Land Use and Land Cover Change of Hulun Lake Nature Reserve in Inner Mongolia, China : a Modeling Analysis

Wang, Guoqiang
College of Water sciences, Beijing Normal University

Song, Jing
College of Water sciences, Beijing Normal University

Xue, Bao-Lin
College of Water sciences, Beijing Normal University

Xu, Xinyi
College of Water sciences, Beijing Normal University

他

https://doi.org/10.5109/22075

出版情報：九州大学大学院農学研究院紀要. 57 (1), pp.219-225, 2012-02. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **57** (1), 219–225 (2012)

Land Use and Land Cover Change of Hulun Lake Nature Reserve in Inner Mongolia, China: a Modeling Analysis

Guoqiang WANG[1], Jing SONG[1], Bao–Lin XUE[2,*], Xinyi XU[1] and Kyoichi OTSUKI[2]

Laboratory of Ecohydrology, Division of Forest Sciences, Department of Agro–environmental Sciences,
Faculty of Agriculture, Kyushu University, Fukuoka 811–2415, Japan
(*Received October 31, 2011 and accepted November 9, 2011*)

Based on three–year remote sensing data and cellular automata (CA)–Markov model, this study analyzed the temporal and spatial variation features of land use and land cover change in Hulun Lake Nature Reserve from 1999 to 2007. The result indicated that during the period between 1999 and 2007, there had been relatively great changes in land use type in Hulun Lake Nature Reserve, with ecological problems such as grassland degradation and water area shrinkage, becoming increasingly serious. Via analyzing the area variations of various land use types and the historical statistics of Hulun Lake's water level during this period, the study found that the water use of the upstream by the population pressure and economy development might be related with the decline in Hulun Lake's water levels which caused the increase in the sandy area. This kind of information is necessary for the land management of the area and will help in the ecosystem conservation in future.

Key words: cellular automata, Hulun Lake, land use and land cover, Markov

INTRODUCTION

It is widely accepted that land use and land coverage change (LUCC) is one of the most essential issues in the environmental changes (Turner *et al.*, 1995; Lambin *et al.*, 2001). Both natural and anthropogenic LUCC can significantly impact the earth ecosystem functioning (Lambin *et al.*, 2001; Lambin *et al.*, 2003). Many researches showed that LUCC could influence the biodiversity through the loss of habitat (Falcucci *et al.*, 2007), change the water balance and climate (Taylor *et al.*, 2002; Marshall and Randhir 2008) and also cause the land degradation at regional and global scales (Lambin and Strahler 1994a, 1994b; Lambin *et al.*, 2001). In China, LUCC is very intense due to the large population and economical pressure (Reid *et al.*, 2000; Vega *et al.*, 2009). Therefore, it is necessary to understand when, where and how the LUCC occurs, continues and influences on environment and ecosystems at different temporal and spatial scales.

Researches on LUCC mainly focus on effects of urbanization on the surrounding environment in China (Weng 2002; Wu *et al.*, 2006; Fan *et al.*, 2008). However, researches paid attention to the LUCC for grassland in semi–arid and arid areas are relatively few in China (Guo and Zhang 2009; Guo *et al.*, 2010) even though the grassland biome occupy about 30% of the total area of China (Piao *et al.*, 2006; Piao *et al.*, 2007). To understand how the grassland interacted with the human activity and the climate change is necessary for the sustainable development of the grassland ecosystem and the functional service for the social economy development.

Satellite data combined with GIS method has been widely used in monitoring LUCC in these days (Lambin and Strahler 1994a; Logsdon *et al.*, 1996; Loveland *et al.*, 2000). By integrating the multi–temporal and multi–spatial remote sensing data, this method has the advantage of low cost and synchronous detection of where and how the LUCC was developed. In addition, the historic data make this method has a potential to detect the driving force for the LUCC for different temporal and spatial scales (Janssen and van der Wel 1994; Lambin and Strahler 1994a; Lambin *et al.*, 2003).

In this study, with the aid of remote sensing and GIS, we try to quantify the LUCC in Hulun Lake Nature Reserve grassland in northern Inner Mongolia, China. The Hulun Lake Nature Reserve grassland is a reserved grassland to be least influenced by the human activity. Thus, it is an ideal place to investigate the LUCC transition in response to the climate change in the area strongly influenced by the aeolian erosion (Guo *et al.*, 2010). Major objectives of the research include: 1) to investigate the temporal and spatial dynamics of the LUCC, i.e. when and where the LUCC occurred; 2) to identify the major transition types, i.e. how the vegetation types transited and 3) to project the future patterns of land use for this area by a cellular automata (CA)–Markov model.

MATERIALS AND METHODS

Study area

Hulun Lake Nature Reserve is located at the west part of Hulunbeier League, within the north–eastern region of Inner Mongolia Autonomous region, lying on the borders of three countries, namely, China, Mongolia and Russia (47°45′50″~49°20′20″N, 116°50′10″~118°10′10″E). The total area of the reserve is around 7,400 km^2 with multiple ecosystems including lakes, grasslands and

[1] College of Water sciences, Beijing Normal University, Xinjiekouwai Street 19, Beijing 100875, China
[2] Kasuya Research Forest, Kyushu University, Sasaguri, Fukuoka 811–2415, Japan
* Corresponding author (E–mail: xuebaolin@forest.kyushu–u.ac.jp)

sandy lands, etc. The area has a mid–temperate semi-arid continental climate with the dominance of mid–temperate zone characterized by drastic changes in winter and summer. The precipitation is concentrated in summer, with annual precipitation of 247~319 mm. The average annual relative humidity is 68%. The arid climate with the strong wind makes the soil surface thin and coarse, and thus vulnerable to desertification. Hulun Lake and the grasslands within the reserve play a significant role in climatic adjustment and water resource conservation. The grasslands are also very suitable for inhabitation and breeding of many wild animals. Intensification of stockbreeding and the other human activities have made tremendous changes in land use and continuous deterioration in Hulun Lake Nature Reserve including lake shrinkage, grassland degeneration, wetland disappearance and land desertification, which threatens the ecosystems of the reserve.

Data sources and processing

In this study, the remote sensing images of Hulun Lake area of Landsat TM in 1999, 2005 and 2007 were used as major information sources. The relevant data including fundamental geographical information and land–use maps were collected for assisting the interpretation of the remote sensing images on the basis of the preprocessing of geometrical and atmospheric corrections, data fusion, etc. The land–use types in the research area were divided into five types: (1) high–coverage grassland, (2) middle–coverage grassland, (3) low–coverage grassland, (4) sandy land and (5) water body, by using Erdas Image 8.4, ArcGIS 9.2 software, etc. in combination with the field observations of the spatial distribution of land–use types in Hulun Lake area; finally, the spatial database of LUCC in Hulun Lake area based on these three issues was thus built.

Modeling approach

Markov model

The Markov model is a theory based formation of Markov random process systems for the prediction and optimal control theory method (Jiang *et al*., 2009). The Markov model plays an important role in analyzing the flow direction among various land–use types, which not only explains the quantification of conversion states between land–use types but also reveals the transfer rate among different land–use types. It is usually used in the prediction of geographical features with no after-effect event that has now become an important predicting method in geographic research (Sang *et al*., 2011). Based on the conditional probability formula, the prediction of land–use changes can be calculated from

$$S(t+1) = P_{ij} \times S(t) \tag{1}$$

where $S(t)$, $S(t+1)$ are the system status at the time of t and $t+1$ respectively, and P_{ij} is the transition probability matrix in a state which is calculated from

$$P_{ij} = \begin{vmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{vmatrix} \tag{2}$$

where n is the number of land–use types. P_{ij} possess the following characteristics:

(1) $0 \leq P_{ij} < 1$

(2) $\sum_{j=1}^{n} P_{ij} = 1, (i, j = 1, 2 \cdots, n)$

Cellular automata model

Cellular automata (CA) is a dynamic and spatially explicit modeling approach that encompasses five components: (1) a space composed of discrete cells, (2) a finite set of possible states associated to each cell, (3) a neighborhood of adjacent cells whose state influences the central cell, (4) uniform transition rules through time and space, and (5) a discrete time step to which the system is updated (Wolfram, 1984). CA model focuses mainly on the local interactions of cells with distinct temporal and spatial coupling features and the powerful computing capability of space, which is especially suitable for dynamic simulation and display with self–organizing feature systems. The use of geographic CA for land use change simulations not only takes into account comprehensive consideration soil conditions, climatic conditions, topography and other natural factors, but also considers a comprehensive policy, economy, other human factors, and the historical trends of land use with strong applicability (Sang *et al*., 2011). CA can be expressed as

$$C(t, t+1) = f(C(t), N) \tag{3}$$

where C is the set of limited and discrete cellular states, N is the cellular field, t is the time, and f is the transformation rules of cellular states in local space.

CA–Markov model

CA–Markov model is a combined approach of cellular automata and Markov chain for LUCC prediction that adds an element of spatial contiguity as well as knowledge of the likely spatial distribution of transitions to Markov chain analysis. The Markov model focuses only on the quantity in LUCC predictions, while the CA model has a strong capability of space–time dynamic evolution with complex space systems. The CA–Markov model integrates the functions of CA filter and Markov processes using conversion tables and conditional probability of the conversion map to predict land use changes. The CA–Markov model can improve models describing complex land use patterns (Fan *et al*., 2008; Peterson *et al*., 2009).

In this study, the CA–Markov module in IDRISI software is used to simulate the LUCC in the study area. The module allows simultaneous simulation of a group of land use and land coverage categories, and requires a land use/coverage dataset to represent the initial states, a Markov transition matrix, a group of suitability images (one for each land cover class), a number of iterations and a contiguity filter (Mitsova *et al.*, 2011). The 30 m×30 m land–use maps were used as input with the assumption that a matrix of the observed transition probabilities between maps in 1999 and 2007 could be used to project future changes from current land–use patterns. Through spatial overlay analysis, the transition probability matrix was calculated as the transformation rules. In this study, the standard 5×5 contiguity filter was used as the neighborhood definition to produce CA filters, that is, each cellular center was surrounded by a matrix space which was composed by 5×5 cellular to impact the cellular changes significantly.

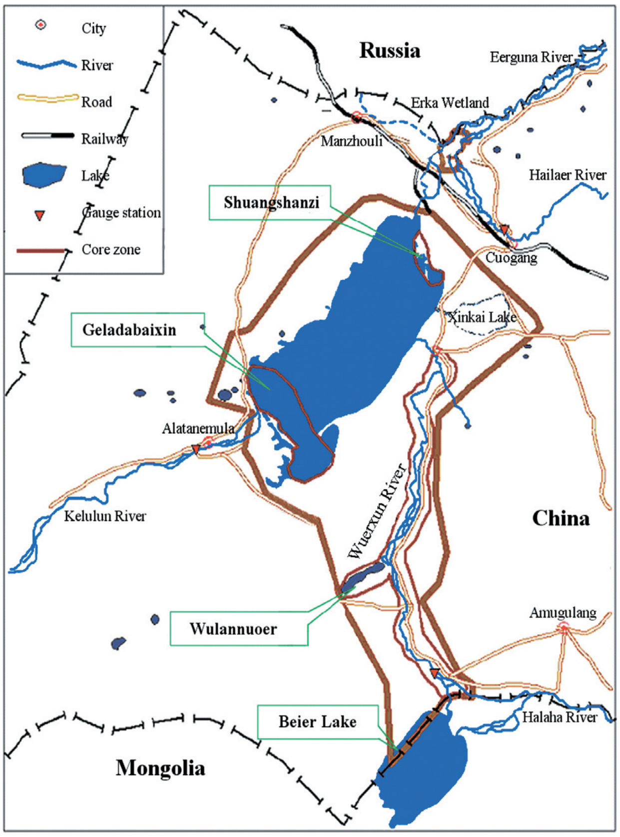

Fig. 1. Location map of Hulun Lake Nature Reserve.

RESULTS

LUCC in 1999, 2005 and 2007

Based on the different ground cover, the grassland was classified into high (>70%), moderate (30–70%) and low coverage (<30%). At last, the LUCC in this area was classified into five different types: high coverage grassland, moderate coverage grassland, low coverage grassland, water and sandy land (Fig. 2). The Hulun Lake, which located in the northern part of the study area, occupies around 2379.09 km^2 in 1999 (over 30% in area). However, the area of the lake decreased to 1967 km^2 in 2007 (25% in area) (Table 1). The grasslands covered

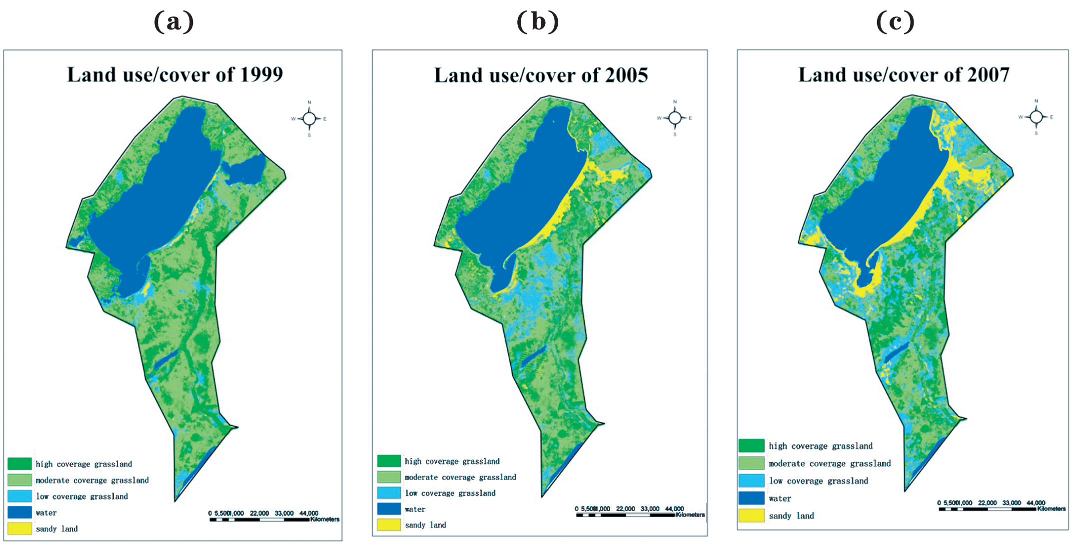

Fig. 2. Land use and land cover maps in (a) 1999, (b) 2005 and (c) 2007.

Table 1. Spatial and temporal changes of land use and land cover in Hulun Lake Nature Reserve from 1999 to 2007

Year\type		High coverage	Moderate coverage	Low coverage	water	Sandy land
1999	area (km^2)	1487.44	3349.06	409.88	2379.09	49.45
	percentage	19.38%	43.64%	5.34%	31.00%	0.64%
2005	area (km^2)	1433.19	2973.21	925.42	2039.31	303.79
	percentage	18.67%	38.74%	12.06%	26.57%	3.96%
2007	area (km^2)	1261.19	2352.15	1494.50	1967.02	600.05
	percentage	16.43%	30.65%	19.47%	25.63%	7.82%

almost all the other areas in the three years with coverage changed obviously. Area of the sand land was very small in 1999, while it increased markedly in 2005, mainly to the eastern side of the Hulun Lake.

Change rate and change map among the period

Changes in the areas of the different LUCC over the three years are significant (Table 2; Figs 2, 3). The moderate coverage grassland decreased largest (around 30%, Table 2) with a moderate decrease in high coverage and water. In contrast, area of the sandy land increased much over the three years and a substantial increase in low coverage grassland was also observed. The changes areas among different land use were shown in Fig. 3. The change areas overall the three years were large and spread all over the research area (Fig. 3 and Table 2). A change from moderate coverage to low coverage was obvious from 1999 to 2005, with the prominent change to the south of the Hulun Lake (Fig. 3a). This might explain the large increase in low coverage grassland over the years (Table 2). On the other hand, change area from high coverage to low coverage was more significant from 2005 to 2007, showing the vulnerability of the high coverage grassland (Fig. 3b). The change area from water to sandy land was more obvious from 2005 to 2007, compared with from 1999 to 2005. These results indicate that land degradation in this area was intensified in recent years.

Transition matrix and possibility during the period

To get a detailed description of the land use transition among the different land use, the transition matrix from 1999 to 2005 and the corresponding transition probability matrix are shown in Tables 3–6. A substantial change from high coverage to moderate and low coverage was observed from 1999 to 2005 with the probability being 18.95% and 8.65%, respectively (Tables 3, 4). Change areas from moderate coverage to low coverage were more obvious with the probability of 16.84% for the same period (Tables 3, 4). This is consistent with the results from the change map (Fig. 3a). The change area from low coverage to sand increased markedly from 1999 to 2005 with a probability around 20% (Tables 3, 4). A more obvious change area was observed from high coverage to moderate and the probability increased from 8.65% to 28.99%, showing the high coverage became more vulnerable from 2005 to 2007 (Tables 4, 5; Fig. 3b). On the other hand, despite the change probability from water to sandy land decreased from 20.87% to 2.38% in this period and a high probability from low coverage to moderate and high coverage, high and moderate coverage seemed to be more transitioned to the sandy land (Table 4, 5). Interestingly, a high probability of transition

Table 2. Change rate of land use and land cover of Hulun Lake Nature Reserve

Year\Type	High coverage grassland	Moderate coverage grassland	Low coverage grassland	water	Sandy land
1999~2005	–0.61%	–1.87%	20.96%	–2.38%	85.71%
2005~2007	–6.00%	–10.44%	30.75%	–1.77%	48.76%
1999~2007	–1.90%	–3.72%	33.08%	–2.17%	139.17%

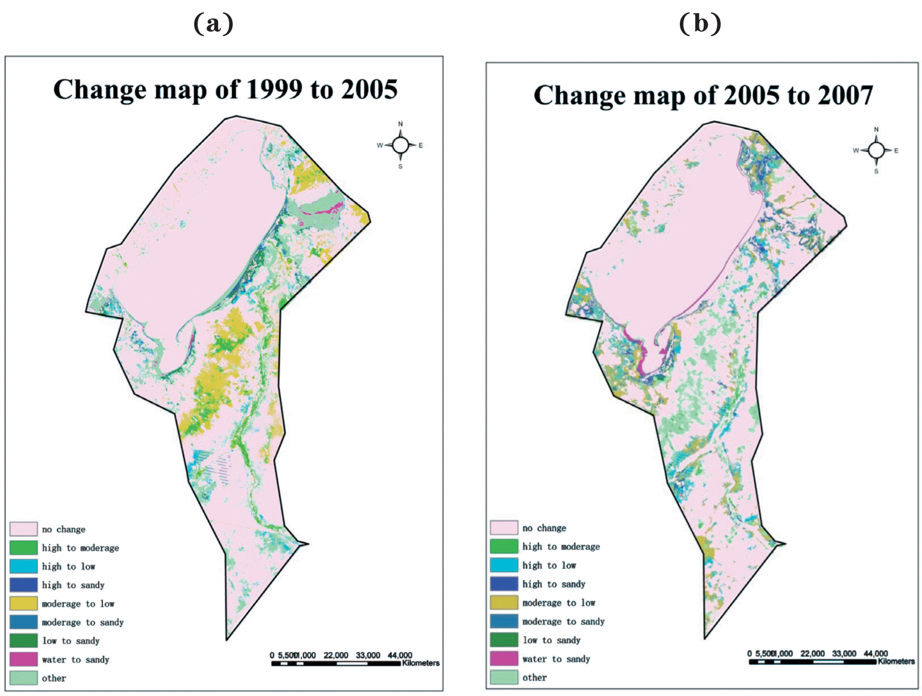

Fig. 3. Change maps of (a) 1999–2005 and (b) 2005–2007.

Table 3. Transition matrix of land use and land cover of Hulun Lake Nature Reserve for 1999 and 2005 (km^2)

1999\2005	high coverage	moderate coverage	low coverage	water	sandy land
high coverage	1036.33	281.84	128.66	10.33	30.29
moderate coverage	366.58	2381.79	564.13	1.13	35.43
low coverage	8.21	136.60	179.36	0.16	85.54
water	21.97	166.36	46.01	2027.66	117.08
sandy land	0.11	6.62	7.26	0.02	35.45

Table 4. Transition probability matrix of Hulun Lake Nature Reserve for 1999 and 2005

1999\2005	high coverage	moderate coverage	low coverage	water	sandy land
high coverage	69.67%	18.95%	8.65%	0.69%	2.04%
moderate coverage	10.95%	71.12%	16.84%	0.03%	1.06%
low coverage	2.00%	33.33%	43.76%	0.04%	20.87%
water	0.92%	6.99%	1.93%	85.23%	4.92%
sandy land	0.21%	13.39%	14.69%	0.04%	71.68%

Table 5. Transition matrix of land use and land cover of Hulun Lake Nature Reserve for 2005 and 2007 (km^2)

2005\2007	high coverage	moderate coverage	low coverage	water	sandy land
high coverage	884.84	54.47	415.42	2.58	75.89
moderate coverage	206.49	2082.59	547.85	3.85	132.44
low coverage	168.56	181.48	497.62	1.01	76.76
water	0.19	24.07	7.32	1959.11	48.61
sandy land	1.12	9.54	26.29	0.48	266.37

from low coverage to moderate and high coverage is found (Table 4, 5), which may be explained by the implementation of the policy of "grain to green" of the Chinese government (Piao *et al*., 2005; 2006).

Projected LUCC in 2020 and 2030

In this study, we used cellular automata–Markov chains model to simulate changes in five LUCC classes as a result of land degradation. Fig. 4 and Table 8 show the projected LUCC in 2020 and 2030. The results show

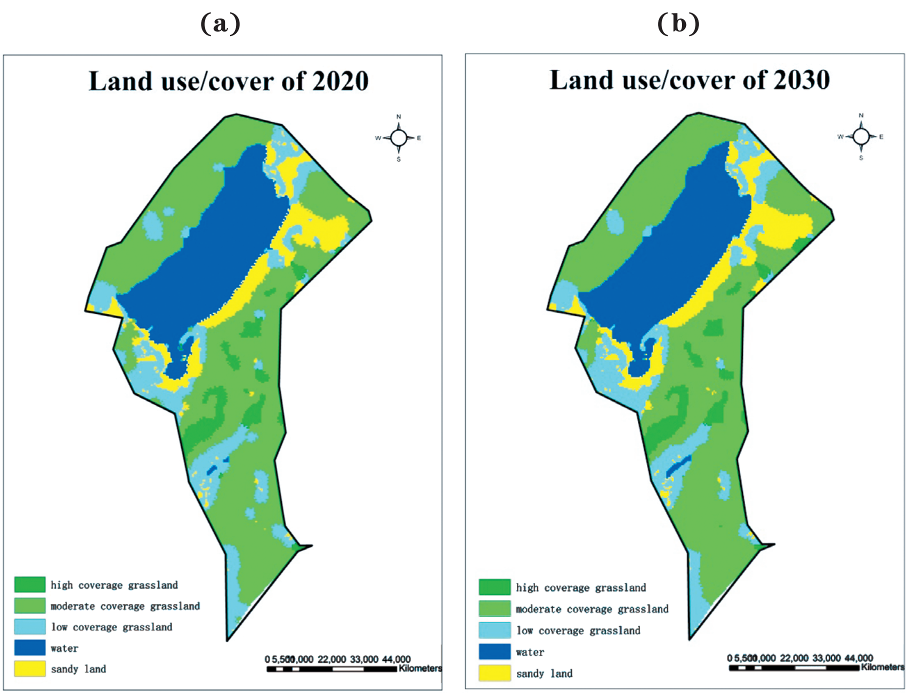

Fig. 4. Land use and land cover maps in (a) 2020 and (b) 2030 by CA–Markov.

Table 6. Transition probability matrix of Hulun Lake Nature Reserve for 2005 and 2007

2005\2007	high coverage	moderate coverage	low coverage	water	sandy land
high coverage	61.74%	3.80%	28.99%	0.18%	5.29%
moderate coverage	6.95%	70.05%	18.43%	0.13%	4.45%
low coverage	18.21%	19.61%	53.77%	0.11%	8.29%
water	0.01%	1.18%	0.36%	96.07%	2.38%
sandy land	0.37%	3.14%	8.65%	0.16%	87.68%

Table 7. Projected land use and land cover in 2020 and 2030 by the CA–Markov model (km^2)

Year\type	High coverage	Moderate coverage	Low coverage	water	Sandy land
2020	864.25	2057.25	2051.75	1808.75	903.5
	11.25%	26.77%	26.70%	23.53%	11.76%
2030	813.5	2019	2217.25	1697	998.75
	10.58%	26.27%	28.85%	22.08%	13.00%

that high and moderate coverage will consistently decrease in future; while low coverage grassland will increase, occupying nearly one third of the whole area. The water body will increasingly change into sandy land, decreased by 14% from 2007 to 2030 and will occupy around 20% of the whole area. Correspondingly, the sandy land increased by nearly 50% from 2007 to 2030, occupying 13% of the whole area. This result indicates that the land degradation in this area would be more severe in future if without any land management.

DISCUSSION

Our results show that the land use in this area is vulnerable, especially for the high and moderate coverage grassland (Tables 3–6, Fig. 3). The water in this area (large of Hulun Lake) was also vulnerable to change the sandy land, especially in recent years and that this kind of change might be more severe in future (Tables 3–6; Fig. 4). Thus, much caution should be paid to the land degradation in this area.

Both meteorological and anthropic reasons might be responsible for the land degradation (Reid *et al.*, 2000; Lambin *et al.*, 2001). The Hulun Lake is the most important land use (water) in this area and this water was found to be most vulnerable to change into sandy land (Table 3–6). This happened because of the decline in the Hulun lake water level. Actually, the water level of the Hulun Lake declined by 2.9 m during the period from 1999 to 2006 (data not shown). Therefore, we investigated how the water level was influenced by the meteorological and anthropic reasons. Fig. 5 shows the time series of precipitation, water evaporation from the lake and inflow from Wuerxun and Kelulun rivers from 1960 to 2008. The annual precipitation fluctuated much from middle 1980s and showed large value in 1998, which may be caused by the El Niño Southern Oscillation (ENSO) (Fig. 5a). Even though a slight decrease trend was observed; the trend was no significant during this period ($p>0.5$). The annual evaporation rate showed similar

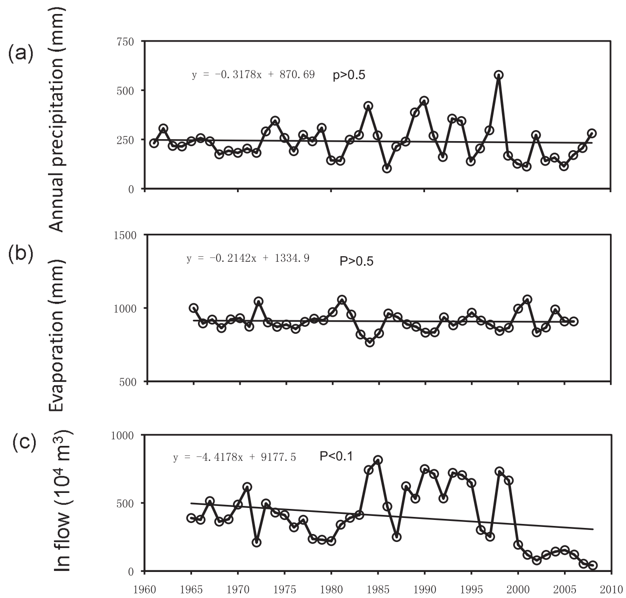

Fig. 5. Time series of (a) precipitation, (b) evaporation and (c) inflow in Hulun Lake Nature Reserve from 1960 to 2008.

trend with the precipitation, but this trend was also not significant ($p>0.5$). In contrast, the inflow decreased significantly during the same period, especially since the 2000s ($p<0.1$). Therefore, it seems that precipitation and the evaporation were not the major reasons for the decline in the water level. Instead, the increased water use by the population and economy development upstream of the two rivers, which result in small inflow to the lake, might be response for the decline of the water level.

CONCLUSION

With the aid of remote sensing statistics and the adoption of analytical methods of CA–Markov model, a systematic quantitative analysis was conducted on the temporal and spatial variation features of land use and land cover changes in Hulun Lake Nature Reserve from 1999 to 2007 in this paper. The result indicated that during the period between 1999 and 2007, there had been relatively great changes in LUCC in Hulun Lake Nature Reserve, with ecological problems such as grassland degradation and water area shrinkage becoming increasingly serious. Via analyzing the area variations of various land use and the water level of Hulun Lake during this period, the study found that the water use of the upstream by the population pressure and economy development might be related with the decline in Hulun Lake's water levels, which caused the increase in the sandy area. This kind of information is necessary for the land management of the area and will help in the ecosystem conservation in future.

ACKNOWLEDGEMENTS

This research is supported by the Chinese National Special Science and Technology Program of Water Pollution Control and Treatment (No.2009ZX07528–003) and Kyushu University Research Institute for East Asia Environment.

REFERENCES

Falcucci, A., L. Maiorano and L. Boitani 2007 Changes in land–use/land–cover patterns in Italy and their implications for biodiversity conservation. *Landscape Ecol.,* **22**(4): 617–631

Fan, F., Y. Wang and Z. Wang 2008 Temporal and spatial change detecting (1998–2003) and predicting of land use and land cover in Core corridor of Pearl River Delta (China) by using TM and ETM+ images. *Environ. Monit. Assess.,* **137**(1–3): 127–147

Guo, B. and G. Zhang 2009 Land use change in farming–pastoral region of Inner Mongolia based on GIS and Markov model. *Tran. CSAE.,* **25**(12): 291–298

Guo, J., T. Wang, X. Xue, S. Ma and F. Peng 2010 Monitoring aeolian desertification process in Hulunbir grassland during 1975–2006, Northern China. *Environ. Monit. Assess.,* **166**(1): 563–571

Janssen, L. L. F. and F. J. M. van der Wel 1994 Accuracy assessment of satellite derived land–cover data: A review. *Photogramm. Eng. Rem. S.,* **60**(4): 419–426

Jiang, G., F. Zhang and X. Kong 2009 Determining conversion direction of the rural residential land consolidation in Beijing mountainous areas, *Tran. CSAE.,* **25**(2): 214–221

Lambin EF, Geist HJ, Lepers E 2003 Dynamics of land–use and land–cover change in tropical regions. *Annu. Rev. Environ. Resour.,* **28**: 205–241

Lambin, E. F. and A. H. Strahler 1994a Change–vector analysis in multitemporal space: A tool to detect and categorize land–cover change processes using high temporal–resolution satellite data. *Remote Sens. Environ.,* **48**(2): 231–244

Lambin, E. F. and A. H. Strahler 1994b Indicators of land–cover change for change–vector analysis in multitemporal space at coarse spatial scales. *Int. J. Remote Sens.,* **15**(10): 2099–2119

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E. F. Moran, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H Skånes, W. Steffen, G. D. Stone, U. Svedin, T. A. Veldkamp, C. Vogel and J. Xu 2001. The causes of land–use and land–cover change: Moving beyond the myths. *Global Environ. Change,* **11**(4): 261–269

Logsdon, M. G., E. J. Bell and F. V. Westerlund 1996 Probability mapping of land use change: A GIS interface for visualizing transition probabilities. *Comput. Environ. Urban Sys.,* **20**(6): 389–398

Loveland, T. R., B. C. Reed, J. F. Brown, D. O. Ohlen, Z. Zhu, L. Yang and J. W. Merchant 2000 Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data. *Int. J. Remote Sens.,* **21**(6–7): 1303–1330

Marshall, E. and T. O. Randhir 2008 Spatial modeling of land cover change and watershed response using Markovian cellular automata and simulation. *Water Resour. Res.,* **44**(4): W04423, doi:10.1029/2006WR005514

Mitsova, D., W. Shuster and X. Wang. 2011 A cellular automata model of land cover change to integrate urban growth with open space conservation. *Landscape Urban Plan,* **99**: 141–153

Peterson, L. K., K. M. Bergen, D. G. Brown, L. Vashchuk and Y. Blam 2009 Forested land–cover patterns and trends over changing forest management eras in the Siberian Baikal region. *Forest Ecol. Manage.,* **257**: 911–922.

Piao, S., J. Fang, H. Liu and B. Zhu 2005 NDVI–indicated decline in desertification in China in the past two decades. *Geophys. Res. Lett.,* **32**(6): 1–4

Piao, S., J. Fang, L. Zhou, K. Tan and S. Tao 2007 Changes in biomass carbon stocks in China's grasslands between 1982 and 1999. *Global Biogeochem Cy.,* **21**(2): GB2002, doi:10.1029/2005GB002634

Piao, S., A. Mohammat, J. Fang, Q. Cai and J. Feng 2006 NDVI–based increase in growth of temperate grasslands and its responses to climate changes in China. *Global Environ. Change,* **16**(4): 340–348

Reid, R. S., R. L. Kruska, N. Muthui, A. Taye, S. Wotton, C. J. Wilson and W. Mulatu 2000 Land–use and land–cover dynamics in response to changes in climatic, biological and socio–political forces: The case of southwestern Ethiopia. *Landscape Ecol.,* **15**(4): 339–355

Sang, L., C. Zhang, J. Yang, D. Zhu and W. Yun 2011 Simulation of land use spatial pattern of towns and villages based on CA–Markov model. *Math. Comput. Model.,* **54**: 938–943

Taylor, C. M., E. F. Lambin, N. Stephenne, R. J. Harding and R. L. H. Essery 2002 The influence of land use change on climate in the Sahel. *J. Climate,* **15**(24): 3615–3629

Turner, B. L., D. Skole, S. Sanderson, G. Fischer, L, Fresco and R. Leemans 1995 Land–Use and Land–Cover Change: Science/Research plan, IGBP Report No. 35 (Sweden), p. 132

Vega, E., G. Baldi, E. G. Jobbágy and J. Paruelo 2009 Land use change patterns in the Río de la Plata grasslands: The influence of phytogeographic and political boundaries. *Agr. Ecosyst., Environ.,* **134**(3–4): 287–292

Weng, Q. 2002 Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. *J. Environ. Manage.,* **64**(3): 273–284

Wolfram, S. 1984 Cellular automata as models of complexity. *Nature,* **311**: 419–424

Wu, Q., H. Li, R. Wang, J. Paulussen, Y. He, M. Wang, B. Wang and Z. Wang 2006 Monitoring and predicting land use change in Beijing using remote sensing and GIS. *Landscape Urban Plan.,* **78**(4): 322–333