Dynamic simulation of land use change in Bashang desertification region of Hebei Province using CA-Markov Model

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Abstract: Study of regional land use is important for planning of urban construction and ecological restoration. We report the dynamic characteristics of land use and modeled direction of land use transformation using the ARCGIS and IDRISI software in the desertification region in Hebei Province. Analysis is based on the interpretation data of remote sensing images of 2004, 2009 and 2014. The CA-Markov model was employed to simulate and predict the land use trend in the study area in 2019. It was found that (1) The land use changed significantly between 2004 and 2014. The area of cultivated land continued to increase, the area of forestland and grassland decreased continuously, the construction land increased rapidly, and the water area changed little. (2) There was obviously directional movement of cultivated land, forestland, grassland and construction land from 2004 to 2014. Grassland cultivated land and construction land had a trend of convergence, while forestland and other types of land were scattered (3) Compared with the period from 2004 to 2014, the areas of cultivated land, forestland and construction land increased, and the area of grassland continued to decrease from 2014 to 2019. The increasing speed of cultivated land significantly slowed down and the construction land increased sharply. The approach demonstrated in this study can be utilised to guide the coordinated development of land use and ecological protection in desertification areas.

Keywords: Desertification area, Land use, CA-Markov, Dynamic simulation

1. Introduction

The change of land use is the succession of the interference of human activities to land. As an important procedure of global and regional environmental change, land use affects the ecological environment (Wang and Zang, 2006; Yu and Yang, 2002; Xu et al., 2017) and brings the changes in many ecological processes of ecosystems on different scales, such as soil erosion, surface runoff and non-point source pollution (Guo et al., 1999; Yu et al., 2004). Land use is closely related to land desertification resulted by climate and unreasonable utilization of resources (Chen, 1996; Xu et al., 2009; Xu, 2007). Unreasonable land use will lead to a sharp decline in land productivity, continuous decreases in land resources and biodiversity (Wang and Wu, 1999; Bai and Li, 2013). Study on the characteristics and its dynamic changes and prediction on the future status of regional land use on different spatial and temporal scales helps to understand the process and mechanism of ecological environment change under the influence of human activities, which is of great significance for ecological protection and sustainable development.

Presently different types of dynamic simulation model are used for studying land use change analysis viz., System Dynamic (SD) (Xie et al., 2008), Cellular Automata (CA) (Zhou and Li, 2012), Markov (Markov) (Guan and Weijun, 2008; Zhou et al., 2010) and Logistic, etc. CA-Markov, also known as spatial-temporal Markov chain (STMC), is a widely used coupling model (Mondal et al., 2016; Halmy et al., 2015), which combines the advantages of long-term prediction of Markov model and the ability of CA on simulating the spatial change of complex system. It improves the prediction accuracy of the transformation and effectively simulate the spatial change of land use type (Liu et al., 2010; Wu et al., 2017).

Bashang desertification area, located in the north-west of Hebei Province, is an ecologically fragile area. Deteriorating ecological condition of this region is due to grassland degradation and reduction of biodiversity due to the long-term human disturbance, such as excessive grazing, felling, and reclamation. In this study, Bashang desertification area was chosen as the research area. The data of land use in 2004, 2009 and 2014 are collected and used as input parameters in the MEC model, Markov model, land use focus conversion model and single dynamic of land use. Based on the IDRISI Andes 17.0 software, the CA-Markov model was employed to predict and analyse the spatial pattern of land use in the study area for 2019. It reveals the trend of land use, which is of vital importance to the ecological environment protection and sustainable development of the Bashang Desertification Area.

2. Methodology

2.1 Research area and data

The Bashang desertification area located in the north-western part of Hebei Province, which is between 114°50′38′′ and 116°04′09′′ E, 41°14′33′′ and 41°56′55′′N with temperate continental grassland environment. The annual average temperature of the region is 1.6°C. The annual average precipitation is 426 mm. The frost-free period is 117 days, and the rainy season of the region is mainly in June, July, and August, with 53% of the annual precipitation.

The Landsat TM images of 2004, 2009 and 2014 were collected as the main data with resolution of 30 m. According to the land use classification criteria documented in the Land Administration Law of the People's Republic of China (National People's Congress Standing Committee, 1998), the land uses in the study area are classified into five main categories: arable land, forestland, grassland, water, and construction land.

2.2 Markov Model

Markov model is a stochastic model with a finite time series: $t_1 < t_2 < t_3 \ldots t_n$. In the Markov process, the state a_n at time t_n is only related to the state a_{n-1} at time t_{n-1}. This simulation is mainly used in the study of the change in land use. The area or ratio of land use types converted to each other constitutes the state conversion probability. The future status of land use is predicted by the conversion matrix. The formula is as follow (Gao and Zhao, 2002):

$$S_{t+1} = P_{ij} \times S_t$$

Where, S_{t+1} and S_t are the states of the land use system at the time of t+1 and t, respectively.

P_{ij} is a state conversion matrix, which can be expressed by the following formula:

$$P_{ij} = \begin{vmatrix} P_{11} & \cdots & P_{1n} \\ \cdots & \cdots & \cdots \\ P_{n1} & \cdots & P_{nn} \end{vmatrix}$$

Where, $0 \le P_{ij} \le 1$ and $\sum_{j=1}^{n} P_{ij} = 1, \ (i, j = 1, 2, \ldots, n)$.

2.3 MCE Model

The MCE model is applied to find out the optimal decision and set a series of evaluation criteria (Fang et al., 2014), formulate corresponding criteria for different objectives, and to assist decision-making through a comprehensive analysis of many factors affecting the objectives (integrating the information of two kinds of decision-making criteria: constraint conditions and suitable factors).

In this study, distance and land use are applied as constraints, while the binary values of five factors, town, water, road, slope and construction land, are standardized as Boolean images. The following six main standards are adopted:

1. Distance constraints: Considering the shortage of water source and water pollution, the value is 0 in the buffer range of 50m, and the values of others are 1.
2. Current land use constraints: According to the classification of this study, the suitability score of water area and construction land is set to 0, and those of other types are set to 1.
3. Distance factor of water area: For environmental protection, the buffer distance within 100m is not suitable for development, with a score of 0. The values of others are set to 1.
4. Distance from roads: Knowing the impact of road traffic on economic development is very strong. Within 500 meters from road traffic, the value is 1, and the values of others are 0.
5. Slope factor: According to China's "Work Regulations on Soil and Water Conservation", the lands with slope gradient above 25 degrees are no-tillage area. The suitability values for the areas with slope gradient above 25 degrees are set to 0 and other values are set to 1.
6. Distance factor of construction land: Construction land has a significant impact on the conversion of surrounding land, and the longer the distance, the smaller the attraction until no difference is achieved. Therefore, the value of distance less than 300 m from the construction land is set to 1, the values of others are set to 0.

2.4 Dynamic Degree of Land Use

The dynamic degree of land use refers to the quantitative change of a certain land use type in a certain time range in a certain research area. The dynamic degree indicates the stability of the land use type (Duan et al., 2005). This rate reflects the level of a dramatic change of the regional land use. The following formula indicates the method for calculating the dynamic degree of a type of land use:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$$

Where, U_a is the original state of the land type, U_b is the area of land use at the end of the period; T is the duration of the data collection in these years.

2.5 Focus conversion model of land use

The focus of land use is used to characterize the spatial position and change in the process of land development and utilization (Li et al., 2017).

The calculation method is as follows:

$$X_k = \frac{\sum_{i=1}^{n}(A_{ki} \times X_{ki})}{A_k}, Y_k = \frac{\sum_{i=1}^{n}(A_{ki} \times Y_{ki})}{A_k}$$

Where, X_k and Y_k are the coordinate barycentres of X and Y for land use types of k, A_{ki} is the area of i patches for land use type of k, X_{ki} and Y_{ki} are the geometric coordinate centres of X and Y for i patches of the land use type of k, and A_k denotes the total area of k land use types.

2.6 CA-Markov Model

Cellular automata (CA) is a dynamic model with discrete time, space and state, which can effectively simulate the spatial changes of the system. The CA model formula (Zhou et al. 2003) is:

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

Where, S is a finite and discrete set of states, t, T + 1 are different times, N is the neighborhood of cells, and f is the rule of cell transformation in local space.

Using the IDRISI Andes 17.0 software and the data of Markov and CA, land use change prediction is carried out. The results of future land use are analyzed according to land use dynamic degree. CA-Markov Model releases the spatial relationships to ensure the land use is converted into the most recently stored land use type, rather than completely randomized (Liu and He, 2003).

The specific prediction process is as follows:

1. Calculating the conversion matrix of land use: The interpreted data of 2004 and 2009 are analyzed by superposition (Figure 1, area matrices of conversion probability and conversion are calculated by the Markov model in IDRISI).

2. Establishment of suitability atlas: The Collation Edit module of IDRISI software is used to produce conversion suitability Atlas of different types of land use by MCE model to integrate different criteria and predict the change of land use.

Setting relevant parameters: The current data of land use in 2009 was used as the basic data, and the year 2009 was set as the basic point of prediction time. The default 5*5 cellular filter was used to define neighbors and predict the distribution of land use in 2014. The kappa coefficient of 0.7593 was used to test the actual interpretation data in 2014. The higher simulation prediction accuracy makes the year 2014 suitable for being the base period data, and the spatial distribution of land use in the year of 2019 was then measured.

3. Results and Analysis

3.1 Dynamic Change Characteristics of Land Use

The area under cultivated land and construction land had increased steadily from 2004 to 2014 (Figure 1 and Table 1). Among them, the area of cultivated land increased by 133.49 km^2 and the area of construction land increased by 22.75 km^2. The area of forestland and grassland decreased by 77.23 km^2 and 79.53 km^2, respectively. Decrease in water area was less significant. For the structural change, the arable land area ratio has increased significantly, and the proportion of arable land area in the total study area exceeded 40% by 2014. The proportion of land area decreased from 28.44% to 26.06% and grassland from 29.04% to 26.60%. The proportion of construction land increased from 2.87% to 3.57% in 10 years. The water area changed very small, and the proportion of the water area is keeping nearly stable at 2.4% of the total area.

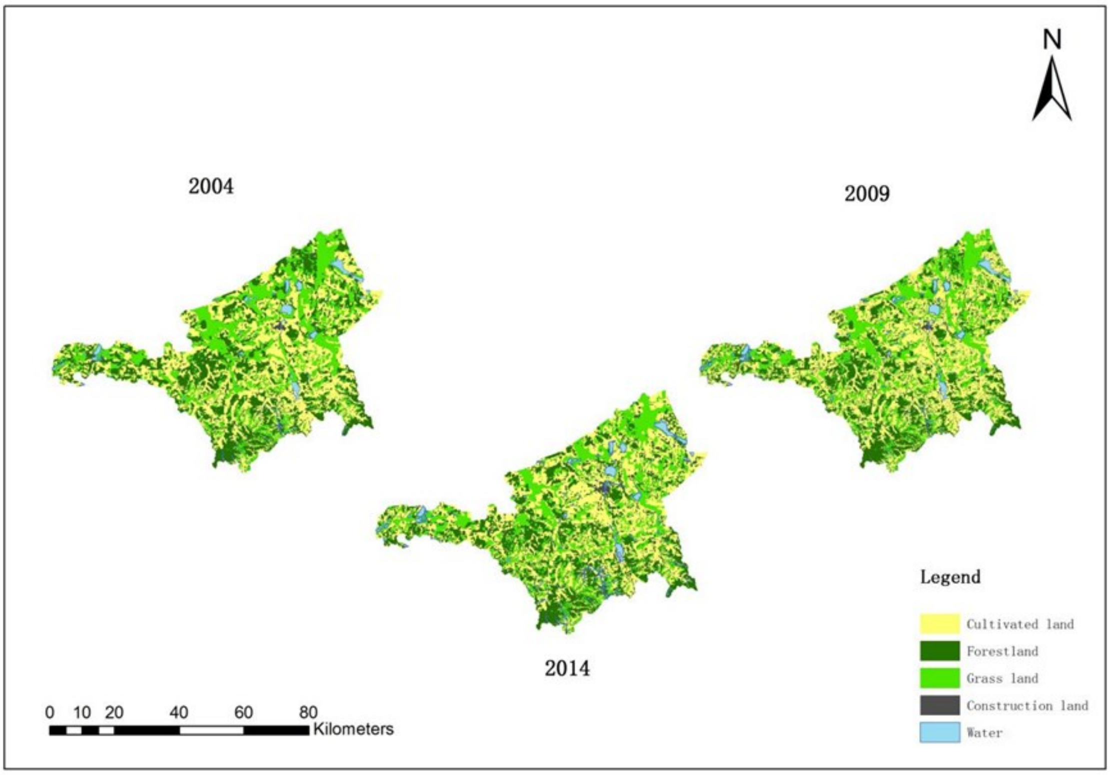

Figure 1: Interpretation of land use in the study area from 2004 to 2014

Table 1: Areas of different types of land use in different stages of desertification in Bashang

Land use types	2004		2009		2014	
	Area/ km^2	Proportion %	Area/ km^2	Proportion %	Area/ km^2	Proportion %
Cultivated land	1210.75	37.28	1297.78	39.96	1344.24	41.39
Forest land	923.61	28.44	859.53	26.46	846.38	26.06
Grass land	943.38	29.04	916.48	28.22	863.85	26.6
Construction land	93.29	2.87	97.85	3.01	116.05	3.57
Water	76.99	2.37	76.39	2.35	77.51	2.39

3.2 Spatial Direction Conversion of Land Benefit

The conversion matrix of land use can be obtained by the Markov module of IDRISI software from 2004 to 2014. Between 2004 and 2014, the land conversion in the study area is slightly larger and more complex. The area of converted cultivation land is the largest and mainly come from grassland and forestland. The intensity of grassland conversion is higher. The grassland was mainly converted to cultivated land and construction land by the areas of 287.05 km^2 and 5.93 km^2, respectively. Forestland conversion intensity mainly converted to grassland and cultivated land conversion area is 206.12 km^2 and 34.37 km^2 respectively. Construction land conversion is more obvious. The Construction land is mainly come from cultivated land by the area of 16.05 km^2. The change in the water area is very small, and the area is mainly from the conversion of cultivated land, grassland, and forestland (Table 2).

3.3 Simulated Prediction of Land Use Change

3.3.1 Change of land use focus

From 2004 to 2014, except water, the other four types of land use changed significantly. These four types of land use are important factors affecting socio-economic development and grain yield in the study area. Taking these four types of land as representatives, the change of the focus is analyzed, and the distribution of the focus of the study area in 2004-2014 and the forecast results are obtained by using (Geographic Information System) GIS spatial analysis tools (Figure 2), to predict the future change of land use.

From figure 2, it can be seen that the centre of gravity of cultivated land moved 1148 m eastward and 1622 m southward from 2004 to 2009, with the fastest moving speed. Grassland and construction land moved 568 m to the southwest and 1065 m to the northwest respectively. It shows that while the cultivated land and construction land expanded around, they tended to develop toward flattening areas in the study area. Between 2009 and 2014, the cultivated land moved 1145 m to the northwest, almost unchanged from 2004 to 2009. It moved 1484 m to the southeast and the moving speed slowed down. The grassland maintained its development direction and speed in the last period. The construction land moved 144 m to the northeast and the moving speed slowed down. From 2004 to 2014, the centre of gravity of cultivated land moved to the north, the forestland moved to the southeast, the grassland moved to the southwest, and the construction land moved to the northwest.

3.3.2 CA-Markov Model Simulation Accuracy Test

At present, the CA-Markov model does not have a model accuracy-test standard, therefore, this study uses the kappa coefficient as a criterion to determine the accuracy of the model. The area of each land use type in the simulation results is compared with the area of actual land use area (Figure 3). If the image of land use benefit in the two periods is completely consistent, Kappa equals 1; When $0 \leq$ Kappa ≤ 0.4, the results have a low consistency. If $0.4 \leq$ Kappa ≤ 0.75, which indicates that the consistency is general. When Kappa ≥ 0.75, the consistency is high. Through the Crosstab module, the accuracy of quantitative analysis of the Kappa coefficient is obtained by comparing the simulation results and interpretation results. The Kappa coefficient obtained in this study is 0.7593, which indicates the accuracy of simulation prediction is relatively high and the results have high credibility and applicability.

3.3.3 Analysis of simulation results of the CA-Markov model

According to the predicted results of land use in 2019 (Table 3), it can be seen that the area of cultivated land decreased during the period between 2014 and 2019 is even more than the total area of grassland decreased in the two periods, 2004-2009 and 2009-2014; the change in the land area shows a greater fluctuation. The area of forestland between 2004 and 2014 is in a decreasing stage, but the speed of reduction is continuously decreasing, and the area of forestland has an increase between 2014 and 2019. But from the number, the area of forestland in 2004-2019 is still decreasing. Construction land shows a strong growth trend during the study period, it increased by 4.56 km^2 in 2004-2009. According to the prediction results, the growth of construction land will reach 31.07 km^2 in 2014-2019. From the dynamic degree of land use type change, the growth rate of the cultivated land area is slowing down, and the dynamic degree is decreasing.

Table 2: Area of land transferred to desertification area in Bashang area from 2004 to 2014, unit in km^2

Land use types		2014				
		Cultivated land	**Forestland**	**Grassland**	**Construction land**	**Water**
2004	**Cultivated land**	1019.14	164.78	9.02	16.05	1.77
	Forestland	34.37	675.27	206.12	6.74	1.11
	Grass land	287.05	5.08	643.69	5.93	1.64
	Construction land	2.32	0.69	2.76	87.16	0.36
	Water	1.37	0.57	2.27	0.16	72.63

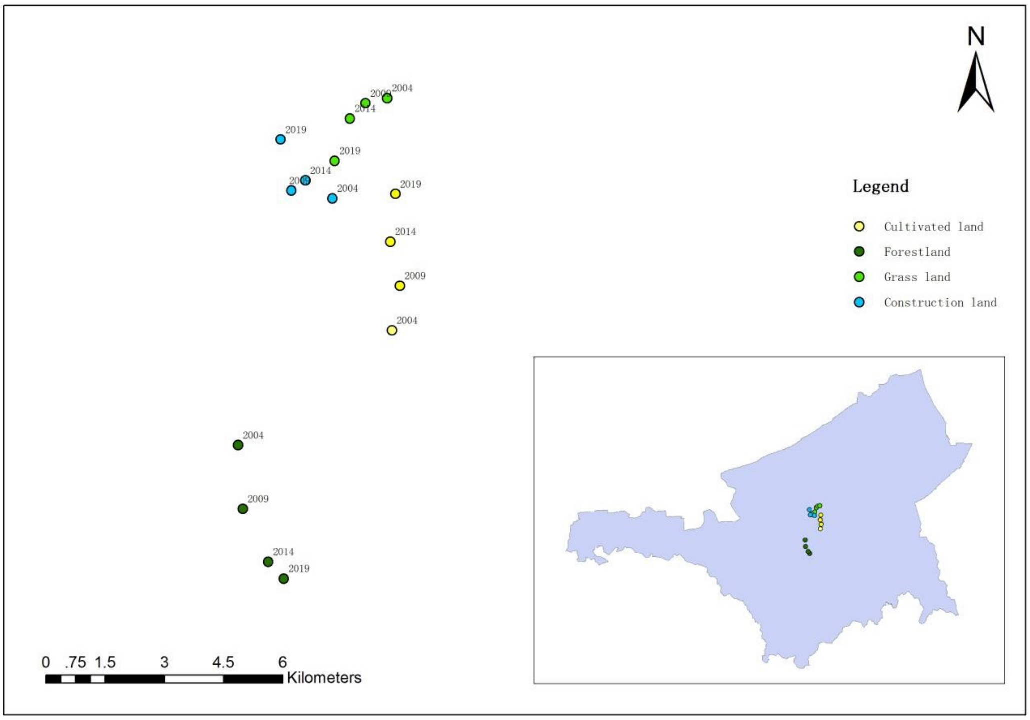

Figure 2: Spatial distribution of land use centre of gravity

Table 3: Changes in land use space in the study area from 2004 to 2019

Land use types	Predicted Area/km^2	From 2004 to 2009		From 2009 to 2014		From 2014 to 2019	
	2019	Area change (km^2)	Dynamic degree (%)	Area change (km^2)	Dynamic degree (%)	Area change (km^2)	Dynamic degree (%)
Cultivated land	1360.37	87.03	1.44	46.46	0.72	16.14	0.24
Forestland	884.74	-64.08	-1.39	-13.15	-0.31	38.34	0.91
Grass land	779.44	-26.90	-0.57	-52.63	-1.15	-84.42	-1.95
Construction land	147.12	4.56	0.98	18.19	3.72	31.07	5.36
Water	76.37	-0.61	-0.16	1.13	0.29	-1.14	-0.29

The dynamic degree of 2004-2009 is 1.44, the dynamic degree of 2009-2014 and 2014-2019 is 0.72 and 0.24 respectively; the forest area is increasing, and the dynamic degree is changing from negative to positive; the grassland is decreasing rapidly, and the dynamic degree from 2009 to 2014 and from 2014 to 2019 are negative 1.15 and negative 1.95. The area of construction land increases rapidly, and the dynamic degree reached 3.72 and 5.36 in 2009-2014 and 2014-2019, respectively.

As can be seen from figure 4, the cultivated land and construction land in the study area are mainly distributed in the flat terrain, low altitude area, mostly around grassland, and construction land is expanding outward. With the acceleration of urbanization, the increase of construction land area is an inevitable result, and the increase of population will intensify reclamation, resulting in the transformation of other land use types, especially grassland to cultivated land and construction land. Urbanization and population growth are bound to require social and economic support, which requires forestland to provide services for them, resulting in the conversion of part of the forestland into arable land. After forestland and grassland degenerated and reclaimed as arable land, the soil lost the protection of vegetation in the idle season. This resulted in soil loosening, which led to land desertification, accelerated the expansion of sandy land and the activities of desert marginal dunes, coupled with technical and socio-economic constraints, which made the land lose nutrients, and then continued to expand the area of arable land, forming a vicious circle.

4. Discussion

Numerous studies have shown that there are some differences in the impact of land use types on desertification (Ge et al., 2010; Wang et al., 2010; Lv et al., 2007; Zhang et al., 2009). Over the past 10 years, the area of cultivated land has been increasing, the forestland and grassland have been decreasing, and the expansion of construction land must occupy a large amount of cultivated land and grassland, which undoubtedly changes the land use pattern of the desertified area. In order to increase grain production and further increase economic benefits, local people continue to reclaim the flat forestland and grassland around cultivated land, and the over-reclamation has resulted in the increase of cultivated land and the degradation of grassland. It makes the soil loose and leads to desertification. After the forestland and grassland are reclaimed as cultivated land, the soil loses the protection of vegetation in the fallow season, thus accelerating the expansion of desertified land and the activities of sand dunes on the edge of the desert. Together with technical and socio-economic constraints, the land loses nutrients, and consequently expands the area of cultivated land and forms a vicious circle. The forest land resources in the study area are relatively abundant, distributed in areas with a high elevation and complex topography. The proportion of water area is small, and the ecology is relatively fragile, so it is difficult to recover after damage. Due to the limitation of landform, cultivated land and grassland are greatly affected by human activities. According to the simulation results, the land use change in desertification area is very active, and the desertification control is still a tough job. Therefore, controlling sufficient arable land per capita, reducing fertilization intensity, improving farmers' technical level and land use level, retaining enough ecological land in desertification areas and saving intensive use of construction land are important measures to slow down land desertification.

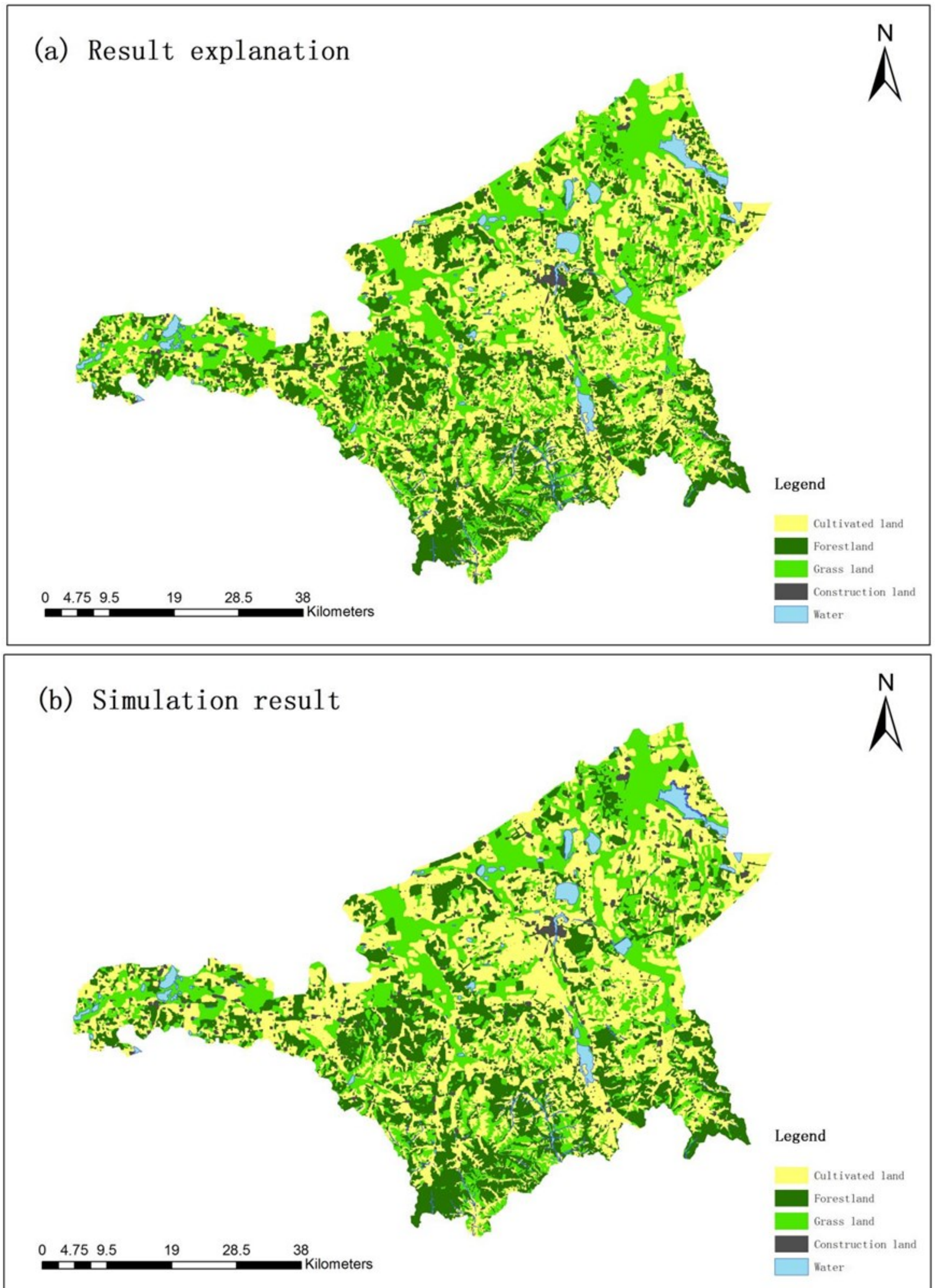

Figure 3: Verification of land use type prediction accuracy in the study area: (a) Result explanation; (b) Simulation result

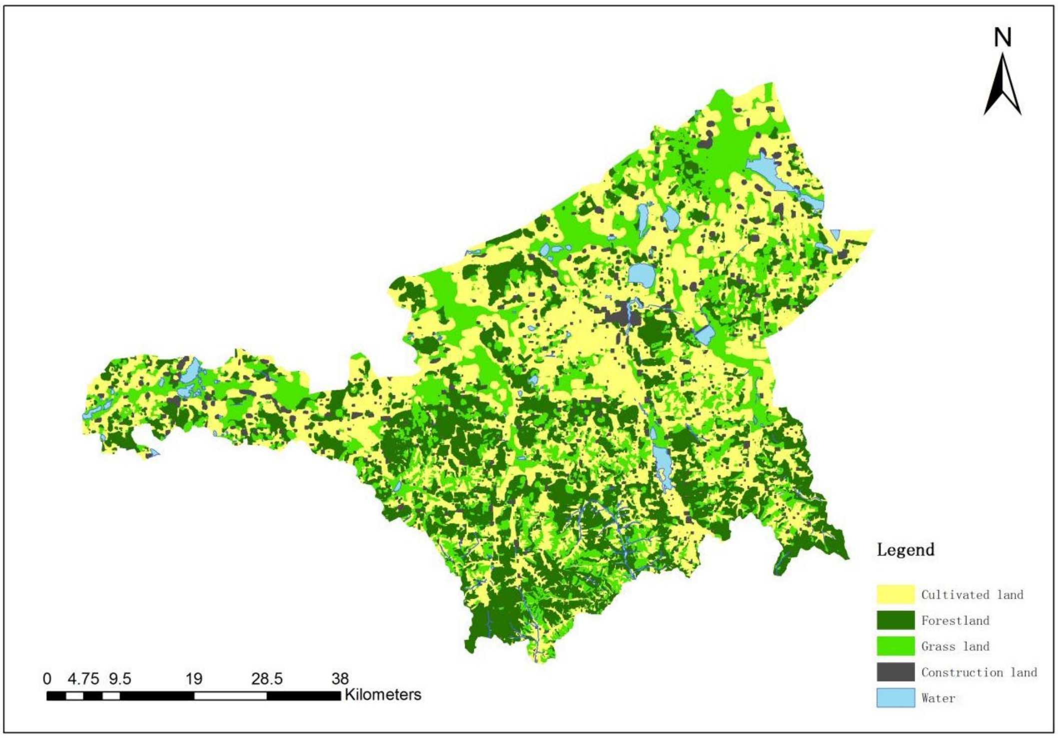

Figure 4: Predicted land use types in the study area using CA-Markov model

Table 4: Changes in land use space in the study area from 2004 to 2019

Land use types	**Predicted Area/km^2**	**From 2004 to 2009**		**From 2009 to 2014**		**From 2014 to 2019**	
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Land use simulation is a complex process, which is affected by many factors. These factors are often difficult to quantify. In addition, the spatial resolution and interpretation accuracy of TM remote sensing images limit the accuracy of model simulation results to some extent. In the future, we should further identify key drivers, especially human factors, taking into account the scale effect. The simulation results are more realistic and reasonable to guide the coordinated development of land use and ecological protection in desertification areas.

5. Conclusion

Based on the Markov model and GIS and remote sensing technology, we analyzed the spatial-temporal characteristics and trends of land use types in desertification areas from 2004 to 2014. Six influencing factors of distance and land use area were selected to participate in the formulation of conversion rules. IDRISI software is used to simulate and forecast land use in Desertification Area in 2019. MCE method is used to simulate the change of land use spatial pattern in 2014 with GIS. The actual interpretation results in 2014 are compared and validated. The Kappa coefficient of the simulation results is 0.7593, with high accuracy and reliability, which can be used for future land use simulation and prediction. The formulation of conversion rules can improve the accuracy of prediction results, so as to provide a scientific basis for the protection of land resources and decision-making of regional land use planning.

The main characteristics of land use conversion are as follows: from 2004 to 2014, the cultivated land area increased continuously, mainly from grassland and forestland, and the center of gravity of cultivated land moved steadily to the northward; because of the continuous degradation of forestland and the conversion from forestland to grassland, the area of forestland continued to decrease and its center of gravity of forestland moved southeast; grassland was the main utilization type of human beings, and the area of grassland was mainly converted to cultivated land and construction land. As a result, the grassland area continued to decrease, and the grassland gravity center accelerated to move to the southwest; the transfer of cultivated land, and the construction land gravity center moving to the northwest bring the continuous expansion of construction land; the water area changed very little, and the figure of the change was not obvious.

From 2014 to 2019, the area of cultivated land continued to increase, but the increase rate decreased, which is about one-third of the area of cultivated land increased in 2009-2014 and one-fifth of the area of cultivated land increased in 2004-2009. With the continuous increase of cultivated land, it is bound to occupy the land area of other land use types. Forest land showed a trend of decreasing first and then increasing and forest land in 2004-2014. The speed of the land area has slowed down, and the average annual reduction rate has changed from 1.39% in 2004-2009 to 0.31% in 2009-2014. This is mainly due to the implementation of the local policy of returning farmland to forestry. The area of forest land has begun to reverse in 2014-2019, and the area of forest land has increased. However, from the quantitative point of view, the area of forest land in 2004-2019 is still decreasing. Grassland area showed a drastic decreasing trend, the area of grassland reduction in 2014-2019 even exceeded the total area of grassland reduction in 2004-2009 and 2009-2014, and the dynamic degree of land in 2014-2019 was -1.95. Construction land showed a strong growth trend, the dynamic degree of construction land in 2014-2019 reached 5.36, which shows the change of construction land was very active. The change in water area is not obvious.

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