Spatio-temporal Dynamic Simulation of Urban Land Use in Karst Areas Based on CLUE-S Model—A Case Study of Dahua Yao Nationality Autonomous County in Guangxi Zhuang Autonomous Region

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Abstract This article uses TM images in 1999 and 2006 in Dahua County, selects the driving factors having great impact on urban land use change, and conducts data processing using GIS software. It then uses CLUE-S model to simulate land use change pattern in 2006, and uses land use map in 2006 to test the simulation results. The results show that the simulation achieves good effect, indicating that we can use CLUE-S model to simulate the future urban land use change in karst areas, to provide scientific decision-making support for sustainable development of land use.

Key words CLUE-S model, Dynamic simulation, Dahua County, Karst areas, Urban land

Land, as a kind of valuable natural resource and an important asset, is the basis and carrier for human survival and development, thus the rational use of land resources is directly related to sustainable socio-economic development[1]. Especially in the process of rapid development of urbanization, the supply and demand conflicts of land become more acute, to a certain extent, restricting the development of China's cities and towns. Therefore, the rational use of land resources has become an important guarantee for the healthy development of cities and towns.

As to the simulation of land use, a variety of models have been developed and widely used in a number of study areas with prominent regional characteristics, and many scholars also have done a lot of researches, but so far, there is still a shortage of researches on dynamic simulation of land in karst areas. In particular, the researches, on the simulation of dynamic spatio-temporal change, in expansion of urban land use in karst areas, have not yet been reported. Taking the typical county in the karst areas (Dahua County in Guangxi Zhuang Autonomous Region) as the research object, according to the spatial map data, we construct the spatial model of land use change (CLUE-S), to simulate the dynamic spatio-temporal change in expanded use of urban land in this study area, in order to provide reference for exploring the change use change and environmental effects in the process of regional urbanization in the near future.

1 Overview of the study area, data source and research method

1.1 Overview of the study area The karst area in Guangxi Zhuang Autonomous Region is one of the ecologically fragile areas with highly concentrated poor population in China[2]. In the context of rapid process of urbanization and limited supply of total regional land resources, the development of urbanization in karst areas is in face of conflicts between environmental protection, and large-scale, high-intensity resources development. In less-developed western karst areas, the area of urban construction land is small, but the expansion of urban construction land often causes the transformation of woodland, grassland, farmland and other land use types, thereby leading to changes in urban-rural elements, and regional environment.

Dahua County, Guangxi Zhuang Autonomous Region (E107°9′45″ –108°2′22″, N23°33′22″ –24°22′20″), located in the west central Guangxi Zhuang Autonomous Region and hinterland of Hongsuihe River, is a typical karst area in Guangxi Zhuang Autonomous Region. Within the area, the karst topography is predominant, and the karst area accounts for 68% of total land area. The topography of northeast and southwest is mainly peak clusters and depressions; the topography of southeast is grotesque peaks, peak clusters, depressions and valleys; the topography of the central and northwestern areas is mainly mountains and hills. It is subtropical monsoon climate zone, with average annual temperature of 18.2 –21.7 ℃, and annual rainfall of 1 249.0 –1 673.4 mm. The native vegetation has been destroyed. Most of the vegetation in rocky hills is bush; most of the vegetation in soil hills is artificial masson pines, firs, and fruit trees. The main soil type is limestone soil, red soil, paddy soil, yellow soil, purple soil and alluvial soil. Constrained by the characteristics of karst soil and water, flood and drought are the major disasters in regional land use. The karst environmental characteristics, and long-term irrational human activities, are responsible for regional soil erosion and increasing deterioration of land desertification. According to statistics from forestry departments in Guangxi Zhuang Autonomous Region, the area of land desertification in whole county accounts for as high as 50.24% of the total area of land, and the ratio of potential area of desertification to the total area of land is 10.7%. In the context of the western development and regional economic development, the national economy in Dahua County grows rapidly; the course of urbanization is

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gradually promoted; the expansion of urban space follows the principal-transport-axis-style urban expansion mode.

1.2 Data source Taking TM images in 1999 and 2006 as the basic data sources, I divide the land use type in the study area into farmland (paddy field, dry land), woodland, grassland, urban and mining land, rural settlements, water area, and unused land using supervised classification method. After automatic classification by computer, I compare the classification results with the land use map in the study area and then revise these classification results, to get two periods of data concerning the status quo of land use in the study area. Given that what I research is the expansion of urban land use, I cut an area out of whole county covering about 39 185.55 hm^2 of Dahua County as the study area, in order to save time and workload (Fig.1).

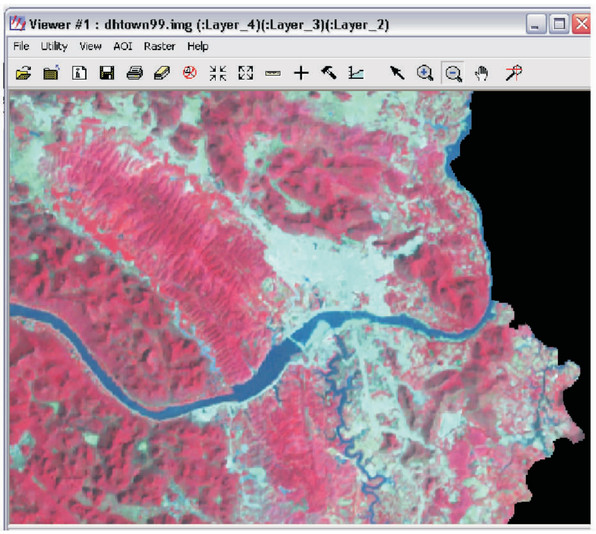

Fig.1 The TM image of the study area in 1999

The area of all land use types in the study area in 1999 and 2006 is obtained from two periods of spatial statistics. According to the area in the two periods, the annual area of all land use types in the period 1999 – 2006 is obtained using linear interpolation method (Assuming the area of all land use types is linear change.). As for the selection of driving factors of land use pattern distribution in urban areas, it mainly includes 9 factors: road traffic system, the distribution of towns and settlements, water area, slope degree, elevation, county planning, population, economy, land use policy. DEM for the study is provided by NASA, other maps and data are collected from social statistics and research subjects.

1.3 Research method I adopt CLUE-S model simulation method. CLUE-S model is established by Land Use Change and Impact Research Group from Wageningen University in the Netherlands on the basis of earlier CLUE-S model. Through the empirical study of several cases, CLUE-S model is established based on high-resolution spatial graphic data, which can be applied to research of regional land use changes. Based on the perspective of system theory, it views the regional land use change as a whole system, and gives full consideration to hierarchy of land use change, connectivity of land use change, competition of land use change, stability of land use change and other characteristics, in dealing with competitive relationship between all land use types, with capability of carrying out synchronized simulation of different land use changes.

CLUE-S model is established based on the grid graphic data. In order to complete simulation of dynamic spatio-temporal change of regional land use, we must input the following 3 types of grid graphic data or model parameters (Fig.2): spatial distribution pattern of all land use types and coefficients of relationship of corresponding driving factors at the beginning of the simulation; transition rules of all land use types; annual area of all land use types. Based on comprehensive analysis of the spatial distribution figure, land use change rules and land use distribution map at initial stage, I conduct spatial distribution of quantity change in land use according to the size of total probability, in order to achieve dynamic simulation of spatio-temporal change of land use.

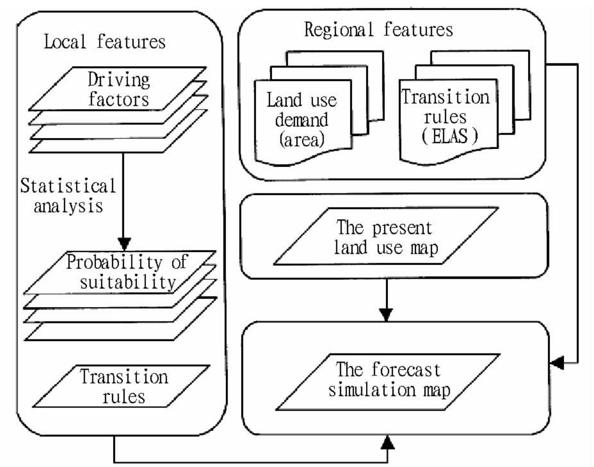

Fig.2 The spatial distribution of CLUE-S model[3]

2 Results and analysis

2.1 Non-spatial analysis The non-spatial driving factors I select include population, economy, land use policy, and the county planning. Dahua Yao Autonomous County covers 2 716 km^2, with population of 414 000 (as of the end of 2000), and population density of 152 persons/km^2. Rapid population growth is the most dynamic influencing factor in land use change. Population grows rapidly, but the land resources are limited, therefore, in order to expand living space, other land use types are likely to translate into urban land. The more the population, the greater the need for living space, the greater the area of expanded urban land. If the population grows rapidly, the expansion rate of urban land will also accelerate accordingly. Economic development is the most direct driving force of land use change, while unreasonable use of land will also eventually restrict economic development. The total installed capacity of two large national water and electricity stations (Dahua Water and Electricity Station and Yantan Water and Electricity Station) built within the region is 1.61 million kw. After Dahua Water and Electricity Station and Yantan Water and Electricity

Station store water and generate electricity, it has promoted the development of local economy to a certain extent. Driven by economic development, the development of urbanization also quickens, and there is a certain direct proportion relationship between increase in the area of urban construction land and the level of economic development. In the mean time, driven by the visible economic interests, land use tend to the type with high profit, such as commercial land, and real estate construction land, so that the local urbanization becomes more prominent.

Land use policy can regulate the distribution of land use types macroscopically, optimize the allocation of land resources, and protect some land types, such as nature reserves, arable land and so on. The land use policy in Dahua County is to seriously implement the basic national policy of "Treasure and rationally use every inch of land, effectively protect farmland", strictly protect basic farmland, and control the non-agricultural construction occupying agricultural land; improve land utilization rate; make overall arrangements for various types of land in various regions; protect and improve the ecological environment, and safeguard sustainable use of land; balance the farmland occupied with farmland developed and reclaimed. These factors will have an impact on parameter setting in the process of simulation. The county planning plays a decisive role in guiding urban construction, and guiding the coordinated development of urban construction and management.

2.2 Spatial analysis The spatial driving factors I select include road traffic system, the distribution of towns and settlements, water area, slope degree, and elevation. The regions with convenient transportation are easily to be tapped and used, the changes in landscape before and after development are prominent, and especially the regions near the major trunk roads have a high probability of becoming urban development areas. The impact of roads on urbanization varies along with different distances, therefore, we should conduct spatial analysis. The characteristics of the distribution of towns and settlements reflect changes in regional land use types arising from man-made interference. The further expansion of urban land use is established on the basis of the existing towns and settlements, and in these places, there is prominent advantage of urbanization. The regions with different water resource conditions are suitable for the growth of different vegetation, showing that there are diverse land use types; the distribution of water area is good, and in the places with abundant water resource, it is convenient for the human to better use land resources; the frequency of changes in land use types is also high. We can get gradient and elevation using altitude data. According to the size of gradient and altitude, by analyzing degree of difficulty of land use and probable vegetation type, when the gradient is small and the altitude is low, it is fit to develop cities and towns, and the land use types tend to change. In CLUE-S model, the spatial analysis module can assign value to the stability degree of changes in each land use type by setting the value of elastic parameter of change ELAS, to make the value of ELAS change in 0 – 1.

First, ELAS = 1 indicates that under normal circumstances, this land type does not transform into other land use types, but keeps the original land use type more than 10 years.

Second, ELAS = 0 indicates that this land use type experiences more than one change within one year.

Third, ELAS = 0 – 1 signifies the land use types with stability degree between the above two.

As for the distribution of land use demand in module of spatial distribution, we should give consideration to the relationship between alternative driving factors and restricting spatial factors, measure the distribution suitability of different land use types in each spatial unit, and determine the distribution probability of all land use types in each grid, so as to be used in dynamic simulation. The below is logistic regression model, and I use diagnose the distribution probability of land use using this method. The formula is as follows:

$$\text{Log}\left\{\frac{k_i}{1-k_i}\right\}=\alpha_0+\alpha_1 X_{1,i}+\alpha_2 X_{2,i}+\cdots+\alpha_n X_{n,i} \quad (1)$$

where k_i is the probability of one certain land use type probably appearing in each grid; X is the alternative driving factor. I select the factors having significant impact on the land use pattern, and eliminate the factors with inconspicuous impact, to finally get the spatial distribution probability figure of all land use types.

2.3 Dynamic simulation The dynamic simulation is the process of carrying out spatial allocation of the land use demand based on the size of total probability. This distribution is achieved through multiple iterations, and the specific steps of the iterative allocation can be seen in Fig.3.

$$\text{SUM}=k_{i,u}+ELSA_u+ITER \quad (2)$$

where SUM is the total probability; k is the total probability of grid i being suitable for land use type u; $ELSA$ is the transition rule parameter of land use type u; $ITER$ is the iteration variable value. When in the initial distribution, the ITER value simulated of all annual land use types is the same, and grid i is distributed according to the size of the total probability SUM.

After the initial distribution is completed, I compare the initial distribution area of different land use types and the demand area in the same year. If the initial distribution area of land is larger than the demand area, ITER value will be reduced; if the initial distribution area of land is smaller than the demand area, ITER value will be increased. I conduct the secondary distribution of land use change, until the distribution area of all land types meets the need. Therefore, the competitiveness of land type is mainly reflected in the difference between the current area of land type and the demand area of this land type. The greater the difference between the two, the greater the competitiveness of the land type, the smaller the difference between the two, and the smaller the competitiveness of the land type[4].

2.4 Simulation results I conduct simulation of the land use change in the study area in 2006, using spatial graphical data of land use from Dahua Yao Autonomous County in Guangxi Zhuang Autonomous Region in 1999 and the above driving factors. Prior to simulation, the land use maps in 1999 and 2006

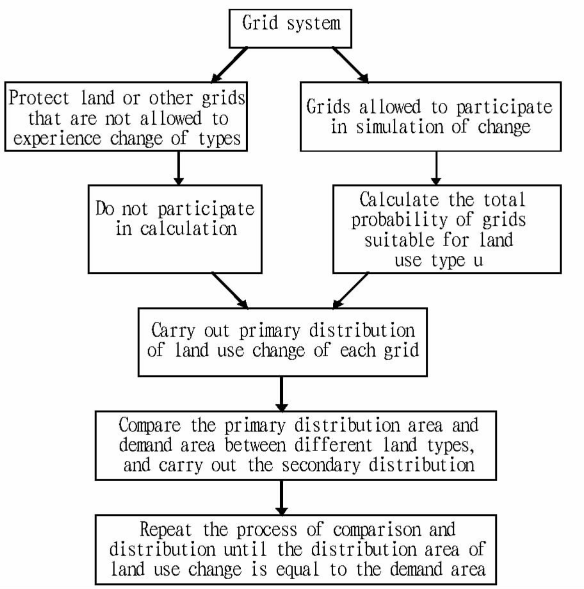

Fig. 3 Dynamic simulation

have been collected, and we can get the area of all land use types from the land use map. By linear interpolation of the area in the maps in two periods, I get annual total demand of all land types. The simulation result I get can be seen in Fig. 6.

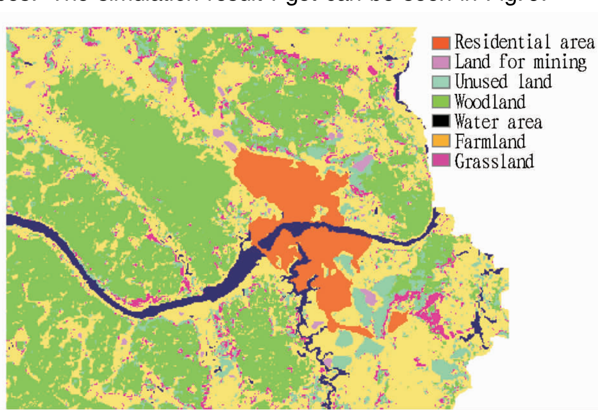

Fig. 4 The status quo of land use in Dahua County in 1999

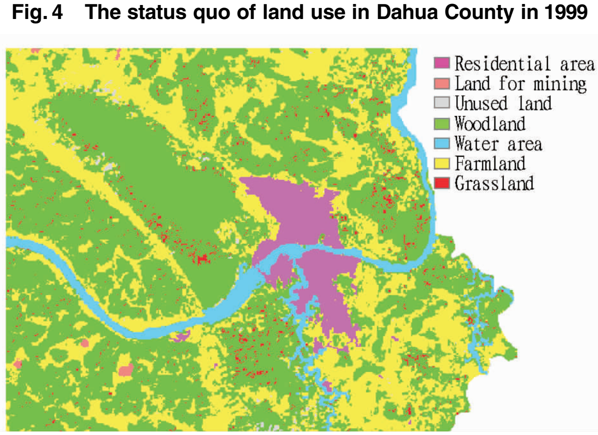

Fig. 5 The status quo of land use in Dahua County in 2006

2.5 Test of simulation precision We can test the simulation precision using Kappa index[5], and the formula is as follows:

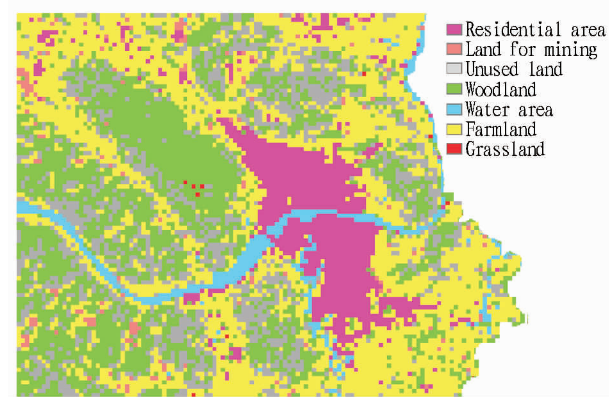

Fig. 6 The simulation of land use in Dahua County in 2006

$$Kappa = (p_0 - p_c)/(p_p - p_c) \quad (3)$$

where p_0 is the correct proportion simulated; p_c is the expected correct proportion in random cases; p_p is the correct proportion simulated when classification is perfect.

In comparison with Fig. 5, I analyze the simulation map with resolution of 100 x 100 meter: the total number of grids is 11 408, and the number of grids correctly simulated is 8 556, accounting for 75.1% of the total number of grids. I divide the land use types into seven categories, therefore the expected correct proportion simulated of each grid in random cases = 1/7, and Kappa = (0.750 1 − 0.142 9)/(1 − 0.142 9) = 0.714 2. It can be clearly seen that Kappa value reaches a high level.

3 Conclusions and discussions

3.1 Conclusions From the simulation results, we can find that the simulation accuracy has met certain requirements, and achieved satisfactory results. Obviously, the results of simulating the future land change using CLUE-S model have high credibility, which can provide reasonable basis for decision-making of land management departments[6]. In CLUE-S model, I set different situations for simulation, and the simulation results of the model based on economic development, are closest to the land use map, which shows that the economic development, to some extent, contributes to the development of cities and towns, and economy is the most principal driving factor of urban land use change in this region.

Dahua is a region with typical karst characteristics, where the terrain is grotesque peaks, depressions, valleys, and eroded hills, with great undulation, therefore, there is a great difficulty in land use and it is devoid of farmland. The land use under the model of economic development goal, can fully guarantee the needs of economic construction land, resulting in the rapid expansion of construction land, but this expansion is achieved through squeezing and occupying the farmland with high quality near cities and towns, rural settlements, mining area and traffic trunks. This land use pattern is not sustainable. The existing China's land policy requires us to strictly protect the basic farmland, and control non-agricultural construction occupying agricultural land. If we do not pay attention to the protection of farmland in the process of development, the economic development will be subject to certain constraints, so the urban land use cannot be expanded blindly, and we must develop it reasonably. In addition, the rapid population growth also brings pressure on urban development. If the population growth is in excess of the carrying capacity of the land, it will lead to the imbalance between natural environment and socio-economic development, which is not conducive to the continued development of cities and towns[7].

3.2 Discussions First, the reality of change in land use system and the process of potential environmental impact and feedback is a a complex issue. I conduct the spatio-temporal dynamic simulation of situational change in land use, integrating various kinds of human and natural driving factors, concerning all land use types. It is a simple attempt, and in fact, does not substantially touch upon the ecological effect process of land use system, such as the evaluation and research of soil erosion, biodiversity and other processes. However, in current research of change in land use system, we should pay positive attention to the reality of change in land use system in ecologically fragile regions and the evaluation of potential ecological effects. Especially in karst areas, the ecological environment is extremely fragile, thus the evaluation of ecological effects in the dynamic process of urbanization is of great significance to the sustainable development of land use in this region[8].

Second, through the simulation results and many other research results, it shows that this CLUE-S model has certain reliability, which can provide help for the current understanding of complex driving behavior of land use system to some extent, and evaluation of the underlying trend of change in land use system in ecologically fragile regions. In this paper, I select several factors with great impact in simulation, and consider the driving role of these factors in the land use system. It is only a simplified model. However, there are many factors affecting land use change, and these factors are interrelated and constrain each other. In terms of socio-economic driving factors, it is quite complicated, involving many aspects. There may be some changes in socio-economic growth pattern at different stages, therefore, for different scales of time and space, the impact may be different. At the same time, CLUE-S model also has its own limitations. The driving factors set can not exceed a certain number, and the range of regions simulated cannot be too wide. Therefore, the simulation results will deviate from the actual situation.

Third, as for the data involving the empirical analysis in the model, these data related to experience contain the subjective factors, and the data obtained vary in terms of different people, for example, as for the setting of ELAS value of each land type, different people may assign different values. In addition, whether the processing way of the raw data is correct or not and whether it can achieve the best results or not, is also an important aspect influencing the effect of simulation, for example, the interpretation of remote sensing images is related to personal visual interpretation experience and the image resolution, which will affect the accuracy of the simulation results, so we should ensure the accuracy of the data source in the process of simulation[9].

Fourth, the quantification of many socio-economic driving factors is very difficult, such as systems, policies and other factors, and it is difficult to be spatially explicit, thus affecting various kinds of spatial analysis and making the data acquisition difficult. Especially for small-scale study area, the acquisition of spatial data of land use with high resolution is relatively easy, but the acquisition of socio-economic data is difficult. Moreover, many statistical data are from statistical information provided by the national statistical departments, and some of these statistics are estimated, which are difficult to reflect the true situation. It is also the negative factor that is difficult to rule out in simulation.

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