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Scenario simulation of change of forest land in Poyang Lake watershed

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Abstract

Forest land is the largest carbon storage of the terrestrial ecosystem for its giant biomass and plays a very important and irreplaceable role in mitigating and adapting to the global climate change. Much attention has been paid to its function and role in alleviating and adapting to the global climate change, Poyang Lake watershed as one of the most important wetland nature reserve in the world is also one of the regions where forest land is most densely distributed in China. The authors have studied the spatial dynamics of the forest land in this region during the past 20 years based on panel data of four periods (1988, 1995, 2000, 2005), and comprehensively characterized its changing patterns under the macroscopic context of rapid economic growth, social change and technical progress. A simultaneous equations model was established and the significance ranking of various factors was obtained in order to analyze the driving mechanism of the spatial-temporal process of the forest land. Three scenarios, i.e. economic priority, ecologic conservation and constant scenarios were designed according to the driving mechanism and trends of economic, policy and technical progress. The module functions of Dynamic of Land System (DLS) were employed and extended to develop possible scenarios of spatial-temporal explicit expression of the forest land.

Key words: Carbon sequestration, Change of forest land, Poyang Lake watershed, Scenario simulation, DLS;

1. Introduction

Carbon sequestration has become the hot topic in many fields with the development of global warming. The role of forest in carbon sequestration has received more and more attention from the international community, the contribution of the forest carbon sequestration to alleviating the global warming has been recognized in the Kyoto protocol (IPEC, 2000); besides, forestation for carbon sequestration has widely carried out because it is much

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cheaper to obtain the CO2 emission right by planting forest than by directly reducing CO2 (UNFCCC, 1999) and it will not have much negative impact on the pattern and speed of economic development (Xi and Li, 2006). So it is an effective way to adapt to the climate change by expanding the forest area and improving the forest quality.

Changes in land use and land cover are key factors for global environmental change (Turner et al., 1995) and the forestry development is of great significance to alleviating the global warming. Forest land is the largest carbon storage of the terrestrial ecosystem for its giant biomass and plays a very important and irreplaceable role in mitigating and adapting to the global warming. The Kyoto protocol suggests that management of natural terrestrial carbon sinks, primarily forestation and reforestation at the global scale, can increase sink strength and thus reduce atmospheric CO2. However, eighty percent of the forests that originally covered the earth have been cleared, fragmented, or otherwise degraded. The forest degradation at the global and regional scales has aroused wide concern of scholars at home and abroad and related national organization (FAO, 1992; FAO, 1997; Mertens et al., 2000; Scrieciu, 2007; Lorena and Lambin, 2009).

The authors have studied the change of forest land in Poyang Lake watershed during the past 20 years, which can lay a firm foundation for further study of its carbon sequestration potential. A simultaneous equations model is established and the significance ranking of various factors is obtained in order to analyze the driving mechanism of the spatial-temporal process of the forest land. Scenario design is used to study the possible changing trend of the forest land in the study site according to the driving mechanism and trends of economic, policy and technical progress. The module functions of Dynamic of Land System (DLS) are employed and extended to develop possible scenarios of spatial-temporal explicit expression of the forest land. Suggestions can be provided to decision-makers by studying the possible change of forest land in Poyang Lake watershed under the influence of various influencing factors and exploring the changing direction of forest land under different scenarios, which is of great significance to increasing regional carbon storage potential and alleviating the global warming.

2. Data and handling

A database was first built, which included the land use data and the factors that might affect the process of land-use conversion from 1988 to 2005. The land use data was interpreted by Chinese Academy of Sciences according to the Landsat Thematic Mapper (TM) and/or Enhanced Thematic Mapper (ETM) images in 1988, 1995, 2000 and 2005 at a scale of 1:100,000 (Liu et al., 2005). The interpretation accuracy of land use data is as high as 92.7%. Only the first class land use types, i.e. cultivated land, forest land, grassland, water area, built-up area and unused land are taken into account in the simulation; the secondary land use types are first integrated into the first class land use types so as to simplify the simulation. The land use data is converted into binary data, representing the existence of one certain land use type in the cells with “1” or “0” (Zhan et al., 2010).

The driving factor data can be categorized into terrain and landform data, meteorological data, soil data, location data and socioeconomic data (Table 1). The terrain data was derived according to the Digital Elevation Model (DEM) at a scale of 1:250,000 in Jiangxi Province. The meteorological data was derived from China Meteorological Bureau and finally interpolated onto the climatic surface data at 1 km×1 km grid scale with the gradient plus inverse distance squares method (Mardiskis et al., 2005). The socioeconomic data in the year of 1988, 1996, 2000 and 2005 were derived from the census data of Jiangxi Province. The socioeconomic data was then disaggregated onto the grid with the method and process of pixelizing the statistical population data (Deng et al. 2004; Jiang and Wang. 2002).

Table 1. Driving factor data of change of forest land in Poyang Lake watershed

Categories	Driving factors	Unit	Variables	Mean	S.D
Terrain and landform data	Elevation	m	dem1k	251.64	229.43
	Terrain slope	°	slo_f	2.29	2.95
	Hilly region	-	lfm_1	-	-
	Plain	-	lfm_2	-	-

	Platform	-	lfm_3	-	-
Meteorological data	Cumulative temperature above 0℃	1000℃	ct0_f	6.16	0.48
	Annual average temperature	℃	ta_f	16.41	1.34
	Annual average precipitation	1000mm	pa_f	1.63	0.11
Soil data	Soil organic content	%	soil_org	3.08	0.91
	Soil pH	-	soil_ph	4.69	0.759
	Loam content	%	loam	25.99	4.68
Location data	Distance to the expressway	km	d2express	18.99	14.82
	Distance to provincial highway	km	d2highw	153.64	78.44
	Distance to provincial capital	km	d2pvcap	173.27	82.05
	Distance to other road	km	d2otherw	16.28	11.56
Socioeconomic data	Population	person	pop	245	8.01
	GDP	yuan	gdp	109.9	8.046

3. Methodology

3.1. Change of forest land in Poyang Lake watershed

Poyang Lake watershed, which covers 97.2% of Jiangxi Province, is one of the most important wetland nature reserves in the world as well as the regions where forest land is most densely distributed in China. The rich forest resource in this region forms giant carbon stock and plays an important economic and ecological role; the great forest area and forest stock determine the important role of Poyang Lake watershed in the national forest carbon sequestration. Natural environment allocates the distribution of forest land in Poyang Lake watershed, but the socioeconomic factors also influence the change of forest area to a certain extent. The forest land in Poyang Lake watershed has changed greatly with the rapid economic development. The forest land in Poyang Lake watershed was once seriously damaged, but it has gradually recovered. According to the remotely sensed data, the forest area in Poyang Lake watershed increased by 147 km^2 from 1988 to 1995 and 127 km^2 from 1995 to 2000; but the increasing pace has gradually slowed down with the economic development and population growth; the forest area in 2005 is only 87 km^2 more than it was in 2000. The newly increased part of forest land were mainly converted from cultivated land and grassland, which accounted for approximately 80% and 14% of the newly increased forest land; the lost part of forest land was also mainly converted to cultivated land and grassland, which accounted for about 82% and 13% of the lost forest land. Therefore, the change of forest land in Poyang Lake watershed was characterized by the mutual conversion between the forest land and the cultivated land and grassland.

3.2. DLS

The DLS model is the collection of a set of application programs used to simulate the changing process of land system. It is an effective way to simulate the spatial-temporal succession patterns of regional land systems to assist the land-use planning and land management decision-making. DLS mainly consists of three modules, i.e. the analysis module of driving forces of land distribution, scenario analysis module and spatial explicit allocation module (Deng et al., 2007). The analysis module of driving forces of land distribution aims to represent the spatial statistical relationship between the land distribution and driving factors and mainly measures the influence of driving factors on the distribution of different land use types; the scenario analysis module provides the change of demand for each land use type during a given period, with time steps of one year; the spatial explicit allocation module is mainly based on a spatial regression analysis of the influence of socio-economic and biophysical driving factors on the changes of land systems at the pixel scale, it realizes the spatial allocation of land use dynamics. The simulation process of DLS is shown in Fig. 1.

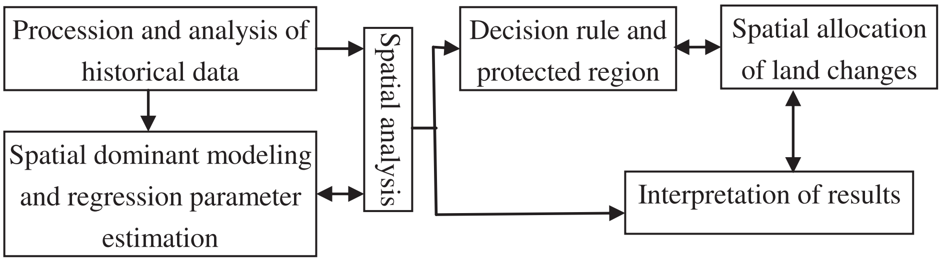

Fig. 1. Simulation process of DLS

3.3. Simulation based on DLS

There are mainly three processes in the simulation of spatial-temporal pattern change of forest land in Poyang Lake watershed, i.e. the spatial regression analysis, demand analysis of different land use types and spatial allocation of land use changes.

- Spatial regression analysis

The spatial regression analysis aims to determine the statistical relationship between the quantitative changes and spatial dynamics of land use types, figure out the driving factors and determine the weight coefficient matrix of driving factors of land use change (Pontius et al., 2001; Bai et al., 2005). The Logistic regression was used to estimate the probability of the existence of one certain land type in the cells with the estimation formula was as follows.

$$Log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \cdots \beta_n X_n \quad (1)$$

where P_i is the probability of existence of one certain land type in the cells under given driving factors; $X_1, X_2, \ldots, X_n$ represent the driving factors of different categories such as the climate, landform, location, population, economic growth and policy; $\beta_1, \beta_2, \ldots, \beta_n$ are coefficients of regression analysis of driving factors for further estimation; β_0 is the constant.

- Scenario design

The scenario design manages to determine the demand for the area of different land use types at the regional scale, i.e. calculate the dynamic change of demand for the area of different land use types under the macro background of population growth and economic development and predict the trend of structural change of land use. There are many methods to design the scenario of land use change, including the easy trend extrapolation and the relatively complicated economic mode; different scenarios of land use change in the next 15 years were established by integrating the analysis of historical data of land use in Poyang Lake watershed and the estimation result of spatial regression analysis in this research.

- Spatial allocation of land use change

Based on the weight coefficients of driving factors and the possible scenarios, the spatial allocation of land use change distributes the quantitative change of land use to spatial location by combining the analysis results of driving force analysis of land system changes. The decision rule of structural change of land use is needed in the spatial allocation of land use change; the value of decision rule is between zero and one, the bigger the value is, the more difficult the conversion of one certain land use type to another land use type is, and vice versa. In this research, the decision rule of cultivated land, forest land, grassland, water area, built-up area and unused land were set to be 0.6, 0.8, 0.5, 0.9, 1.0 and 0.4, respectively.

4. 4 Result

4.1. Result of spatial regression analysis

The laws of influence of driving factors on the spatial distribution of land use types can be quantified by the spatial regression analysis between the spatial distribution of land use types and the driving factors. The result of the spatial regression analysis is checked with ROC (Relative Operating Characteristics) proposed by Pontius et al (Pontius, 2001; Pontius et al., 2004); ROC of all the land use types except grassland exceeded 0.8, which indicated the driving factors are of good explanatory capacity. The result indicates that the landform plays a key role in the distribution of forest land, especially the hilly region; while the population growth and GDP increase will have a negative impact on the distribution of forest land (Table 2).

Table 2. Weight matrix of driving factors

Driving factors	Cultivated land	Forest land	Grassland	Water area	Built-up area	Unused land
ct0_f	0.179	0.155	-0.214	-0.045	0.233	0.856
ta_f	-0.123	-0.096	0.038	0.176	-0.246	0.651
pa_f	-0.915	2.7	-3.387	-2.766	-0.794	-3.865
dem1k	-0.004	0.001	0.001	-0.013	-0.005	0.0002
loam	-0.003	-0.026	0.002	0.02	-0.001	0.011
slo_f	-0.078	0.073	-0.026	-0.165	-0.105	-0.585
lfm_1	-1.090	1.295	-0.283	-0.933	-1.003	0.336
lfm_2	-0.713	0.993	0.527	-1.531	-1.17	0.490
lfm_3	0.371	0.259	0.334	-1.276	-0.278	1.449
soil_org	0.173	0.064	-0.061	-0.141	0.092	0.092
soil_ph	0.024	0.021	0.005	-0.038	0.019	0.042
d2express	-0.007	-0.002	-0.007	0.01	0.0001	0.066
d2highw	0.002	-0.005	0.008	-0.002	0.002	-0.013
d2pvcap	-0.001	0.007	-0.005	0.006	0.0002	-0.015
d2otherw	0.001	-0.006	-0.004	0.011	-0.012	-0.015
pop	0.069	-0.403	-0.094	-0.112	0.053	-0.8473
gdp	-0.047	-0.011	0.049	0.036	0.018	-0.070
Constant	1.314	-4.667	2.653	1.743	-0.312	-13.909
ROC	0.805	0.866	0.669	0.897	0.883	0.981

4.2. Scenario analysis

Scenario analysis is used to study the possible land use change in Poyang Lake watershed in the next 15 years. Three possible scenarios of land use change in Poyang Lake watershed in the next 15 years, i.e. the baseline scenario, environmental protection scenario and economic development scenario, are constructed on the basis of the results of spatial regression analysis and study of the laws of historical structural change of land use in Poyang Lake watershed. The demand for forest land under different scenarios is listed in Table 3.

- Baseline scenario

The baseline scenario takes into account the current changing trend of each land use type, based on which the change of forest land is analyzed. The baseline scenario is constructed on the basis of the historical statistical data and current socioeconomic development in Poyang Lake watershed, which can reflect the pattern succession of land use following the historical development trend and explore the future land use structure under the further implementation of economic reform policies related to land use.

- Economic development scenario

The economic development scenario is designed in sight of the relatively backward economic development in Poyang Lake watershed. The economic development scenario mainly takes into account that the regulation policy of industrial structure and technical progress will promote the rapid population growth and economic development; under this scenario the population growth rate and GDP increase rate will be one time higher than they are under the baseline scenario. More cultivated land will be converted into built-up area rather than forest land, the expansion of built-up area will accelerate by times under the economic development scenario.

- Environmental protection scenario

The environmental protection scenario is designed in sight of deforestation and soil erosion in Poyang Lake watershed in this research. Poyang Lake watershed is an important soil and water conservation area where it is rich in forest resource; the forestry policy plays an important role in the structural change of local land use, the environmental protection scenario mainly considers the influence of returning cultivated land to forest land on the land use change.

Table 3. Demands for forest land under the three scenarios

Year	Baseline scenario	Environmental protection scenario	Economic development scenario
2010	10425754 ha	10520917 ha	10461049 ha
2015	10434503 ha	10581503 ha	10490675 ha
2020	10438280 ha	10618231 ha	10507494 ha

4.3. Results under different scenarios

The model parameters were reconfigured on the basis of the three scenarios and the demand for each land use type under different scenarios; the change of forest land during 2005 and 2020 was simulated with DLS and the simulation maps were produced. The regions where the forest land changes significantly can be found by comparing the change of forest land under the three scenarios, which can provide reference information for the protection and management of forest land.

- Results under the baseline scenario

The forest land will change following the historical trend under the baseline scenario, mainly expanding or shrinking around the existing forest land as the time goes (Fig. 2) The newly increased forest land is mainly converted from the cultivated land, grassland and water area, which account for 64.5%, 14.2% and 17.9% of the newly increased forest land, respectively; the lost forest land is mainly converted into cultivated land, water area and built-up area, which account for 23.5%, 29.9% and 46.6% of the lost forest land, respectively. The result of the spatial allocation of change of forest land indicated that the forest land will reduce intensively in the regions around Poyang Lake, e.g. Nanchang municipality and the southeastern part of Jiujiang municipality, besides the southern part of Pingxiang municipality; while in other regions such as Shangrao municipality, the forest land only shrinks around the existing forest land; the forest land will increase intensively in the border area and middle part of some municipalities, for example, the middle and southern parts of Shangrao municipality, southwest part of Fuzhou municipality, the southeast part of Ganzhou municipality and the southern part of Yichun municipality; besides, the forest land also increases greatly near Jiujiang City, where it is Lushan Nature Reserve.

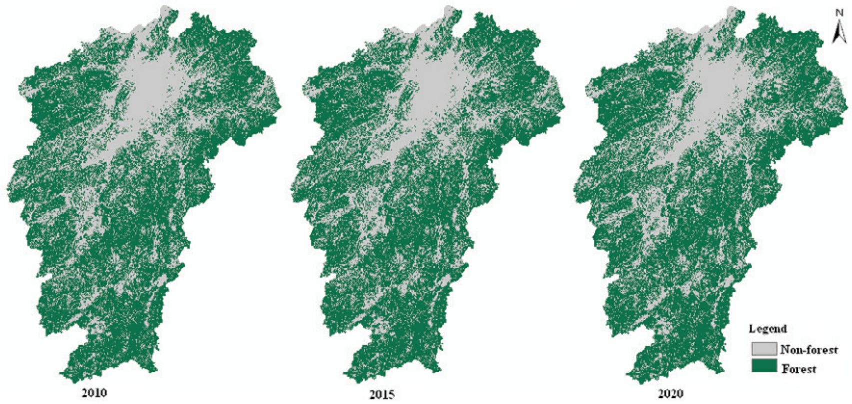

Fig. 2. Forest land in Poyang Lake watershed under the baseline scenario during 2010-2020

- Results under the environmental protection scenario

The forest land will increase more rapidly under the environmental protection scenario (Fig. 3). The newly increased forest land mainly comes from the cultivated and water area, which account for 81.1% and 15.1% of the newly increased forest land, respectively. The lost forest land is mainly converted into built-up area and water area, only very little forest land will be converted into cultivated land. The result of spatial allocation indicates that the forest land will increase intensively around Lushan Nature Reserve to the south of Jiujiang City and in the southern part of Jiujiang, southwest part of Yichun municipality where the forest land increases along the border area of the counties, the eastern part of Shangrao municipality, the southwest border area of Poyang Lake watershed, e.g. the western boundary of Ganzhou municipality and Ji'an municipality, the border area of Ganzhou municipality and Fuzhou municipality and the middle part of Pingxiang municipality; the forest land will reduce intensively in the northeast part of Jiujiang municipality, especially the northern part of Changdou county, beside the middle part of Pingxiang municipality; the forest land mainly reduces near the border area of Nanchang municipality; the forest land will shrink dispersedly around the existing forest land in Shangrao municipality.

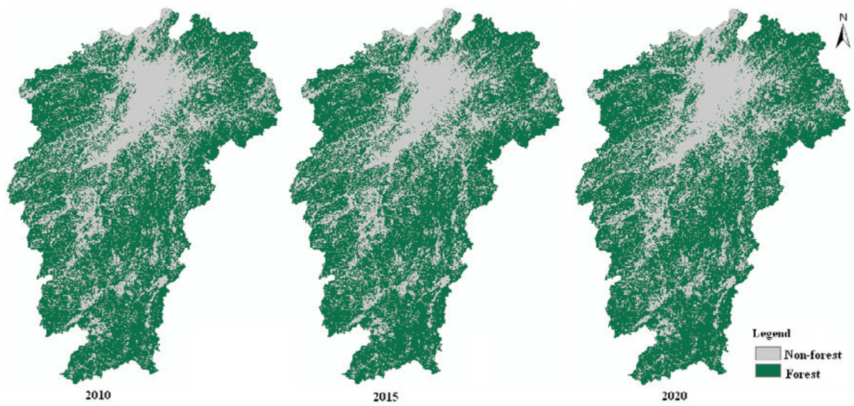

Fig. 3. Forest land in Poyang Lake watershed under the environmental protection scenario during 2010-2020

- Results under the economic development scenario

The forest land will increase relatively slowly under the economic development scenario due to the rapid expansion of built-up area (Fig. 4). The newly increased forest land is mainly converted from cultivated land, grassland and water area, which account for 822 ha, 303 ha and 179 ha, respectively; the lost forest land is mainly converted into built-up area and water area, which account for 130ha and 69ha, respectively. The result of spatial allocation suggests that the forest land will increase intensively in the northwest part of Yichun municipality, mainly along the border area of counties and the border area of Yichun municipality and the western part of Jiujiang municipality, the eastern part of Shangrao municipality, southwest part of Fuzhou municipality, northern part of Ganzhou municipality, mainly along the border area of Lean county and Yihuang county, the western and southeast parts of Ganzhou municipality. The forest land will reduce in the regions around Jiujiang City and Duchang county, Pingxiang municipality and the border area of Nanchang municipality.

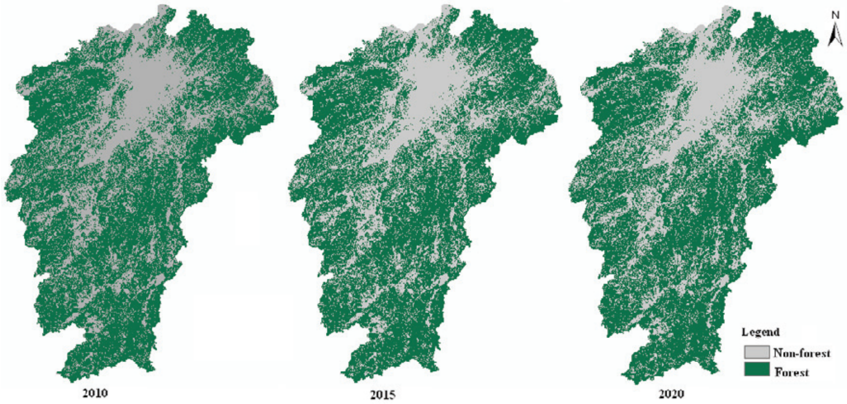

Fig. 4. Forest land in Poyang Lake watershed under the economic development scenario during 2010-2020

5. Conclusion and discussion

The historical change of the forest land in Poyang Lake watershed during the past 20 years was studied and comprehensively characterized. The change of forest land in Poyang Lake watershed in the next 15 years is simulated with DLS in this research. Three scenarios of change of forest land are designed to study the possible change of forest land in the next 15 years. The research result indicates that the change of forest land in Poyang Lake watershed is characterized by the mutual conversion between the forest land and the cultivated land and grassland during the past 20 years.

The simulation result indicates the forest land will increase most rapidly under the environmental protection scenario and most slowly under the economic development scenario. The result suggests the newly increased forest land will be mainly converted from cultivated land and water area and the lost forest land will be converted into water area and built-up area. The spatial regression analysis shows that the landform plays a key role in the distribution of forest land; the population and economic development have negative impacts on the distribution of forest land. The forest land mainly reduces intensively in these regions around Poyang Lake such the southeast part of Jiujiang municipality, Nanchang municipality, where there is a lot of cultivated land, the population is dense and the economy is relatively developed and the human disturbance on the forest land is serious; the forest land increases intensively in the middle part and border area of some municipalities, where the forest resource is rich, the economic development is relatively backward and the human disturbance on the forest land is relatively slight; the forest land generally expands or shrinks around the existing forest land in other regions except the regions near Jiujiang City, where the existence of Lushan Nature Reserve promotes the expansion of forest land.

The result of scenario simulation can provide decision-makers with important reference information for decision making according to the influence of various driving factors and the changing trend of forest land under different scenarios. Corresponding measures and policies can be formulated for different regions according to the research result so as to promote the expansion of forest land, which is of great significance to increasing regional carbon storage potential and alleviating the global warming; for example, it is an effective way to establish nature reserves to reduce the influence of economic development on the forest land in these regions where the forest land reduces intensively.

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