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GIS-based Towns and Villages Spatial Structure Analysis and Optimization Method

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Abstract: The essay firstly defined the research ideas analyzing the town-village spatial structure in county. Then put forward the GIS-based research method analyzing and optimizing town-village spatial structure. It described the GIS-based researching process, that is to establish GIS database and DEM(terrain digital elevation model), then to elect indicators including TI (terrain index), DI (distribution index), CV (area coefficient of variation of Voronoi diagram), NNI (the nearest neighbor index) and other basic Indicators and then using the GIS spatial analysis function to analyze the relationship between the settlements and topography and the roads, the water system and to finally optimize the town-village spatial structure.

Key words: GIS technology, spatial structure of towns and villages, analysis and optimization, methods

INTRODUCTION

The GIS technology is used not only to check all the information in the database, but also to integrate different information and to seek the relationship among spatial phenomena, even to reveal the inherent regularity and characteristics of things. So, the GIS technology plays an important role during studying geographic spatial phenomenon. At present, the GIS technology has been widely used in field of research about the residential spatial analysis, such as the distribution characteristics of the residents, the layout optimization of residents, etc. (Fan *et al*., 2008; Liang and Zhao, 2001; Wang *et al*., 2003 and Sun *et al*., 2007). The town-village is the place for social, economic and cultural activities. The Spatial structure of town-village is the inner link and the external performance of the activities and functions of the town-village. The essence of the town-village spatial structure optimization is to match all levels of town-village layout and spatial resources by human intervention and to implement the nature-economy-society harmonious and sustainable development (Luo and Zhang, 2010). The town and village are geographical spatial entities. Their spatial distribution regularity can be revealed using spatial analysis method. Basis on the existing researches, the article will discuss the train of thought and the basic method about the town-village spatial structure analysis and optimization, based on GIS.

BASIC IDEAS AND THE METHOD OF STUDYING THE TOWN-VILLAGE SPACE STRUCTURE

Basic ideas of the town-village space structure analysis and optimization: The town-village is a place for social economic and cultural activities in county. The town-village spatial structure is the inner link and the external performance of the activities and functions of the town-village. According to the geometric properties, the town-village spatial structure can be decomposed into three kinds of material elements including the node, the channel and the domain surface. The nodes are all levels of town and rural settlements; the channel, that is the linear infrastructure connecting towns and villages, such as transportation network, information network. Domain surface is the open space, such as the forests, the farmland etc. The spatial permutations and their interactions among the node, the channel and the domain surface constitute the corresponding spatial structure. Optimization of the town-village spatial structure essentially is making all levels towns and villages layout to match the space resources, by human intervention, to achieve natural-economic-social sustainable development in county.

Basic ideas of studying the town-village space structure analysis and optimization include: (1) Analyzing of relevant factors of town-village spatial structure, to

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establish the GIS database about the town-village space present situation, (2) Using GIS technology to analyze the inner relationship between all levels settlements distribution and natural conditions and the roads networks, (3) Using the GIS spatial analysis technology, to analyze and study the ecological sensitivity, to distinct space constraints for structure optimization, (4) Based on the radius of farming, to determine the village's location and the moving direction, then to optimize the spatial layout of all levels nodes, (5) According to the accessibility requirements of transportation service facilities, to optimize the channels, (6) Based on the ecological environment protection and agricultural modernization requirements, put forward domain surface optimization scheme.

Research methods of analyzing and optimizing the town-village spatial structure: According to the characteristics of the region and the research object and the GIS spatial analysis function, the research methods of the town-village spatial structure optimization basically can be summarized as three main steps, including the data preparation, data analysis and Plan determination. The research method process is shown in Fig. 1.

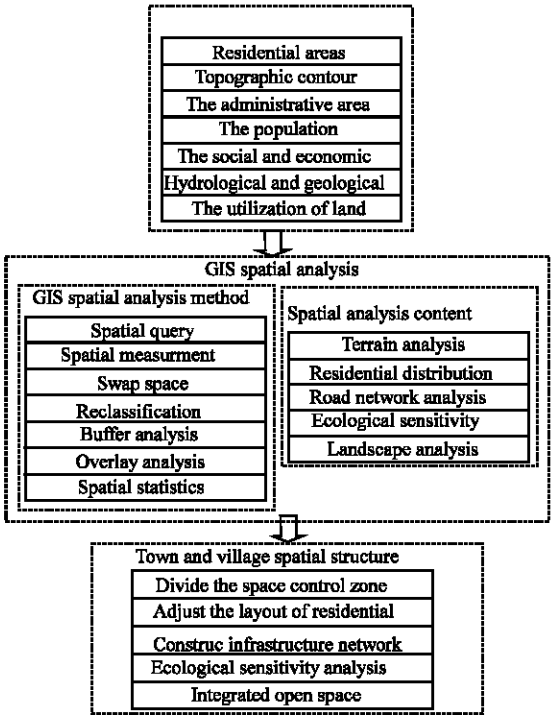

Fig. 1: Flow chart for the research method

ESTABLISH THE GIS DATABASE

Establish basic information data: To build complete objective and accurate information databases, is the foundation of the succeeding analysis and research. The relevant factors of town-village spatial structure in county include the land resources information such as land area, land use type; and include the natural conditions information like the natural topography, geology, river system; and include the roads, the communications and other infrastructures; the factors also involve the administrative boundaries of all towns and villages, the population, the economic, social and cultural factors.

Establish DEM: To establish Digital Elevation Model (DEM) is the basis of analyzing the terrain environment. Studying the town-village space structure in county, scholars often use 1:25000 topographic map to generate DEM. Modeling steps are as follows: (1) Scan the map and input TIFF format images into the computer; (2) Correct the scanning image, (3) Tracing digitizing each contour and elevation point in the topographic map, (4) Input the altitude data, to generate DEM model with GRID format by ARCGIS, (5) Based on the digital elevation model, to extract terrain factors such as the slope and the aspect based on ARCGIS software.

Preprocess the land use data: According to the research needs, to transform the figure spot layer of the current land use database to E00 format in MAPGIS software; then transform to SHAPE format and import into ARCGIS; to extract residential areas, roads, farm land, mining land etc., layers; To input statistical and survey data to attribute table of the figure spot .

TOWN-VILLAGE SPATIAL DISTRIBUTION CHARACTERISTICS ANALYSIS BASED ON GIS

The town-village space is a comprehensive result of interaction between human activities and nature under the specific geographical and social and economic background. Town-village spatial distribution pattern is the reflection of the natural, social, economic and historical development and is spacial expression of intensity of human activities. Analyzing the town-village spatial distribution pattern and its impact factor, can reveal the formation and evolution mechanism of spatial structure and is the foundation of town-village spatial structure optimization.

Technical route of the settlements spatial distribution analysis based on the gis technology: Based on the GIS technology, the technical route of analyzing the settlements spatial distribution follows: (1) Using GIS software, to extract the town-village distribution graph from the current land use database, (2) Using the spatial analysis module of ARCGIS to convert the format into a Grid format, (3) Overlay the terrain niche index layer on the rural settlement distribution layer, to quantified the distribution characteristics of settlements on the different terrain, (4) Calculate the rural settlement landscape index and to analyze the town-village spatial distribution characteristic.

Main Indicators: The main indicators about the distribution characteristics of settlements in county include the terrain niche index (T) describing attributes of the terrain elevation and slope, the Distribution Index (DI) reflecting the characters of space distribution of town-village settlement and the Cv value of voronoi graph and the Nearest Neighbor Index (NNI) and other basic Indicators.

Terrain niche index: Terrain niche index can comprehensively descript the elevation and slope properties, the equation refers with Eq. 1 (Si *et al*., 2009).

$$T = \log\left[\left(\frac{E}{\overline{E}}+1\right)\times\left(\frac{S}{\overline{S}}+1\right)\right] \quad (1)$$

(T is terrain niche index; E and $\overline{E}$ represent the sigle grid elevation value and the average height research domain; S and$\overline{S}$ is, respectively grid slope value and average slope in the study area).

After conversion, each grid has a T value showing the elevation and slope properties. Under normal circumstances, the region with lower elevation and smaller slope usually has the smaller T value.

The distribution index: In order to eliminate the influence of area differences, the distribution index is introduced to describe the distribution of rural settlements in space. Equation refers with Eq. 2(Shi *et al*., 2010).

$$P = (S_{ie}/S_i)/(S_e/S) \quad (2)$$

(P: The distribution index, S_{ie}: The area of i rural settlements in e region, S_i is all the rural residential areas in the study area, S_e is total area of rural settlements in region e, S is the land area).

If P>1, it means the proportion of the residential areas in a certain region is greater than the proportion in research district, which means the region is the strength of the rural settlement distribution area. p-value is larger, the more obvious advantages. If P<1, the area is edge area.

CV (Area of coefficient of variation): The voronoi graph is called Thiessen polygon in the two-dimensional space. Existing research results show that the Voronoi graph is a kind of effective method to reflect the spatial distribution characteristics for dotted features. The Coefficient of Variation (CV) value of Voronoi polygon area can measure the degree of relative change about the phenomenon in space. The Voronoi diagram is defined as follow.

Assume that there is a set of control points in the plane, $P = \{P_1, P_2, ..., P_n\}$, in which any two points are not altogether and any four points are not a round, then the Voronoi diagram of P_i point is defined as Eq. 3 (Liu *et al*., 2009).

$$T_i = \{x: d(x,p_i)<d(x, p_j)|p_i, p_j\in s, p_i\neq p_j\} \quad (3)$$

(d: Euclidean distance, x stands for the elements in the set T_i; T_i is a convex polygon).

In an arbitrary convex Voronoi polygons, the distance from an arbitrary interior point to the source point pi in the convex polygon is less than point to any other source point p_j, these occur. The source points also called the center of mass of Voronoi figure. CV (coefficient of variation) value is the ratio of the standard deviation and average of the Voronoi polygon area. Its formula is Eq. 4.

$$CV = SD/MN\times 100\% \quad (4)$$

(CV: The coefficient of variation, SD: The standard deviation of the Voronoi polygon area, MN: The mean number of the Voronoi polygon area)

CV value can measure the degree of relative change of the spacial phenomenon. Duyckaerts put forward that when the Cv value is less than 33%, the point sets are uniform distribution; when the Cv value is between 33% and 64%, they are random distribution; when the Cv value is greater than 64%, the points sets are the cluster distribution (Fig. 2).

Adjacent point index: As a punctiform geographical phenomenon, the space distribution types of villages and towns are likely to be uniform, centralized, or be random. The most neighboring point index is used to measure the agglomeration or discrete degree of the spatial point phenomenon. The formula follows Eq. 5.

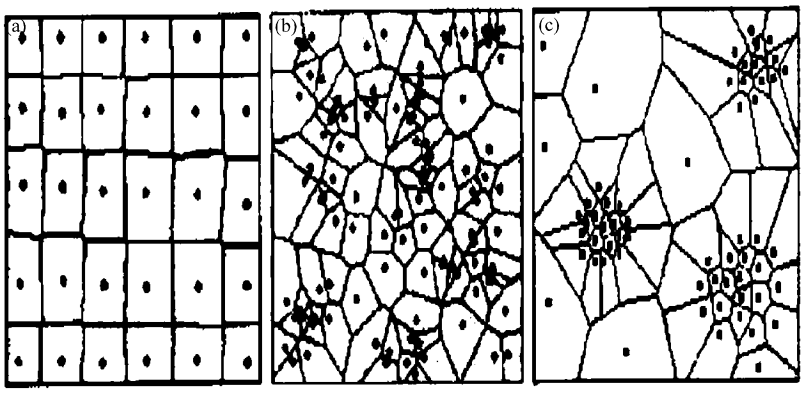

Fig. 2(a-c): Voronoi graph of different sets of points: (a) uniform distribution, (b) random distribution, (c) cluster distribution

$$R = \overline{D}_{obs} / \overline{D}_{ran} \quad (5)$$

($\overline{D}_{obs}$ is the average distance between the nearest neighbor point to other points; $\overline{D}_{ran}$ is the average distance among the random distribution points).

When R = 0.5, it is the intensive distribution; When 0.5<R<1.5, it is the random distribution; When R = 1.5, it is the Uniform distribution.

Landscape index: Adopt the index such as the settlement total area (CA), residential plaque number (NP), the mean number of patch area (AREA_MN), the mean number of shape index (SHAPE_MN), the mean number of the patch fractal dimension (FRAC_MN) etc., to study the characteristics of rural settlements distribution in different terrain.

Town-village spatial distribution analysis method based on GIS technology

To analyze the relationship between town-village spatial distribution and terrain: Using spatial statistical analysis and overlay analysis function of GIS , the article analyze the relationship between town-village spatial distribution and terrain.First, using spatial statistical analysis function of GIS, to statistical analyze the rural redidential total area (CA), residential plaque number (NP), the mean number of patch area (AREA_MN), the mean number of shape index (SHAPE_MN), the mean number of the patch fractal dimension (FRAC_MN) etc., to get the settlement distribution landscape. Second, to statistical analyze terrain niche and get the terrain layer. Then, using spatial overlay analysis function of GIS, to overlie the settlement distribution landscape layer on the terrain niche layer, it will intuitivly show town-village settlement distribution characteristics in different terrain. Generally, where has smaller terrain niche and where the rural settlement has a big size, much number and large patches. That because, with the terrain niche increasing ,the land size is broken bits and the tranfic is more inconvenient, the environment is more vulnerable, all these limit the Size, number, large patches Scale and layout of rural settlements.

To analyze the relationship between town-village spatial distribution and the roads or the rivers: Transportation is the important influence factor for the formation of rural residential areas. Roads are the important carrier throng which the material, the energy and the information will flow and transfer; the town-villages are often distributed in the area where the road can reach to. The size and distribution of rural settlements has close relationship with the traffic. Rivers provide a rich source of water and comfortable environment for people. Generally, the area near water sources, there is better production and living environment, so a large-scale settlement is easy to form. Buffer analysis is one of the several important analysis functions of GIS. Using the buffer analysis function, to quantitatively analyze the change of the settlements quantity, size etc., what caused by the distance increase from settlement to rivers or roads.

TOWN-VILLAGE SPACIAL STRUCTURE OPTIMIZATION BASED ON GIS

Space control division in county: The town-village spatial structure optimization should give full consideration to the natural ecological environment. The town-village layout should avoid all kinds of natural disaster prone areas, geological bearing weak areas and important ecological reserves areas. Therefore, to optimize the town-village spatial structure, first of all should to analyze ecological sensitivity of the study area, to make define the direction of town-village spatial layout adjustment. There are many factors which influence the regional ecological

environment. Such as water system, vegetation, cultivated land, marshes, etc.. But theirs influence degree on the ecological sensitivity is different. So, in the study area of ecological sensitivity, first of all, these factors are endowed with different values according to the importance degree of different factors on the ecological sensitivity. Under the ARCINFO support, to respectively give the corresponding rank index value to all kinds of landscape patches such as waters, altitude and embankments, vegetation, then to make the ecological sensitivity diagram of single factor. Selecting the factor superimposed calculating maximum value method and using GIS vector superposition technology, total ecological sensitivity results are obtained. Lastly, according to the ecological sensitivity index, the study area is divided into four areas: high sensitivity, moderate sensitive area, low sensitive area and non sensitive area. During adjusting the town-village spatial structure, the high sensitive area should be strictly protected and the moderate sensitive area should be as control development area, low and non sensitive area as suitable development area (Zhu *et al*., 2010).

Layout optimization of the town-village in county: In view of the current main problems of the town-village, centralization should be the main direction of rural settlement space reconstruction. During optimize the town-village space structure, first of all is to build the "key towns-common town-central village-village" network structure at the county level. At town level, to select and determine some central villages by the principle of adjust measures to local conditions and the principle of economical use of land. These central villages should have the more convenient transportation and better development condition. Then to guide rural residents from living scattered, natural villages to the civilized village with good infrastructure and comfortable environment. Last, to expand the radiation scope of central village and to promote the development of village.

Infrastructure network optimization in county: The infrastructure is the carrier by which population, the material and information flow among all level towns and villages in county. Perfect and efficient infrastructure network is a guarantee of social and economic development in county. The infrastructure network optimization is an important aspect of town-village spatial structure optimization. In essence, optimization of infrastructure is to reasonably match the infrastructure and residential areas. In the case of county road network, to improve residential accessibility of transportation is the main target of network optimization. And to realize the network of infrastructure is an important means to improve accessibility.

REFERENCES

Fan, H.M., Q.B. Wang and Z.X. Bian, 2008. Spatial distribution characteristics analysis of kuandian county settlements based on GIS. J. Southwest China Normal Univ., 2: 99-1103.

Liang, H.M. and J. Zhao, 2001. Study on the special distribution of settlement in loess plateau by GIS. Hum. Geogr., 16: 81-83.

Liu, X.T., X.Q. Zhen and D.B. Li, 2009. Based on Voronoi Diagram spatial distribution of rural settlements and its influencing factors- a case of Beijing Chang ping district. J. Ecol. Rural Environ., 2: 30-33.

Luo, Y.L. and C.X. Zhang, 2010. Characteristic analysis of county and rural spatial structure: A Case of Jinhu County in Jiangsu Province, China. J. Anhui Agri. Sci., 17: 9329-9332.

Shi, S.Y., Z.L. Bao and X.L. Zhang, 2010. Rural residential landscape pattern and its influencing factors-a case of eight villages in Yixing city Chinese. Agri. Sci. Bull., 8: 290-293.

Si, J.L., W. Qi and Y.B. Qu, 2009. Land Use distribution characteristics on terrain gradient in Jiaodong mountainous areas. J. Appl. Ecol., 3: 679-685.

Sun, H.S., J.F. Huang and Y. Jin, 2007. Spatial distribution characteristics analysis and optimization of county-level settlements based on GIS. J. Zhejiang Univ., 3: 348-354.

Mao-Jun, W., Z. Xue-Xia and L. Wei-Xin, 2003. Structure and spatial analysis of evaluation of residential environment in dalian city. Sci. Geog. Sinica, 1: 87-94.

Zhu, X.X., H.M. Wang and X.J. Yuan, 2010. GIS-based evaluation of rural residential location and spatial pattern optimization. Agric. Eng., 6: 290-296.