

Spatio-Temporal Location Simulation of Wetlands Evolution of Yinchuan City Based on Markov-CA Model

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Abstract: - Geographical Information System (GIS) is currently still in description and processing the static spatial data, it is difficult to express the dynamic data effectively and can not achieve the spatio-temporal analysis of geographical processes. Classic prediction models of geographic processes are based on larger geographic unit or administrative unit as the research object, not applying the high-resolution spatial information and achieving visual expression of simulation results. The expression of time, space and state in GIS is discrete. Cellular Automata (CA) is a grid dynamic model whose spatial interaction and time cause-effect relationship are local; its expression for time, space and state also is discrete. CA and GIS can be seamlessly combined so that the two could complement each other in spatio-temporal modeling. Markov combined with Cellular Automata model, under the support of GIS, 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, Spatio-Temporal location simulation, Markov-CA, transition probability transition rules, Yinchuan city.

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 [1]. 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. In recent years, the dynamic changes of wetlands monitoring and forecasting based on GIS (Geographic Information System) and remote sensing technology are deeper [2]. 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 [3]. Researchers apply the new theories about system dynamics theory, information theory and control theory to study the dynamic evolution of wetlands landscape [4][5] and adopt the mathematical methods and computer simulation to conduct their research about wetlands process. A lot of mathematical models of scientific value are set up, and the researches on the evolutions of the wetlands landscape mechanism are deepened [6][7]. 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. However GIS describes the time space and state in discrete, it is difficult to connect the GIS technology and continuous model directly [8][9]. 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 [10]. 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 [11]. 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 [12].

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 Markov model

(1)Markov chain

In 1907, A. A. Markov began the study of an important new type of chance process. In this process, the outcome of a given experiment can affect the outcome of the next experiment. This type of process is called a Markov chain [13].

Markov process is a widely used stochastic model. It has a properties, called non- aftereffect. We usually describe the non-aftereffect as follows: If the chain is currently in state T_m , and the probability at this state is already known, then it moves to the next step. This probability at the next state only depends upon states T_m and has nothing to do with other the states [14].

A Markov chain is a stochastic process with the space and time all discrete. It is defined formally as follows: A stochastic process $\{X(n), n=1, 2, \dots\}$ taking values in a discrete set E , for any sequence $n_1 < n_2 < \dots < n_m$, positive integer n and values i_0, i_1, \dots, i_n and $k \in E$, the following identity involving conditional probabilities holds:

$$\begin{aligned}
 & p\{X(n_m+k)=j|X(n_1)=i_1, X(n_2)=i_2, \dots, X(n_m)=i_m\} \\
 & = p\{X(n_m+k)=j|X(n_m)=i_m\} \tag{1}
 \end{aligned}$$

Then the stochastic process $\{X(n), n=1, 2, \dots\}$ is called Markov chain. A Markov chain works in this way: first by studying the initial probability of different states and the transition probability of the states in the system, we can determine the trends of each state in the system; consequently we will achieve the purpose of forecasting the future trends.

(2) Transition probability matrix

In a sequence of discrete states, the probability of transitioning from state i in T_m to state j in T_{m+1} in a single step is p_{ij} . p_{ij} depends only on the state in T_m and T_{m+1} and has nothing to do with any previous state of T_m .

Arrange p_{ij} in sequence, then the transition probability matrix comes:

$$P = \begin{bmatrix} P_{00} & P_{01} & \dots & P_{0m} \\ P_{10} & P_{11} & \dots & P_{1m} \\ \dots & \dots & \dots & \dots \\ P_{m1} & P_{m2} & \dots & P_{mm} \end{bmatrix} \tag{2}$$

where p_{ij} is the transition probability of wetland landscape types from type i to j . There are three assumptions: first, Markov chain is stochastic. The transition probability from state i to j follows: $\sum p_{ij} = 1, j=1, 2, 3, \dots, m$. Second, Markov chain is usually assumed as a first-order model so that the state of motion system in $T+1$ depends only on that of T . Third, the assumption that transition probabilities do not change [15].

In accordance with the Markov stochastic process theory, we can use the probability matrix in the initial state to simulate the area ratio of different wetland type and wetland landscape in a number of states after initial state and even a stable state. The n th Markov transition probability is calculated as:

$$P_{ij}^{(n)} = \sum_{k=0}^{m-1} P_{ik}^{(n-1)} P_{kj}^{(n-1)} \quad (3)$$

where m is the number of rows or columns of the transition probability matrix, and the n th transition probability matrix equivalent to the n -th power of the first transition probability matrix.

According to the matrix of the initial area in percent $A(0)$ and the transition probability of the n th stage $P^{(n)}$, we can calculate the matrix of the area in percent $A(n)$, that is

$$A(n) = A(n-1) \times P^{(1)} = A(0) \times P^{(n)} \quad (4)$$

2.3 Cellular Automata Model

Cellular Automata Model (CA model) was proposed by the famous mathematician Von Neumann in 40s. And the "Game of Life" established by Conway JH in 1970 was one of the most well-known CA model which was implemented on the computer. In short, cellular automata is a grid dynamic model whose time, space and time are separated and spatial interaction and time cause-effect relationship are local. Its greatest advantage is: Simulating and expressing the spatio-temporal dynamic changes in entire system through defining the relationship between local neighboring cells, as well as the simple local transformation rules acted on cells area, not solving complex differential equations or partial differential equations [16]. It is suitable for simulating and displaying the spatio-temporal behavior and processes of systems with self-organizing feature.

A standard CA system is consisted of cells, states, neighbors and transition rules. The cells space is formed by discrete cells. In a certain state each cell only has one state which comes from a finite set [17]. Neighbors, impacting the next state of the center cell, are a cell set defined by a certain shape around cells. Transition rules define the rules of cell state transition. CA system time, which is also a discrete time and has no physical meaning, has similar meaning with the system time in temporal GIS. Us the language of set to describe CA model is:

$$S_{t+1} = f(S_t, N) \quad (5)$$

Where S is a finite set on behalf of cell state, N denotes the neighbor, t stands for time and f is the local transition rule.

2.4 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 [18]. 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 [17].

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

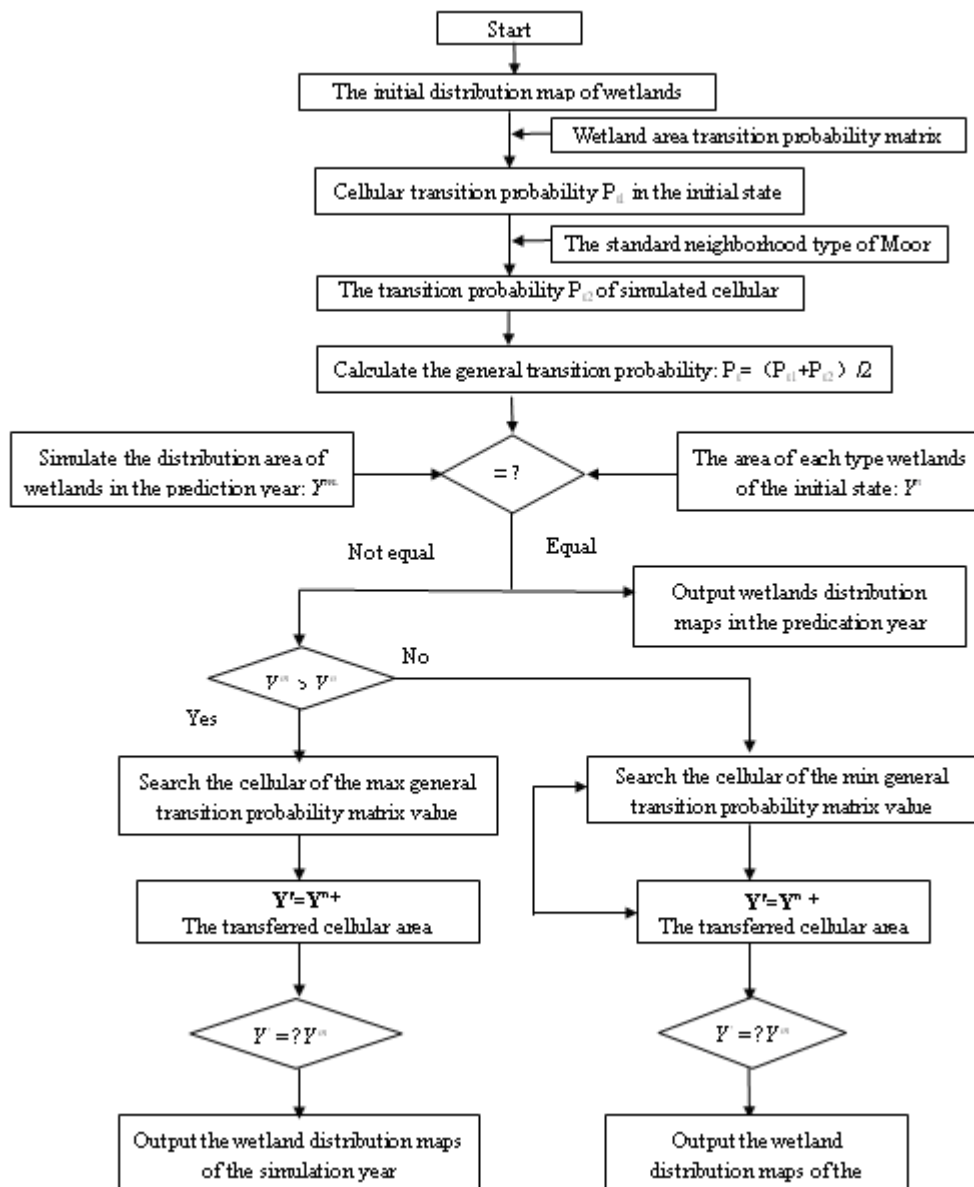


Fig.1 Markov-CA Model Flow Chart

2.5 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. [19][20]. The source code of systems integration and implementation is as follows.

(1) Get the transition probabilities of each land type convert into river and the river convert into this kind of land type.

```
double Change River(int x, int y, BOOL bAdded)
```

x,y represent the pixel coordinate of any point on the map. When the value of bAdded is true, it means the rivers are increased, the returned value is the transition probability of this land type turning into river; When the value of bAdded is false, it means the rivers are decreased, the returned value is the transition probability of river turning into this land type.

Code:

```

double CPrjCADlg::ChangeLake(int x, int y,
BOOL bAdded)
{
    CLOCK clocks[7];
    if (bAdded)
    {
        clocks[0].dwColor = 16646144;
        clocks[0].nClock = 0.0434;
        clocks[1].dwColor = 15592704;
        clocks[1].nClock = 0.5537;
        clocks[2].dwColor = 35328;
        clocks[2].nClock = 0.0768;
        clocks[3].dwColor = 9044106;
        clocks[3].nClock = 0;
        clocks[4].dwColor = 65150;
        clocks[4].nClock = 0.0046;
        clocks[5].dwColor = 33996;
        clocks[5].nClock = 0.0026;
        clocks[6].dwColor = 13415628;
        clocks[6].nClock = 0.0015;
    }
    else
    {
        clocks[0].dwColor = 16646144;
        clocks[0].nClock = 0.0043;
        clocks[1].dwColor = 15592704;
        clocks[1].nClock = 0.5537;
        clocks[2].dwColor = 35328;
        clocks[2].nClock = 0.1735;
        clocks[3].dwColor = 9044106;
        clocks[3].nClock = 0.0217;
        clocks[4].dwColor = 65150;
        clocks[4].nClock = 0.1289;
        clocks[5].dwColor = 33996;
        clocks[5].nClock = 0.0704;
        clocks[6].dwColor = 13415628;
        clocks[6].nClock = 0.0475;
    }
}

```

```

DWORD dwColor = GetPixel(x, y);
for (int i=0; i<7; i++)
{
    if (clocks[i].dwColor == dwColor)
        return clocks[i].nClock;
}
return 0;
}

```

(2) Get the overall transition probability of cellular
Calculate the overall transition probability in six cases: the increase of river, the decrease of river, the increase of lake, the decrease of lake, the increase of paddy, the decrease of paddy. The following is the case of river decreasing.

```

for(int j=0; j<m_dwHeight; j++)
    for(int i=0; i<m_dwWidth; i++)
    {
        //river increase
        int nCount = 0;
        dValue = 0;
        if (i>=1 && j>=1)
        {
            dValue = ChangeRiver(i-1, j-1, TRUE);
            nCount++;
        }
        if (i>=1)
        {
            dValue += ChangeRiver(i-1, j, TRUE);
            nCount++;
        }
        if (i>=1 && j<m_dwHeight-1)
        {
            dValue += ChangeRiver(i-1, j+1, TRUE);
            nCount++;
        }
        if (j>=1)
        {
            dValue += ChangeRiver(i, j-1, TRUE);
            nCount++;
        }
        if (j<m_dwHeight-1)
        {
            dValue += ChangeRiver(i, j+1, TRUE);
            nCount++;
        }
        if (i<m_dwWidth-1 && j>=1)
        {
            dValue += ChangeRiver(i+1, j-1, TRUE);
            nCount++;
        }
        if (i<m_dwWidth-1)

```

```

    {
        dValue += ChangeRiver(i+1, j, TRUE);
        nCount++;
    }
    if (i<m_dwWidth-1 && j<m_dwHeight-1)
    {
        dValue += ChangeRiver(i+1, j+1, TRUE);
        nCount++;
    }
    dValue /= nCount;
    dValue += ChangeRiver(i, j, TRUE);
    adoRecordSet.PutCollect("RiverAdd", dValue);
}

```

(3) Simulate of the wetlands distribution maps according to the overall transition probability of wetlands in the database.

```

while(!adoRecordSet.IsEOF())
{
    adoRecordSet.GetCollect("X", x);
    adoRecordSet.GetCollect("Y", y);
    dwColor = GetPixel(x, y);
    if (dwColor != dwCurColor && dwColor != 0xFFFFFFFF)
    {
        if (bAdded)
        {PutPixel(x, y, dwCurColor);
        nChangeCount++;
        if (nChangeCount >= dwChangeCount)
            break;
        }
        else
        {
            if (x>=1 && y>=1)
            if (GetPixel(x-1, y-1) == dwCurColor)
            {
                PutPixel(x-1, y-1, dwColor);
                nChangeCount++;
                if (nChangeCount >= dwChangeCount)
                    break;
            }
            if (x>=1)
            if (GetPixel(x-1, y) == dwCurColor)
            {
                PutPixel(x-1, y, dwColor);
                nChangeCount++;
                if (nChangeCount >= dwChangeCount)
                    break;
            }
            if (x>=1 && y<m_dwHeight-1)
            if (GetPixel(x-1, y+1) == dwCurColor)
            {
                PutPixel(x-1, y+1, dwColor);
                nChangeCount++;
                if (nChangeCount >= dwChangeCount)

```

```

                    break;
                }
            if (y>=1)
            if (GetPixel(x, y-1) == dwCurColor)
            {
                PutPixel(x, y-1, dwColor);
                nChangeCount++;
                if (nChangeCount >= dwChangeCount)
                    break;
            }
            if (y<m_dwHeight-1)
            if (GetPixel(x, y+1) == dwCurColor)
            {
                PutPixel(x, y+1, dwColor);
                nChangeCount++;
                if (nChangeCount >= dwChangeCount)
                    break;
            }
        }
        if (x<m_dwWidth-1 && y>=1)
        if (GetPixel(x+1, y-1) == dwCurColor)
        {
            PutPixel(x+1, y-1, dwColor);
            nChangeCount++;
            if (nChangeCount >= dwChangeCount)
                break;
        }
        if (x<m_dwWidth-1)
        if (GetPixel(x+1, y) == dwCurColor)
        {
            PutPixel(x+1, y, dwColor);
            nChangeCount++;
            if (nChangeCount >= dwChangeCount)
                break;
        }
        if (x<m_dwWidth-1 && y<m_dwHeight-1)
        if (GetPixel(x+1, y+1) == dwCurColor)
        {
            PutPixel(x+1, y+1, dwColor);
            nChangeCount++;
            if (nChangeCount >= dwChangeCount)
                break;
        }
    }
}
adoRecordSet.MoveNext();
}

```

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 [21].

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(1991 and 1999) 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 [22]. 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.

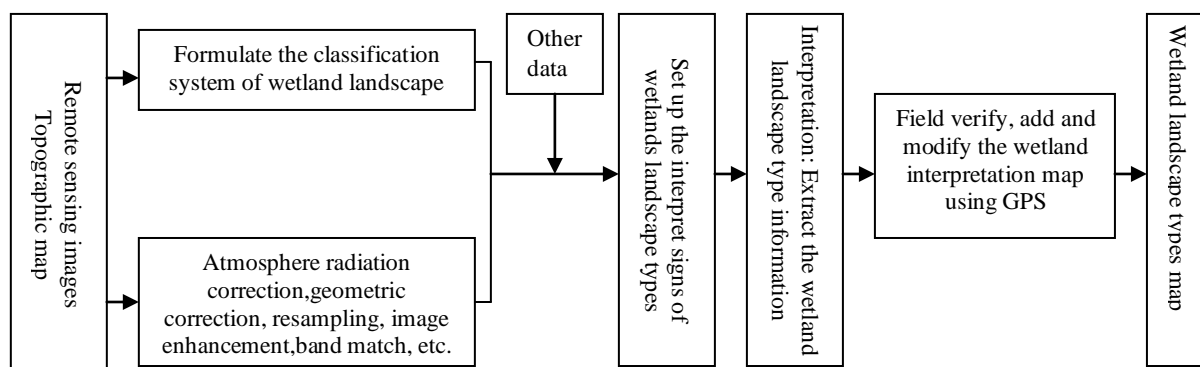


Fig.2 Technology route of wetland distribution information extraction based on TM remote sensing images

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 , unit: km^2):

$$p = \begin{bmatrix} 111.4204 \\ 142.3720 \\ 133.6371 \\ 6594.7040 \end{bmatrix} = \begin{bmatrix} \text{river} \\ \text{lake} \\ \text{paddyfield} \\ \text{non-wetland} \end{bmatrix} \quad (6)$$

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 1 The transition probability matrix of northern region of Ningxia Plain from 1991 to 1999

Classes	river	lake	paddy field	non-wetland
river	0.7279	0.0434	0.0801	0.1486
lake	0.0043	0.5537	0.1735	0.2685
paddy field	0.0229	0.0768	0.6044	0.2959
non-wetland	0.009	0.0087	0.0095	0.9728

Table 2. The predict area of each wetland landscape with Markov chain (km²)

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

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

Wetland classes	right analog area	TM image interpretation area	analog accuracy
Paddy field	41.3475	55.1925	74.92%
River	19.4358	26.9781	72.04%
lake	18.7660	23.8100	78.82%
total	79.5493	105.9806	75.06%

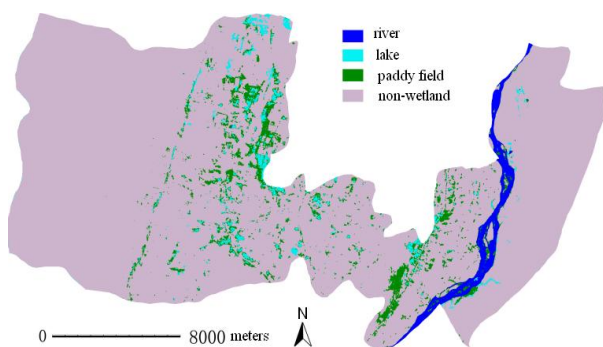


Fig. 3 The distribution map of Yinchuan wetland in 1991

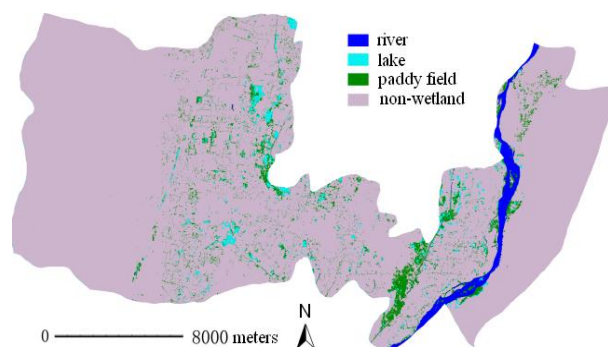


Fig. 4 The distribution map of Yinchuan wetland in 1999

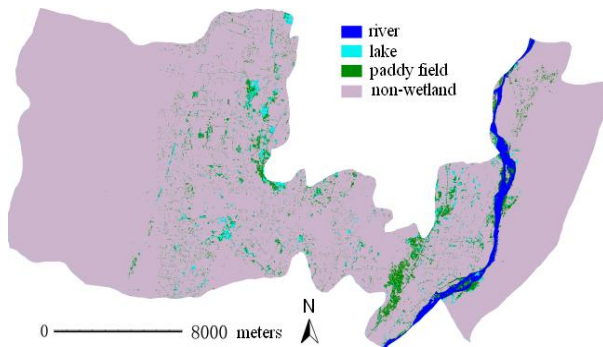


Fig. 5 The distribution map analog of Yinchuan wetland in 1999

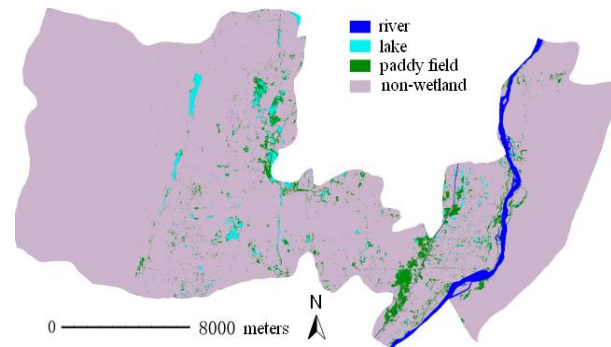


Fig. 6 The distribution map of Yinchuan wetland in 2006

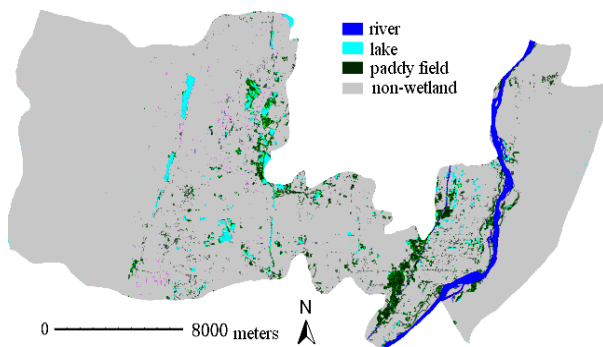


Fig. 7 The distribution analog map of Yinchuan wetland in 2006

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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