Simulation of Wetlands Evolution Based on Markov-CA Model

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Abstract: - The location simulation of geographic information is a hot issue in the current research. Markov combined with Cellular Automata(CA) model, under the support of GIS(Geographical Information System), can match the results of the classic prediction model with the spatial information at the micro scale, and achieve the analog integration of time, property and space. In this paper the Landsat images of 1991, 1999 and 2006 are used as the basic information source. After established the classification system and interpretation signs, we can get wetlands landscape distribution maps the three periods of Yinchuan Plain. The wetlands landscape distribution maps of 1991 and 1999 are used to set up the initial state matrix and transition probability matrix of wetland landscape types of the Yinchuan Plain. The approach of establishing the Markov-CA model is proposed, the transition rules and technical system of establishing these rules are explained in details. Finally using the established analog system, the evolution of Yinchuan Plain wetlands distribution status is simulated and the wetlands distribution map interpreted from TM image of 2006 is regarded as a true value to complete the accuracy analysis. The study result shows that the simulation model established by this method is able to meet the requirement of wetlands evolution location simulation.

Key-Words: - wetlands simulation, location simulation, Markov-CA, transition rules, transition probability.

1 Introduction

Wetlands are the unique ecosystems forming by interaction between the lands and water on the earth, and also the important survival environment as well as one of ecological landscape which have the richest biological diversity in nature. Because of their specificity and importance, great concerns are paying to the wetlands all over the world. And the science of wetlands has become a common concern of many international scientists and a cutting-edge research area [Bai Junhong, et al 2005 & Chen Shupeng, 2001]. In recent years, the dynamic changes of wetlands monitoring and forecasting based on GIS (Geographic Information System) and remote sensing technology are deeper. Scholars are focusing on the high-resolution and high-precision remote sensing image. They study the process of wetlands formation, development and evolution with the interference of human activities. Researchers apply the new theories about system dynamics theory, information theory and control theory to study the dynamic evolution of wetlands landscape and adopt the mathematical methods and computer simulation to conduct their research about wetlands process [Allan Crowe., 2000 & Ammanda L Azous. 2001]. A lot of mathematical models of scientific value are set up, and the researches on the evolutions of the wetlands landscape mechanism are deepened [Kadlee R H, et al 1996 & Keddy P A, 2000]. But impacted by the limitation of the time and spatial analysis function, the dynamic change monitoring model of wetlands are mostly the continuous model based on differential equations [Farina A, 1998, & Deadman P D, et al 1993, & Stefan Weiers, 2004]. However GIS describes the time space and state in discrete, it is difficult to connect the GIS technology and continuous model directly [Li Xia, et al, 2007, & Zhou Chenghu, et al, 1999]. At present, the best way to solve this problem is to adopt a bottom-up micro-discrete simulation method. Cellular Automata (CA) simulation technology is a grid dynamic model whose spatial interaction and time cause-effect relationship are local; it has the capacity of simulating time and space evolution process of complex systems. And its description of time, space and state are discrete. At present, CA simulation technology has been widely used in the simulation expression and the analysis of complex geographical situation as well as the space-time dynamic process simulation, but the applications in wetlands evolution simulation are few. GIS technology and CA model
describe the time, space and state in a discrete way; the two are able to couple with each other easily. First of all, CA model can enhance the function of dynamic modeling of GIS technology; secondly, GIS technology can provide detailed spatial information for CA model; thirdly, remote sensing can supply the training samples and testing data which are required by the simulation model of wetlands dynamic evolution.

2 Markov-CA model

2.1 The overall structure

Markov-CA model consists of three modules. First, the data acquisition module based on remote sensing technology provides the basic maps for the Markov chains and CA simulation. Second, the analysis module of Markov chains providing the transition probability between different wetland types (including non-wetlands) and the prediction data of dynamic changes in wetland area. Third, the cellular automata module realizing priority ranking of cellular transfer.

First of all, according to transition probability matrix of the wetland area set up by the Markov chains to determine the transition probability $P_{t1}$ of each cellular on the initial wetlands distribution maps. And then calculate the simulation transition probability $P_{t2}$ of each cellular in the prediction year using the standard moor neighborhood types. Sum $P_{t1}$ and $P_{t2}$, and use the average value of the two as the general transition probability $P$ for each central cellular. Finally using the distribution area of each type wetlands in every prediction year as the constraint, in accordance with the size of general transition probability of each cellular, determine the state of each cellular in order in every prediction year, until it is equal or near with the distribution area of each type of wetlands. (Fig.1)

2.2 Probability transition matrix

Markov chain model is a kind of stochastic model which is widely used. It studies the initial probability and the transition probability between the different states of one system to determine the trends of the states, so as to achieve the purpose of prediction the future trends.

In accordance with the theory of Markov random process, it is possible to simulate the areas of different wetlands in a number of years after the initial year, which is also called the landscape pattern of wetland, using the probability matrix of initial state. The Period of the first n Markov transition probability is calculated as:

$$P_{ij}^{(n)} = \sum_{k=0}^{m-1} P_{ik}^{(n-1)} P_{kj}^{(n-1)}$$  (1)

Where, $m$ is the number of rows or columns of the transition probability matrix, and the transition probability matrix of the nth period is the transition probability matrix of the first period to the nth power.

2.3 Technical Route

(1) The transition probability of the cellular in the initial state. According to the wetlands distribution map of initial state and the transition probability matrix of the wetlands area, the transition probability of each cellular in initial state is determined

(2) The establishment of the constraints. Many uncertainties exist in the geographic phenomena. CA model with constraints are widely used in the simulation of geographic process in order to consistent with the actual situation. Here the predicted distribution areas in Markov are used as constrains in the CA simulation. When the simulated wetland area reaches the predicted distribution areas in Markov, the simulation is stopped.

(3) The establishment of the cellular system. A standard CA system is consisted of cells, states, neighbors and transition rules.

Cellular space is a kind of discrete grid divided in accordance with certain resolution in the real geo-space. Each unit is a square unit, which is basically the same grid structure as GIS. In the actual treatment process, we take a pixel on the wetland distribution maps, which is raster structure, as the research object. Therefore, all pixels in our study constitute the cellular space. Cellular states show the states of units corresponding to the surface. Here each cellular has four kinds of states, that is, river wetlands, lake wetlands, paddy field wetlands and non-wetlands. The number of neighbors (excluding the central cellular) is $(2r + 1)^2 - 1$. The given neighbor radius $r=3$, the neighborhood set is a block whose central is the current cellular. That is, take the standard Moor neighborhood type, each cellular use the eight adjacent cellular as its neighborhood cellular.

The establishment of transition rules is the key to set up geographic cellular system. In this paper the transition probability value of each cellular and the wetlands distribution of each type in the predicted year are used to set up the transition rules. See in Fig.1
2.4 Model Integration

The entire model implements in a loosely integrated manner. Use C++ to realize the Markov chain. The
wetland distribution maps are obtained by using commercial image processing software ENVI. CA model and GIS technology tightly integrated. ARCGIS GRID module is called by AML macro language to implement CA model. Wetland distribution transition probability of different periods as well as the area data of wetlands distribution of the simulation years is obtained through the Markov model. Wetlands area spatial allocation is dynamically simulated in the manner that priority sort method is combined with heuristic searching method.

3 Model Applications

3.1 Wetland distribution information extraction based on TM remote sensing images

In this paper, the data processing is finished in the image processing software ENVI and geographic information system software Arcview (Fig.1). The data of wetland landscape types are from the TM remote sensing images of September of 1991, 1999 and 2006. These images are done with atmosphere radiation correction and initial geometric correction in the satellite ground station. 1:50000 topographic maps are used to select the control points, and the images are been precisely geometric corrected by using these control points.

Wetland information is extracted. Three bands are combined for the color display. These bands are TM4 (red), TM3 (green), and TM2 (blue). The vector boundary file of Yinchuan plain are used to mask the study area, thus two periods remote sensing images of the study area is obtained. And several pre-processing are done to the images to meet the requirement of classification and the treatment of post-classification, such as stretching and enhancement. According to the international Convention on Wetlands and China Wetlands Investigation Outline, combining with the distribution characteristic of Yinchuan Plain wetlands as well as the characteristics of TM images, the wetland in study area is divided into three kinds: river, lakes and paddy field. Supervised classification and the post-processing methods are used to extract the distribution of wetland types of three periods.

Technology route of wetland distribution information extraction based on TM remote sensing images is shown in Fig.2.

3.2 Markov simulation

Simulation steps are as follows:

The first step is determining the initial state matrix. Dividing the wetland into a series of state evolving mutually based on the type of wetland landscape and building the initial state matrix with the areas of each wetland types in 1999. 

$$p = \begin{bmatrix} 111.4204 \\ 142.3720 \\ 133.6371 \\ 6594.7040 \end{bmatrix}$$

The second step is to determine the transition probability matrix. The landscape types from 1991 to 1999 are set as the basic map. With the support of ArcView software, the two period wetland landscape raster maps are overlapped and the corresponding properties in the overlay map database PAT.DBF are extracted. And the transition probability and the average annual transition probability matrix from 1991 to 1999 are obtained (Table 1).

The third step, the dynamic simulation of the evolution trends. Use Markov model to predict the area of wetland landscape between 2000 and 2120 in Yinchuan (Table 2).

3.3 Simulation results

In this paper, the wetland distribution in 1991 is set as the initial distribution of wetland state; we simulate the distribution of Yinchuan wetland in 1999 and 2006 with the Markov-CA model. The simulation results of are shown in Figure 3, 4,5,6,7.

3.4 Accuracy assessment

The wetland positioning distribution analog map in 2006 was compared with the wetland map interoperated from remote sensing data (Table 3). The overall accuracy is 75.06%, the accuracy of lake is 78.82%, which is the highest accuracy. Followed by paddy field simulation accuracy and the simulation accuracy in river is last.

<table>
<thead>
<tr>
<th>Classes</th>
<th>river</th>
<th>lake</th>
<th>paddy field</th>
<th>non-wetland</th>
</tr>
</thead>
<tbody>
<tr>
<td>river</td>
<td>0.7279</td>
<td>0.0434</td>
<td>0.0801</td>
<td>0.1486</td>
</tr>
<tr>
<td>lake</td>
<td>0.0043</td>
<td>0.5537</td>
<td>0.1735</td>
<td>0.2685</td>
</tr>
<tr>
<td>paddy field</td>
<td>0.0229</td>
<td>0.0768</td>
<td>0.6044</td>
<td>0.2959</td>
</tr>
<tr>
<td>non-wetland</td>
<td>0.009</td>
<td>0.0087</td>
<td>0.0095</td>
<td>0.9728</td>
</tr>
</tbody>
</table>
Table 2. The predict area of each wetland landscape with Markov chain (km²)

<table>
<thead>
<tr>
<th>year</th>
<th>river</th>
<th>lake</th>
<th>paddy field</th>
<th>non-wetland</th>
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</thead>
<tbody>
<tr>
<td>2000</td>
<td>90.8693</td>
<td>126.2934</td>
<td>134.1244</td>
<td>6630.8465</td>
</tr>
<tr>
<td>2005</td>
<td>115.8117</td>
<td>136.2670</td>
<td>159.4339</td>
<td>6570.6209</td>
</tr>
<tr>
<td>2006</td>
<td>120.8002</td>
<td>138.2618</td>
<td>164.4958</td>
<td>6558.5757</td>
</tr>
<tr>
<td>2010</td>
<td>136.7303</td>
<td>145.0714</td>
<td>180.6296</td>
<td>6519.7022</td>
</tr>
<tr>
<td>2020</td>
<td>168.2950</td>
<td>159.3590</td>
<td>212.6642</td>
<td>6441.8151</td>
</tr>
<tr>
<td>2050</td>
<td>213.8824</td>
<td>182.2296</td>
<td>260.1305</td>
<td>6325.8907</td>
</tr>
<tr>
<td>2100</td>
<td>231.3907</td>
<td>191.9821</td>
<td>279.5449</td>
<td>6279.2152</td>
</tr>
<tr>
<td>2105</td>
<td>231.9125</td>
<td>192.2891</td>
<td>280.1522</td>
<td>6277.7790</td>
</tr>
<tr>
<td>2110</td>
<td>232.3405</td>
<td>192.5423</td>
<td>280.6531</td>
<td>6276.5968</td>
</tr>
<tr>
<td>2115</td>
<td>232.6769</td>
<td>192.7426</td>
<td>281.0491</td>
<td>6275.6642</td>
</tr>
<tr>
<td>2120</td>
<td>232.9907</td>
<td>192.9296</td>
<td>281.4188</td>
<td>6274.7940</td>
</tr>
</tbody>
</table>

Table 3. The accuracy of wetland positioning distribution analog in 2006 (km²)

<table>
<thead>
<tr>
<th>Wetland classes</th>
<th>right analog area</th>
<th>TM image interpretation area</th>
<th>analog accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddy field</td>
<td>41.3475</td>
<td>55.1925</td>
<td>74.92%</td>
</tr>
<tr>
<td>River</td>
<td>19.4358</td>
<td>26.9781</td>
<td>72.04%</td>
</tr>
<tr>
<td>lake</td>
<td>18.7660</td>
<td>23.8100</td>
<td>78.82%</td>
</tr>
<tr>
<td>total</td>
<td>79.5493</td>
<td>105.9806</td>
<td>75.06%</td>
</tr>
</tbody>
</table>

Fig. 3 The distribution map of Yinchuan wetland in 1991

Fig. 4 The distribution map of Yinchuan wetland in 1999

Fig. 5 The distribution map analog of Yinchuan wetland in 1999

Fig. 6 The distribution map of Yinchuan wetland in 2006
4 Conclusion
In this paper, the binding Markov-CA model can be used to describe the discipline of the proliferation in geological phenomena and simulate the evolution rules in features that areas are getting narrower. Cellular automaton model, for a long time is used to describe the growth reproduction of study object. The occurrence and development of geological phenomena are uncertainty, and they may growth or in narrowing at a certain period of time. The CA model which we used to describe the growth of city is belonged to growth model. The area changes in land-use and wetland types not only in growth state but also in a narrower state. Research shows that the advantage of Markov-CA model is setting the wetland system as a unified and whole object. And it takes into account the distribution and development of wetland in the regional macro-level and the suitability of micro-level (cellular level). This method could help us to understand the evolution characteristics of wetland in the micro-scale. From the simulation results, the area of Yinchuan wetland will be narrowing in the future and the spatial distribution of wetland will be subject to serious interference with the human activity.

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References: