ISSN: 1813-4890

Study on the Method of Cultivated Land Functional Zoning

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Abstract

The scientific delineation of cultivated land functional zoning is helpful to formulate regionally differentiated cultivated land protection measures, which is an important means to coordinate cultivated land protection and economic development and maintain urban food security. This paper uses the literature method to sort out the previous research results and summarize the main methods by collecting relevant studies on cultivated land functional zoning at home and abroad. The main methods include comprehensive index evaluation method, k-means cluster analysis method, hot spot analysis, Moran 's I index, self-organizing feature map(SOM). This study can provide theoretical support for the scientific allocation of cultivated land resources, the rational formulation of cultivated land zoning control plan, and the formulation of multi-functional cultivated land management and utilization policies.

Keywords

Cultivated land, Functional Zones, Comprehensive Evaluation, Spatial Autocorrelation Analysis, Spatial Clustering.

1. Introduction

Food security is related to the development of the national economy and is an important foundation for national security. As the foundation of food production, the quantity and quality of cultivated land resources play an important role in food production and social and economic development. However, with the rapid development of urbanization and industrialization, the problems of tight cultivated land resources, declining quality, and fragmented spatial distribution of cultivated land have become increasingly prominent due to the medium and high intensity of land development and utilization in urban expansion[1]. The situation of high-quality cultivated land protection is grim. How to scientifically allocate limited cultivated land resources and rationally formulate the zoning control plan of cultivated land has become an important link to take into account food security and economic development.

The function of cultivated land is the ability of cultivated land system to provide various products and services that meet the needs of human survival and development.From a global perspective, since the 1970s, single-function productive agriculture has had a huge impact on soil quality, food security, ecological environment, etc.As the most important element of agricultural operations, multifunctional arable land has been used as a strategy to sustain agriculture and rural development in a sustainable way[2]. However, due to the diversity of cultivated land function types, the imbalance of spatial distribution and the selectivity of human use, there are trade-offs and synergies between cultivated land functions[3].

The functional zoning of cultivated land is based on the comprehensive study of various elements of cultivated land, considering its current characteristics and differentiation rules, and carrying out geographical zoning according to regional differences. That is conducive to promoting the formulation of cultivated land protection policies and the implementation of differentiated management of cultivated land[4]. The functional zoning of cultivated land can meet the needs of multi-functional comprehensive protection of cultivated land in the new era, which is conducive to the scientific allocation of cultivated land resources, the rational formulation of cultivated land zoning control schemes, and the formulation of multi-functional cultivated land management and utilization policies. It is an important part of taking into account food security and economic development. In addition, the functional zoning of cultivated land lays a foundation for quantifying the multi-functional value of cultivated land, which is conducive to strengthening the multi-functional planning and functional design of cultivated land, improving the ecological utilization rate and promoting the sustainable use of cultivated land. There are two main ideas for the division of multi-function of cultivated land. First, from the perspective of ecosystem services, the multi-function of cultivated land is decomposed into supply, regulation, support and cultural functions [5], and further subdivided into secondary functions such as water resources purification, carbon sequestration, and provision of biological habitats[6]. Second, from the perspective of primary and secondary, the multi-function of cultivated land is divided into production functions mainly for food production and non-production functions including landscape, culture, ecology, and space bearing [7], which can be further divided into ecological functions and life functions. In addition to the comprehensive index evaluation method, the k-means cluster analysis, hotspot analysis, Moran's I index , and self-organizing feature map are mostly used in the functional zoning method of cultivated land. Based on the quantitative results of multi-level evaluation indicators, combined with regional characteristics, the spatial division of cultivated land functions is carried out, and differentiated protection measures are taken for regional cultivated land resources. This paper uses the literature method to sort out the previous research results and summarize the main methods by collecting relevant studies on cultivated land functional zoning at home and abroad. The main methods include comprehensive index evaluation method, k-means cluster analysis method, hot spot analysis, Moran 's I index, self-organizing feature map(SOM). This study can provide theoretical support for the scientific allocation of cultivated land resources, the rational formulation of cultivated land zoning control plan, and the formulation of multi-functional cultivated land management and utilization policies.

2. The Comprehensive Index Evaluation Method

The cultivated land has multi-functional characteristics, including food production function, ecological regulation function, social security function and landscape culture function, etc[8]. The production function indexes mainly include food production, vegetable production, fruit production, multiple cropping index and so on. The ecological function indexes mainly include the diversity index of farmland ecosystem, the fragmentation degree of cultivated land landscape, the environmental load of cultivated land use, etc. The social security function indicators mainly include per capita food output, per capita cultivated land, the proportion of the number of employees in the primary industry, and the proportion of cultivated land output value. The landscape culture function indicators mainly include the planting area of flowers, the number of agricultural sightseeing parks, the number of farmhouses, etc. The function of cultivated land is not a simple superposition of production function, ecological function, social security function, landscape culture function and other functions, but a complex of various subfunctions with interaction and interconnection[9]. In addition, in addition to the above four main functions, cultivated land also has other functions such as urban barrier. However, these are not the focus of current cultivated land protection, resulting in less consideration when selecting indicators.

Moreover, the multi-function of cultivated land has scale characteristics, such as plot scale, regional scale, national scale and so on. The selection of evaluation indicators and the evaluation results of cultivated land multi-function at different scales will be different[10]. Raudsepp-Hearne and Peterson analyzed the scales of production, consumption, and management of 12 ecosystem services and to analyze how interactions among 7 of these ecosystem services change across 3 scales of observation (1, 9, and 75 km^2)[11]. Stürck and Verburg tested different multi-functionality indicators on different spatial scales, and the results showed that the scale of analysis determined the interpretation of landscape versatility[12]. However, the existing literature on the scale effect of multiple functions of cultivated land is still not enough, and there are few studies on multi-scale[11].

3. k-means Cluster Analysis Method

Cluster analysis is a quantitative method to study the classification of multi-factor things. Cluster analysis is to quantitatively determine the affinity between samples according to their own attributes and a certain similarity or difference index, and cluster the samples according to the degree of kinship. The k-means spatial clustering method based on Euclidean distance takes the mean value of all data samples in each cluster subset as the representative point of the cluster, and divides the data set into different categories through the iterative process, so that the criterion function for evaluating the clustering performance is optimized. Thus each generated cluster is compact and independent between clusters. Some studies have found that the k-means clustering algorithm with contour coefficient is implemented based on Python 's sklearn library. Compared with the k-means clustering algorithm integrated in SPSS, GeoDa and other software, the contour coefficient is introduced to help determine the optimal number of clusters and get the best clustering results[13].The formula is as follows:

$$D(X_{\mathrm{m}}, X_{\mathrm{n}}) = \sqrt{\sum_{\mathrm{k}=1}^{\mathrm{z}} (X_{\mathrm{mk}}, X_{\mathrm{nk}})^2} \tag{1}$$

$$\mathrm{SSE} = \sum_{\mathrm{m}=1}^{\mathrm{k}} \sum_{\mathrm{p} \in X_{\mathrm{m}}} \mathrm{p} - \mathrm{C}_{\mathrm{m}}^2 \tag{2}$$

where: $D(X_{\mathrm{m}}, X_{\mathrm{n}})$ refers to the distance between the sample X_{m} and X_{n}, and the smaller the distance, the smaller the sample difference is; k refers to the number of clusters; The X_{mk} and X_{nk} refer to the sets of samples when the cluster is class k; The m and n refer to the clustering elements; z refers to the cluster object; SSE (Sum of Squared Error) refers to the sum of squared errors across all samples; p refers to the cluster object; C_{m} refers to the cluster center of the cluster subset X_{m}.

4. Hot Spot Analysis

Hot spot analysis is one of the global clustering test methods, which calculates the local autocorrelation index (G) through the dataset elements, and uses the local index to explore the spatial autocorrelation. The formula is as follows:

$$\mathrm{G}_{\mathrm{i}}^{*} = \frac{\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{w}_{\mathrm{ij}} (\mathrm{x}_{\mathrm{j}} - \bar{\mathrm{x}})}{\mathrm{S} \sqrt{\frac{\left[\mathrm{n} \sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{w}_{\mathrm{ij}}^2 - \left(\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{w}_{\mathrm{ij}}\right)^2\right]}{\mathrm{n}-1}}} \tag{3}$$

where: G_i^* refers to the local autocorrelation index in region i; n refers to the number of blocks divided by grid; x_i and x_j refer to the logarithmic values of the comprehensive dynamics of plot i and plot j plus 1, respectively; w_{ij} refers to the spatial weight matrix; S refers to the standard deviation; $\bar{x}$ refers to the mean value of x_i and x_j.

The higher the absolute value of G_i^*, the more non-random the result is, and the more statistically significant it is. When G_i^* is greater than 0, the region is a clustered hotspot. When G_i^* is less than 0, the region is a negative cluster hotspot. When G_i^* is 0, it means that the result is randomly generated and is not statistically significant. The significance test of the obtained G_i^* value is carried out, and the cold and hot spots with confidence intervals can be obtained.

5. Moran's I Index

The first law of geography states that the spatial distribution of geographical things or attributes is spatially related to each other, and there are clustered, random, and regular distribution[14]. Spatial autocorrelation analysis is to determine whether a variable is correlated in space. Local spatial autocorrelation analysis can further reflect the correlation between each plot and its adjacent plots in a certain attribute[15].

Moran 's I index is the most classical method for calculating spatial autocorrelation [16], generally divided into two types : global spatial autocorrelation and local spatial autocorrelation[17]. The global Moran 's I is derived from the Covariance relationship based on the statistical correlation coefficient. The size of the covariate represents the correlation between the two groups. The function of the global Moran 's l value is to describe the overall distribution and cluster of a phenomenon. At the 5% significant level, with Z (I)> 1.96, there is a significant spatial autocorrelation in the distribution of a phenomenon within the study range. And with Z (I)< 1.96, there is a negative spatial autocorrelation in the distribution of a phenomenon within the study range. The formula is as follows:

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ji}} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ji}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{4}$$

where: W_{ji} is the spatial adjacent weight matrix of each spatial unit i and j (j = { 1, 2, 3,..., n }) in the study area. 1 means that i is adjacent to j. 0 means that i and j are not adjacent. x_i is the value of each item of one set of variables, and x_j is the value of each item of another set of variables. $\bar{x}$ refers to the mean value of x_i and x_j.

Local Moran 's *I* is a spatial autocorrelation local test statistic, which is used to identify the location of spatial clustering and spatial outliers. The formula is as follows:

$$I_i = \frac{n(x_i-\bar{x})\sum_{j=1}^{n} W_{ji}(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{5}$$

Each variable is defined similarly to the formula (4). The value of Moran's *I* is calculated according to equation (5). The value ranges from -1 to 1, with a positive correlation greater than 0 and a negative correlation less than 0. The larger the value, the greater the correlation of spatial distribution, that is, the spatial aggregation distribution is obvious. The smaller the value, the smaller the spatial distribution correlation. The value that tends to 0 indicates that the spatial distribution is random. Generally, GeoDa software is used to obtain the spatial autocorrelation classification results of global and local Moran 's index.

6. Self-organizing Feature Map (SOM)

The learning rule of the self-organizing feature map (SOM) model is a similar algorithm to the competitive inhibition of the cerebral cortex[18]. The input patterns are automatically classified according to the learning rules, which reduces the subjectivity of the index weight and improves the objectivity and accuracy of the classification.The topology of the SOM model network is shown in Fig 1. The model consists of a structural input layer and a competition layer. The input layer has as many neurons and variables as possible. All neurons in the input layer are connected to the neurons in the competition layer by connecting weights. The competition layer introduces the topological structure of the network, which can simulate the phenomenon of lateral inhibition in biology. Adjacent competition layer neurons are connected by weights. The competition layer neurons are arranged in a one-dimensional or multi-dimensional topological structure. The network performs unsupervised training on the input vector. The competition layer neurons determine the inhibition relationship according to the distance, and constantly adjust the network structure and connection weights. When a new sample is inputted, the system outputs the classification result in the form of a topology[19].

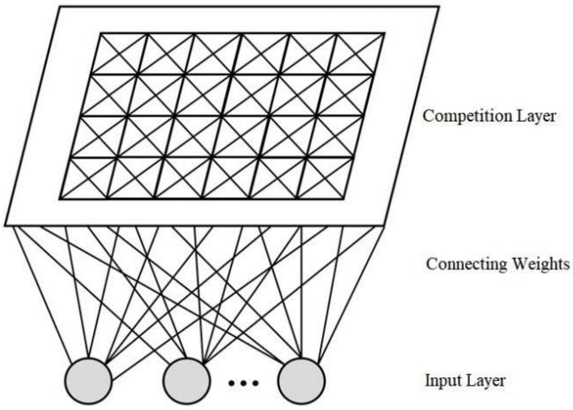

Figure 1: SOM model network topology structure

Acknowledgements

This paper was granted by Technology Innovation Center for Land Engineering and Human Settlements, Shaanxi Land Engineering Construction Group Co., Ltd and Xi'an Jiaotong University (Grant No. 2024WHZ0242). This work was supported by the Scientific Research Item of Shaanxi Provincial Land Engineering Construction Group (DJNY-ZD-2023-4, and 2023-NBYY-02). This work was supported by Young Talent Fund of Association for Science and Technology in Shaanxi, China(20240609).

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