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Land Use/Cover Changes and Environmental Consequences in Songnen Plain, Northeast China

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Abstract: The Songnen Plain in Northeast China, one of the key national bases of agricultural production, went through remarkable land use/cover changes in recent years. This study aimed to explore the long-term land use/cover changes and the effects of these changes on the environment. The Landsat-based analysis showed that, during 1986–2000, cropland, built-up land and barren land had increased, among which cropland had the largest increase of 9,198km^2 with an increase rate of 7.5%. Woodland, grassland, water body and swampland had decreased correspondingly, among which grassland had the most dramatic decrease of 6,127km^2 with a decrease rate of 25.6%. The transition matrix results revealed that grassland, woodland and swampland were the three main land use types converted to cropland. Climate warming created the potential environment for the conversion of grassland and swampland into cropland. Land resources policy made by central and provincial governments of China affected the pattern and intensity of land use. Land use/cover changes accompanied by climatic variation brought out a series of environmental consequences, such as sand desertification of land, land salinization and alkalinization, grassland degradation, and more frequent floods. Under this circumstance, optimized land use structure and restoration measures are needed.
Keywords: land use change; remote sensing; sustainable development; Songnen Plain; China

1 Introduction

Land use/cover changes result from the alterations of the earth′s surface by human beings. With the rapid growth of human population, such alterations are taking place at unprecedented rates, magnitudes, and spatial scales (Turner II et al., 1994). Land use/cover changes play a vital role in environmental and ecological changes, furthermore contribute to global change (Meyer and Turner II, 1991; Lambin et al., 2001). The changes have important consequences on natural resources (Houghton, 1994; Turner II et al., 1995), and significantly affect key aspects of the earth′s system functions. These changes also directly impact the worldwide biodiversity (Sala et al., 2000), local and regional climate changes (Chase et al., 1999) and global warming (Houghton et al., 1999). They are the primary sources of soil degradation (Tolba et al., 1992), and, by altering ecosystem services, they affect the ability of ecosystem to support human needs (Vitousek et al., 1997).

The Songnen Plain, located in the central part of Northeast China, is one of the main agricultural regions of China. Its cropland area accounts for 9% of the national total. In the past decades, the Songnen Plain has experienced remarkable land use/cover changes as a result of human activities. Many efforts were made to analyze climate changes, landscape changes, and effects of agricultural activities on the local environment in the Songnen Plain (Li et al., 1998; Liu, 2001; Meng and Zhang, 2001; Huang et al., 2002; Luo et al., 2002; Meng, 2004). Yet quantitative knowledge on the land use/cover changes and environmental consequences at the regional level for the whole area was limited (Liu, 2001). Thus, the objectives of this study are to quantify the land use/cover changes in the Songnen Plain from 1986 to 2000, to elucidate the main driving factors of the

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changes, and to explore the impacts of land use/cover changes on the environment.

2 Materials and Methods

2.1 Study area

The Songnen Plain lies in the central part of Northeast China and covers an area of 239,184km^2 (Fig. 1). It includes 35 counties of Heilongjiang Province and 20 counties of Jilin Province, with a population of 34×10^6 in 2000. It has a typical temperate continental monsoon climate between maritime humid and continental arid zones, characterized with cold and arid winter and warm and rainy summer. The mean annual temperature ranges from 0℃ to 5℃. The mean temperature in January is from –16℃ to –26℃ and that in July is from 21℃ to 23℃. The average annual precipitation is 380–600mm and decreases from east to west. The Songhua River main stream, the Nenjiang River, the Second Songhua River, the Lalin River, the Raohe River, the Hulan River, the Wuyu’er River, and so on flow through the study area. The main soils include black soil (Luvic Phaeozem, FAO), chernozem (Haplic Chernozem, FAO), meadow soil (Eutric Vertisol, FAO), Solonetz (Solonetz, FAO), Solonchak (Solonchak, FAO), and aeolian soil (Arenosol, FAO). The dominant native plant genera include *Artemisia*, *Carex*, *Polygonum*, *Potentilla*, *Astragalus*, *Salix*, *Vicia*, *Adenophora*, *Allium*, *Chenopodium*, *Potamogeton*, *Corispermum* and *Ranunculus.*

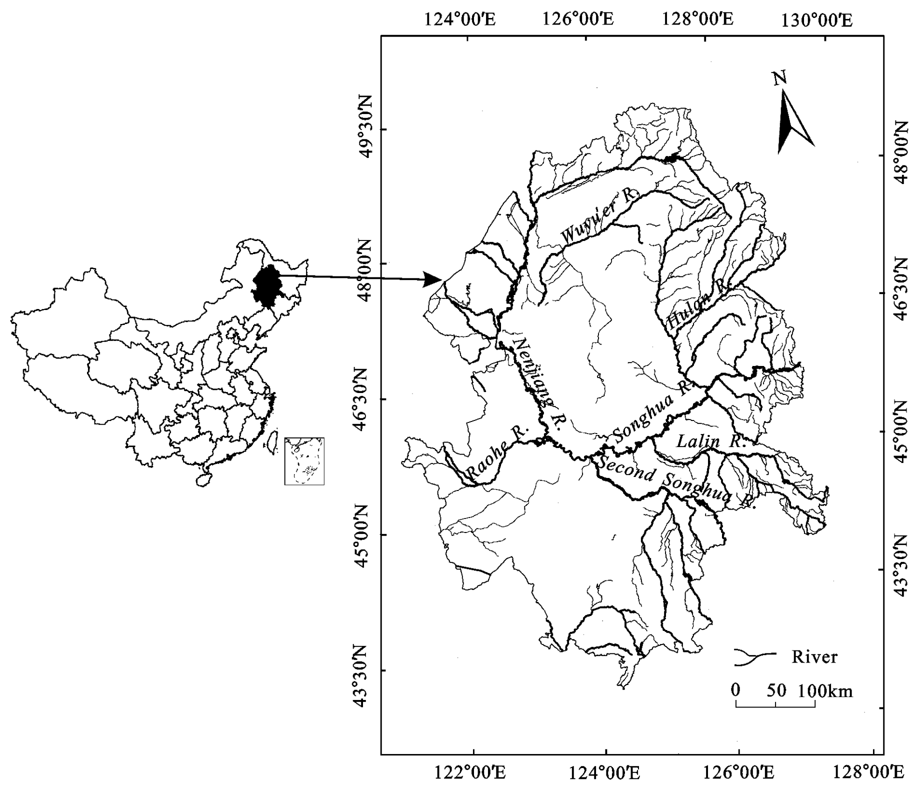

Fig. 1 Location sketch of Songnen Plain in China

2.2 Data sources and processing

ERDAS image processing software and ArcGIS software were used for data processing. In order to rectify satellite images, topographic maps (scanned indexed color maps with a scale of 1∶100,000) draw in 1954 were used. In 1986 and 2000, 18 cloud-free Landsat TM scenes were acquired to cover the entire study area. The images recorded from June to October in 1986 and 2000 were selected, because plant grows exuberantly in Northeast China in this period, thus facilitating the easy identification of land use types. The images were a composite of band 4 (red), band 3 (green), and band 2 (blue). The Albers Equal Area Conic Projection System and Beijing 1954 Coordinate System were selected to integrate different spatial data. First, a fishnet was generated. Then, all topographic maps were rectified against the fishnet. Before the interpretation was started, remote sensing images were geo-rectified against the 1∶100,000 topographic maps using ground control points (GCPs) collected by GPS. For each TM scene, there were at least 20 evenly distributed sites which served as GCPs. The images were re-sampled to the 30m×30m pixels by using the nearest neighbor method. The Root Mean Squared Error (RMSE) of the geometric rectification was less than one pixel (30m).

The remote sensing images were masked by using the boundary of counties. In this study, unsupervised classification was carried out by using the Interactive Self-organizing Data Analysis (ISODATA) algorithm to identify spectral clusters in the images. Based on the results of the unsupervised classification, training sites were chosen from the images. For each image, spectral signatures for the training sites were carefully chosen and examined. A maximum likelihood classifier was then employed for the image classification. The preliminary classification results were therefore revised according to visual interpretation and ground survey.

Finally, land cover maps for 1986 and 2000 have shown seven land cover types: cropland, woodland, grassland, water body, swampland, built-up land, and barren land. The classification accuracy for land cover maps extracted from the Landsat images was assessed by using a reference data of randomly selected patches. Various maps, field data, photos, and information from interviews with local people were used as reference data. The accuracy assessment was based on an evaluation of 1,822 and 1,460 patches for 1986 and 2000, respectively. The accuracy of the two land cover maps interpreted from remote sensing images were 93.6% (1986) and 91.3% (2000), respectively.

In order to determine the natural and socio-economic factors influencing land use changes, an extensive literature search and a series of interviews with the local people were conducted. Furthermore, historical information about the natural resources and agricultural policies of the study area for the past years provided an auxiliary context to analyze their impact on land use/cover changes in this region. To explain the reasons for the land use changes, related data were selected to reflect the climatic changes and human activities. The climatic data were obtained from the Meteorological Information Center, China Meteorological Administration. The statistical data on floods of the Songnen Plain were derived from *Jilin Statistical Yearbook 1986–2000* (Jilin Statistical Bureau, 1987–2001) and *Heilongjiang Statistical Yearbook 1986–2000* (Heilongjiang Statistical Bureau, 1987–2001) .

2.3 Methods

The ArcGIS 9.0 software was used for the analysis of land use area changes and the transition matrix analysis between land use types. Spatial analysis was carried out to describe the patterns of land cover changes over time and to measure the change rates. Based on the information, a land cover type transformation layer (1986–2000) was then generated and analyzed by using the cross-tabulation function of the ArcGIS. Then a transition matrix of land use types was produced. Consequently, the changes of the overall land uses in relation with the gains and losses in each category could be compiled.

3 Results and Discussion

3.1 Land use changes

The land use changes of the Songnen Plain from 1986 to 2000 are shown in Table 1. The data reveal that cropland was the largest land use type of the study area, accounting for more than 50% of the total land area. In the study period, cropland, built-up land and barren land had increased, among which cropland had the largest increase, with an increase area of 9,198km^2 and an increase rate of 7.5%. Although the increase rate of cropland was not so high, its increase area was large due to the high proportion of cropland area in the study area. During the study period, woodland, grassland, water body and swampland had decreased correspondingly, among which grassland had the most dramatic decrease, with a decrease area of 6,127km^2 and a decrease rate of 25.6%, followed by swampland, water body and woodland.

The results of the transition matrix reflect the increase or decline in the area of each land use type (Table 2). It was clear that between 1986 and 2000, the transition replacement rates of grassland and swampland were as high as 32.71% and 15.29%, respectively. However, cropland, woodland, water body, and barren land had relatively lower transition rates of 1.50%, 9.11%, 11.83% and 11.99%, respectively. Built-up land hardly had any

Table 1 Land use changes in Songnen Plain in 1986–2000

Type	1986		2000		1986–2000		
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Change (km^2)	Change rate (%)	Annual change rate (%)
Cropland	122752	54.93	131950	59.04	9198	7.5	0.4
Woodland	28146	12.59	27235	12.19	–911	–3.2	–0.2
Grassland	23938	10.71	17811	7.97	–6127	–25.6	–1.5
Water body	11929	5.34	10961	4.90	–968	–8.1	–0.4
Swampland	15136	6.77	13718	6.14	–1418	–9.4	–0.5
Built-up land	9456	4.23	9641	4.31	185	2.0	0.1
Barren land	12124	5.43	12165	5.44	41	0.3	0.0
Total	223480	100.00	223480	100.00	—	—	—

Table 2 Transition matrix of land use types in 1986–2000 (%)

1986	2000						
	Cropland	Woodland	Grassland	Water body	Swampland	Built-up land	Barren land
Cropland	**98.50**	0.68	0.34	0.11	0.20	0.13	0.03
Woodland	8.14	**90.89**	0.65	0.05	0.24	0.02	0.02
Grassland	26.42	2.77	**67.29**	0.15	0.51	0.05	2.81
Water body	3.59	0.03	1.29	**88.17**	2.85	0.00	4.08
Swampland	9.41	0.00	2.51	1.52	**84.71**	0.01	1.84
Built-up land	0.03	0.00	0.00	0.00	0.00	**99.97**	0.00
Barren land	4.69	1.13	4.97	0.15	1.04	0.01	**88.01**

transition to other land use types. Between 1986 and 2000, about 26.42% of grassland, 9.41% of swampland, 8.14% of woodland, and 3.59% of water body were transformed into cropland.

Based on the interpretation, the intensive ground-truth studies during summer 2002, and the interviews with relevant experts and farmers, it was clear that the agricultural reclamation was the dominant process of land use/cover changes in the study area. For this reason, the driving forces of land use/cover changes and their consequences were analyzed mainly in relation to cropland changes.

In Northeast China, temperature is an indispensable factor that controls the latitudinal distribution of crops. Reminiscent of the global trend of climate warming, temperature in the Songnen Plain has risen steadily over the past decades. The elevated air temperature in this region accounted for the partial incentives for land reclamation. The regression relationship between the average annual temperature and year was:

$$T = 0.0844Y–163.73 \quad R^2 = 0.4976, n=21, p<0.05 \quad (1)$$

where T is average annual temperature, and Y is year.

From the slope of 0.0844 in Equation (1), it was found that the average annual temperature had raised by 1.688℃ during the period 1986–2000.

Land resources policy made by central and provincial governments affected the pattern and intensity of land use. At the end of the 1978, the Chinese government reformed the land tenure policy and introduced the system of household contract responsibility. In the Songnen Plain, newly reclaimed cropland has increased since the 1980s. Since 1992, the market-directed economic system has replaced the planned economic system. Since lowland rice growing could yield more income than dry or upland farming, farmers paid more attention to the shift from dry farming to paddy field farming in 1992–1995. In the late 1990s, the ecological functions of grassland and swampland were recognized widely, thus national ecological projects such as “Cropland to Forest and Grassland” and “Ecological Province Project” for Jilin Province, Heilongjiang Province, and other provinces were adopted. During this period, several national and provincial nature reserves for grassland and swampland were set up.

The population growth and the concomitant requirement for grain made cropland area increase in general. The population density of the study area increased from 105 persons/km^2 in 1986 to 142 persons/km^2 in 2000, which accelerated the land reclamation from woodland, grassland and swampland.

3.2 Environmental consequences

3.2.1 Sand desertification of land

Land use structure and land use changes affected the intensity and extensity of sand desertification in the Songnen Plain. From the middle of 1980s to 2001, the area of sand desertification increased by 861km^2 with an annual rate of 0.44%, caused by excessive utilization and land use changes (Zhang et al., 2008). In this area, cropland with a denuded surface was more prone to soil erosion and land degradation than woodland and grassland (Liu et al., 2005). During 1986–2000, 8.14% of woodland (2,291km^2) and 26.42% of grassland (6,324 km^2) were transformed into cropland, which altered natural vegetation cover conditions. After land fertility reduced to a certain level through the removal of the topsoil, farming became less viable, resulting in the abandonment of the cropland. Moreover, the croplands converted from grasslands in wet years were often abandoned in dry years, which had caused land degradation at an accelerated rate (Liu and Huang, 2002). The long-term abandonment of the cropland fueled the mobility of sands, further accelerating sand desertification of land. Reversely, sand desertification of land threatened the productivity of cropland (Liu et al., 2005). In the case of black soil, one of the important soil types in the study area, the soil nutrients were degraded after reclamation, and the most dramatic decrease of soil nutrients was observed during the 10-year period after reclamation (Zhang et al., 2003). To rehabilitate ecosystems with fragile sand desertification characteristics, optimized eco-productive paradigms, such as reasonable allocation of cropland and grassland, in farming-pastoral zone of the Songnen Plain can be used to control sand desertification and restore degraded ecosystems (Wu, 2005).

3.2.2 Land salinization and alkalinization

Unreasonable changes in land use/cover (e.g., reclamation of natural vegetation as cropland) had also resulted in an increase in salinized land. In the western part of the Songnen Plain, salinized land had been expanding at an annual rate of more than 2% since the early 1990s (Qiu et al., 2003). Physiographically, rivers in this region originate from the Da Hinggan Mountains whose surface rocks are mainly andesite, liparite, basic basalt, tuff and granite. These weathered rocks, rich in MgO, CaO, Na_2O and K_2O, have been etched by rivers, and a large amount of salts and debris had been transported into the mid-downstream plain of the study area, which provided abundant salt for land salinization (Pan et al., 2003). It was estimated that there were 1.1×10^6ha of salinized land in the Songnen Plain. On the one hand, land salinization and alkalinization usually happened when water body and swampland with higher groundwater table were reclaimed as cropland. On the other hand, the reduction of natural vegetation and the increase of evaporation, due to conversion from woodland and grassland into cropland, accelerated land salinization and alkalinization. The land salinization had led to the abandonment of reclaimed cropland (Li, 2000). Taking the Da'an County, located in the Songnen Plain, as a case, Li et al (2007) found that the salinized wasteland of this county increased by 38% during 1986–2004. It was found that grasslands, croplands and swamplands were the three main land use types converted into salinized wasteland. The expansion trend of salinized wasteland of the study area was generally consistent with increasing trend of population growth.

3.2.3 Grassland degradation

The grassland in the Songnen Plain is dominated by the C_3 plant *Leymus chinensis* with high palatability, which is ideal for grazing and forage. However, under climate warming and human disturbance, grassland shrinkage and degradation in the plain had been a serious environmental problem. The results obtained in this study indicated a significant decrease in grassland area from 23,938km^2 in 1986 to 17,811km^2 in 2000. Due to the increasing need for livestock products, as well as the improved living standard, especially since the opening-up and reform policy was adopted in China in the late 1980s, most of the existent grasslands were overgrazed, which destroyed the original structure of the landscape. The area of the salt-affected patch in the grassland was expanded, which generated the vicious cycle and the continuous decrease of grassland productivity (Wang et al., 2009). The decrease of grassland cover caused by the unreasonable development of stockbreeding had increased the evaporation, soil temperature, and soil organic decomposition. The overgrazing had not only aggravated the conversion from grassland to salina, but substantially damaged the grassland quality as well. In this area, the dominant species of grassland were wiped out, meanwhile the average vegetation coverage, grass height, density, and productivity decreased to a great extent (Li et al., 2007).

3.2.4 More frequent floods

Despite the generally insufficient precipitation in the Songnen Plain, the high and uneven distribution of precipitation within a year and the low and flat terrain make the area prone to flooding. This reduced food production, damaged property, caused loss of human life, and brought about substantial soil erosion and other complications (Xu et al., 2003; Liu et al., 2005). Severe floods had become much more frequent at an interval of two or three years since the mid-1980s. For Jilin Province, only one flood (in 1985) which damaged more than 500km^2 of cropland occurred in 1970–1985. However, from 1986 to 2000, four times of floods with this damage degree occurred (in 1986, 1991, 1994, and 1998) (Jilin Statistical Bureau, 1987–2001). For Heilongjiang Province, the times of floods which damaged more than 500km^2 of cropland were 2 and 5 during 1970–1985 and 1986–2000, respectively (Heilongjiang Statistical Bureau, 1987–2001). The worst flooding in the recorded history occurred in 1998. To a large degree, the increased frequency and magnitude of flooding can be traced back to the inappropriate change from swampland or woodland to cropland. Such reclamation has drastically reduced the buffer zone for storm water and caused the water level of the river to rise sharply during heavy rainfall. From 1986 to 2000, a total of 2,291km^2 of woodland had been converted into cropland. Such a change had contributed to flooding in deforested areas and the destruction of vegetation, which severely altered the rainwater distribution of the land surface. Instead of percolating downward, most of the rainwater entered the channel directly and carried away the surface soil during a rainfall. Consequently, the silt deposit which was washed down from the cropland raised the riverbed substantially.

4 Conclusions

Widespread land use/cover changes took place in the Songnen Plain, Northeast China, during 1986–2000. In this period, cropland, built-up land, and barren land had increased. Conversely, woodland, grassland, swampland, and water body had decreased. The most remarkable land use changes were the increase of cropland (9,198 km^2) and the decrease of grassland (6,127km^2). Land cover change and conversion in the Songnen Plain were driven by the interaction between biophysical and human dimensions. Climate warming created a potential environment for the conversion of grassland and swampland into cropland. The increase in the size of cropland and built-up land in the Songnen Plain was related to the rapid population growth and the improved quality of life since the opening-up and reform policy was adopted in China. The increasing human activities led to the acceleration of deforestation and the cultivation of grassland and swampland. Due to the land use changes, the Songnen Plain suffered environmental consequences which can not be ignored such as sand desertification of land, land salinization and alkalinization, grassland degradation, and more frequent floods.

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