Scenario simulation and landscape pattern dynamic changes of land use in the Poverty Belt around Beijing and Tianjin: A case study of Zhangjiakou city, Hebei Province

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Abstract: Land use/cover change has been recognized as a key component in global change and has attracted increasing attention in recent decades. Scenario simulation of land use change is an important issue in the study of land use/cover change, and plays a key role in land use prediction and policy decision. Based on the remote sensing data of Landsat TM images in 1989, 2000 and 2010, scenario simulation and landscape pattern analysis of land use change driven by socio-economic development and ecological protection policies were reported in Zhangjiakou city, a representative area of the Poverty Belt around Beijing and Tianjin. Using a CLUE-S model, along with socio-economic and geographic data, the land use simulation of four scenarios—namely, land use planning scenario, natural development scenario, ecological-oriented scenario and farmland protection scenario—were explored according to the actual conditions of Zhangjiakou city, and the landscape pattern characteristics under different land use scenarios were analyzed. The results revealed the following: (1) Farmland, grassland, water body and unused land decreased significantly during 1989–2010, with a decrease of 11.09%, 2.82%, 18.20% and 31.27%, respectively, while garden land, forestland and construction land increased over the same period, with an increase of 5.71%, 20.91% and 38.54%, respectively. The change rate and intensity of land use improved in general from 1989 to 2010. The integrated dynamic degree of land use increased from 2.21% during 1989–2000 to 3.96% during 2000–2010. (2) Land use changed significantly throughout 1989–2010. The total area that underwent land use change was 4759.14 km², accounting for 12.53% of the study area. Land use transformation was characterized by grassland to forestland, and by farmland to forestland and grassland. (3) Under the land use planning scenario, farmland, grassland, water body and unused land shrank significantly, while garden land, forestland and construction land increased. Under the natural development scenario, construction land and forestland increased in 2020 compared with 2010, while farmland and unused land decreased. Under the ecological-oriented scenario, forestland increased dra-

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matically, which mainly derived from farmland, grassland and unused land. Under the farmland protection scenario, farmland was well protected and stable, while construction land expansion was restricted. (4) The landscape patterns of the four scenarios in 2020, compared with those in 2010, were more reasonable. Under the land use planning scenario, the landscape pattern tended to be more optimized. The landscape became less fragmented and heterogeneous with the natural development scenarios. However, under the ecological-oriented scenario and farmland protection scenario, landscape was characterized by fragmentation, and spatial heterogeneity of landscape was significant. Spatial differences in landscape patterns in Zhangjiakou city also existed. (5) The spatial distribution of land use could be explained, to a large extent, by the driving factors, and the simulation results tallied with the local situations, which provided useful information for decision-makers and planners to take appropriate land management measures in the area. The application of the combined Markov model, CLUE-S model and landscape metrics in Zhangjiakou city suggests that this methodology has the capacity to reflect the complex changes in land use at a scale of 300 m×300 m and can serve as a useful tool for analyzing complex land use driving factors.

Keywords: land use change; Markov model; CLUE-S model; landscape metrics; Zhangjiakou city

1 Introduction

Land use changes result from the interaction between humans and nature (Vitousek *et al.*, 1997; Liao *et al.*, 2011) and involve complex mechanisms and processes (Sohl and Claggett, 2013). Land use and land cover change (LUCC) is a complex process subject to the interactions between natural and social systems on different temporo-spatial scales (Veldkamp and Lambin, 2001). It is a principal component, and main cause, of global environmental changes, and it has emerged recently as an important focus in the study of land use change. At present, the study of LUCC and its effects has increasingly become a core element of global environmental change and sustainable development research (Feng *et al.*, 2013; Xu *et al.*, 2011; Xu *et al.*, 2013b). Increasing attention has been paid to the driving factors involved in such processes, and the effects of LUCC. The simulation of global and regional land use changes has been employed as a new method for studying LUCC (Liu *et al.*, 2002; Couclelis, 2005). Models and scenario analysis are useful tools for understanding land use patterns and the complex mechanisms of socio-economic and physical variables that influence land use change, and have been recognized as excellent tools for simulating land use changes (Li *et al.*, 2001; Britz *et al.*, 2011; Deng *et al.*, 2013). Currently, different approaches and models have been widely used in many researches on LUCC and have yielded good results (Evans *et al.*, 2001; Tang *et al.*, 2009; Zhang *et al.*, 2014b). Some models, especially dynamic models, can support decision makers in simulating future scenarios. For instance, Markov chains, system dynamics (SD) models, cellular automata (CA) models, multi-agent system (MAS) models, and the Conversion of Land Use and its Effects at Small regional extent (CLUE-S) model have frequently been applied to the simulation of spatio-temporal land use changes (Hu *et al.*, 2013; Liang *et al.*, 2011; Ou *et al.*, 2014; Chen *et al.*, 2009; Tian and Ren, 2012; Zeng *et al.*, 2014; Wu *et al.*, 2014). The CLUE-S model has been considered as an excellent tool for simulating land use changes. It can be used to explore the competition between different types of land uses based on systems theory, to simulate different land uses simultaneously, and to produce a spatially explicit display of the simulation results (Overmars and Verburg, 2007; Hu *et al.*, 2013). Recently, the CLUE-S

model has been used to simulate land use change in certain hot spots, such as plateau cities, mining cities, Heihe River basin, Huangshui River basin, Luoyugou watershed, metropolitan fringe areas, loess hilly areas, and the Danjiangkou reservoir area (Zhang *et al.*, 2013a; Dai and Zhang, 2013; Feng *et al.*, 2013; Huang *et al.*, 2012; Deng *et al.*, 2013; Li *et al.*, 2011b). In terms of hot spots, it is necessary to pay more attention to the ecologically fragile areas, where land use changes remarkably. Analyzing land use changes with the CLUE-S model in such areas makes a significant contribution to the research into global change.

Land use is a direct indicator of human interaction with the landscape. Land use cover may be defined as the primary landscape on the earth's surface influenced by both human activities and natural conditions. Landscape patterns may be defined as the quantitative description of the spatial composition and configuration of land use, which have both spatial and temporal characteristics. Landscape pattern indexes are proposed to quantitatively describe landscape patterns. Currently, many researches on landscape patterns are focused on analyzing landscape pattern changes in land use. However, landscape pattern indices have not been included in land use change models (Yang *et al.*, 2014).

Recently, remote sensing (RS) and geographical information system (GIS) have often been combined to assess land use change effectively. RS integrated with GIS provides an excellent framework for data capture, storage, processing and analysis (Wang *et al.*, 2010). In order to analyze land use changes systematically, landscape metrics have been integrated into LUCC models such as the CLUE-S model, Markov-CA (cellular automata) model, Markov-CLUE-S model and SD (system dynamics)-CLUE-S model (Zeng *et al.*, 2014; Wang *et al.*, 2014; Hu and Dong, 2013; Zhang *et al.*, 2014b; Hu *et al.*, 2013; Luo *et al.*, 2010; Zheng *et al.*, 2015). These methods have proved useful in the analysis and prediction of land use changes. The Markov-CA and CLUE-S models integrate landscape pattern indices (LPIs) to accomplish the simulation of land use dynamics, which can provide scientific bases for land use planning and management.

The Poverty Belt around Beijing and Tianjin, located in the north of Hebei Province, bordering with Beijing and Tianjin city, is a typical ecologically fragile area and comprises 31 administrative districts. This belt involves the whole of Chengde city and Zhangjiakou city, and part of Baoding city. Owing to the harsh natural environment, population pressure, and unreasonable human activities such as over logging and steep-slope farming, the Poverty Belt has been experiencing serious soil erosion, desertification of land, natural disasters and environmental deterioration, resulting in a vicious cycle of poverty. With the initiation of the integrated and coordinated development of the Beijing-Tianjin-Hebei region, the society and economy in the Poverty Belt will develop rapidly. The competition for land use among different industries and departments will intensify, and the contradiction between land supply and demand will become more marked. Although there have been many researches into the causes of, and solution to, the poverty of the Poverty Belt around Beijing and Tianjin, most of these have focused on development strategies and patterns relating to the regional economy, ecological compensation mechanisms, environmental deterioration, and the effects of land use changes (Sun *et al.*, 2014). Few researches on land use changes using LUCC models and scenario analysis have been conducted in relation to the Poverty Belt around Beijing and Tianjin. The main problems of this area are closely associated with land use changes, so the effective analysis and simulation of land use changes is critical to

rectifying many of the problems relating to the eco-environmental management of the Poverty Belt. There is an urgent need to simulate land use change scenarios driven by socio-economic and ecological protection policies to ensure sustainable land use planning and management in this particularly fragile and poverty-stricken environment.

The principal aims of this study were: (1) to propose an integrated model based on the Markov-CLUE-S model and LPIs; (2) to describe the temporal and spatial characteristics of land use change and identify the primary driving factors; and (3) to predict and simulate the evolution of land use patterns and landscape characteristics under different scenarios.

2 Study area

Zhangjiakou city, located in the northwest of Hebei Province, is a main part of the Poverty Belt and plays a key role in water conservation and ecological security for Hebei and Beijing. The region’s latitude ranges from 39°30’ to 42°10’N, while its longitude ranges from 113°50’ to 116°30’E. It covers an area of 3.68×10^4 km² (Figure 1), which includes 13 counties (Kangbao, Zhangbei, Guyuan, Shangyi, Huai’an, Wanquan, Xuanhua, Yuxian, Yangyuan, Zhuolu, Huailai, Chongli and Chicheng) and 4 districts (Qiaoxi, Qiaodong, Xuanhua and Xiahuayuan). Its elevation ranges from 320 m to 2841 m above sea level. The study area is located in the transition zone of the North China Plain and the Inner Mongolia Plateau, with elevations increasing from southeast to northwest. Zhangjiakou city is one of the most important areas for conserving water and providing an ecological defense for Beijing and Tianjin. Moreover, it is also a typical mountainous region with ecosystem vulnerability and sensitivity. It is characterized by a typical temperate continental monsoon climate. The mean annual precipitation is about 350 mm and the annual average temperature is 7.8°C, both of which have clear seasonal variations. However, with the growth in population and economic activities, land use in the study area has changed dramatically over the past two decades. The ongoing land use change shows obvious spatial differentiation characteristics. There is higher terrain in Bashang Plateau with a significantly undulating plateau landscape. While the landscape under the dam is characterized by hills and mountains, which has changed

Figure 1 Location of the study area and its elevation

dramatically with complex terrain, Zhangjiakou has undergone rapid urbanization and economic growth since the economic reforms of 1995, and by 2010 the total population of the city had reached 4.35 million according to China's sixth population census. With per-capita grain output up to 315 kg, the city's per-capita net income for farmers was 4119 yuan RMB, and its GDP was approximately 966.42 billion yuan then. Therefore, Zhangjiakou city is a typical representative of the Poverty Belt around Beijing and Tianjin.

3 Data and methods

3.1 Data sources and processing

The data used in this study comprised: (1) remote sensing (RS) data, including Landsat Thematic Mapper (TM) data images for 1989, 2000 and 2010; (2) data for soil organic matter (at a resolution of 100 m), derived from the Institute of Remote Sensing Applications, Chinese Academy of Sciences; (3) terrain data, supplied by the national digital geomorphic database at a 1:1,000,000 scale and the geospatial data cloud information platform (<http://www.gscloud.cn/>; accessed November 2015); (4) socio-economic data, derived from annual statistics of Zhangjiakou city and rural annual statistics of Hebei Province; and (5) road data (i.e., highways, railways, state roads) and river data, derived from the present land use map of Zhangjiakou city at a scale of 1:10,000.

The processing procedure for the source data was as follows: (1) Subjects for land use were determined from the original data. The data for land use cover was derived from historical TM data images by means of a user-computer interactive interpretation method and by conducting a field survey to check selected points in the field and on maps (Li *et al.*, 2006). Following geometrical image correction and geo-referencing, the average location errors were estimated at less than 30 m (about one pixel). Global accuracies of 86.82%, 88.92% and 90.46% were obtained for the 1989, 2000 and 2010 images, respectively. The Kappa coefficients were 0.84, 0.87 and 0.88, respectively for the same years. This accuracy met the recommended value (Ellis *et al.*, 2010), so the data was available for further study (Zhang *et al.*, 2013b). Based on the classification system reference to the national resources and environmental background dynamic remote sensing survey database, these land use maps of 1989, 2000 and 2010 were classified into eight land use types: farmland, garden land, forest land, grassland, residential and industrial land, transportation land, water body and unused land (Gong *et al.*, 2009). Simultaneously, considering the requirement for the CLUE-S model, the proportion of land use type must be over 1% of the total area (Zhang *et al.*, 2013a). Residential and industrial land and transportation land are classified as construction land. As a result, we chose farmland, garden land, forest land, grassland, construction land, water body and unused land as data sources for the CLUE-S model (Figure 2). Furthermore, ESRI ArcGIS 9.3 was used for the spatial analysis. Topographic maps were collected for establishing the digital elevation model (DEM) to obtain other data (i.e., slope, aspect) and also had a spatial resolution. (2) For the unification of the geo-reference of subjects, we used the Gauss Kruger (GK) projection coordinates with original longitude 117°E, original latitude 0°N, Xi'an geodetic datum and Krassovsky ellipsoid. (3) For the rasterization of the vector data, a one-sample Kolmogorov-Smirnov (KS) test was initially used to test the socio-economic data. The results showed that the asymptotic significance level was

above 0.05. They indicated that the population and per-capita net income of the farmers followed a normal distribution, and that other socio-economic data approximated to a normal distribution by log transformation. Therefore, the spatial distribution of socio-economic data could be obtained by spatial interpolation using the Kriging and natural neighbor methods. According to the requirements of the CLUE-S model combined with the actual location of Zhangjiakou city, many types of data layers were transferred to a grid format with a resolution of 300 m×300 m using the same projection coordinates, on which spatial logic and algebraic computations were calculated at each subject layer. Finally, all variables were normalized to allow a uniform measurement system (Locantore *et al.*, 2004).

Figure 2 Land use pattern in Zhangjiakou city throughout 1989–2010

3.2 Methods

3.2.1 Land use change measurement

Based on the research, the land use dynamic degree (D) is used as a base indicator to describe the rate of land use change. The land use dynamic degree is calculated as follows (Zhang *et al.*, 2014a):

$$D_i = \sum_{i=1}^N |S_{bi} - S_{ai}| / 2 \sum_{i=1}^N S_{ai} \times T^{-1} \times 100\% \quad (1)$$

where D_i is the dynamic degree of land type i in the period T ; N is the number of land use type; S_{ai} and S_{bi} represent the area of land that uses type i at the beginning and end of the period, respectively; and T is the study period. The land use dynamic degree is an index that can quantitatively describe the regional difference in the rate of land use change and predict the trend in land use change (Wang and Bao, 1999). Moreover, the land use dynamic degree reflects the comprehensive influence of socio-economic activities on land use changes.

The land use change intensity index (C) can be used to recognize the main types of land use change, which can be expressed as follows (Luo *et al.*, 2014):

$$C_i = A_i / \sum_{i=1}^N A_i \times 100\% \quad (2)$$

where C_i represents the intensity index of land use change type i ; A_i is the area of land use change type i ; and the value of C_i is between 0 and 1. The closer the value of C_i to 1, the more marked the land use change in a given region. Next, we can select the main types of land use changes by the rank of the value of C_i .

3.2.2 Markov model

The Markov model is used for state transition analysis and forecasting, and is suitable for predicting the conversion of land use in a given region (He *et al.*, 2011; Hu *et al.*, 2013). The Markov model is closely related to dynamic distributed-lag models and consists of two primary land components: the transition matrix and the transition probability matrix, which represent the number and the probability of land shifting from one land use type to other types in an observed period (Han *et al.*, 2015). The land use distributions at the beginning (S_t) and at the end (S_{t+1}) of a time period, as well as a transition probability matrix (P_{ij}) representing land use change that occurred during the defined period, are used to construct the Markov model, which is expressed as follows:

$$S_{t+1} = S_t \times P_{ij} \quad (3)$$

where S_{t+1} and S_t are the land use statuses at the time-points $t+1$ and t , respectively, and P_{ij} is a transition probability matrix satisfying the following conditions:

$$0 \leq P_{ij} \leq 1$$

$$\sum_{j=1}^n P_{ij} = 1$$

where i and j are the land use types at the time points $t+1$ and t , respectively.

3.2.3 Landscape metrics analysis

Landscape change is the visual sign of land use change (Feng *et al.*, 2010). A large set of landscape metrics has been developed recently (Su *et al.*, 2012). The capacity of landscape metrics to indicate an ecological process has been discussed by several researchers (Su *et al.*, 2012; Jones *et al.*, 2013; Fan and Myint, 2014; Tian *et al.*, 2014). The selection of landscape metrics in this paper was based on the capacity to reflect the characteristics of landscape patterns for the study area. The landscape fragmentation index (F), landscape shape index (LSI), perimeter-area fractal dimension index (PAFRAC), Shannon's diversity index (SHDI), interspersions and juxtaposition index (IJI), contagion index (CONTAG) and aggregation index (AI) were selected to describe the differences in landscape patterns in different scenarios. The landscape metrics above were calculated using Fragstats 4.2 software (Frazier, 2014).

3.2.4 The CLUE-S model and scenarios of land use changes

(1) The CLUE-S model

The land use simulation model CLUE-S (the Conversion of Land Use and its Effects at Small regional extent) utilizes the spatial dominant dynamic simulation model established by Wageningen University (Verburg and Veldkamp, 2004; Verburg and Overmars, 2009). The CLUE-S model includes a non-spatial demand module and spatially explicit land use

allocation module, which needs to consider the following four elements: land use requirements, location characteristics and suitability, spatial policies and restrictions, and land use type specific conversion settings (Luo *et al.*, 2010). The model can be developed to simulate land use change using empirically quantified relations between land use and its driving factors in combination with dynamic modeling of competition and interactions between the spatio-temporal dynamics of land use systems (Verburg *et al.*, 2002; Verburg and Veldkamp, 2004). To date, the CLUE-S model has been widely used in international researches, and many scholars have conducted simulation by controlling different scenario settings and the total demand for the corresponding land patterns (Batisani and Yarnal, 2010; Verburg and Overmars, 2009; Luo *et al.*, 2010; Wu *et al.*, 2014; Zheng *et al.*, 2015).

(2) Logistic regression

Generally, conversions of land use are expected to take place at locations that have the highest preference for a specific type of land use at a given moment. It can be calculated as a probability of a certain grid cell by logistic regression, as follows (Luo *et al.*, 2010; Zeng *et al.*, 2014; Wang *et al.*, 2014; Zheng *et al.*, 2015):

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_n X_{ni} \quad (4)$$

where P_i is the probability of a grid cell for the occurrence of the considered land use type i , the parameters X refer to the driving factors, n is the number of driving factors, and the coefficients β are estimated through logistic regression using the actual land use pattern as a dependent variable. β_0 is the constant coefficient. $\text{Exp}(\beta)$ values indicate the change in odds upon one unit change in the independent variable. When $\text{Exp}(\beta) > 1$, the probability increases upon an increase in the value of the independent variable. When $\text{Exp}(\beta) < 1$, the probability decreases. The relative operating characteristic (ROC) is used as a quantitative measure to evaluate the fit of the logistic regression model (Pontius and Schneider, 2001). The value of ROC ranges from 0.5 to 1.0. An ROC above 0.70 shows that the driving factors had a greater explanatory power for a certain land use type.

(3) Scenarios setting and land use elasticity

Based on local statistical socio-economic information from 1989 to 2010, and related land use planning and policies in Zhangjiakou city, we designed four variable settings of population increase, economic growth and urban development for the 10 years following 2010. Then, according to the combination of these settings, we defined four scenarios – namely, the land use planning scenario, natural development scenario, ecological-oriented scenario and farmland protection scenario – to predict land use demand for 2020 by applying various models, such as the Markov model, GM (1, 1) model and Grey prediction model. (1) *The land use planning scenario*: this scenario is the reference one, which may hasten the socio-economic development with an 11.7% annual increase in GDP rate during 2010–2020. Total population may increase by 3.82‰ annually from 2010 to 2020 and the urbanization rate will increase to 54.2% in 2020. Based on the planning targets of land use types from the Land Use Master Plan of Zhangjiakou (2006–2020), the structure of land use can be obtained by data interpolation according to the restrictions under land use planning in 2020. (2) *The natural development scenario*: this scenario almost keeps the present pace with socio-economic development, under which the GDP will increase by 12.0% annually and the total population will increase by 4.98‰ annually from 2010 to 2020. In addition, the ten-

dency of land use changes is predicted by applying time series methods and the GM (1, 1) model. (3) *The ecological-oriented scenario*: this scenario emphasizes protecting natural reserves, water resources, and biological diversity protection areas and requires all growth to be allocated outside these designated areas. In this scenario, the GDP will increase 10.0% annually and the forest coverage rate will add up to 34.0% in 2020. (4) *The farmland protection scenario*: in this scenario, basic farmland will be designated as a restricted area in which the farmland cannot be converted into other land use types. The GDP will increase 9.6% annually and the total population will increase by 4.53‰ annually from 2010 to 2020 under this scenario. The Grey prediction model and multi-objective programming model were used to simulate the land use demand for Zhangjiakou city in 2020.

The last decision rule concerns elasticity, which is an indicator of the conversion cost. For a given type of land use, the elasticity ranges from 0 (easy conversion) to 1 (irreversible change), and the value is positively related to the difficulty in converting this type of land use to other types (Wassenaar *et al.*, 2007; Batisani and Yarnal, 2010). The transition matrix of land use types is calculated to ensure that the relative elasticity is extrapolated from current data. Based on the reference data in the study area during 1989–2010, the values of conversion elasticity for different land use types were tuned so that they were suitable for the calibration of the model. According to the defined scenarios, specific conversion elasticity values of land use types were defined and implemented in the model during 2010–2020 (Table 1).

Table 1 Values of land use type conversion elasticity (ELAS) in Zhangjiakou city

Relative elasticity	Farmland	Garden land	Forestland	Grassland	Construction land	Water body	Unused land
Land use planning scenario	0.7	0.9	0.8	0.8	0.9	0.9	0.5
Natural development scenario	0.8	0.8	0.8	0.9	0.9	0.9	0.4
Ecological-oriented scenario	0.8	0.9	0.9	0.9	0.9	0.9	0.6
Farmland protection scenario	0.9	0.9	0.9	0.9	0.9	0.9	0.8

4 Results and analysis

4.1 Land use dynamics

In this section, we have described the characteristics of land use dynamics by changes in land use quantity structure and land use types.

4.1.1 Change in land use quantity structure

Land use has changed significantly over the whole period from 1989 to 2010 in Zhangjiakou city (Table 2). The main types of land use in Zhangjiakou city are farmland, forestland and grassland, which accounted for about 85% of the total area, while garden land and other land use types occupied a relatively small proportion of the total area. Apparently, the area of farmland, grassland, water body and unused land shrank significantly throughout 1989–2010, decreasing by 11.09%, 2.82%, 18.20% and 31.27%, respectively. By the end of 2010, the area of garden land, forestland and construction land all increased, expanding by 5.71%,

20.91% and 38.54%, respectively, relative to 1989. Over the two decades, farmland, forestland, construction land and unused land underwent marked changes. Specifically, farmland and unused land lost 1208.56 km² and 679.17 km², respectively, but forestland and construction land increased significantly by 1913.40 km² and 385.49 km², respectively.

Table 2 Land use changes in Zhangjiakou city throughout 1989–2010

Land use types	1989		2010		1989–2010	
	Area (km ²)	Proportion (%)	Area (km ²)	Proportion (%)	Change area (km ²)	Change rate (%)
Farmland	10900.30	29.61	9691.74	26.33	–1208.56	–11.09
Garden land	1412.81	3.84	1493.49	4.06	80.68	5.71
Forest land	9149.40	24.86	11062.80	30.06	1913.4	20.91
Grassland	11207.94	30.45	10891.42	29.59	–316.52	–2.82
Construction land	1000.24	2.72	1385.73	3.77	385.49	38.54
Water body	963.16	2.62	787.84	2.14	–175.32	–18.20
Unused land	2171.62	5.90	1492.45	4.05	–679.17	–31.27

The rate of land use change in different periods is illustrated by the land use dynamic degree (Table 3). From 1989 to 2000, the value of the land use integrated dynamic degree was 2.21%, which indicated that the rate of land use change was relatively slow. Meanwhile, from 2000 to 2010, the value of the land use integrated dynamic degree was 3.96%, which demonstrated that the rate of land use change had accelerated compared with that of the previous period and that the effects of socio-economic activities on the land use pattern had intensified. At the same time, the area of farmland, grassland, water body and unused land decreased gradually: the rate changed from 0.27%, 0.15%, 0.88% and 0.73% to 0.83%, 0.11%, 0.94% and 2.53%, respectively, while the area of garden land, forestland and construction land increased continuously. Furthermore, the rate of garden land decreased from 0.51% during the former period to 0.01% during the latter period, and that of forestland and construction land increased from 0.56% and 1.32% to 1.39% and 2.10%, respectively.

Table 3 Rate of land use change during different periods in Zhangjiakou city

Periods	Land use dynamic degree (%)							Integrated dynamic degree (%)
	Farmland	Garden land	Forest land	Grassland	Construction land	Water body	Unused land	
1989–2000	–0.27	0.51	0.56	–0.15	1.32	–0.88	–0.73	2.21
2000–2010	–0.83	0.01	1.39	–0.11	2.10	–0.94	–2.53	3.96

On the spatial scale, the expansion of construction land was strikingly clear from the urban center to the outskirts (Figure 2). The direction of construction land expansion was primarily along the highways and national roads, from administrative districts (i.e, Qiaoxi, Qiaodong, Xiahuayuan and Xuanhua districts) to Zhangbei, Yangyuan and Yuxian counties in the suburbs. Meanwhile, the area with growth in forestland mainly occurred in Bashang Plateau and its neighboring mountainous areas. In addition, the reduction in farmland was

mainly located in administrative districts and their surrounding regions in Zhangjiakou city. This indicated that the urban-rural fringe was the area most sensitive to urbanization. With the socio-economic development, the conflict between urban development and farmland preservation was found to be gradually increasing. The administrative districts and their surrounding regions were the hot spots witnessing much faster land use changes.

4.1.2 Change in land use types

By overlaying the 1989 and 2010 land use maps, the area changes in land use types in the study area over the two decades were further calculated (Table 4). Investigating from the conversion direction of land use types revealed that there was an obvious interaction among farmland, forestland, grassland, construction land and unused land. Changes mainly occurred in Bashang Plateau, river valley and mountainous areas. The total changed area throughout 1989–2010 was 4759.14 km², accounting for 12.93% of the study area. As shown in Table 4, land use transformation types were characterized by grassland to forestland, and by farmland to forestland and grassland. Among the transformation types of land use, the area of grassland to forestland, farmland to forestland, grassland to farmland, unused land to forestland, unused land to grassland, farmland to construction land, and farmland to garden land represented more than 80% of the area undergoing land use change. It was obvious that land use changes in 1989–2010 were dramatic and dominated by these seven transformation types. During 1989–2000, the conversions of grassland to forestland, and farmland to grassland, comprised the principal transformations in land use. Construction land expansion was mainly derived from farmland, and unused land was changed into forestland and grassland. However, throughout 2000–2010, the conversions of farmland and grassland to forestland accounted for 45.52% of the total area of land use changes, which was mainly affected by the Grain for Green Project. The conversion of farmland to forestland mainly occurred in Bashang Plateau and its neighboring mountainous areas around the junction between Chongli county and Chicheng county. The conversion of grassland to forestland mainly occurred in mountainous areas involving Chongli, Chicheng and Zhuolu counties. The conversion of farmland to construction land was distributed in administrative districts and their surrounding regions, and was caused by the urbanization process and the development of infrastructure.

Table 4 Main types of land use change in Zhangjiakou city throughout 1989–2010

1989–2000		2000–2010		1989–2010	
Transformation type	C _i (%)	Transformation type	C _i (%)	Transformation type	C _i (%)
Grassland to Forestland	29.61	Grassland to Forestland	27.69	Grassland to Forestland	29.15
Farmland to Grassland	18.67	Farmland to Forestland	17.83	Farmland to Forestland	16.26
Farmland to Forestland	8.05	Grassland to Farmland	10.96	Grassland to Farmland	11.30
Unused land to Forestland	6.65	Unused land to Grassland	10.09	Unused land to Forestland	8.44
Farmland to Construction land	6.21	Unused land to Forestland	8.55	Unused land to Grassland	8.21
Grassland to Farmland	5.17	Farmland to Construction land	5.67	Farmland to Construction land	6.04
Unused land to Grassland	4.16	Farmland to Garden land	3.65	Farmland to Garden land	4.21
Other 31 types	21.48	Other 43 types	15.56	Other 36 types	16.39
Total	100.00	Total	100.00	Total	100.00

4.2 Regression analysis of land use change

The CLUE-S model requires setting the relationship between location factors and different land use (Zheng *et al.*, 2015). In this study, a logistic regression model was used to explore the relationship between land use change and the related driving factors (Braimoh and Onishi, 2007). Certain driving factors – including landform (X_1), soil organic matter (X_2), elevation (X_3), slope (X_4), aspect (X_5), distance to the nearest river (X_6), distance to the nearest town center (X_7), distance to the nearest county center (X_8), distance to the nearest main road (X_9), distance to the nearest railway (X_{10}), population density (X_{11}), urbanization rate (X_{12}), economic density (X_{13}), fixed assets investment (X_{14}) and per-capita net income of farmers (X_{15}) – were selected for the purpose of analyzing the location suitability of a certain grid to be devoted to a land use type.

As shown in Table 5, the ROC test statistics for various land use types were all above 0.70. This revealed that the factors selected performed well in terms of explaining the land use pattern of the study area, but different driving factors resulted in some differences in various land use types. Slope was a negative explanatory variable for farmland, suggesting that steep areas with higher elevation and slope would experience a smaller probability of

Table 5 Logistic regression results of the spatial distribution of land use types in Zhangjiakou city throughout 2000–2010

Drivers	Farmland		Garden land		Forestland		Grassland		Construction land		Water body		Unused land	
	β	EXP(β)	β	EXP(β)	β	EXP(β)	β	EXP(β)	β	EXP(β)	β	EXP(β)	β	EXP(β)
X_1	-0.0228	0.9775	0.0117	1.0118	0.0250	1.0253	0.0117	1.0118	-0.0453	0.9557	-0.0730	0.9296	—	—
X_2	—	—	—	—	-0.0340	0.9666	0.0441	1.0451	—	—	—	—	—	—
X_3	-0.0009	0.9991	-0.0093	0.9908	0.0008	0.9992	0.0227	1.0229	-0.0026	0.9974	-0.0020	0.9980	0.0185	1.0187
X_4	-0.2729	0.7612	-0.4639	0.6288	0.0345	1.0351	-0.1669	0.8463	-0.197	0.8212	0.0276	1.0280	0.0415	1.0424
X_5	0.0006	1.0006	—	—	—	—	-0.0005	0.9995	—	—	—	—	—	—
X_6	-0.0065	0.9935	0.0568	1.0585	-0.0120	0.9881	0.0154	1.0155	-0.0163	0.9839	-0.0545	0.9470	—	—
X_7	-0.0083	0.9917	0.0435	1.0445	0.0100	1.0100	-0.0066	0.9935	-0.0189	0.9813	—	—	-0.0024	0.9976
X_8	-0.0285	0.9719	—	—	0.0269	1.0272	—	—	-0.1232	0.8841	0.0999	1.1051	-0.1026	0.9025
X_9	—	—	-0.0472	0.9539	0.0055	1.0055	0.0019	1.0019	—	—	0.0106	1.0106	-0.0159	0.9843
X_{10}	—	—	—	—	—	—	0.009	1.0091	—	0.9998	—	—	-0.0852	0.9183
X_{11}	-0.0009	0.9991	0.0015	1.0015	-0.0008	0.9992	-0.0007	0.9993	-0.0002	—	—	—	—	—
X_{12}	-0.0282	0.9722	0.0354	1.0360	-0.0297	0.9707	-0.0046	0.9954	—	—	—	—	-0.1562	0.8554
X_{13}	0.0007	1.0007	-0.0018	0.9982	-0.0002	0.9998	-0.0004	0.9996	0.0004	1.0004	—	—	0.0014	1.0014
X_{14}	0.0044	1.0045	0.0074	1.0074	-0.0034	0.9966	-0.0038	0.9962	0.0014	1.0014	—	—	0.0243	1.0246
X_{15}	-0.0001	0.9999	0.0004	1.0004	—	—	—	—	—	—	0.0002	1.0002	-0.0002	0.9998
Constant	-0.1458	0.8643	-12.7820	0.0001	-8.7846	0.0002	-9.8221	0.0001	-4.4890	0.0112	-2.0367	0.1305	-9.9562	0.0014
ROC value	0.896		0.878		0.870		0.862		0.915		0.835		0.798	

Note: The mark “—” denotes the factors removed. X_1 —landform, X_2 —soil organic matter, X_3 —elevation, X_4 —slope, X_5 —aspect, X_6 —distance to the nearest river, X_7 —distance to the nearest town center, X_8 —distance to the nearest county center, X_9 —distance to the nearest main road, X_{10} —distance to the nearest railway, X_{11} —population density, X_{12} —urbanization rate, X_{13} —economic density, X_{14} —fixed assets investment, X_{15} —per-capita net income of farmers.

farmland. The probability distribution of farmland decreased 0.2729 times when slope increased by one unit. Distance to the nearest river and distance to the nearest town center were positive explanatory variables of garden land, which was located in river valley, as well as the area around Guanting Reservoir. Slope became an important factor restricting the development of garden land in Zhangjiakou city. Soil was also an important factor shaping land use patterns. However, soil organic matter and slope played an important role in the distribution of forestland and grassland. Forestland was mainly distributed in areas with high elevation and slope as well as in certain remote regions, while grassland was distributed in Bashang Plateau, i.e., Kangbao, Shangyi, Zhangbei and Guyuan counties. Thus, many factors affected the distribution of construction land. Moreover, elevation, slope, distance to the nearest river, distance to the nearest town center, and distance to the nearest county center were negative explanatory variables of construction land. However, economic density and fixed assets investment were positive determinants of construction land. In addition, physical variables had different effects on the distribution of water body.

4.3 Simulation of land use demand

Based on the land use change from 1989 to 2010, the Markov model, GM (1, 1) model, Grey prediction model and multi-objective programming model were used to predict the demand for different land use types in 2020 according to the four future scenarios defined above. The prediction results were presented in Table 6. As shown in the table, there was significant difference in the demand for various land use types under different scenarios.

Table 6 The prediction results of land use under different scenarios (km²)

Year	Scenario design	Farmland	Garden land	Forestland	Grassland	Construction land	Water body	Unused land
2010	Actual land use	9691.74	1493.49	11062.80	10891.42	1385.73	787.84	1492.45
2020	Land use planning scenario	8721.00	1500.49	12932.90	10634.90	1535.00	725.48	755.70
	Natural development scenario	8288.79	1521.89	13061.68	10819.07	1744.20	722.96	646.88
	Ecological-oriented scenario	8844.12	1495.98	12478.14	10756.97	1521.87	728.66	979.73
	Farmland protection scenario	9429.17	1562.82	11543.47	10712.17	1516.48	712.91	1328.45

4.4 Simulation of land use scenarios

Based on the results of the logistic regression model and the transition matrix, the CLUE-S model was used to simulate the distribution of land use pattern in 2010. The accuracy of the temporal predictions of the CLUE-S model was analyzed based on the Kappa index by comparing the actual land use map in 2010 with the simulated map of land use pattern for Zhangjiakou city in 2010 (Figure 3). The Kappa statistic was employed to evaluate the accuracy of the model (Pontius, 2000). The value of the Kappa statistic was 0.902 throughout the temporal scale of 10 years during 2000–2010, which indicated that the consistency was good between the simulated map and the actual land use map. Moreover, this showed that the model was reliable for Zhangjiakou city and could be used to predict future land use patterns under different scenarios (Pan *et al.*, 2011).

Combined with the land use demand under different scenarios, land transfer rules, related driving factors and the calibrated model settings, the CLUE-S model was used to simulate the distribution of land use patterns of Zhangjiakou city in 2020 (Figure 4). As shown in

Figure 3 Land use map (a) and simulation map (b) of Zhangjiakou city in 2010

Figure 4 Land use simulation maps of Zhangjiakou city in 2020
(a) Land use planning scenario; (b) Natural development scenario; (c) Ecological-oriented scenario; (d) Farmland protection scenario

Figure 4, farmland, forestland and grassland were the main land use types. Farmland was primarily concentrated in mid river valley. Forestland and grassland were mainly distributed in Bashang Plateau and its neighboring mountainous areas, as well as southern mountainous areas. In addition, land use types underwent different dynamics under the four scenarios, as follows:

(1) *Land use planning scenario* (reference scenario, Figure 4a). Apparently, farmland, grassland, water body and unused land shrank significantly in 2020 compared with 2010, while garden land, forestland and construction land increased. During 2010–2020, forestland increased by 1900.61 km². The increase in forestland was mainly derived from farmland and unused land. Thus, the conversion of farmland to forestland was expected to be distributed in the Bashang Plateau and the southern mountainous areas, accounting for 49.63% of the total area in new forestland. In addition, the conversion area of unused land to forestland was 664.20 km², and was mainly located in the mountainous areas of Wanquan and Yuxian counties. Moreover, the expansion of construction land was concentrated in administrative districts and their surrounding regions.

(2) *Natural development scenario* (Figure 4b). There was an obvious expansion of construction land with a concentrated distribution in 2020. Compared with the land use pattern in 2010, construction land increased by 358.47 km², which had expanded by occupying farmland and unused land. The conversion of farmland to construction land was 195.48 km², which mainly occurred in districts and their surrounding regions. The conversion of unused land to construction land was 128.79 km², and had been concentrated in the regions along roads and river valley of Yangyuan county. Forestland increased by 1998.88 km². The area of the new forestland from farmland was 1142.62 km², which mostly occurred in the Bashang Plateau and mountainous areas around the junction among Zhangbei, Guyuan, Chongli and Chicheng counties as well as the junction between Zhuolu and Yuxian counties with high elevation. The area of new forestland from unused land in the mountainous areas of Huai'an and Yuxian counties, occurring mostly from 2010 to 2020, was 710.19 km².

The results of the simulation in the natural development scenario were similar to those in the land use planning scenario, but the changes in land use types were more fundamental. There were significant differences in most land use types, including farmland, forestland, grassland, construction land and unused land. In the natural development scenario, the area of farmland and unused land was 432.21 km² and 108.82 km² less, respectively, than that in the land use planning scenario, while the area of forestland, grassland and construction land was 128.78 km², 184.17 km² and 209.20 km², respectively, more than that in the reference scenario. On the spatial scale, some differences were found to be distributed in the Bashang Plateau and mountainous areas between the two scenarios. More farmland converted to forestland than the reference scenario in the Bashang Plateau and its neighboring mountainous areas, and much more farmland was used for construction in Qiaodong district. In addition, more conversion of unused land to construction land primarily occurred in Zhangbei, Yangyuan and Yuxian counties under the natural development scenario.

(3) *Ecological-oriented scenario* (Figure 4c). In this scenario, farmland and unused land shrank by 847.62 km² and 512.72 km², respectively, while construction land experienced slow expansion and forestland underwent an obvious expansion. During 2010–2020, forestland increased by 1415.34 km², which was mainly derived from farmland, grassland and unused land, with 709.20 km², 120.51 km², 455.22 km², respectively. The conversion of

farmland to forestland was mostly located in the hilly areas, river valleys and mountainous areas. The predicted grassland/unused land–forestland conversion areas mainly occurred in the following regions: the hilly area in Bashang Plateau, the northeast mountainous areas of Yanshan Mountain, and the southern mountainous area of Xiaowutai.

Less change in land use occurred under the ecological-oriented scenario from 2010 to 2020. This showed that there was less demand for garden land, forestland and construction land in this scenario. The area of forestland was 454.76 km² less than that in the land use planning scenario, which was mainly located in Shangyi, Zhangbei, Huai'an and Yuxian counties. Meanwhile, more demand for farmland, grassland and unused land was required in the ecological-oriented scenario. The area of farmland, grassland and unused land was 123.12 km², 122.07 km² and 224.03 km², respectively, more than that in the reference scenario. There was more grassland, which was mainly distributed in mountainous areas within Chicheng, Yuxian and Zhuolu counties. Moreover, more unused land was scattered in high-altitude areas in Shangyi, Zhangbei, Huai'an and Yuxian counties.

(4) *Farmland protection scenario* (Figure 4d). This study assumed that the land use was under a strict farmland protection policy from 2010 to 2020. Comparing the simulated results in 2020 with the actual map, the changes in farmland and forestland were relatively obvious. In particular, farmland was primarily converted to forestland, with an area of 225.63 km². Moreover, grassland/unused land–farmland conversion mostly occurred in regions of the surrounding districts (i.e., Huai'an county, Xuanhua county) and the mountainous area within Yuxian county. Similar to the above scenarios, farmland was concentrated in the flat areas. Construction land was scattered in Zhangjiakou city, which was mainly surrounded by farmland.

Compared with the land use planning scenario in 2020, this showed that there was less demand for forestland and more demand for farmland and unused land under the farmland protection scenario. Much more unused land existed in the mountainous areas of Huai'an and Yuxian counties. However, more farmland was scattered in the region around the junction among Guyuan, Zhangbei, Chongli and Chicheng counties. However, the conversion of farmland to construction land and forestland still existed in the mountainous areas of Huai'an, Chicheng, Chongli and Yuxian counties, which indicated that Zhangjiakou would continue to face pressure in farmland protection.

4.5 Landscape metrics analysis

The heterogeneity of landscape can be used to characterize the stability and safety of an ecological system (Feng *et al.*, 2010; Jones *et al.*, 2013; Wang *et al.*, 2014), which can be used to reflect the simulation results of land use patterns under different scenarios. Compared with the landscape pattern of land use in 2010, the study area will exhibit more homogeneity and its landscape pattern will become less marked in 2020, evidenced by the reduction in the fragmentation index (F) and landscape shape index (LSI), and the increase in the contagion (CONTAG) and aggregation index (AI) (Table 7). Grassland and unused land will become more fragmented, while other land use types will become less fragmented in 2020. A reduction in PAFRAC for farmland and water body indicates that patch shapes will tend to be simpler. However, an increase in PAFRAC and LSI of construction land will occur from 2010 to 2020 (Table 8).

Table 7 Landscape metrics of Zhangjiakou city under different scenarios

Land use scenario	F	LSI	PAFRAC	SHDI	IJI	CONTAG	AI
2010 Actual land use	0.0097	131.4746	1.5738	1.5691	73.8408	29.6276	59.4424
Land use planning scenario (Reference scenario)	0.0090	126.4539	1.5730	1.5875	73.9858	32.2885	61.0127
Natural development scenario	0.0089	126.6271	1.5768	1.5519	73.2345	32.5534	60.9583
Ecological-oriented scenario	0.0093	128.0227	1.5744	1.5706	72.5546	31.1907	60.5223
Farmland protection scenario	0.0095	129.8600	1.5750	1.5733	70.5517	30.0865	59.9485

Table 8 Class metrics of Zhangjiakou city under different scenarios

		Farmland	Garden land	Forestland	Grassland	Construction land	Water body	Unused land
2010 Actual land use	F	0.0055	0.0177	0.0068	0.0076	0.0447	0.0377	0.0181
	PAFRAC	1.6025	1.5709	1.5594	1.6022	1.4809	1.5045	1.4974
	LSI	127.6094	67.2558	126.8260	141.3391	82.5360	51.7500	57.0814
Land use planning Scenario (Reference scenario)	F	0.0048	0.0176	0.0057	0.0079	0.0427	0.0345	0.0204
	PAFRAC	1.5989	1.5712	1.5613	1.6038	1.4983	1.5014	1.5112
	LSI	118.6083	66.3977	123.0988	141.0610	85.2759	47.5944	44.5054
Natural development scenario	F	0.0048	0.0170	0.0054	0.0076	0.0417	0.0340	0.0182
	PAFRAC	1.6003	1.5693	1.5667	1.6028	1.5134	1.4991	1.5189
	LSI	116.2158	63.9960	125.3124	141.2334	90.3011	46.9441	40.1000
Ecological-oriented scenario	F	0.0049	0.0177	0.0059	0.0077	0.0434	0.0339	0.0214
	PAFRAC	1.5992	1.5727	1.5622	1.6033	1.5106	1.4971	1.5078
	LSI	119.4530	66.4690	123.6671	141.1055	89.5018	46.3911	50.6555
Farmland protection scenario	F	0.0052	0.0170	0.0066	0.0077	0.0435	0.0342	0.0195
	PAFRAC	1.6008	1.5731	1.5595	1.6031	1.4988	1.4941	1.5091
	LSI	124.5201	67.0455	124.7448	140.7728	85.5211	46.1638	56.3827

4.5.1 Landscape-level metric analysis

The results of landscape-level metrics analysis are shown in Table 7. There are many superior indices in land use planning scenarios, including the landscape shape index (LSI), fractal dimension index (PATRAC), Shannon’s diversity index (SHDI), interspersion and juxtaposition index (IJI) and aggregation index (AI). There are significant characteristics of landscape pattern at the landscape level in this scenario. LSI and PATRAC are at their lowest value in this scenario, indicating that the landscape is more regular. The natural development scenario reflects the relevant difference in the landscape pattern of land use. The fragmentation index (F) and contagion index (CONTAG) are the superior indices in this scenario, whose landscape is less fragmented with better spatial connectivity. It is indicated that appropriate human interventions can regulate the spatial form of land use effectively to avoid excessive dispersion of the landscape. The increases in SHDI, IJI and AI suggest that landscape diversity becomes more significant and the distribution of landscape patches tends to be accumulative. However, there is no superior index under an ecological-oriented scenario

or farmland protection scenario, in which the landscape pattern exhibits more fragmented and homogeneous. Given all that, the combination of land use types in land use planning scenarios is less marked than other scenarios. In this section, reductions in F and LSI and increases in CONTAG and AI indicate that landscapes become less fragmented under different scenarios. At the same time, the spatial structures of landscapes tend to be simpler, while shapes of landscape will become more regular in 2020 than in 2010. Moreover, the aggregation and connectivity of land use patterns will increase gradually. The complex changes in landscape patterns are examined with three metrics (i.e., PAFRAC, SHDI and IJI). In addition to SHDI, its increase indicates that the heterogeneity and diversity of landscapes increases under different scenarios, except with the natural development scenario.

4.5.2 Class-level metric analysis

Table 8 shows the results from the landscape pattern changes at class level under different scenarios. The land-use classes incorporated into the class-level metric analysis were farmland, garden land, forestland, construction land, water body and unused land. Fragmentation index (F), fractal dimension index (PATRAC) and landscape shape index (LSI) reveal important information about the landscape characteristics of each land use type under different scenarios. In the land use planning scenario, F and PAFRAC are at the highest values for landscapes of grassland and water body, indicating that their landscape patches become fragmented and more complex during 2010–2020. Furthermore, landscapes of forestland and construction land are characterized by the lowest values of LSI. This finding shows that the effective protection of landscapes of grassland and water body cannot be achieved by the total amount of control in the transition zone between the cropping area and the nomadic area. Considering the quantity demand of farmland and construction land, some guidance on the spatial changes in the major land use types by human factors must be enhanced to realize reasonable allocation of land resources and promote the coordinated development of socio-ecological systems (S-ESSs). Under the natural development scenario, the landscape is characterized by low fragmentation of land use types and more complex shapes of construction land and unused land with high PAFRAC value. In addition to forestland and grassland, LSI is at its highest value, indicating the concentrated condition. Owing to the economic development and Grain for Green Project in the study area, farmland is occupied by construction land and ecological land. The changes in land use types dominated by human activities have an important influence on the landscape pattern of land use in Zhangjiakou city. Under the ecological-oriented scenario, there is low fragmentation of landscapes of garden land and unused land. The landscape of ecological land gets effective protection, which contributes to the policy of the Grain for Green Project as well as the Sandstorm-Control Program. Under the farmland protection scenario, the landscapes of farmland, garden land, forestland and construction land exhibit more fragmented and heterogeneous. Moreover, patch shapes of farmland and garden land will become more complex and irregular than other scenarios in 2020. However, a reduction in the fractal dimension index (PATRAC) of grassland and water body suggests that their structures present simpler and more regular. According to the above analysis, the strict measures of farmland protection cannot effectively relieve the potential impact of the landscape pattern, which was caused by human activities in the environmental fragile zone.

5 Discussion

Land use changes are caused by both natural factors and human activities (Vitousek *et al.*, 1997; Liao *et al.*, 2011). Since 1989, human activities, such as population growth, rapid economic development, increased urbanization and land use policy, have had a major impact on land use changes in Zhangjiakou city. In addition, administrative policies and natural factors have played important roles in land use changes. From 1989 to 2010, the land use structure of Zhangjiakou city changed dramatically, as shown in Table 2. Land use changes were characterized by the decline in farmland, grassland, water body and unused land, and the increase in garden land, forestland and construction land. Throughout 1989 to 2000, ecological deterioration and farmers' poverty were the two critical problems of Zhangjiakou city. Owing to low productivity, population pressure and unreasonable human activities, the irrational land use mode of over-reclamation, overgrazing and deforestation prevailed in this area. The conversions of grassland to forestland and farmland to grassland constituted the main direction of land use changes. The economic development was at a lower level owing to unreasonable industrial structure and serious land desertification during the same period. As a result, the land use intensity and rate of land use change were much lower in Zhangjiakou city. All these indicated the characteristics of land use changes in farming-pastoral zones. At the same time, throughout 2000–2010, Zhangjiakou city experienced rapid socio-economic development and urbanization. The gross domestic product (GDP) increased by 296.06%, and the urbanization rate increased from 24.00% to 32.65%, during the same period. The poor transport infrastructures were further improved from 2000 to 2010, and the total roadways mileage increased from 5368 km to 19,234 km, with an increase of 13,866 km. Construction land (including residential land and transportation land) increased by 240.30 km² over the same period. The implementations of reform and opening-up policy in 1995 and the Grain for Green Project in 2000 had profound impacts on land use changes in Zhangjiakou city. The changes in land use intensified. Forestland and construction land increased dramatically, at a rate of 1.32% and 2.10%, respectively. As a result, grassland and farmland were more likely to convert to forestland in Bashang Plateau and mountainous areas. Construction land expanded by occupying farmland and grassland, and mostly occurred in administrative districts and their surrounding regions. Overall, the land use integrated dynamic degree increased from 2.21% during 1989–2000 to 3.96% during 2000–2010. Considering the socio-economic development and eco-environmental protection, as well as local government policies, four scenarios (land use planning scenario, natural development scenario, ecological-oriented scenario, farmland protection scenario) were designed to simulate land use changes in the study area. With the rapid growth in population and urbanization, and further implementation of the Grain for Green Project, forestland and construction land increased significantly, while farmland and unused land decreased dramatically under the natural development scenario. With the land use planning scenario, land use demands were related to the Land Use Master Plan of Zhangjiakou city (2006–2020), which highlighted farmland protection by strictly controlling the expansion of construction land. Forestland and construction land increased steadily, while the areas of farmland, grassland, water body and unused land were on the decline under this scenario. With the ecological-oriented scenario, there were wide changes in land use in Zhangjiakou city, which were mainly reflected

in farmland, forestland, grassland and unused land. The conversions of farmland, grassland and unused land to forestland were the principal transformation of land use under this scenario. In addition, policies aimed at the protection of farmland suppressed the increase in land use intensity and the expansion of construction land under the farmland protection scenario.

Landscape metrics can quantify landscape patterns and facilitate the comparison between different land use scenarios. Moreover, metrics can reveal important information about landscape patterns. As a result, landscape metrics have been widely used to analyze landscape patterns of land use changes as well as urban expansion, i.e., metropolitan areas (Jenerette and Wu, 2001; Luck and Wu, 2002; Weng, 2007; He *et al.*, 2011; Wu *et al.*, 2015), desert-oasis areas (Meng *et al.*, 2005; Li *et al.*, 2013; Li *et al.*, 2014), coastal areas (Wu *et al.*, 2013; Fan *et al.*, 2013; Hu and Dong, 2013) and arid inland river basins (Tian *et al.*, 2014; Zhang *et al.*, 2014c). In this study, landscape metrics such as F, LSI, PAFRAC, SHDI, IJI, CONTAG and AI were used to analyze landscape patterns under different scenarios. This revealed that the changes in landscape patterns under different scenarios in 2020 will tend to be less marked as human activities intensify. Fragmentation and irregularity of landscapes decreased from 2010 to 2020, while concentration and connectivity of landscapes were further improved. Owing to the rapid economic development, and further implementation of the Grain for Green Project, the landscape was characterized by homogeneity and connectivity under the natural development scenario. Land use pattern was more closely related to land use master plan and policies under the land use planning scenario. With increasing urbanization, the landscape became more regular in shape, and landscape diversity increased as well as aggregation under this scenario during 2010-2020. However, in the ecological-oriented scenario and farmland protection scenario, consideration of the responses to human activities, ecological land and farmland protections were the major goals. Fragmentation, heterogeneity and complexity were the most obvious characteristics of landscape changes. Overall, there were also spatial differences in landscape patterns in Zhangjiakou city, which were consistent with the basic pattern of socio-economic conditions and the trend toward changes in future land use pattern.

Owing to the complexity of the land use system, it is necessary to consider and combine different land use processes within a single modeling framework to model land use dynamics (Luo *et al.*, 2010). The CLUE-S model has been recognized as an excellent tool for simulating land use changes (Overmars and Verburg, 2007; Sohl and Claggett, 2007; Pan *et al.*, 2011; Hu *et al.*, 2013; Wang *et al.*, 2014; Zeng *et al.*, 2014). This model has been widely applied to the dynamic studies of land use changes in smaller-scale regions, especially the hot spots of LUCC research in China, such as sandy areas (Zhang *et al.*, 2003), tourism areas (Wang *et al.*, 2014), urban areas (Sheng *et al.*, 2008; Wu *et al.*, 2011; Zhang *et al.*, 2013b; Zheng *et al.*, 2015) and ecologically fragile areas (Li *et al.*, 2011b; Huang *et al.*, 2012; Xu *et al.*, 2013a). In this study, the Markov-CLUE-S model was used to analyze land use changes from both spatial and temporal dimensions. This model obtained the spatial characteristic information of land use changes by analysis tools using GIS. The model parameters were based on the historical land use data from 2000 to 2010 in Zhangjiakou city and were tested by comparing the simulation scenarios of land use with the actual land use in 2010 of the study area. The Kappa value was 0.902, indicating the reliability of the model simulation.

The results of land use simulation in 2020 showed the land use alternatives under four different scenarios in the future. The simulation results indicated that land use change was influenced by physical, locational, political and socio-economic factors. Moreover, to a large extent the selected factors can be used to explain land use allocation.

By using multi-temporal remote sensing data and statistical analysis, the CLUE-S model and landscape metrics analysis are combined to simulate the changes in landscape patterns under different scenarios in 2020, which is an efficient method, as proved by certain case studies (Wang *et al.*, 2014; Zhang *et al.*, 2014b; Zeng *et al.*, 2014). This research is a pilot study for applying a simulation model to explain land use dynamics in an urban fringe. The results of combining a Markov model, CLUE-S model and landscape pattern indices (LPIs) suggest that this integrated model has the capacity to reflect the complex changes in land use in Zhangjiakou city, which indicate that the approach can serve as a useful tool for analyzing related driving factors and estimating related effects of the land use dynamic. The integrated model developed in this research considers land use allocation factors including physical, locational and socio-economic attributes, which are comparatively comprehensive. However, the effects of various policy factors and unexpectedness of natural disasters are not considered in the simulation process. Consequently, improving the accuracy of socio-economic factors and reducing the influences caused by the uncertainty of natural disasters and regional policies are likely to become increasingly important in terms of simulating land use changes. Furthermore, it is well known that the land use change process is dynamic and results from the interaction between natural and socio-economic elements at different scales. The simulation of land use change and landscape metrics analysis rely heavily on scale, and results will vary with particle sizes (Røpke, 2005; Hu and Dong, 2013; Wu *et al.*, 2015). In this study, good results were achieved at a scale of 300 m×300 m in Zhangjiakou city. A further study could employ regional spatial factors and policy-related factors together in the simulation of further land use change in Zhangjiakou city, which could guide more informed decision making. In addition, multi-scale analysis of land use simulation and landscape pattern changes should be carried out to enhance the reliability of simulation in future research.

6 Conclusions

Based on the remote sensing data of Landsat TM images in 1989, 2000 and 2010, using a Logistic regression model, CLUE-S model and landscape metrics, this paper selected Zhangjiakou city – a representative area of the Poverty Belt around Beijing and Tianjin – as an example to simulate land use scenarios driven by different socio-economic and ecological policies and analyzed the landscape pattern dynamic change, aiming to provide useful information for decision-makers and planners to take appropriate land management measures in the study area. The results can be shown as follows:

(1) The land use integrated dynamic degree increased from 2.21% during 1989–2000 to 3.96% during 2000–2010. Comparing the period 1989–2000 with 2000–2010, the rate of farmland, grassland, water body and unused land changed from 0.27%, 0.15%, 0.88% and 0.73% to 0.83%, 0.11%, 0.94% and 2.53%, respectively. At the same time, the rate of garden land, forestland, and construction land changed from 0.51%, 0.56% and 1.39% to 0.01%, 1.32% and 2.10%, respectively. The administrative districts and their surrounding regions

were the hot spots in land use changes, where land use changed much faster.

(2) Land use changed significantly throughout 1989–2010. The total area experiencing land use change was 4759.14 km², accounting for 12.53% of the study area. Land use transformation was characterized by grassland to forestland, and by farmland to forestland and grassland. During 1989–2000, the conversions of grassland to forestland, and farmland to grassland, constituted the principal transformation of land use. However, throughout 2000–2010 the conversions of farmland and grassland to forestland constituted the principal transformations of land use. The land use changes mostly occurred in Bashang Plateau and river valleys from 1989 to 2010.

(3) The spatial distribution of land use types could be explained, to a large extent, by the driving factors. The results of land use simulation showed that the CLUE-S model conforms to reality with an accuracy of 90.2%, implying that this model is appropriate for simulating the temporal and spatial variations in the land use of Zhangjiakou city. Under the natural development scenario, the simulation of land use in 2020 indicated significantly rapid reductions in farmland and unused land due to human activities. Additionally, increases in forestland and construction land resulted from the Grain for Green Project and rapid socio-economic development. Under the land use planning scenario, farmland, grassland, water body and unused land shrank significantly, while garden land, forestland and construction land increased. The expansion of construction land had been concentrated in administrative districts and their surrounding regions. Under the ecological-oriented scenario, forestland increased by occupying other landscapes, such as farmland, grassland and unused land. The ecological land is mostly distributed in the river valleys and the mountainous areas. Under the farmland protection scenario, farmland was well protected and stable, and was concentrated in the flat areas. The expansion of construction land was restricted to some extent by farmland in this scenario.

(4) Compared with the actual landscape in 2010, the landscape patterns under the four scenarios in 2020 were found to be less marked. The fragmentation of land use landscapes decreased and landscape shapes became more regular, while the aggregation of landscape patches and connectivity of landscapes increased. There were significant differences among land use patterns under different scenarios. In the land use planning scenario, the landscape pattern tended to be more optimized. Shapes of landscape became more regular and the degree of landscape diversity and aggregation increased. The landscape became less fragmented and heterogeneous under the natural development scenario, as evidenced by the reductions in F and SHDI and the increase in CONTAG. At the same time, under the ecological-oriented scenario and farmland protection scenario, landscapes were characterized by fragmentation and spatial heterogeneity. Spatial differences in landscape patterns also existed in Zhangjiakou city in 2020.

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