6] designed an evaluation index system for unused land development, combining GIS software with econometric models to examine development suitability and spatial distribution in Liucheng County, Guangxi, classifying unused land into agriculture-suitable, forestry-suitable, and

unsuitable categories.

The northern Tianshan Mountain slope region represents a traditional oasis agricultural area in Xinjiang with favorable natural conditions including light, heat, water, and soil resources. However, accelerating industrialization and urban-rural integration have increased construction land demand, reducing both cultivated land quantity and quality, which directly impacts regional grain production capacity. The Xinjiang Autonomous Region government has formulated a series of preferential policies to encourage differentiated development of state-owned unused land where conditions permit, providing necessary policy support for exploiting Xinjiang' s vast unused land resources. Dai Bing et al. [7] explored suitability of unused land development in Xinjiang from natural, ecological, and economic perspectives using GIS technology. Fan Zhaoju et al. [8] calculated development potential in Xinjiang based on land survey data and development potential expressions. While these studies have advanced research on unused land development in Xinjiang, they have not examined development potential based on suitability evaluation. Converting unused land to cultivated land serves as an important means to ensure food security in current socio-economic development, helping alleviate conflicts between construction land expansion and farmland protection [9]. This study takes Fukang City in the Northern Tianshan Mountain Economic Belt as a case study, employing an ecological niche fitness model to evaluate unused land development suitability and subsequently calculating development potential and zoning. This research provides important guidance for improving comprehensive benefits of unused land resources and promoting sustainable regional economic development in the Northern Tianshan Mountain Economic Belt.

1. Study Area Overview and Data Sources

1.1 Study Area Overview

Fukang City is located in the central part of Changji Hui Autonomous Prefecture, Xinjiang Uygur Autonomous Region, situated north of the Tianshan Mountains and south of the Junggar Basin, with terrain sloping from southeast to northwest. Geographically, it lies between 87°46 -88°44 E and 43°45 - 45°30 N, bordering Jimsar County to the east, Midong District of Urumqi City to the west, and Fuhai County of Altay Region to the north. The city governs three sub-district offices, four towns, and three townships, with a total land area of 8,444.71 km^2. Unused land covers 179,017.41 hm^2, representing 21.20% of the total land area. Large tracts of shrub forest and natural grassland are distributed in the northern desert and southern hilly areas, while unused land is mainly located in southern mountainous regions, central plains, and northern desert fringe areas [Figure 1: see original paper].

Unused land primarily includes other grassland, bare land, saline-alkali land, sandy land, inland beaches, rivers, lake surfaces, and glaciers/permanent snow. Rivers, lakes, glaciers, and permanent snow are difficult to develop, while other

grassland, bare land, saline-alkali land, sandy land, and inland beaches—which constitute a large proportion of unused land—can be developed as cultivated land reserves. Seven major rivers originate from the northern Tianshan Mountains, replenished mainly by meltwater from alpine glaciers and snow as well as atmospheric precipitation. Due to minimal topographic relief in river basins and slow flow velocity, distance from rivers has greater influence on unused land development than elevation differences. The region features a typical temperate continental climate, with more precipitation in southern mountainous areas and scarce rainfall in northern desert and central plain zones, forming extensive dryland areas north of the central region. Major soil types include irrigated gray desert soil, irrigated cultivated soil, fluvo-aquic soil, irrigated warp soil, and salinized soil.

1.2 Data Sources

This study primarily utilized data from the Ministry of Land and Resources' project on dynamic monitoring and evaluation of cultivated land quality (Fukang City pilot). Unused land data were derived from Fukang City' s 2013 land use database and change data (excluding Xinjiang Production and Construction Corps). Soil physicochemical data came from the agricultural department' s soil testing and formulated fertilization project. The $ $10 ℃ cumulative temperature distribution map was obtained from the *Xinjiang Meteorological Handbook*. Soil erosion and annual precipitation data were sourced from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. Soil erosion intensity was classified according to the *Standard for Classification and Gradation of Soil Erosion* (SL190-2007). Annual precipitation was calculated using inverse distance weighted averaging for spatial interpolation of meteorological station data. River annual runoff data were obtained from the Fukang City Hydrological Gazette, with watershed area derived from DEM-based hydrological analysis; watershed average runoff depth was calculated as their ratio. River network distribution data were obtained through spatial analysis of Fukang City' s DEM, and distance from rivers was determined via buffer analysis of extracted river data. Qualitative statistical data were collected from Fukang' s national economic statistics and field survey interviews.

1.3 Research Methods

Unused land development potential zoning is closely related to suitability. Calculating development potential based on suitability evaluation results facilitates more scientific potential zoning [10]. This study evaluates the suitability of unused land for agricultural production in Fukang City, determining the quantity and distribution of unused land suitable for cultivation in each township based on suitability grades. According to different suitability grades, the development potential of unused land in each township is calculated using the unused land development potential formula, and township potential is zoned through cluster

analysis based on the proportion of unused land resources, potential coefficient for new cultivated land, and area of new cultivated land.

1.3.1 Division of Suitability Evaluation Units Evaluation units serve as the basic spatial units for land assessment, delineated from relatively homogeneous land parcels. Methods for dividing land evaluation units include parcel method, geographic grid method, overlay method, and polygon method [11]. This study adopted the geographic grid method, using unused land patches from the 2012 land use status map as the base map. Evaluation grids were created at a standard of 250 m × 250 m, yielding 54,931 evaluation units for unused land across the city.

1.3.2 Selection of Suitability Evaluation Indicators The scale and benefits of unused land development are determined by comprehensive conditions including agricultural location, resource endowment, and ecological environment, with each indicator reflecting suitability from different perspectives. Considering Fukang City' s regional characteristics and agricultural production conditions, twelve indicators were selected to establish an evaluation index system for unused land development suitability based on principles of dominance, comprehensiveness, relative stability, and regional differentiation (Table 1) [12–13].

1.3.3 Ecological Niche Fitness Model Natural environmental conditions formed after unused land development constitute the actual ecological niche for cultivated land use, while the most ideal values of influencing factors form the demand ecological niche. Niche fitness refers to the coupling relationship between actual and demand ecological niches, with their matching degree reflecting the suitability of unused land development. When the actual resource niche in an evaluation unit fully meets ideal conditions for cultivated land use, niche fitness equals 1; when it completely fails to meet ideal requirements, niche fitness equals 0. Generally, environmental impact factors for arable unused land development can be classified into three categories [17]:

Type I: Environmental factors should not be lower than the minimum requirements for sustainable cultivated land use, and larger actual ecological niches of constraint factors are more favorable for unused land development. The niche fitness calculation formula is:

$$N_i = \begin{cases} 0 & \text{if } X_i < D_{\min} \\ \frac{X_i - D_{\min}}{D_i - D_{\min}} & \text{if } D_{\min} \le X_i \le D_i \\ 1 & \text{if } X_i > D_i \end{cases}$$

Type II: The demand ecological niche of environmental factors should fall within a suitable range, where either excessively large or small actual ecological niches adversely affect unused land development. The niche fitness calculation formula is:

$$N_i = \begin{cases} \frac{X_i - D_{\min}}{D_i - D_{\min}} & \text{if } D_{\min} \le X_i \le D_i \\ \frac{D_{\max} - X_i}{D_{\max} - D_i} & \text{if } D_i < X_i \le D_{\max} \\ 0 & \text{otherwise} \end{cases}$$

Type III: The demand ecological niche of environmental factors should be lower than the maximum requirement for sustainable cultivated land use, and smaller actual ecological niches are more favorable for unused land development. The niche fitness calculation formula is:

$$N_i = \begin{cases} 1 & \text{if } X_i < D_i \\ \frac{D_{\max} - X_i}{D_{\max} - D_i} & \text{if } D_i \le X_i \le D_{\max} \\ 0 & \text{if } X_i > D_{\max} \end{cases}$$

Where: Xi is the actual ecological niche of evaluation indicator i in the evaluation unit, Dmin is the minimum actual ecological niche value of the evaluation factor, Dmax is the maximum actual ecological niche value of the evaluation factor, and Di is the ideal ecological niche value of the evaluation factor.

In addition to quantitative factors, the index system includes descriptive qualitative factors. Suitability values for qualitative indicators reference classification standards from agricultural land grading and classification regulations. For example, in irrigation guarantee rate, fully meeting requirements is assigned a value of 1, basically meeting is 0.8, generally meeting is 0.6, and no irrigation conditions is 0. For geomorphology type, location in the lower part of alluvial fans is 1, upper part is 0.8, piedmont slopes are 0.5, and desert edge is 0.

1.3.4 Calculation of Niche Fitness Index for Unused Land Development According to Shelford' s Law of Tolerance, the survival and development of biological communities are closely related to surrounding environmental factors. When any environmental factor quantitatively or qualitatively reaches or exceeds the organism' s tolerance limit, organisms cannot endure the extreme conditions and decline. Similarly, the conversion process of unused land interacts with surrounding environmental factors in the same way. When any impact factor reaches or exceeds the limit for cultivated land use, both post-development cultivated land quality and surrounding ecosystems will decline due to limiting factors. When the niche fitness of unused land development approaches or equals 1, current environmental conditions are suitable for development. The suitability of unused land development for cultivated land in Fukang City can be obtained through the following formula:

$$S = \sqrt[n]{\prod_{i=1}^{n} N_i}$$

Where: S is the niche fitness of unused land resource development, and n is the dimension number of factors constraining unused land development.

1.3.5 Ecological Suitability Evaluation of Unused Land Development Using Fukang City' s land use status map as the base map, the grid method was employed to divide unused land parcels into rectangular evaluation units. The niche fitness model was applied to calculate suitability scores for unused land development, and suitability grades were determined based on the frequency distribution histogram of evaluation unit scores (Figure 2, Table 2).

1.3.6 Calculation of Ecological Suitability Potential for Arable Unused Land Development The potential for arable unused land development in Fukang City is based on suitability evaluation results. This study uses townships as the basic evaluation units and calculates development potential using the unused land development potential model according to the following formula [18]:

$$F_i = \frac{G_i}{M}$$

$$P_{ij} = \frac{S_{ij}}{M_{ij}}$$

$$\Delta G_i = \sum_j S_{ij} \times P_{ij}$$

$$H = \frac{N}{Q}$$

Where: Fi is the proportion of unused land area in region i relative to the total unused land area, Sij is the area of unused land suitable for development at grade j in region i, Mij is the total area of unused land at grade j in region i, M is the total unused land area, Pij is the potential index for unused land development at grade j in region i, Gi is the unused land area in region i, ΔGi is the potential for new cultivated land in region i, H is the plot fragmentation index, N is the number of plots of arable unused land, and Q is the average plot area of arable unused land.

Based on the suitability evaluation results and considering the actual conditions of the ecologically fragile study area, unused land classified as highly suitable and basically suitable for cultivation was selected as developable. Using the unused land development potential formulas, the development potential of unused land in each township of Fukang City was calculated.

2. Results

2.1 Ecological Suitability and Zoning of Unused Land Development

As shown in Figure 2, large areas of unsuitable unused land are distributed in southern mountainous regions and northern desert margins due to natural constraints. Highly suitable unused land is mainly scattered in the lower-middle parts of piedmont alluvial fans with adequate irrigation water and relatively flat terrain. Basically suitable unused land appears in belts and patches along river banks and in central piedmont alluvial fan areas. Reluctantly suitable unused land is sporadically distributed between basically suitable and unsuitable areas.

According to evaluation results, unused land relatively suitable for cultivation (including highly suitable and basically suitable) accounts for 22.21% of total unused land area, primarily distributed in other grassland and inland beach areas in central regions. These areas are located in the lower-middle parts of piedmont alluvial fans with fertile soil, gentle southeast-northwest sloping terrain, and predominantly sandy loam soil with higher nitrogen, phosphorus, potassium, and organic matter content than surrounding areas. Rivers originating from the Tianshan Mountains—including the Baiyang River, Xigou River, Sangong River, and Huangshan River—provide ample irrigation water. Moreover, being distant from northern desert landscapes, soil erosion is minimal. Consequently, these areas possess favorable agricultural production conditions, making unused land resources highly suitable for conversion to cultivated land.

Reluctantly suitable unused land comprises only 16.36% of Fukang City' s total unused land, mainly distributed at northern desert margins and upper parts of southern piedmont alluvial fans. These areas have some topographic relief, with soil texture dominated by sand, clay, and gravel, and lower organic matter content than lower alluvial fan areas. Rivers such as the Ganhezi River provide relatively adequate water sources. However, since cultivation conditions are not fully met, development of reluctantly suitable unused land should adhere to moderate principles to maintain its ecological barrier function.

Unsuitable unused land for development accounts for 61.43% of total unused land area, primarily distributed in steep piedmont slopes at the northern Tianshan Mountains, piedmont alluvial fan edges, and areas near the northern desert margin. Adjacent to the Gurbantunggut Desert edge, these areas feature poor soil texture and fertility dominated by gravelly and sandy soils, with land use types mainly comprising bare land and sandy land. Low forest coverage, frequent strong winds and sandstorms, and severe soil erosion, combined with distance from rivers and inability to guarantee basic water requirements for agriculture, necessitate protection and prohibition of arbitrary development.

2.2 Ecological Suitability Potential and Zoning for Arable Unused Land Development

Based on potential calculation results, a matrix was constructed using indicators including potential index, new cultivated land potential, township unused land area, arable unused land development area, proportion of arable unused land, average plot area, and plot fragmentation index. Systematic cluster analysis was performed using SPSS 20.0 software [19–20] to generate a dendrogram for zoning unused land development potential across Fukang City, resulting in five potential zones (Table 3, Figure 3).

Research findings (Figure 3) indicate that areas with greater unused land development potential are concentrated in eastern and central regions with better cultivation conditions. Grade I potential zone has 21,000.97 hm^2 of developable unused land with potential for 15,222.92 hm^2 of new cultivated land, mainly distributed in Shanghugou Township. Although the development potential index is relatively small, this area has the largest unused resource area with high contiguous concentration, making it the township with greatest potential for new cultivated land and thus suitable for prioritized development.

Grade II potential zone encompasses 12,875.69 hm^2 of developable unused land with 10,155.41 hm^2 of new cultivated land potential, mainly in Shuimogou and Sangonghe townships. Despite large quantities of unused land resources, the development potential index is relatively small due to steep slopes and fragmented parcels, resulting in limited additional cultivated land area. Therefore, this region is suitable for secondary-priority development of qualified unused land.

Grade III potential zone includes 5,008.84 hm^2 of developable unused land with 4,165.35 hm^2 of new cultivated land potential, covering Jiuyunjie and Ziniquanzi towns. Although total unused land resources are relatively limited, these towns have high proportions of arable unused land and large development potential indices and new cultivated land potential, making them suitable for focused development given favorable agricultural conditions and high plot concentration.

Grade IV potential zone comprises 878.67 hm^2 of developable unused land with 753.78 hm^2 of new cultivated land potential, concentrated in Chengguan Town, Ganhezi Town, and the Zhundong Agency. As economically developed areas of Fukang City with relatively concentrated urban land use, these towns have limited arable unused land and small potential for additional cultivated land, necessitating moderate development principles.

Grade V potential zone, managed by Fukang City proper, is dominated by natural grassland and shrub forest with 660.86 hm^2 of unused land. Constrained by natural conditions unsuitable for cultivation, this zone has the lowest development suitability and minimal potential for new cultivated land.

3. Conclusions and Discussion

Located in the farming-pastoral ecotone of northwestern arid regions, Fukang City has a relatively fragile ecological environment. Therefore, development must be moderate, following principles of adapting to local conditions, ecological protection, and efficient development. Based on agricultural land classification regulations, this study constructed an index system selecting factors that strongly constrain unused land development in northwestern arid regions, analyzing development suitability using the ecological niche fitness model. Results show that 39,764.16 hm^2 of unused land in Fukang City is suitable for development, representing 22.21% of total unused land area, mainly distributed in other grassland and inland beach areas of Shanghugou, Shuimogou, Sangonghe, and Ziniquanzi. With favorable light, heat, and water conditions, these areas exhibit high niche fitness for unused land resource development, indicating substantial development suitability.

Systematic cluster analysis of potential indices, new cultivated land potential, average plot area, and plot fragmentation indices enabled classification of arable unused land into five potential zones. In Shanghugou, Shuimogou, and Sangonghe townships, the proportion of arable unused land and development potential indices are relatively small, but large-scale unused land resources create substantial potential for new cultivated land. Differences in new cultivated land potential, plot fragmentation indices, and arable unused land proportions led to their classification as Grade I and Grade II potential zones. Jiuyunjie and Ziniquanzi towns have relatively limited total unused land resources but high proportions of arable unused land and large development potential indices, resulting in considerable new cultivated land potential and classification as Grade III potential zone. Chengguan Town, Ganhezi Town, and Zhundong Agency have limited unused land area; despite high proportions of arable unused land and large development potential indices, the amount of additional cultivable land is restricted, placing them in Grade IV potential zone. Fukang City proper contains some unused land, but all falls within unsuitable development categories, representing minimal potential as Grade V potential zone. This zoning provides temporal and spatial guidance for unused land development in Fukang City and offers practical significance for exploring future differentiated development patterns.

Based on prudent and moderate development principles, this study employed the ecological suitability model to examine unused land development suitability, with results that generally reflect actual conditions in ecologically fragile areas. However, considering data availability limitations and the need for representative indicators, the study selected twelve natural factors for evaluation. Future research should further explore indicator selection and quantitative grading standards due to the lack of unified quantification criteria.

This study' s potential zoning selected indicators based on unused land distribution, contiguous concentration, and post-development cultivated land incre-

ments, visually demonstrating development potential across townships to provide local development guidance. However, the research only considered resource characteristics and development difficulty, leaving quality variations within potential zones for further investigation. Meanwhile, Fukang City should actively explore differentiated development models based on suitability, adhering to the principle of "developing for agriculture where appropriate, for forestry where appropriate, for construction where appropriate, and leaving barren where appropriate" [21-22].

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Note: Figure translations are in progress. See original paper for figures.